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Chapter 4

The maturity of sovereign bond issuance in the euro area

4.1 Introduction

One of the most important choices sovereign debt managers face is the maturity structure of the outstanding stock of debt. In particular, they are confronted with a trade-off between borrowing costs and roll-over risks. With Treasury yield curves that are upward sloping most of the time, debt managers can reduce average annual funding costs by tilting the issuance of new debt towards a shorter maturity. However, by doing so, they also increase roll-over risks, as the stock of outstanding debt has to be refinanced more frequently.

Questions concerning the determinants of the maturity structure of the public debt are particularly interesting for the euro area, which recently went through a debt crisis with some countries losing access to the capital market. Hence, the roll-over of outstanding debt was a real concern for some countries. Moreover, such concerns may re-emerge from in the future, for example if interest rate increases raise financing costs of high-debt countries.

In this paper, we investigate the determinants of the maturity structure of the public debt using a unique and comprehensive database of sovereign bond issues in the euro area from 1 January 1999 to 31 December 2017, consisting of data for Germany, The Netherlands, France and Belgium, henceforth referred to as the “Core”, and Italy and Spain, henceforth referred to as the “Periphery”. We focus on the maturity structure of *new* debt issues rather than of the complete stock of

outstanding debt, because the maturity structure of the latter is only a slow-moving variable and, hence, it would be more difficult to unearth the driving factors behind the debt managers' choice of the maturity structure.

Our empirical analysis is motivated with a theoretical model that trades off the liquidity providing benefits and lower costs of holding short debt against the likelihood of a debt roll-over crisis resulting from unexpected increases in repayment risk. Our model extends that by Broner *et al.* (2013) of the debt maturity choice in the presence of fiscal risk by including the liquidity services of safe short-term debt, hence by combining the Broner *et al.* (2013) model with a premium on short-term debt that is a key feature of the model by Greenwood, Hanson and Stein (2015).³⁵ While the empirical analysis of Broner *et al.* (2013) focuses on developing countries, some of which experienced repeated episodes of elevated fiscal risks, the euro area debt crisis has shown that fiscal risks can also be non-negligible for advanced economies, and in particular for those that are member of a monetary union such as the euro area. Despite the possible occurrence of elevated fiscal risk, euro area sovereign debt may also carry a liquidity premium. Such a liquidity premium reflects the monetary services of safe short-term government debt, and features also in Krishnamurthy and Vissing-Jorgensen (2012) and Greenwood, Hanson and Stein (2015). Our model combines the investors' preferences for the liquidity services of safe short debt with the risk of non-repayment of long-term debt ("fiscal risk").

Our main empirical results are the following. We find strong evidence that the average maturity of newly-issued euro-area public debt is negatively related to both the level of the yield curve and the spread

³⁵ Kacperczyk *et al.* (2018) find that Treasury bills generally carry a safety premium. In line with this finding, Jiang, Krishnamurthy and Lustig (2018) provide strong evidence of liquidity services of short-term debt by showing a "convenience yield effect" of U.S. Treasuries on the determination of the dollar exchange rate.

between long- and short-term yields. Our theoretical framework suggests that the negative relationship between the yield curve level and debt maturity is driven by investors' risk aversion and fiscal risk shocks, while the negative relationship between the spread and maturity suggests a dominance of risk aversion and liquidity preference shocks. Further analysis directly linking the maturity structure and yield curve to variables intended to capture the various shock sources indicates a substantial role for liquidity preference shocks, which give effects generally in line with our theoretical predictions. The role of the other shock sources is less obvious and the effects that they exert provide mixed support for the theoretical framework. Yet the effects of changes in fiscal risk on the long-short spread in the yield curve are in line with our theory.

Our chapter is related to the literature on fiscal insurance, which suggests that debt management can provide insurance against fiscal shocks, therewith contributing to a smoother tax profile (Missale, 2012). Lucas and Stokey (1983) show that governments can optimize their tax profile through the issuance of contingent securities. Angeletos (2002) and Buera and Nicolini (2004) show that the same can be achieved by issuing non-contingent debt at different maturities. Debortoli *et al.* (2016) introduce imperfect commitment, whereas Niepelt (2014) models imperfect commitment in combination with the social costs of default. Nosbusch (2008) focuses on the case where governments can only issue two maturities, while Lustig *et al.* (2008) endogenize inflation. Faraglia *et al.* (2008) find limited empirical evidence for OECD countries over the period 1970 – 2000 that debt management has helped to insulate the public finances against fiscal shocks.

Our analysis also relates to earlier empirical analyses of the determinants of the maturity of public debt. Porath (2015) studies the response of the maturity of new debt issuance to changes in financial and

economic variables in 11 OECD countries between 2004 and 2012. De Broeck and Guscina (2011) analyze the determinants of the share of fixed coupon bonds with a long maturity issued in local currency between 2007 and 2009 for 16 European countries, and Hoogduin *et al.* (2010) estimate the relationship between the share of short-term debt issuance and the spread between long- and short-term yields in 11 euro-area countries between 1990 and 2009. Beetsma *et al.* (2017) show that an increase in the maturity of public debt is associated with lower long-term interest rates in OECD countries. Focusing on emerging markets, Arellano and Ramanarayanan (2012), Bai *et al.* (2015), Broner *et al.* (2013) and Perez (2017) estimate the relationship between the maturity of newly-issued debt and the spread between short- and long-term debt. The relationship between the level of government debt and its average maturity is explored by Missale and Blanchard (1994) and De Haan *et al.* (1995), who find that it is negative *prior* to the introduction of the euro, which could be driven by the need (forced upon by the capital markets) to reduce the temptation to inflate away high debt burdens. Greenwood, Hanson, Rudolph and Summers (2015) instead find that the maturity of US Treasury issuance is positively related to the debt-to-GDP ratio, which is consistent with the trade-off between roll-over risks and the demand for liquid T-bills in their model. A more recent analysis for the euro area is found in Equiza-Goñi (2016). Our analysis differs in various ways from previous work by: (i) constructing a theoretical framework that combines shocks to risk preferences, liquidity preferences and fiscal risk, allowing one to analyze the trade-offs among price risk of long-term debt, the provision of liquidity services by safe debt and roll-over risks of short debt, and (ii) exploring the consistency of the model's predictions with the empirical relationship between the maturity of newly-issued Eurozone debt and the

yield curve, as well as with the factors directly driving debt maturity and the yield curve.

The remainder of this chapter is organized as follows. Section 2 constructs our theoretical model that outlines how fundamental shocks affect the weighted average maturity (WAM) and the yield curve. Section 3 describes our data and our measure of the WAM. Section 4 presents the empirical results, first linking the WAM to the yield curve and then investigating in more detail the fundamental shocks underlying the movements in the yield curve and WAM. We close this section with instrumental variables estimation of the relationship between the WAM and the yield curve, using as instruments variables that proxy for these shocks. Finally, Section 5 concludes the main text of the paper.

4.2 The theoretical model

In this section we develop a theoretical model that distinguishes different fundamental shocks affecting the yield curve and the choice of the public debt maturity structure. The model extends that in Broner *et al.* (2013) by including liquidity services of short-term debt, and yields empirically testable implications about the responses of the maturity structure and the yield curve to these shocks.

Broner *et al.* (2013) model decisions about the maturity structure of the government debt in a small open economy that borrows from international investors. In this three-period model, investors face fiscal risk that follows from an uncertain revenue stream in the third period. All else equal, risk averse investors prefer short-term debt to limit their exposure to the price risk associated with holding long-term debt. However, issuing more short-term debt also enhances the risk of a roll-

over crisis which requires costly fiscal adjustment and which makes issuing long-term debt more attractive.

The model by Broner *et al.* (2013) focuses on emerging markets and does not consider the potential monetary services that investors may derive from holding safe government debt. These monetary services are a key element in the model by Greenwood, Hanson and Stein (2015), which focuses on how the preference of investors for safe short-term debt affects the optimal maturity structure of the government debt.³⁶ However, fiscal risk in their model is limited to a random discount factor.

Our theoretical model combines both approaches. Hence, it combines in one model both fiscal risk and a potential safety premium on sovereign debt. This setup is particularly suitable in the context of sovereign euro-area debt (see e.g. Coeuré, 2016):

- Including default risk is not unreasonable in a model of sovereign debt issuance of euro-area countries: euro-area sovereign bonds have Collective Action Clauses since 2013, privately-held Greek government debt was subject to a haircut in 2012, the ESM Treaty mentions the possibility of debt restructuring (“private sector involvement”), and the introduction of a Sovereign Debt Restructuring Framework is a recurring element in discussions about the future of the EMU (see e.g. Regling, 2018, and Bénassy-Quéré *et al.*, 2018).
- At the same time, euro-area sovereign debt is used as a safe asset in financial transactions and in investors’ portfolios. For some

³⁶ Greenwood, Hanson and Stein (2015) further analyze the effect of short-term debt issuance on financial stability through its crowding-out effect on maturity transformation in the financial sector. In particular, banks issue safe short-term debt, e.g. deposits, to finance long assets. The role of a safe short-term debt instrument in terms of its liquidity services, and hence the premium on it, is increasing in its supply. Hence, more issuance of safe public short-term debt crowds out the private issuance of such debt (see also Kacperczyk *et al.*, 2018). However, these considerations are beyond the scope of our analysis.

European Union (EU) Member States, the safe status of their debt was called into question during the recent sovereign debt crisis, which resulted into higher sovereign bond yields and flight-to-safety episodes.

4.2.1 The government and international investors

The government

There are three periods, labeled 0, 1 and 2. The government maximizes a two-period expected utility function with government consumption G_t as its argument:

$$U = E_0[u(G_1) + \sum_{j=1}^S Pr(j = s)u(G_{2s})], \quad (4.1)$$

where $u(\cdot)$ is twice differentiable, increasing and strictly concave, $u(0) = 0$, $u'(0) = \infty$, s is the state of the economy in period 2, S the number of possible states and $Pr(j = s)$ the *stochastic* probability that state s occurs in period 2. The government has an initial outstanding stock of short-term (maturing in period 1) and long-term (maturing in period 2) debt. In period 0, the government can adjust its maturity structure by replacing the existing stock of debt with principal values \overline{B}_{01} and \overline{B}_{02} for short-, respectively long-term, debt with new debt with principal values (B_{01}, B_{02}) , subject to the following budget constraint:

$$P_{01}B_{01} + P_{02}B_{02} = P_{01}\overline{B}_{01} + P_{02}\overline{B}_{02}. \quad (4.2)$$

where P_{01} and P_{02} are the prices of short and long debt in period 0.

Newly-issued short-term debt with principal value B_{12} in period 1 is needed to finance the repayment of the maturing stock of short-term

debt and government consumption in period 1. Hence, the government budget constraint in period 1 is:

$$B_{01} + G_1 = P_{12}B_{12}, \quad (4.3)$$

where P_{12} is the price of new one-period debt issued in period 1. We assume that default never takes place in period 1. This requires B_{01} not to be too high (see below), so that new short-term debt can still be issued in period 1.

In period 2 the government receives an exogenous flow of fiscal revenues y , which is stochastic and can take on two values:

- $y = \bar{y}$ with probability $\pi > 0$ *repayment*
- $y = 0$ with probability $1 - \pi$ *default*

Hence, period 2 features two possible states, a “good” one, in which $y = \bar{y}$, and a “bad” one, in which $y = 0$. When viewed from the perspective of period 0, the chance π of the good state occurring in period 2 is uncertain.

International Investors

International investors derive utility from consumption in periods 0, 1 and 2, as well as from the liquidity services associated with holding short-term sovereign debt issued in period 0. Similar to Greenwood, Hanson and Stein (2015), we assume that these liquidity services cannot be provided by the short-term debt issued in period 1, which is in line with the fact that this short-term debt is subject to default risk. The utility function of the representative international investor is thus equal to

$$U = C_0 + E_0[m_1 C_1 + m_1 m_2 C_2] + v(B_{01}),$$

where $v(B_{01})$ represents the liquidity services enjoyed by investors from holding safe short-term government debt issued in period 0. We assume that $v' > 0$ and $v'' < 0$. Further, m_1 and m_2 are stochastic discount factors that materialize in periods 1 and 2. These are assumed to be unaffected by the maturity structure chosen by the government, but negatively correlated with bond returns. We assume that the risk-free short-term rate is 0 in both periods, so $E_0[m_1] = E_1[m_2] = 1$.

In period 0 short-term debt is riskless, so:

$$P_{01} = E_0[m_1] + v'(B_{01}) = 1 + v'(B_{01}). \quad (4.4)$$

Long-term debt issued in period 0 and short-term debt issued in period 1 carry credit risk. The price of period-1 short-term bonds is equal to $P_{12} = E_1[\chi m_2]$, where χ is an indicator denoting repayment in period 2. We assume that χ and m_2 are negatively correlated, so $P_{12} < \pi$. We also assume a constant risk premium on period-1 short-term bonds, so:

$$P_{12} = \rho\pi, \quad (4.5)$$

where $\rho \leq 1$ is a scalar. The price of period-0 long-term bonds is equal to $P_{02} = E_0[P_{12} m_1] = E_0[\rho\pi m_1]$. Assuming that π and m_1 are negatively correlated,

$$P_{02} = \sigma\rho\pi_0, \quad (4.6)$$

where $\pi_0 = E_0[\pi]$ and $\sigma < 1$.

4.2.2 Derivation of the optimal maturity

To summarize, the timing of events is as follows. In period 0, the government chooses the optimal maturity structure (B_{01}, B_{02}) of the public debt, given the inherited maturity structure $(\overline{B}_{01}, \overline{B}_{02})$, while investors choose their bond holdings, resulting in the prices for short- and long-term debt. In period 1, the probability π of a good state in period 2 materializes and, given this probability, the government decides about the amount of public consumption in period 1, which, together with the amount of maturing short-term debt, determines the amount of new short-term debt to be issued in that period.

The government repays its debt in period 2 to the maximum possible extent given its available resources, which implies that strategic default does not take place, and it allocates the remainder of its revenues in that period to government consumption. Hence, the maximum possible amount of short-term debt when entering period 1 is $P_{12}\bar{y}$. With this amount of short-term debt entering period 1, the amount of long-term debt issued in period 0 must be zero and all the government's income in the good state in period 2 will be used to pay off the short-term debt. Hence, if $B_{01} = P_{12}\bar{y}$, government consumption in periods 1 and 2 is zero in all states of the world.³⁷

We solve the government's optimization problem backwards.

³⁷ To rule out any chance of not repaying the maturing short-run debt in period 1 and allowing for positive consumption in period 1 and in period 2 in the good state, we impose the restriction that $B_{01} < \rho\underline{\pi}\bar{y}$, where $\underline{\pi} > 0$ is the lowest possible probability of a good state in period 2, so that $P_{12} = \rho\underline{\pi}$ is the lowest possible price of short-term debt in period 1.

Period 1

Combining the government budget constraint in the good state in period 2,

$$G_{2g} = \bar{y} - B_{02} - B_{12},$$

where G_{2g} denotes period-2 government consumption in the good state, with the government budget constraint (4.3) in period 1 and the bond price P_{12} in (4.5), we obtain, for given initial maturity structure, the relationship between public consumption in period 1 and in the good state in period 2:

$$G_{2g} = \bar{y} - B_{02} - \frac{G_1 + B_{01}}{\rho\pi}.$$

Substituting into the government's objective function in period 1 and differentiating with respect to G_1 , the first-order condition is³⁸

$$u'(G_1) = u'(G_{2g})/\rho.$$

Period 0

We now turn to the government's choice of the optimal maturity structure in period 0. Using the expressions for the bond prices in period 0, $P_{01} = 1 + v'(B_{01})$ and $P_{02} = \sigma\rho\pi_0$, we can write the period-0 government budget constraint as:

$$B_{02} = \bar{B}_{02} - \frac{(1+v'(B_{01}))(B_{01} - \bar{B}_{01})}{\sigma\rho\pi_0}$$

³⁸ Broner *et al.* (2013) assume a government utility function which is concave in period 1 consumption and linear in period 2 consumption. In period 1, the government chooses the amount of fiscal adjustment. For fiscal adjustment at the internal (unconstrained) optimum, period 2 government consumption cannot be guaranteed to be positive, assuming default in the good state is excluded. The result is that fiscal adjustment may have to be set at a level higher than its internal optimum. The current setup thus abstracts from these complications.

Hence, government consumption in the good state in period 2 is:

$$G_{2g} = \bar{y} - \bar{B}_{02} + \frac{(1+v'(B_{01}))(B_{01}-\bar{B}_{01})}{\sigma\rho\pi_0} - \frac{G_1+B_{01}}{\rho\pi} \quad (4.7)$$

Substitution into the government's utility function yields:

$$U^* = E_0[u(G_1^*) + \pi u(G_{2g}^*)] = E_0\left[u(G_1^*) + \pi u\left(\bar{y} - \bar{B}_{02} + \frac{(1+v'(B_{01}))(B_{01}-\bar{B}_{01})}{\sigma\rho\pi_0} - \frac{G_1+B_{01}}{\rho\pi}\right)\right],$$

where the superscript * denotes the optimum, as evaluated in period 1.

Differentiating U^* with respect to B_{01} yields the first-order condition:

$$E_0\left[\left(u'(G_1^*) + \pi u'(G_{2g}^*)\frac{\partial G_{2g}^*}{\partial G_1}\right)\frac{dG_1^*}{dB_{01}} + \pi u'(G_{2g}^*)\frac{\partial G_{2g}^*}{\partial B_{01}}\right] = 0.$$

Substituting $\frac{\partial G_{2g}^*}{\partial G_1} = -\frac{1}{\rho\pi}$ from (4.7) and exploiting the first-order condition of period 1, we obtain $E_0\left[\pi u'(G_{2g}^*)\frac{\partial G_{2g}^*}{\partial B_{01}}\right] = 0$. Using (4.7) again, this can be written out as:

$$E_0\left[\pi u'(G_{2g})\left(\frac{1+v'(B_{01})+(B_{01}-\bar{B}_{01})v''(B_{01})}{\sigma\rho\pi_0} - \frac{1}{\rho\pi}\right)\right] = 0. \quad (4.8)$$

This first-order condition can be rewritten further as:

$$[1 + v'(B_{01}) + (B_{01} - \bar{B}_{01})v''(B_{01})]\left[1 + Cov_0\left(\frac{u'(G_{2g})}{E_0[u'(G_{2g})]}, \frac{\pi}{\pi_0}\right)\right] = \sigma. \quad (4.9)$$

Because $\sigma < 1$, for a positive solution to $v'(B_{01})$, we need that $Cov_0\left(\frac{u'(G_{2g})}{E_0[u'(G_{2g})]}, \frac{\pi}{\pi_0}\right) < \sigma - 1 < 0$. Appendix 4.A shows that using a first-order Taylor approximation of $u'(G_{2g})$ around the point $\pi = \pi_0$ and

assuming CARA utility, i.e. $u(x) = -\exp(-\alpha x)$. Hence, we can write the first-order condition (4.9) as:

$$[1 + v'(B_{01}) + (B_{01} - \overline{B_{01}})v''(B_{01})] \left[1 - \alpha \text{Var}_0(\pi) \left(\frac{G'_{2g}(\pi_0)}{\pi_0} \right) \right] = \sigma. \quad (4.10)$$

To simplify the algebra, we set $\rho = 1$ from now on. Appendix 4.A also shows that

$$\frac{G'_{2g}(\pi_0)}{\pi_0} = \frac{1}{\pi_0} \frac{1}{(1+\pi_0)^2} \left[\bar{y} + B_{01} - \overline{B_{02}} + \frac{(1+v'(B_{01}))(B_{01} - \overline{B_{01}})}{\sigma \pi_0} \right] > 0. \quad (4.11)$$

In the sequel we make the simplifying assumption that the initial amount of short-term debt is optimal (again, indicated by superscript *), i.e. $\overline{B_{01}} = B_{01}^*$. This assumption eliminates the income effects associated with changes in bond prices.³⁹ Hence, for (4.10) to have a solution, we will assume from now on that

$$\alpha \text{Var}_0(\pi) \left(\frac{\bar{y} + \overline{B_{01}} - \overline{B_{02}}}{\pi_0(1+\pi_0)^2} \right) < 1.$$

In other words, the variance of the repayment probability and the CARA coefficient are assumed to be not too high. Finally, Appendix 4.A also shows that the second-order condition is fulfilled under weak assumptions.

³⁹ When doing the comparative statics, we always differentiate with respect to B_{01} first, after which we impose $\overline{B_{01}} = B_{01}^*$.

4.2.3 The term premium and the spread between long and short yields

Using (4.4) and (4.6), the spread between the long- and short-term yields, henceforth “spread”, is

$$\sqrt{\frac{1}{P_{02}}} - \frac{1}{P_{01}} = \sqrt{\frac{1}{\sigma\pi_0}} - \frac{1}{1+v'(B_{01})} = \frac{1}{\sigma} \left[\sqrt{\frac{\sigma}{\pi_0}} + \alpha \text{Var}_0(\pi) \left(\frac{G'_{2g}(\pi_0)}{\pi_0} \right) - 1 \right],$$

where the second equality is obtained using the first-order condition (4.10) evaluated at $\overline{B_{01}} = B_{01}^*$. A sufficient, by no means necessary, condition for the spread to be positive is $\pi_0 < \sigma$. A higher variance in the repayment probability and a higher coefficient of absolute risk aversion both raise the spread.

The “term premium”, defined here as the expected excess return of the long-term bond over the short-term bond between periods 0 and 1, is

$$E_0 \left[\frac{P_{12}}{P_{02}} - \frac{1}{P_{01}} \right] = E_0 \left[\frac{\pi}{\sigma\pi_0} \right] - \frac{1}{1+v'(B_{01})} = \frac{1}{\sigma} - \frac{1}{1+v'(B_{01})} = \frac{\alpha \text{Var}_0(\pi) (G'_{2g}(\pi_0)/\pi_0)}{\sigma} > 0.$$

where have made use of (4.4) – (4.6) and where the final equality is obtained using the first-order condition (4.10) evaluated at $\overline{B_{01}} = B_{01}^*$. Hence, the term premium is positive. The most-left expression is the return from holding a long-term bond minus the return from holding a short-term bond from period 0 to period 1. The long-term bond is bought at a price P_{02} and sold at a price P_{12} (the pay-offs of the long-term bond and the new short-term bond are the same in period 1, hence their prices must also be the same). The short-term bond is bought at a price P_{01} in period 0 and sold at a price of 1 in period 1. The first term in the third equality is the yield on the long-term bond between time 0 and time 1,

while the second-term is that on the short-term bond over the same period. Hence, the term premium consists of a risk premium, captured by σ , and a liquidity premium on the short-term debt, captured by the term $v'(B_{01})$. The higher the degree of risk aversion, i.e. the lower is σ , the higher the term premium.

4.2.4 Testable propositions

We are now ready to explore a number of implications of our theoretical setup. In this subsection we show the comparative statics for three different shocks:

- An increase in investor risk aversion via a reduction in σ .
- A reduction in expected fiscal revenue through a fall in the expected likelihood π_0 that the state in period 2 is good
- An exogenous increase in the preference for liquidity services $v'(B_{01})$, i.e. an episode of increased flight-to-safety or a flight-to-liquidity.

We are now ready to state the implications of our theoretical setup. The first proposition deals with an increase in investor risk aversion:

Proposition 1: An increase in the risk aversion of international investors, i.e. a reduction in σ , leads in period 0 to (1) a shortening of the maturity structure, i.e. a higher B_{01}^ and a lower B_{02}^* , (2) a higher short-term bond yield (i.e. P_{01} falls) and a higher long-term bond yield (i.e. P_{02} falls), and (3) an increase in the term premium.*

Appendix 4.A demonstrates Part (1) by differentiating (4.10) and evaluating at $\overline{B_{01}} = B_{01}^*$. The optimal maturity structure, determined by the trade-off between the risk-premium on the long-term bond and the liquidity premium of the short-term bond is altered such that the first-order condition for B_{01} continues to hold. Concretely, when risk aversion increases, hence the risk premium on the long-term bond rises, the liquidity services provided by short-term debt have to increase to restore the equilibrium. This is accomplished by shortening the maturity structure. Regarding Part (2), the effect on P_{01} follows immediately from (4.4), and the effect on P_{02} follows immediately from (4.6). Appendix 4.A proves Part (3) by differentiating expression $E_0 \left[\frac{P_{12}}{P_{02}} - \frac{1}{P_{01}} \right] = \frac{1}{\sigma} - \frac{1}{1+v'(B_{01})}$ with respect to σ and using (4.10) and (4.11) while evaluating at $\overline{B_{01}} = B_{01}^*$. We are not able to establish an unambiguous effect of σ on the spread. While an increase in risk aversion has a direct positive effect on the spread, there is an opposite negative effect resulting from a shortening of the maturity structure.

Next, we have the effect of a reduction in expected fiscal revenue. This is modelled by a reduction in the expected probability π_0 of a good state, i.e. of debt repayment, in period 2:

Proposition 2: A reduction in the expected probability of repayment π_0 leads in period 0 to (1) a lengthening of the maturity structure, i.e. a lower B_{01}^ and a higher B_{02}^* ; (2) a reduction in the short-term bond yield (i.e. P_{01} rises), an increase in the long-term bond yield (i.e. P_{02} falls), and, hence, an increase in the spread; and (3) an increase in the term premium.*

Appendix 4.A demonstrates Part (1) by differentiating (4.10) and evaluating at $\overline{B_{01}} = B_{01}^*$. Issuing long-term debt is relatively expensive compared to short-term debt. However, the government refrains from issuing short-term debt only, because of the roll-over risk in period 1. A reduction of π_0 makes the government less wealthy and, in effect, increases its relative risk aversion. A given variance of the actual repayment probability around π_0 leads to higher (expected) marginal utilities of the government in periods 1 and 2 if the actual probability of repayment in period 2 falls below the expected repayment probability, which induces the government to issue more long-term debt in order to limit these fluctuations in marginal utility. Part (2) of Proposition 2 follows immediately from (4.4) and (4.6). Hence, we observe that the slope of the yield curve increases. Finally, Part (3) follows from (4.4) – (4.6) and $E_0 \left[\frac{P_{12}}{P_{02}} - \frac{1}{P_{01}} \right] = \frac{1}{\sigma} - \frac{1}{1+v'(B_{01})}$, which increases as a result of the lengthening of the maturity structure.

Finally, we have the effect of an increase in the preference for monetary services:

Proposition 3: Assume that $v(B_{01}) = \gamma f(B_{01})$, where γ is a positive constant. An increase in γ leads to (1) a shortening of the maturity structure, i.e. a higher B_{01}^ and a lower B_{02}^* , (2) a reduction in the short-term bond yield (i.e. P_{01} rises), an unchanged long-term bond yield (i.e. P_{02} remains unchanged), and, hence, an increase in the spread; and (3) an increase in the term premium.*

Appendix 4.A demonstrates Part (1) by differentiating (4.10) and evaluating at $\overline{B_{01}} = B_{01}^*$. Part (2) follows by differentiating (4.4), which yields $\frac{dP_{01}}{d\gamma} = f'(B_{01}^*) + \gamma f''(B_{01}^*) \frac{dB_{01}^*}{d\gamma}$. Appendix 4.A shows that

$\gamma f''(B_{01}^*) \frac{dB_{01}^*}{d\gamma} > -\frac{1}{2}f'(B_{01}^*)$, hence P_{01} rises and the result for the short-term bond yield follows. The absence of a change in the long-term bond yield follows immediately from (4.6). Finally, because $E_0 \left[\frac{P_{12}}{P_{02}} - \frac{1}{P_{01}} \right] = \frac{1}{\sigma} - \frac{1}{1+\gamma f'(B_{01})}$ and P_{01} rises, the term premium rises as well.

4.3 Data description and definitions of empirical variables

We compile a database of all public debt auctions by Germany, The Netherlands, France, Belgium, Italy and Spain from 1 January 1999 to 31 December 2017. The countries in our sample are the six largest issuers of public debt in the euro area. In total these countries count for more than 90% of the outstanding stock of debt of the euro area. The auction data is taken from Bloomberg and countries' debt management offices, which reports for each auction the auction date, the maturity of the new issue and the total amount allotted. We cross-check the Bloomberg data with data from the countries' debt management offices. For a more detailed discussion, see also Beetsma *et al.* (2018a, b).

For each country we calculate the weighted average time to maturity (WAM) of newly-issued debt as:

$$WAM_t = \frac{\sum_{m=2}^{50} m * AUC_S_{m,t}}{\sum_{m=2}^{50} AUC_S_{m,t}}, \quad (4.12)$$

where $\sum_{m=2}^{50} AUC_S_{m,t}$ denotes the volume of maturity- m debt auctioned in period t , which can be monthly or quarterly. The range for m results from the fact that we exclude bill issuance with a maturity up to and

including 1 year,⁴⁰ and from the fact that 50 year is the longest maturity for which bonds were issued in our time sample. We exclude bill issuance with a maturity up to and including 1 year because they have a tendency to cause erratic and rather volatile patterns in the WAM.⁴¹ There are two major reasons to exclude bill issuance. First, in their annual funding plans debt management officers distinguish *ex-ante* between bill issuance and bond issuance. Second, they use bill issuance as a buffer for cyclical and unexpected funding needs, such as the cyclical in tax revenues and financial sector support, which are outside the scope of our model.⁴² Hence, it seems far-fetched to view bill issuance as part of a systematic maturity strategy. We also exclude foreign currency debt and inflation-linked debt from our analysis.⁴³

Figure 4.1 shows the WAM of the newly-issued debt at the monthly and quarterly frequency. The peaks at the monthly frequency are higher than at the quarterly frequency. The reason is that in periods in which there is a 30-year issue, the effect of it on the WAM is averaged out to a larger extent within a quarter than within a month by the shorter issues (30-year issues are on average accompanied by a larger number of short issues in a quarter than in a month). Note that at the monthly frequency, the Netherlands and Belgium often have months without bond issuance. We exclude months or quarters in which a country does not issue debt from the empirical analysis.

⁴⁰ For Spain the shortest maturity we include in calculating the WAM is 18 months.

⁴¹ Porath (2015) includes Treasury bill issues when he calculates the WAM.

⁴² For example, Figure 2B in Greenwood *et al.* (2015) exhibits a cyclical pattern in bill issuance for the U.S. that seems related to deadlines for tax payments. De Haan (2009) shows that of the total intervention of 80.5 billion euros in the Dutch financial sector in the fall of 2008, the Dutch Treasury funded 65.5 billion with bill issuance.

⁴³ ECB (2018) shows that the share of foreign currency debt in the countries in our sample is limited. Issuance of inflation-linked debt in OECD countries increased by two-and-a-half times between 2007 and 2015, but its share in central government debt is limited to around 10% for Italy and France and is even lower for the other countries in our sample (OECD, 2017)

We also collect secondary market yields on euro-area debt from Thomson Reuters Datastream. For Belgium and Spain, we collect data on 1-year yields from the national central bank, which is available for the full sample period. For The Netherlands, data on 1-year secondary market yields is available only from 2007 onwards, so we use 2-year yields from 1999 to 2006. Figure 4.2 shows the 1-year secondary market yield and the spread between 10-year and 1-year secondary market yields.

We collect data on a number of additional variables. We obtain the Chicago Board of Exchange VIX, which measures stock market volatility implied by option prices. From Oxford Economics we collect an index constructed out of sovereign credit ratings from the three major credit rating agencies, Fitch, Moody's and Standard & Poor's. It ranges from 0 to 20, where a value of 20 corresponds to the highest possible rating level and is assigned to a country that has an AAA rating from all three credit rating agencies. From Eurostat we obtain industrial production in the manufacturing sector. We gather Merrill Lynch euro area corporate bond indices for AAA- and BBB-rated debts. The series for the VIX, the Oxford Economics credit rating index, and the Merrill Lynch corporate bond index are obtained from Thomson Reuters Datastream. Finally, we obtain the KfW-Bund spread kindly made available by Roberto de Santis.

4.4 Results

The model developed in the Section 2 yields empirical predictions about the relationship between the WAM and the yield curve, as well as about the shock sources driving this relationship. Propositions 1 and 2 predict a negative relationship between the WAM and level of the yield curve, while Proposition 3 predicts a positive relationship. Further, Propositions 1 and 3 predict a negative relationship between the WAM and the spread,

while Proposition 2 predicts a positive relationship. To investigate these hypotheses, this section starts by estimating a baseline relationship between the WAM and the yield curve for the euro area countries in our sample. This is followed by some robustness checks. Because the propositions make some conflicting predictions about the baseline relationship, in a next step we explore how the underlying shock sources directly affect the properties of the yield curve and the maturity structure, thereby providing a more direct assessment of the above hypotheses. Finally, this part of the analysis suggests instruments for a renewed estimation of the relationship between the WAM and the yield curve using instrumental variables.

In the sequel, the “level” of the yield curve refers to the yield on 1-year debt, while the “spread” refers to the long-short spread between 10-year and 1-year debt.

4.4.1 Baseline regression of WAM on yield curve

Our baseline is a regression of the WAM on the level and spread of the yield curve:

$$WAM_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^s D_{j,t} + \beta ST_YIELD_{i,t-1} + \gamma SPREAD_{i,t-1} + \varepsilon_{i,t} \quad (4.13)$$

where c_i is a constant, $\delta_i t$ is a time trend, $ST_YIELD_{i,t}$ is the short-term (one-year) secondary-market yield, $SPREAD_{i,t}$ is the spread, $D_{j,t}$ is a dummy for season j , and $\varepsilon_{i,t}$ is a disturbance term. We always use end-of-month or end-of-quarter values for yields. We use the first lag of the short-term yield and the spread to prevent potential feedback effects that

may arise if yields respond to the maturity of debt issuance.⁴⁴ We include seasonal dummies to account for possible seasonal issuance patterns. For instance, countries typically issue less new debt during the summer months and in December, and we cannot *a priori* exclude that this lower issuance activity is systematically related to the maturity of the issues. Equation (4.13) is estimated at the monthly and quarterly frequency using OLS with Newey-West adjusted standard errors to correct for potential serial correlation and heteroscedasticity in the error terms. The seasonal dummies are month dummies for the monthly estimations and quarter dummies for the quarterly estimations. We estimate equation (4.13) at the country level and as a panel with country fixed-effects and country-specific time trends. Here, country-specific time trends account for potential country-specific trends in debt issuance.

Table 4.1 reports the estimates. For all the countries we find that both the coefficient on the short-term yield and that on the spread are negative. The individual country estimates are strongest for Italy and Spain, for which the coefficients on both variables are (highly) significantly negative. The fact that the individual country parameter estimates are all of identical sign, motivates us to estimate the model as a panel. In addition to estimating the model for the full panel including all countries, we also estimate it for a sub-sample panel of Germany, The Netherlands, France, and Belgium (GNFB), and a sub-sample panel consisting of Italy and Spain (IS). The rationale behind the split in these two sub-panels is that the former group of countries is generally considered to belong to the euro-area core, while the other two countries belong to the periphery of the euro area. The (sub-) panel estimates are also found in Table 4.1. For both the full panel and the two sub-panels, we find (highly) significantly negative coefficients on both the short interest

⁴⁴ In Section 4.4 we will use an instrumental variable approach.

rate (in line with Propositions 1 and 2) and the spread (in line with Propositions 1 and 3). The estimates are also significant in economic terms. For example, for the full sample monthly frequency panel, the effect of a one percentage point upward shift in the yield curve is associated with a reduction in the WAM by 0.6 year, while an increase in the spread by one percentage point is associated with a reduction in the WAM by one year. The magnitudes of the estimated effects with quarterly data are very similar. These magnitudes may seem large. However, one needs to realize that the effects on the maturity structure of the full debt stock of changes in the yield curve can only be small, because the existing debt stock can only be rolled over gradually. In fact, if a government intends to meaningfully adjust the maturity structure of its debt stock in response to a change in the yield curve, then it is forced to substantially change the maturity structure of its new debt issues. Overall, our results would suggest that risk aversion of market participants is the dominant source of shocks. Of course, this does not preclude that other shocks play a role driving the yield curve and the WAM.

4.4.2 Robustness

We explore the robustness of our estimations in various ways. First, we replicate our baseline monthly regression taking twelve-month rolling windows for the WAM, the short-term yield and the spread. Hence, $WAM_{i,t}$ is now calculated as the average of expression (4.12) over the months $t, t-1, \dots, t-11$, while $ST_YIELD_{i,t-1}$ and $SPREAD_{i,t-1}$ are averages over the months $t-1, \dots, t-12$. The rationale for this variant is that the relatively infrequent occurrence of the new debt auctions may cause unwarranted noise in the calculation of the WAM. Obviously, the averaging introduces serial correlation into the regression error term, which is handled by using Newey-West standard errors. The results are

presented in Table 4.B.1. The estimates of the coefficients on the short-term yield and the spread remain negative and highly significant, confirming the baseline estimates. Also the sizes of the estimated coefficients are not too far from their baseline values. The averaging approach is potentially prone to feedback effects from the WAM onto the current and future yield curve. Therefore, in Table 4.B.1 we also report the estimates when the rolling windows of the short-term yield and the spread are lagged by twelve months. We observe that all the full panel and sub-panel estimates remain highly significant and negative.

We also explore whether our estimates differ in the period before the global economic and financial crisis from those during and after the crisis. Hence, we split the sample period into a period before the start of the crisis, indicated with a dummy variable $DPRE$, and a period since the start of the crisis. Specifically, $DPRE$ has a value of 1 over the period 1 January 1999 – 30 June 2007, and zero otherwise. We allow the coefficients in our baseline regression to differ between the two periods. Hence, the regression equation becomes:⁴⁵

$$\begin{aligned}
 WAM_{i,t} = & \delta_i t + \mu \sum_{j=1}^s D_{j,t} + DPRE * (c_{1,i} + \beta ST_YIELD_{i,t-1} + \gamma SPREAD_{i,t-1}) \\
 & + (1 - DPRE)(c_{2,i} + \theta ST_YIELD_{i,t-1} + \varphi SPREAD_{i,t-1}) \\
 & + \varepsilon_{i,t}
 \end{aligned}$$

Table 4.B.2 in the Appendix reports the results. As before, for the full panel and the two sub-panels the estimates of the coefficients of the short-term yield and the spread are always negative. In many instances the coefficients are (highly) significant. Nevertheless, on average the results

⁴⁵ In order to economize on the number of symbols, we re-use them (such as, for example, β and γ) here and in subsequent regression equations – hence their estimated values vary with the estimating equation.

are weaker in terms of significance than those for the baseline model, which may not be surprising, as the number of observations per sub-period is only roughly half the number of the full sample period. Comparing between the two sub-periods, we observe that the estimates for the second sub-period are more significant on average, which may be explained by the generally larger variability in this sub-sample. Nevertheless, the differences in the parameter estimates between the two sub-periods are limited. This is also brought out by the tests for the equality of the coefficients between the two sub-periods, which are only significant in two quarterly panel regressions (the full panel and the Italy-Spain subpanel) for the hypothesis of identical level effects in the two sub-periods, while the equality of the coefficients of the spread and the joint hypothesis that the level and the spread have identical coefficients in the two sub-periods is only once rejected.

4.4.3 Factors underlying the WAM – yield curve relationship

The previous subsection provided strong evidence of negative relationship between the WAM and both the level and spread of the yield curve. The estimated relationship between the WAM and the yield curve level is in line with Propositions 1 and 2, suggesting that shocks to risk aversion and repayment risk are relatively important, while the relationship between the WAM and the spread is in line with Proposition 3, pointing to the relevance of shocks in the need for liquidity. It is conceivable that all sources of shocks are relevant, but that one or two dominate the other(s) in their effects on the relationship between the WAM and the yield curve.

This subsection aims at directly exploring the factors underlying the relationship between the yield curve and the WAM, so as to shed further light on the relevance of the different shock sources. Therefore, we first try to find variables that can potentially proxy for the various shock

sources in our theoretical framework. As a measure of investors' risk aversion, we use the Chicago Board of Exchange VIX, for example, see Bekaert *et al.* (2013) and Groen and Peck (2014).⁴⁶ We use two variables to capture expected fiscal revenue. The first is the monthly year-on-year growth of industrial production, which for Belgium is available from the start of 2001 and for the other countries for the full sample period. An increase in industrial production growth is often perceived as a leading indicator of an expansion in future economic activity, which tends to be a major driver of an improvement in the public budget. Our second measure of expected fiscal revenue is based on the index we construct of the sovereign credit ratings. We demean this variable with the cross-country average in order to get an indicator of the sovereign credit rating relative to the other countries in our sample.⁴⁷ Use of a measure of the relative credit rating is motivated by the possibility that sovereign bond markets are (partially) segmented with investors allocating a given fraction of their budget to euro area sovereign debt (e.g., see Beetsma *et al.*, 2018b). Given the budget for investing in euro area debt, they would then allocate their investments within the euro area among others on the basis of relative credit ratings. Hence, by combining industrial production growth and our relative credit rating variable, we capture both the "absolute" and "relative" ability to repay debt. Finally, following Krishnamurthy and Vissing-Jorgensen (2012), we use the spread between BBB- and AAA-rated corporate bonds to proxy for the demand for safety. They include separate measures for the demand for short- and long-term safety. The short-term safety premium follows from the money-like properties of

⁴⁶ Bekaert *et al.* (2013) decompose the VIX into a risk aversion component and an uncertainty component (based on stock market volatility).

⁴⁷ Preliminary regressions showed that the relative credit rating performs better than the actual credit rating.

short-term government debt, such as its extreme safety and its use as collateral in many financial transactions and by banks as liquid assets to back short-term liabilities. The short-term safety premium is captured by the BBB - AAA corporate bond spread with a maturity from 1 to 3 years.⁴⁸ In a segmented market the long-term safety premium would in particular be driven by investors with a special demand for long-term payoffs, such as pension funds. In addition, as Greenwood, Hanson and Stein (2015) argue, also long-term debt can provide monetary services when it is used as collateral for short-term borrowing. The long-term safety premium is captured by the BBB - AAA corporate bond spread with a maturity of 10 year and higher.

Figure 4.3 plots the aforementioned variables. Note that for the core countries France, Germany and the Netherlands the credit rating index is at its maximum until February 2012, so that for the credit rating index only four separate lines are visible up to then. The VIX peaks during periods commonly seen as turbulent, in particular the second half of 2008 and the end of 2011. These also roughly correspond to the periods when the safety premia are highest. The short-term and long-term safety premia are clearly positively correlated, but they certainly do not always move in tandem. Relative credit ratings are pretty constant during most of the sample period. However, they start to diverge and fluctuate more since mid-2010 when the euro area sovereign debt crisis started to erupt. Growth of industrial production decreases sharply during the global financial crisis and recovers thereafter. Table 4.B.3 reports the correlations of these variables. Not surprisingly, the safety premia tend to

⁴⁸ In Krishnamurthy and Vissing-Jorgensen (2012), the US short-term safety premium as captured by the BBB - AAA corporate spread is shown to decrease if the supply of US Treasuries increases. They conclude that this is due to a safety preference that gets satisfied when supply increases. In their paper, the safety premium is assumed to reflect the utility derived by investors from holding safe short-term debt. Greenwood, Hanson and Stein (2015) explicitly refer to Krishnamurthy and Vissing-Jorgensen (2012) when they introduce $v(\cdot)$ into their model. The safety premium could be seen as substitutes that measures $v'(\cdot)$.

be higher when market uncertainty (the VIX) is higher. Interestingly, in all respects we see a clear division between the two groups of countries already distinguished above, i.e. the core group of Germany, Netherlands, Belgium and France, and the periphery group Italy and Spain. The relative ratings of the first group are all negatively correlated with the VIX. An explanation might be that the relative ratings of the periphery countries tend to deteriorate when market uncertainty increases, meaning that, since these are *relative* ratings, the latter tend to improve for the core countries at the same time. We also note that the relative credit ratings of the countries in the core group are positively correlated among themselves. Growth of industrial production is strongly negatively correlated with the VIX and with our measures of short-term and long-term safety. Finally, correlations of industrial production growth with the relative credit rating measure are low.

We can now present regressions aimed at unearthing the shock sources. Specifically, the baseline for this part of the analysis is formed by the following three equations that we estimate by OLS applying Newey-West standard errors:

$$ST_YIELD_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^S D_{j,t} + \beta X_{i,t-1} + \varepsilon_{i,t}, \quad (4.14)$$

$$SPREAD_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^S D_{j,t} + \beta X_{i,t-1} + \varepsilon_{i,t}, \quad (4.15)$$

$$WAM_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^S D_{j,t} + \beta X_{i,t-1} + \varepsilon_{i,t}, \quad (4.16)$$

where X_t contains the short- and long-term safety premium, the VIX, industrial production growth and the relative credit rating variable. We also include the ECB interest rate on Main Refinancing Operations, MRO_t , to control for the effect of the risk-free rate on the level and the

slope of the yield curve.⁴⁹ To avoid potential feedback effects from the dependent to the independent variables, we include the latter with a one-period lag. Tables 2 – 4 report the estimates of (4.14) – (4.16), respectively, at both the monthly and quarterly frequency. We discuss first the effects on yield curve characteristics, as captured by the short-term yield and the spread. This is followed by a discussion of the results for the WAM.

Table 4.2 shows that, not surprisingly, the short-term yield is always strongly positively linked to the ECB's instrument. The coefficient is generally above 0.90 for the monthly estimations and above 0.80 for the quarterly estimations. The relationship between the spread and the ECB instrument is rather irregular.

The VIX, as a proxy of investor risk aversion, exerts in all instances a (highly) significant negative effect on the short-term yield (Table 4.2) and a positive effect on the spread that is significant for the full panel and the subpanel of the core countries for both the monthly and quarterly estimates (Table 4.3). The effect on the short-term yield contradicts Proposition 1, while the effect on the spread is in line with Proposition 1.

Now, we turn to the effects of the variables intended to capture the ability to repay the public debt. Consistent with Proposition 2, an increase in the growth of industrial production for the full panel and the Italy-Spain subpanel significantly raises the short-term yield (Table 4.2) and reduces the spread (Table 4.3). It has no effect on the core-country sub-panel. As regards the relative credit rating, for the full panel and the periphery sub-panel there appears to be no effect on the short rate, while we observe a highly significant negative effect for the core subsample

⁴⁹ This is analogous to Gagnon *et al.* (2011), who include the U.S. federal funds rate in their regressions.

(Table 4.2). Further, an increase in the relative credit rating has a (highly) significant negative effect on the spread for the full panel and the two sub-panels (Table 4.3).⁵⁰

Finally, we consider the effects of an increase in the short-term safety premium. Rather surprisingly at first sight, when considering the full panel we observe a positive relationship between the short-term safety premium and the short-term yield. However, splitting the full panel into the two sub-panels, we find, in line with Proposition 3 of the theory in Section 2, a (highly) significant negative relationship between the short-term safety premium and the short-term yield of the core countries and a highly significant positive relationship for the periphery countries, which suggests that when the demand for short-term safety increases investors substitute away from periphery to core short-term debt. In other words, the short-term debt of the periphery may not be considered safe by investors. The spread is in all instances (highly) significantly and positively related to the short-term safety premium (Table 4.2), which suggests that an increase in the demand for short-term safety induces investors to substitute away from long towards short-term debt. The effect on the spread is in line with what Proposition 3 predicts. An increase in the long-term safety premium has in all instances a negative effect on the short-term yield (Table 4.2) and no effect on the spread (Table 4.3). While not formally modeled above, this could suggest a general shift of investors from other, risky instruments into sovereign debt.

Table 4.4 reports the estimates of equation (4.16) for the WAM. In line with Proposition 3, in all instances the short-term safety variable is negative, and so is the long-term safety variable. However, the variables are only significant for the periphery sub-panel. The VIX is significant

⁵⁰ In fact, while not shown here, dropping industrial production from the regression has virtually no effect on the estimates of the coefficients on the relative credit rating.

and negative only for the quarterly estimation for the core sub-panel, which would be in line with Proposition 1 that an increase in risk aversion leads to a reduction in the average debt maturity. Higher growth of industrial production is also significant only in one instance, namely for the quarterly sub-panel of the periphery, where, in line with Proposition 2, an increase in industrial production growth implies a shortening of the maturity structure. The relative credit rating yields mixed results: a higher value exerts a negative effect on the WAM for the core and a positive effect for the periphery.

We now conduct a number of robustness checks on regressions (4.14) – (4.16). First, we replace the short-term and long-term safety variables by the KfW-Bund spread. The KfW-Bund spread is the difference between the Kreditanstalt für Wiederaufbau (KfW) loan rate and the rate on German public debt of the same maturity. Because KfW loans are guaranteed by the German government, default risk is identical to that on regular public debt. Hence, the difference between the two rates is most likely attributable to differences in liquidity. An increase in the KfW-Bund spread would correspond to an upward shift in $v'(\cdot)$ in the theoretical model, hence imply an increase in the demand for liquidity. Our implicit assumption is that the KfW-Bund spread measures illiquidity not only for Germany, but also for the other countries in our sample.⁵¹ Figure 4.3 plots the KfW-Bund spread. We observe that it peaks around 2008 and 2012, moments when the global and European financial and debt crises reached their zeniths. Unfortunately, the KfW-Bund spread is only available as of January 2, 2006, hence the sample period becomes substantially shorter, thereby undermining the potential to find significant results and complicating the comparability with the original estimates in

⁵¹ De Santis (2014) finds that the KfW-Bund spread helps to explain the safe-haven role of German bunds during the crisis.

Table 4.1. Still, the estimates for the level and the spread of the yield curve and the WAM reported in Tables A.4 – A.6 are rather similar to those presented in Tables 2 – 4. In terms of sign and significance the coefficient on the KfW-Bund spread corresponds to that on the short-term safety variable – in fact, in the case of the WAM the evidence of maturity shortening in response to an increase in liquidity preference becomes even stronger, while the coefficient estimates on the other variables are largely unaffected. Only for the spread estimates the sign of industrial production becomes ambiguous for monthly data.

To investigate the robustness of the estimates of (4.14) – (4.16), we re-estimate these equations using the VSTOXX, which is the variant of the VIX based on the stocks in the Eurostoxx50. The results, reported in Tables A.7 – A.9 for the short yield, the spread and the WAM, respectively, are rather similar to those for the regressions with the VIX. In fact, in the case of the WAM, the evidence of maturity shortening in response to an increase in the short-term safety premium becomes even slightly stronger. There are some instances in which the long-term safety premium weakens, while there are also some instances in which the coefficient on the VSTOXX is insignificant in contrast to that on the VIX.

4.4.4 Instrumental variables estimation of the baseline regression

The variables used above to capture the underlying shock sources would be natural instruments for a re-estimation of our baseline relationship between the WAM and the yield curve. *A priori*, we do not see a strong reason to use instrumental variables. Instrumental variables regression would in particular be warranted in the case of a feedback from the dependent variable, the WAM, onto the explanatory variables. We already enter the explanatory variables with a lag, which would help in ameliorating any endogeneity issues, while we do not see any obvious

economic reasons for such a feedback.⁵² Indeed, Table 4.5, which repeats the estimates of equation (4.13) replacing ST_YIELD_{t-1} and $SPREAD_{t-1}$ by their values in period t , reports estimates of the coefficients on the short rate and the spread that are very similar in size and significance as the corresponding estimates in Table 4.1.

Nevertheless, as an additional check on the estimates of the relationship between the WAM and the current yield curve, we re-estimate (4.13) with instrumental variables. The instruments are the first lags of our measures for the short- and long-term safety premium, the VIX, the growth of industrial production, the relative credit rating variable and the rate on the ECB's main refinancing operations. The results are found in Table 4.6. These are very similar to those in Table 4.1. For the full panel and both frequencies the WAM is (highly) significantly negatively related to the short-term yield and the spread. This is also the case for the sub-panels in the quarterly-frequency estimation and the spread in the monthly estimation. Only the short-term yield loses significance in the core-country monthly sub-panel, although the coefficients are still negative for both country groups.

As a robustness check, in Table 4.B.10 of the Appendix we replace as an instrument the rate on the ECB's main refinancing operations by the U.S. federal funds rate (*FFR*). The motivation is that, unlike the U.S. federal funds rate, it is not excluded that the rate on the ECB's main refinancing operations responds to developments in the euro-area financial market. The results weaken in terms of significance, although the signs of the coefficients always remain negative and significant in most cases, and their magnitudes remain comparable to the

⁵² Greenwood and Vayanos (2015) find for the U.S. that bond yields and future returns are positively related to the maturity-weighted debt-to-GDP ratio. The idea is that risk averse arbitrageurs need to bear more duration risk if the maturity-weighted debt-to-GDP ratio increases, which they require compensation for.

original ones. The weakening of the significance is likely the result of the U.S. federal funds rate being a weaker instrument.⁵³

As a final robustness check we repeat the rolling-window regressions with instrumental variables. Table 4.B.11 reports the monthly estimates for a twelve-month rolling window of the WAM and the explanatory variables up to $t-1$ and the instrumental variables dated $t-1$ or lagged to $t-12$. In both cases the estimated coefficients on the short-term yield and the spread remain highly significantly negative for the panel and the two sub-panels with coefficients not too different from the original ones reported in Table 4.1.

4.5 Conclusion

The recent euro area debt crisis has brought public debt management to the forefront, as it showed the risks associated with high amounts of sovereign debt to be rolled over. In this paper, we have investigated the determinants of the maturity structure of euro area sovereign debt over the period since the inception of the EMU. Using a unique and comprehensive database of sovereign bond issues of six euro-area countries for the period 1 January 1999 to 31 December 2017, we focused on the maturity structure of new debt issues, which can be more easily steered in the direction preferred by the Treasury than the full stock of outstanding debt, of which the maturity structure is only a slow-moving variable.

We started constructing a theoretical framework with a maturity choice driven by the trade-off between the liquidity services provided by safe short-term debt, the danger of a debt roll-over crisis and price risk from holding long-term debt. We found strong evidence of a negative

⁵³ Replacing *MRO* with *FFR* in the estimation of (4.14) and (4.15) generally leads to some reduction in explanatory power. The estimated coefficients on *MRO* are in all instances (substantially) larger in absolute magnitude than those on *FFR* in (4.14) and (4.15).

relationship between the weighted average maturity of new debt and the level and spread of the yield curve. Based on our theoretical framework, the negative relationship with the level of the yield curve is in line with a dominance of risk preference and repayment risk shocks, while the negative relationship with the spread suggests a role liquidity preference shocks. Further analysis suggests a substantial role for liquidity preference shocks exerting effects that generally go into the direction predicted by our theoretical framework. Evidence on the role of the other shock sources is weaker and, when they are found to be significant, the support for the theoretical framework is mixed. Changes in repayment risk, both absolute and relative, are most visible in their effect on the spread, where their effects appear to be in line with our theory.

The main limitation of our analysis is that we are forced to capture the fundamental shock sources in our theoretical framework with variables that are imperfect proxies of their theoretical counterparts. Finding variables that more accurately capture the theoretical shocks would be a useful avenue for further research.

Appendix 4.A

Derivation of (4.10) starting from (4.9)

Using a first-order Taylor approximation of $u'(G_{2g})$ around the point $\pi = \pi_0$, we can write:

$$u'(G_{2g}(\pi)) = u'(G_{2g}(\pi_0)) + (\pi - \pi_0)u''(G_{2g}(\pi_0))G'_{2g}(\pi_0).$$

Hence,

$$\frac{u'(G_{2g})}{E_0[u'(G_{2g})]} = 1 + (\pi - \pi_0) \frac{u''(G_{2g}(\pi_0))G'_{2g}(\pi_0)}{u'(G_{2g}(\pi_0))}$$

Substituting this expression into the covariance term in (4.9), this term can be written as:

$$Cov_0 \left(\frac{u'(G_{2g})}{E_0[u'(G_{2g})]}, \frac{\pi}{\pi_0} \right) = Var_0(\pi) \left(\frac{u''(G_{2g}(\pi_0))G'_{2g}(\pi_0)}{u'(G_{2g}(\pi_0))\pi_0} \right)$$

Substitute this expression into (4.9) and assume CARA utility, i.e. $u(x) = -exp(-ax)$. The result follows immediately.

Proof of (4.11)

Take (4.7), set $\rho = 1$, and insert $G_1^* = G_{2g}^*$, so as to give:

$$(1 + \pi)G_{2g} = \pi \left[\bar{y} - \bar{B}_{02} + \frac{(1+v'(B_{01}))(B_{01} - \bar{B}_{01})}{\sigma\pi_0} \right] - B_{01}$$

Hence,

$$G_{2g} = \frac{\pi}{1+\pi} \left[\bar{y} - \overline{B_{02}} + \frac{(1+v'(B_{01}))(B_{01}-\overline{B_{01}})}{\sigma\pi_0} \right] - \frac{1}{1+\pi} B_{01}$$

Differentiating with respect to π , holding constant π_0 , and then imposing $\pi = \pi_0$, yields

$$\frac{1}{\pi_0} G'_{2g}(\pi_0) = \frac{1}{\pi_0} \frac{1}{(1+\pi_0)^2} \left[\bar{y} + B_{01} - \overline{B_{02}} + \frac{(1+v'(B_{01}))(B_{01}-\overline{B_{01}})}{\sigma\pi_0} \right]$$

Second-order condition

We differentiate the left-hand side of (4.8) with respect to B_{01} . Applying $B_{01} = \overline{B_{01}}$ and $\rho = 1$, this yields:

$$E_0 \left\{ \pi u''(G_{2g}^*) \frac{dG_{2g}^*}{dB_{01}} \left[\frac{1+v'(\overline{B_{01}})}{\sigma\pi_0} - \frac{1}{\pi} \right] + \pi u'(G_{2g}^*) \frac{2v''(\overline{B_{01}})}{\sigma\pi_0} \right\}$$

Since $\frac{dG_{2g}^*}{dB_{01}} > 0$, a sufficient, but by no means necessary, condition is that $\pi > \sigma\pi_0/(1 + v'(\overline{B_{01}}))$, hence, if π is bounded from below at a not too low value.

Intermediate results

Differentiating (4.11) with respect to B_{01} and then imposing $B_{01} = \overline{B_{01}}$ yields:

$$\frac{1}{\pi_0} \frac{dG'_{2g}(\pi_0)}{dB_{01}} = \frac{1}{\pi_0} \frac{1}{(1+\pi_0)^2} \left[1 + \frac{1+v'(\overline{B_{01}})}{\sigma\pi_0} \right] > 0$$

Hence,

$$-[1 + v'(\overline{B_{01}})]\alpha Var_0(\pi) \frac{1}{\pi_0} \frac{dG'_{2g}(\pi_0)}{dB_{01}} = -[1 + v'(\overline{B_{01}})]\alpha Var_0(\pi) \left[\frac{1 + \sigma\pi_0 + v'(\overline{B_{01}})}{\sigma(\pi_0(1 + \pi_0))^2} \right] < 0.$$

Further, differentiating (4.10) and imposing $B_{01} = \overline{B_{01}}$ yields:

$$\begin{aligned} \frac{1}{\pi_0} \frac{dG'_{2g}(\pi_0)}{d\sigma} &= 0, \\ \frac{d(G'_{2g}(\pi_0)/\pi_0)}{d\pi_0} &= -\frac{(1 + 3\pi_0)(\overline{y} + \overline{B_{01}} - \overline{B_{02}})}{\pi_0^2(1 + \pi_0)^3}, \\ \frac{1}{\pi_0} \frac{dG'_{2g}(\pi_0)}{d\gamma} &= 0, \end{aligned}$$

where the last expression is obtained for the case in which we can write $v'(B_{01}) = \gamma f'(B_{01})$.

The effect of σ

Differentiating (4.10) and evaluating at $B_{01} = \overline{B_{01}}$ yields:

$$\left\{ 2 \left[1 - \alpha Var_0(\pi) \left(\frac{\overline{y} + \overline{B_{01}} - \overline{B_{02}}}{\pi_0(1 + \pi_0)^2} \right) \right] v''(\overline{B_{01}}) - \right. \\ \left. [1 + v'(\overline{B_{01}})]\alpha Var_0(\pi) \left[\frac{1 + \sigma\pi_0 + v'(\overline{B_{01}})}{\sigma(\pi_0(1 + \pi_0))^2} \right] \right\} dB_{01} = d\sigma.$$

The term in the first pair of square brackets is positive, hence $\frac{dB_{01}}{d\sigma} < 0$.

The effect of π_0

Differentiating (4.10) and evaluating at $B_{01} = \overline{B_{01}}$ yields

$$\begin{aligned} & \left\{ 2 \left[1 - \alpha \text{Var}_0(\pi) \left(\frac{\bar{y} + \overline{B_{01}} - \overline{B_{02}}}{\pi_0(1+\pi_0)^2} \right) \right] v''(\overline{B_{01}}) - \right. \\ & \left. [1 + v'(\overline{B_{01}})] \alpha \text{Var}_0(\pi) \left[\frac{1 + \sigma \pi_0 + v'(\overline{B_{01}})}{\sigma(\pi_0(1+\pi_0))^2} \right] \right\} dB_{01} + \\ & [1 + v'(\overline{B_{01}})] \alpha \text{Var}_0(\pi) \frac{(1+3\pi_0)(\bar{y} + \overline{B_{01}} - \overline{B_{02}})}{\pi_0^2(1+\pi_0)^3} d\pi_0 = 0. \end{aligned}$$

Since the term preceding dB_{01} is negative and that preceding $d\pi_0$ is positive, $\frac{dB_{01}}{d\pi_0} > 0$.

The effect of γ

Let $v'(B_{01}) = \gamma f'(B_{01})$ and differentiate (4.10) with respect to γ :

$$\begin{aligned} & \left\{ \left[\frac{\sigma}{1+v'(\overline{B_{01}})} \right] 2\gamma f''(\overline{B_{01}}) - [1 + v'(\overline{B_{01}})] \alpha \text{Var}_0(\pi) \left[\frac{1 + \sigma \pi_0 + v'(\overline{B_{01}})}{\sigma(\pi_0(1+\pi_0))^2} \right] \right\} dB_{01} + \\ & \left[\frac{\sigma}{1+v'(\overline{B_{01}})} \right] f'(\overline{B_{01}}) d\gamma = 0, \end{aligned}$$

or

$$\begin{aligned} & \left\{ 2\sigma\gamma f''(\overline{B_{01}}) - (1 + v'(\overline{B_{01}}))^2 \alpha \text{Var}_0(\pi) \left[\frac{1 + \sigma \pi_0 + v'(\overline{B_{01}})}{\sigma(\pi_0(1+\pi_0))^2} \right] \right\} dB_{01} + \\ & \sigma f'(\overline{B_{01}}) d\gamma = 0. \end{aligned}$$

Hence, as $f'(\overline{B_{01}}) > 0$ and $f''(\overline{B_{01}}) < 0$, we find $\frac{dB_{01}}{d\gamma} > 0$.

The effect of σ on the term premium (Proposition 1)

Differentiate the expression for the term premium $TP = E_0 \left[\frac{P_{12}}{P_{02}} - \frac{1}{P_{01}} \right] = \frac{1}{\sigma} - \frac{1}{1+v'(B_{01})}$, with respect to σ , to give

$$\frac{dTP}{d\sigma} = -\frac{1}{\sigma^2} + \frac{1}{(1+v'(B_{01}))^2} v''(B_{01}) \frac{dB_{01}}{d\sigma}$$

Differentiating (4.10), while also using (4.11) and evaluating at $B_{01} = \overline{B_{01}}$, we have:

$$\left\{ \left[\frac{2\sigma}{1+v'(\overline{B_{01}})} \right] v''(\overline{B_{01}}) - [1 + v'(\overline{B_{01}})] \alpha Var_0(\pi) \left[\frac{1+\sigma\pi_0+v'(\overline{B_{01}})}{\sigma(\pi_0(1+\pi_0))^2} \right] \right\} dB_{01} = d\sigma.$$

Hence,

$$\begin{aligned} \frac{v''(\overline{B_{01}})}{(1+v'(\overline{B_{01}}))^2} \frac{dB_{01}}{d\sigma} &= \frac{v''(\overline{B_{01}})/(1+v'(\overline{B_{01}}))^2}{\left[\frac{2\sigma}{1+v'(\overline{B_{01}})} \right] v''(\overline{B_{01}}) - [1+v'(\overline{B_{01}})] \alpha Var_0(\pi) \left[\frac{1+\sigma\pi_0+v'(\overline{B_{01}})}{\sigma(\pi_0(1+\pi_0))^2} \right]} = \\ &= \frac{v''(\overline{B_{01}})}{(1+v'(\overline{B_{01}})) \left[2\sigma v''(\overline{B_{01}}) - (1+v'(\overline{B_{01}}))^2 \alpha Var_0(\pi) \left[\frac{1+\sigma\pi_0+v'(\overline{B_{01}})}{\sigma(\pi_0(1+\pi_0))^2} \right] \right]} < \frac{1}{2\sigma}. \end{aligned}$$

Hence,

$$\frac{dTP}{d\sigma} < -\frac{1}{\sigma^2} + \frac{1}{2\sigma} < 0.$$

Table 4.1: WAM and yield curve

$$WAM_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^S D_{j,t} + \beta ST_YIELD_{i,t-1} + \gamma SPREAD_{i,t-1} + \varepsilon_{i,t}$$

Monthly									
	DE	NL	FR	BE	IT	ES	Full panel	Panel GNFB	Panel IS
β	-0.22	-0.13	-0.26	-1.37**	-0.52***	-0.67***	-0.62***	-0.58**	-0.63***
γ	-0.27	-1.63***	-0.85***	-1.29*	-0.42**	-1.42***	-1.06***	-1.09***	-0.98***
Adj. R ²	0.47	0.01	0.17	0.13	0.12	0.14	0.17	0.19	0.18
Obs.	225	179	207	152	227	219	1209	763	446
Quarterly									
	DE	NL	FR	BE	IT	ES	Panel	Panel GNFB	Panel IS
β	-0.36***	-0.70	-0.46	-1.80**	-0.55***	-0.67**	-0.73***	-0.87***	-0.63***
γ	-0.47**	-1.63***	-1.03***	-1.46**	-0.51***	-1.19***	-1.03***	-1.20***	-0.88***
Adj. R ²	0.35	0.09	0.14	0.17	0.13	0.24	0.32	0.32	0.32
Obs.	76	76	76	75	76	76	455	303	152

Notes: Estimation is for the period January 1, 1999 – December 31, 2017. Estimation method is Ordinary Least Squares (OLS) with Newey-West adjusted standard errors. The columns under the headers “Full panel”, “Panel GNFB” and “Panel IS” report panel OLS regressions estimated with country fixed effects. Further, *, ** and *** denote significance at the 10%-, 5%-, and 1%-levels, respectively. Finally, “Panel GNFB” is the sub-panel

Table 4.2: Short-term yields and underlying shock sources

$$ST_YIELD_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^S D_{j,t} + \beta X_{i,t-1} + \varepsilon_{i,t}$$

	Monthly			Quarterly		
	Full panel	Panel GNFB	Panel IS	Full panel	Panel GNFB	Panel IS
ST Safety	0.11***	-0.08***	0.52***	0.09**	-0.08*	0.42***
LT Safety	-0.06**	-0.12***	-0.01	-0.04	-0.10*	-0.05
VIX	-0.03***	-0.02***	-0.05***	-0.04***	-0.03***	-0.06***
Rating	-0.02	-0.18***	-0.04	0.02	-0.19***	0.03
IP	0.01***	0.00	0.03***	0.01**	0.01	0.03**
MRO	0.94***	0.91***	0.95***	0.85***	0.81***	0.83***
Adj. R ²	0.91	0.96	0.83	0.88	0.93	0.79
Obs.	1338	884	454	442	292	150

Notes: See Notes to Table 4.1. Further, “ST Safety” is our short-term safety measure based on the BBB - AAA corporate bond spread with a maturity from 1 to 3 years, “LT Safety” is our long-term safety measure based on the BBB - AAA corporate bond spread with a maturity of 10 years or higher, “Rating” is our relative rating measure, “IP” is growth of industrial production and “MRO” is the ECB’s interest rate on Main Refinancing Operations.

Table 4.3: Spreads and underlying shock sources

$$SPREAD_{i,t} = c_i + \delta_{it} + \mu \sum_{j=1}^S D_{j,t} + \beta X_{i,t-1} + \varepsilon_{i,t}$$

	Monthly			Quarterly		
	Full panel	Panel GNFB	Panel IS	Full panel	Panel GNFB	Panel IS
ST Safety	0.35***	0.34***	0.34***	0.34***	0.33***	0.35***
LT Safety	-0.04	-0.04	-0.08	-0.06	-0.06	-0.04
VIX	0.01***	0.01***	0.00	0.01***	0.02***	0.01
Rating	-0.13***	-0.18***	-0.11***	-0.13***	-0.11**	-0.16***
IP	-0.01***	0.00	-0.04***	-0.02***	-0.01	-0.02**
MRO	-0.54***	-0.56***	-0.54***	-0.44***	-0.45***	-0.41***
Adj. R ²	0.70	0.70	0.69	0.67	0.65	0.66
Obs.	1338	884	454	442	292	150

Notes: See Notes to Tables 4.1 and 4.2.

Table 4.4: WAM and underlying shock sources

$$WAM_{i,t} = c_i + \delta_{it} + \mu \sum_{j=1}^S D_{j,t} + \beta X_{i,t-1} + \varepsilon_{i,t}$$

	Monthly			Quarterly		
	Full panel	Panel GNFB	Panel IS	Full panel	Panel GNFB	Panel IS
ST Safety	-0.28	-0.15	-0.62***	-0.28	-0.20	-0.58***
LT Safety	-0.28	-0.45	-0.55**	-0.23	-0.39	-0.56*
VIX	-0.02	-0.05	0.03	-0.03	-0.05*	0.03
Rating	0.20	-0.53*	0.50***	0.18	-0.55*	0.44***
IP	0.00	-0.01	-0.03	0.00	0.01	-0.05*
MRO	-0.02	-0.18	-0.09	-0.28*	-0.52**	-0.22
Adj. R ²	0.17	0.19	0.16	0.31	0.34	0.25
Obs.	1186	742	444	441	291	150

Notes: See Notes to Tables 4.1 and 4.2.

Table 4.5: WAM and yield curve – contemporaneous explanatory variables

$$WAM_{i,t} = c_0 + \delta_i t + \mu \sum_{j=1}^S D_{j,t} + \beta ST_YIELD_{i,t} + \gamma SPREAD_{i,t} + \varepsilon_{i,t}$$

	Monthly			Quarterly		
	Full panel	Panel GNFB	Panel IS	Full panel	Panel GNFB	Panel IS
β	-0.54***	-0.48*	-0.59***	-0.62***	-0.77***	-0.55***
γ	-1.03***	-1.06***	-0.94***	-1.11***	-1.36***	-0.85***
Adj. R ²	0.17	0.19	0.17	0.32	0.33	0.30
Obs.	1209	763	446	455	303	152

Notes: See Notes to Table 4.1.

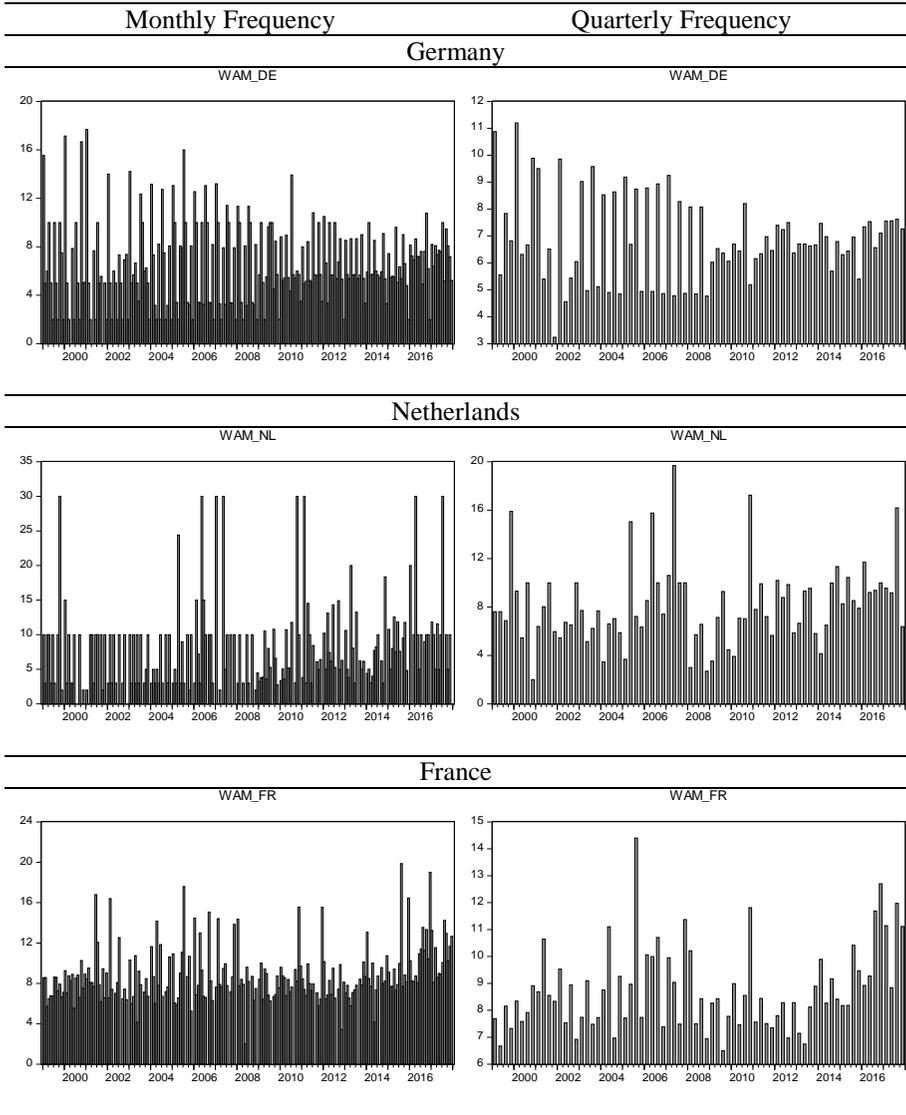
Table 4.6: Instrumental variables regression

$$WAM_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^S D_{j,t} + \beta ST_YIELD_{i,t} + \gamma SPREAD_{i,t} + \varepsilon_{i,t}$$

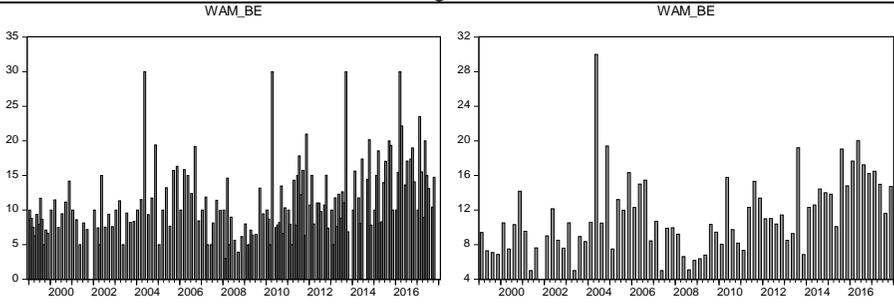
	Monthly			Quarterly		
	Full panel	Panel GNFB	Panel IS	Full panel	Panel GNFB	Panel IS
β	-0.72***	-0.46	-0.62***	-1.05***	-1.10***	-0.59**
γ	-1.26***	-0.95**	-1.08***	-1.47***	-1.64***	-0.96***
Adj. R ²	0.17	0.19	0.17	0.31	0.33	0.29
Obs.	1186	742	444	441	291	150

Notes: Estimation method is Instrumental Variables (IV) regression with Newey-West adjusted standard errors, where $ST_YIELD_{i,t}$ and $SPREAD_{i,t}$ are instrumented with the first lag of the short-term safety premium, the long-term safety premium, the VIX, the relative credit rating, industrial production growth and the interest rate on Main Refinancing Operations. Further, see Notes to Table 4.1.

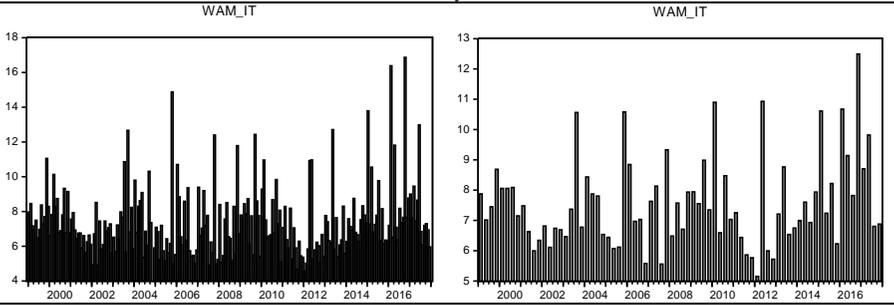
Figure 4.1: Weighted average maturity of bond issues at monthly frequency



Belgium



Italy



Spain

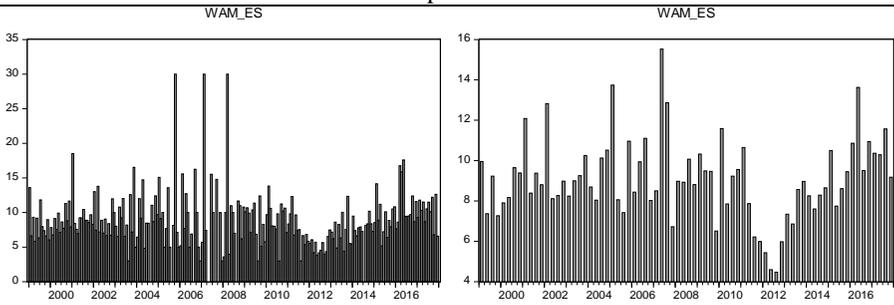


Figure 4.2: Secondary market yields

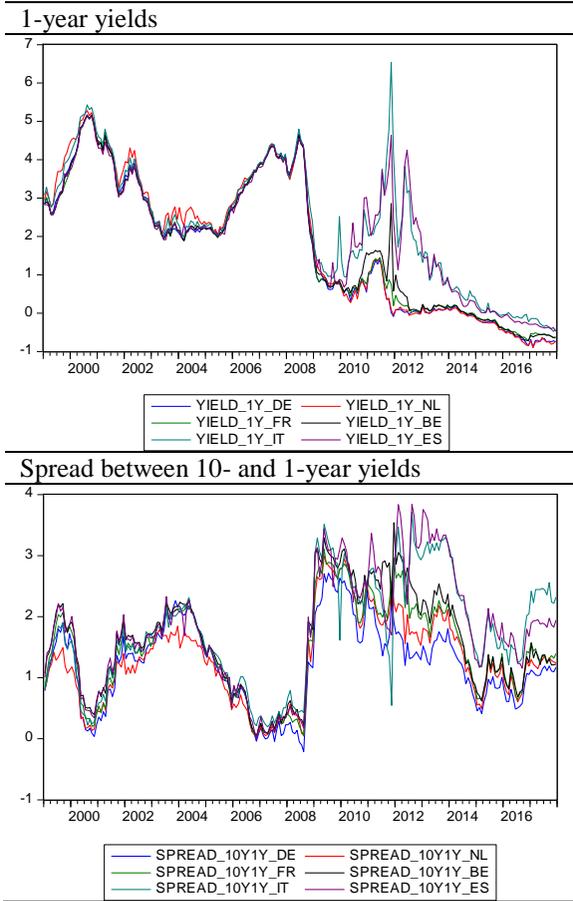
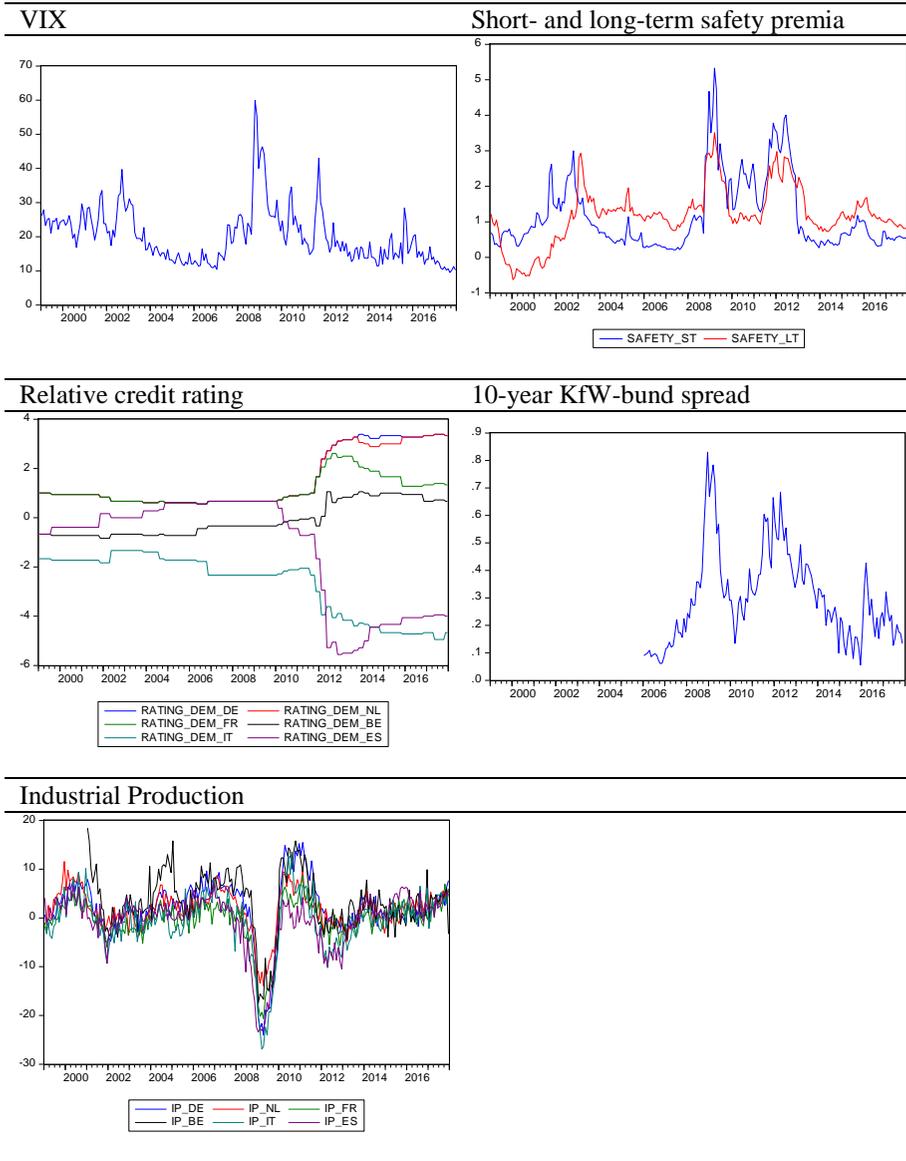


Figure 4.3: Variables to capture underlying shocks



Appendix 4.B: Additional tables

Table 4.B1: WAM and the yield curve – using 12-month rolling variables

	$WAM_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^S D_{j,t} + \beta ST_YIELD_{i,t-1} + \gamma SPREAD_{i,t-1} + \varepsilon_{i,t}$			$WAM_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^S D_{j,t} + \beta ST_YIELD_{i,t-12} + \gamma SPREAD_{i,t-12} + \varepsilon_{i,t}$		
	Monthly			Monthly		
	Full panel	Panel GNFB	Panel IS	Full panel	Panel GNFB	Panel IS
β	-0.73***	-0.89***	-0.62***	-1.05***	-1.33***	-0.70***
γ	-1.30***	-1.52***	-1.09***	-1.03***	-1.20***	-1.01***
Adj. R ²	0.64	0.64	0.65	0.66	0.67	0.62
Obs.	1368	912	456	1302	868	434

Notes: Here, $WAM_{i,t}$ is a rolling average over the months $t, t-1, \dots, t-11$; $ST_YIELD_{i,t-1}$ and $SPREAD_{i,t-1}$ are rolling averages over the months $t-1, \dots, t-12$; and $ST_YIELD_{i,t-12}$ and $SPREAD_{i,t-12}$ are rolling averages over the months $t-12, \dots, t-23$. Further, see Notes to Table 4.1.

Table 4.B.2: Split between before-crisis and crisis periods

	$WAM_{i,t} = \delta_i t + \mu \sum_{j=1}^S D_{j,t} + DPRE * (c_{1,i} + \beta ST_YIELD_{i,t-1} + \gamma SPREAD_{i,t-1}) + (1 - DPRE)(c_{2,i} + \theta ST_YIELD_{i,t-1} + \varphi SPREAD_{i,t-1}) + \varepsilon_{i,t}$					
	Monthly			Quarterly		
	Full panel	Panel GNFB	Panel IS	Full panel	Panel GNFB	Panel IS
β	-0.34*	-0.11	-0.46*	-0.17	-0.14	-0.18
γ	-0.81**	-0.54	-0.87**	-0.31	-0.24	-0.37
θ	-0.54***	-0.30	-0.67***	-0.50***	-0.40*	-0.60***
φ	-0.78***	-0.51	-0.98***	-0.64***	-0.49	-0.79***
$\beta = \theta$	0.98	0.44	0.73	3.73*	1.14	4.87**
$\gamma = \varphi$	0.01	0.00	0.07	1.11	0.30	1.31
Joint test	0.59	0.27	0.37	2.18	0.63	2.92*
Adj. R ²	0.18	0.20	0.18	0.36	0.36	0.31
Obs.	1209	763	446	455	303	152

Notes: $DPRE$ is a dummy with value 1 over the period January 1, 1999 – June 30, 2007. Further, see Notes to Table 4.1.

Table 4.B.3: Correlations between variables

	VIX	ST_SAFETY	LT_SAFETY	RR_DE	RR_NL	RR_FR	RR_BE	RR_IT
ST_SAFETY	0.62							
LT_SAFETY	0.23	0.59						
RR_DE	-0.40	-0.17	0.06					
RR_NL	-0.40	-0.16	0.07	1.00				
RR_FR	-0.28	0.04	0.14	0.85	0.85			
RR_BE	-0.33	-0.07	0.21	0.94	0.93	0.80		
RR_IT	0.37	0.12	-0.15	-0.96	-0.96	-0.77	-0.96	
RR_ES	0.37	0.11	-0.08	-0.98	-0.97	-0.93	-0.92	0.90
IP_DE	-0.36	-0.40	-0.43	-0.06	-0.06	-0.07	-0.04	0.09
IP_NL	-0.37	-0.48	-0.58	-0.05	-0.05	-0.13	-0.09	0.08
IP_FR	-0.47	-0.51	-0.51	0.14	0.14	0.06	0.09	-0.08
IP_BE	-0.28	-0.44	-0.50	-0.19	-0.19	-0.21	-0.17	0.21
IP_IT	-0.39	-0.52	-0.54	0.07	0.06	-0.06	0.04	-0.02
IP_ES	-0.52	-0.69	-0.58	0.16	0.15	-0.02	0.07	-0.07

Notes: Correlation at monthly frequency. The credit rating instruments are relative credit ratings. “RR_X” denotes the relative credit rating of country X.

Table 4.B.4: Short-term yields and underlying shock sources – KfW-Bund spread replaces ST and LT Safety variables

$ST_YIELD_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^S D_{j,t} + \beta X_{i,t-1} + \varepsilon_{i,t}$						
	Monthly			Quarterly		
	Full Panel	Panel GNFB	Panel IS	Full Panel	Panel GNFB	Panel IS
KfW	0.36**	-1.04***	4.08***	-0.35	-1.42***	2.38***
VIX	-0.03***	-0.02***	-0.04***	-0.03***	-0.02***	-0.04***
Rating	-0.07**	-0.02	-0.08*	-0.01	0.02	-0.03
IP	0.01***	0.00	0.07***	0.01*	0.01	0.05***
MRO	0.83***	0.90***	0.67***	0.66***	0.75***	0.49***
Adj. R ²	0.90	0.97	0.84	0.89	0.95	0.80
Obs.	858	572	286	282	188	94

Notes: See Notes to Tables 4.1 and 4.2. “KfW” is KfW-Bund spread.

Table 4.B.5: Spreads and underlying shock sources – KfW-Bund spread replaces ST and LT Safety variables

$$SPREAD_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^s D_{j,t} + \beta X_{i,t-1} + \varepsilon_{i,t}$$

	Monthly			Quarterly		
	Full Panel	Panel GNFB	Panel IS	Full Panel	Panel GNFB	Panel IS
KfW	2.83***	2.76***	3.05***	2.71***	2.60***	3.10***
VIX	0.01***	0.01***	-0.01	0.01***	0.01**	0.01
Rating	-0.17***	-0.26***	-0.09**	-0.17***	-0.23***	-0.13*
IP	0.00	0.01***	-0.01**	0.00	0.01	0.00
MRO	-0.71***	-0.71***	-0.70***	-0.59***	-0.61***	-0.55***
Adj. R ²	0.77	0.78	0.73	0.75	0.74	0.70
Obs.	858	572	286	282	188	94

Notes: See Notes to Tables 4.1, 4.2 and 4.B.4

Table 4.B.6: WAM and underlying shock sources – KfW-Bund spread replaces ST and LT Safety variables

$$WAM_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^s D_{j,t} + \beta X_{i,t-1} + \varepsilon_{i,t}$$

	Monthly			Quarterly		
	Full Panel	Panel GNFB	Panel IS	Full Panel	Panel GNFB	Panel IS
KfW	-4.17***	-3.04*	-4.78***	-3.41***	-2.34	-4.36**
VIX	-0.01	-0.07*	0.02	-0.01	-0.06*	0.01
Rating	0.29	-0.78	0.53***	0.27	-0.62	0.48**
IP	-0.02	-0.03	-0.04	-0.01	0.00	-0.05
MRO	0.10	-0.08	0.45*	-0.09	-0.25	0.29
Adj. R ²	0.19	0.21	0.18	0.41	0.46	0.21
Obs.	770	491	279	282	188	94

Notes: See Notes to Tables 4.1, 4.2 and 4.B.4

Table 4.B.7: Short-term yields and shock sources, replacing VSTOXX by VIX

$$ST_YIELD_{i,t} = c_i + \delta_{it} + \mu \sum_{j=1}^s D_{j,t} + \beta X_{i,t-1} + \varepsilon_{i,t}$$

	Monthly			Quarterly		
	Full panel	Panel GNFB	Panel IS	Full panel	Panel GNFB	Panel IS
ST Safety	0.09***	-0.10***	0.54***	0.05	-0.11***	0.41***
LT Safety	-0.03	-0.09***	0.08	0.00	-0.05	0.08
VSTOXX	-0.02***	-0.02***	-0.04***	-0.03***	-0.02***	-0.05***
Rating	-0.01	-0.16***	-0.07**	0.03	-0.14**	-0.02
IP	0.02***	0.01**	0.05***	0.02***	0.01*	0.04***
MRO	0.90***	0.88***	0.91***	0.78***	0.77***	0.78***
Adj. R ²	0.91	0.96	0.83	0.88	0.93	0.80
Obs.	1338	884	454	442	292	150

Notes: See Notes to Tables 4.1 and 4.2.

Table 4.B.8: Spreads and shock sources, replacing VSTOXX by VIX

$$SPREAD_{i,t} = c_i + \delta_{it} + \mu \sum_{j=1}^s D_{j,t} + \beta X_{i,t-1} + \gamma MRO_{t-1} + \varepsilon_{i,t}$$

	Monthly			Quarterly		
	Full panel	Panel GNFB	Panel IS	Full panel	Panel GNFB	Panel IS
ST Safety	0.40***	0.39***	0.36***	0.39***	0.39***	0.38***
LT Safety	-0.04	-0.05	-0.07	-0.08*	-0.08	-0.06
VSTOXX	0.00	0.00	-0.01	0.00	0.00	0.00
Rating	-0.13***	-0.18***	-0.12***	-0.14***	-0.12**	-0.16***
IP	-0.02***	-0.01**	-0.04***	-0.02***	-0.01*	-0.03***
MRO	-0.52***	-0.54***	-0.53***	-0.41***	-0.42***	-0.39***
Adj. R ²	0.70	0.69	0.69	0.66	0.64	0.65
Obs.	1338	884	454	442	292	150

Notes: See Notes to Tables 4.1 and 4.2.

Table 4.B.9: WAM and shock sources, replacing VSTOXX by VIX

$WAM_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^s D_{j,t} + \beta X_{i,t-1} + \varepsilon_{i,t}$						
	Monthly			Quarterly		
	Full Panel	Panel GNFB	Panel IS	Full Panel	Panel GNFB	Panel IS
ST Safety	-0.39**	-0.38	-0.70***	-0.35**	-0.38	-0.60***
LT Safety	-0.27	-0.41	-0.62**	-0.19	-0.31	-0.65**
VSTOXX	0.00	0.00	0.04	-0.01	-0.02	0.03
Rating	0.20	-0.52	0.52***	0.18	-0.51	0.48***
IP	0.00	0.00	-0.04	0.00	0.02	-0.06**
MRO	-0.06	-0.28	-0.08	-0.33**	-0.61***	-0.20
Adj. R ²	0.17	0.19	0.16	0.31	0.34	0.26
Obs.	1186	742	444	441	291	150

Notes: See Notes to Tables 4.1 and 4.2.

Table 4.B.10: Instrumental variable regression with US Federal Funds Rate

$WAM_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^s D_{j,t} + \beta ST_YIELD_{i,t} + \gamma SPREAD_{i,t} + \varepsilon_{i,t}$						
	Monthly			Quarterly		
	Panel	Panel GNFB	Panel IS	Panel	Panel GNFB	Panel IS
β	-0.46	0.28	-0.59**	-0.66*	-0.27	-0.41
γ	-1.19***	-0.71	-1.06***	-1.29***	-1.11**	-0.91***
Adj. R ²	0.17	0.18	0.17	0.32	0.32	0.28
Obs.	1186	742	444	441	291	150

Notes: Estimation method is Instrumental Variables regression (IV) with Newey-West standard errors. Here, $ST_YIELD_{i,t}$ and $SPREAD_{i,t}$ are instrumented with the first lag of the short-term safety premium, the long-term safety premium, the VIX, the relative credit rating, industrial production growth and the US Federal Funds Rate. Further, see Notes to Table 4.1.

Table 4.B.11: Instrumental variables regression – using 12-month rolling variables

	$ST_YIELD_{i,t}$ and $SPREAD_{i,t}$ instrumented with $X_{i,t-1}$			$ST_YIELD_{i,t}$ and $SPREAD_{i,t}$ instrumented with $X_{i,t-12}$		
	Panel	Panel GNFB	Panel IS	Panel	Panel GNFB	Panel IS
β	-0.77***	-0.74***	-0.65***	-1.37***	-1.23***	-0.59***
γ	-1.37***	-1.34***	-1.20***	-1.60***	-1.83***	-0.91***
Adj. R ²	0.65	0.65	0.65	0.62	0.65	0.65
Obs.	1338	884	454	1272	840	432

Notes: Estimation method is Instrumental Variables regression (IV). Here, $WAM_{i,t}$ is a rolling average over the months $t, t-1, \dots, t-11$; $X_{i,t-1}$ is a rolling average for the short-term safety premium, the long-term safety premium, the VIX, the relative credit rating, industrial production growth and the interest rate on Main Refinancing Operations over the months $t-1, \dots, t-12$; likewise, $X_{i,t-12}$ is a rolling average of these variables over the months $t-12, \dots, t-23$. Further, see Notes to Table 4.1.