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**The Amsterdam Centre for European Studies**

SSRN Research Paper 2019/03

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## **Abstract**

We use information on new sovereign debt issues in the euro area to explore the drivers behind the debt maturity decisions of governments. We set up a theoretical model for the maturity structure that trades off preference for liquidity services of short-term debt, roll-over risk and price risk. The average debt maturity is negatively related to both the level and the slope of the yield curve. A panel VAR analysis shows that positive shocks to risk aversion, the probability of non-repayment and the demand for the liquidity services of short-term debt all have a positive effect on the yield curve level and slope, and a negative effect on the average maturity of new debt issues. These results are partially in line with our theory. A forecast error variance decomposition suggests that changes in non-repayment risk as captured by credit default spreads are the most important source of shocks.

Keywords: Maturity, euro-area public debt auctions, yield curve, liquidity services of short debt, risk aversion, expected repayment probability.

JEL codes: G11, G12, G18, E62.

## 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 shorter maturities. 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 those countries. Such concerns may re-emerge in the future, for example if interest rate increases raise the financing costs of high-debt countries.

In this paper, we investigate the determinants of the maturity structure of the public debt using a newly-constructed comprehensive database of sovereign bond issues in the euro area from 1 January 1999 to 31 December 2017. Our empirical analysis is motivated with a theoretical model that trades off the liquidity providing benefits and lower costs of holding short-term debt against the likelihood of a debt roll-over crisis resulting from unexpected increases in repayment risk. Our model extends the Broner *et al.* (2013) model of debt maturity choice in the presence of fiscal risk by including the liquidity services of safe short-term debt. This setup combines 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).<sup>1</sup> 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 showed that fiscal risks can also be non-negligible for advanced economies. This is particularly the case for countries that are member of a monetary union such as the euro area, since money printing can no longer be used as a last resort to service the government debt. Moreover, despite the possible occurrence of elevated fiscal risk, euro-area sovereign debt may also carry a liquidity premium.

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<sup>1</sup> 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.

Hence, our model combines the risk of non-repayment of long-term debt (“fiscal risk”) with investors’ preferences for the liquidity services of safe short debt.

Our empirical analysis focuses on the maturity structure of *new* debt issues rather than that 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. The main results are the following. We find strong evidence that the average maturity of newly-issued euro-area public debt is negatively related to the level of the yield curve and somewhat weaker evidence of a negative relationship between the average debt maturity and the slope of yield curve. We then perform a panel VAR analysis that shows that positive shocks to risk aversion, the expected probability of non-repayment and the demand for the liquidity services of short debt all raise the level and the slope of the yield curve, while reducing the weighted average maturity of new debt. These effects are partly in line with our theory. In particular, the responses to an increase in risk aversion are consistent with our theory, while the responses to a reduction in the expected repayment probability or an increase in the demand for the liquidity services of short debt are partially in line with our theory. Finally, a forecast error variance decomposition shows that the most important shock source driving the responses is a change in expected repayment risk, especially in the longer run.

Our paper is related to the literature on fiscal insurance, which suggests that debt management can provide insurance against fiscal shocks, thereby 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) demonstrate 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 in which 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. Finally, in the context of

a debt sustainability analysis, Athanasopoulou et al. (2018) optimize the maturity structure of public debt while trading off refinancing risk and borrowing costs.

Our analysis also relates to earlier empirical analyses of the determinants of the maturity of public debt. 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, while 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. 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. Using data on Eurozone sovereign debt auctions over the period 1999-2015, Eidam (2017) explores “gap-filling” behavior: governments increase long-term debt issuance following periods of low aggregate long-term debt issuance, and vice versa. 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), Broner *et al.* (2013), Bai *et al.* (2015) and Perez (2017) find that the maturity of newly-issued debt is shorter when the spread between short- and long-term debt is larger. 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), who suggests that extending debt maturities may result in lower debt in the long run.

Our analysis differs in various ways from previous work by (i) constructing a theoretical framework that combines shocks to risk preferences, fiscal risk and the demand for the liquidity services of short debt, which allows us to analyze the trade-offs among price risk of long-term debt, the provision of the liquidity services by short safe debt and roll-over risks associated with 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 driving both debt maturity and the yield curve. Also, our deployment of a panel VAR analysis is novel in analyzing the relationship among these types of financial variables.

The remainder of this paper 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 defines our measure of the WAM and describes our data. Section 4 presents the empirical results, first linking the WAM to the yield curve and then investigating the fundamental driving factors of the yield curve and the WAM. Finally, Section 5 concludes the main text of the paper.

## 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 builds upon Broner *et al.* (2013) by adding the liquidity services of short-term debt, and yields empirically testable implications about the responses of the maturity structure and the yield curve to shocks to risk aversion, the expected debt repayment probability and the demand for the liquidity services of short debt.

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 liquidity services that investors may derive from holding safe short-term government debt. These services are a key element in the model by Greenwood, Hanson and Stein (2015), which

focuses on how the preference for safe short-term debt affects the optimal maturity structure of the government debt.<sup>2</sup> 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, price risk and a potential safety premium on sovereign debt. This setup is particularly suitable in the context of euro-area sovereign debt (see e.g. Coeuré, 2016):

- Including default risk is not unreasonable in a model of sovereign debt issuance of euro-area countries: 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 euro-area sovereign bonds have dual-limb collective action clauses since 2013. Further, in December 2018 the Eurogroup expressed the intention to introduce single-limb collective action clauses and to enable the ESM to facilitate a dialogue between Member States and private investors in the case of a debt restructuring (Eurogroup, 2018).<sup>3</sup>
- At the same time, euro-area sovereign debt is used as a safe asset in financial transactions and in investors’ portfolios. For some 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.

## 2.1 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:

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

<sup>2</sup> Greenwood, Hanson and Stein (2015) further analyze the effect of short-term debt issuance on financial stability through its crowding-out effect on the 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 short-term public 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.

<sup>3</sup> 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).

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  $Pr(s)$  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:

$$P_{01}B_{01} + P_{02}B_{02} = P_{01}\overline{B}_{01} + P_{02}\overline{B}_{02}. \quad (2)$$

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:

$$B_{01} + G_1 = P_{12}B_{12}, \quad (3)$$

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 all outstanding debt is repaid, and a “bad” one, in which  $y = 0$  and none of the outstanding debt is repaid. Because the world “ends” in period 2, no new debt is issued in period 2. When viewed from the perspective of period 0, the chance  $\pi$  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, because short-term debt issued in period 1 is subject to default risk. Also, long-term debt issued in period 0 is unable to provide liquidity services as it is subject to price risk in period 1 and, therefore, not safe. 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. We assume that the risk-free short-term rate is zero in both periods, so  $E_0[m_1] = E_1[m_2] = 1$ .

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

$$P_{01} = E_0[m_1] + v'(B_{01}) = 1 + v'(B_{01}). \quad (4)$$

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  $\chi$  is an indicator denoting repayment in

period 2, hence  $\pi = E_1[\chi]$ . For convenience, and without loss in terms of results, we assume that the correlation between  $\chi$  and  $m_2$  is zero, hence international investors are risk-neutral with respect to period-1 short-term bonds, so:

$$P_{12} = \pi, \quad (5)$$

The price of period-0 long-term bonds is equal to  $P_{02} = E_0[P_{12}m_1] = E_0[\pi m_1]$ . We assume that the international investors are risk-averse with respect to period-0 long-term bonds and demand a premium to carry the risk of changing repayment probabilities. This implies that  $\pi$  and  $m_1$  are negatively correlated and the price of the two-period bond is

$$P_{02} = \sigma \pi_0, \quad (6)$$

where  $\pi_0 = E_0[\pi]$  and  $\sigma < 1$  is a constant parameter, which captures the risk premium required by the international investors in period 0.

## 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  $\pi$  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.<sup>4</sup> For  $B_{01} < P_{12}\bar{y}$  there will be strictly positive solutions for government consumption in period 1 and in period 2 in the good state (in the bad state in period 2, government consumption is zero).

We solve the government's optimization problem backwards.

### Period 1

Period-2 government consumption in the good state is:

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

With the period 1 government budget constraint in (3) and the bond price  $P_{12}$  in (5), we obtain, for given initial maturity structure, the relationship between public consumption in period 1 and in the good state in period 2:

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

Substituting into the government's objective function (1) and differentiating with respect to  $G_1$ , the first-order condition for period 1 is<sup>5</sup>

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

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<sup>4</sup> 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  $B_{01} < \underline{\pi}\bar{y}$ , where  $\underline{\pi} > 0$  is the lowest possible probability of a good state in period 2, so that  $P_{12} = \underline{\pi}$  is the lowest possible price of short-term debt in period 1.

<sup>5</sup> 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 abstracts from these complications.

## 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  $P_{02} = \sigma\pi_0$ , we can write the period-0 government budget constraint as:

$$B_{02} = \overline{B_{02}} - \frac{(1+v'(B_{01}))(B_{01}-\overline{B_{01}})}{\sigma\pi_0}$$

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

$$G_{2g} = \bar{y} - \overline{B_{02}} + \frac{(1+v'(B_{01}))(B_{01}-\overline{B_{01}})}{\sigma\pi_0} - \frac{G_1+B_{01}}{\pi}. \quad (7)$$

Substitution into the government's utility function yields:

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

where the superscript \* denotes the optimum, as evaluated in period 1. Differentiating  $U^*$  with respect to  $B_{01}$  yields the first-order condition:

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

Substituting  $\frac{\partial G_{2g}^*}{\partial G_1} = -\frac{1}{\pi}$  from (7) and exploiting the first-order condition of period 1, the period-0

first-order condition reduces to  $E_0\left[\pi u'(G_{2g}^*)\frac{\partial G_{2g}^*}{\partial B_{01}}\right] = 0$ . Using (7) again, this can be written out as:

$$E_0\left[\pi u'(G_{2g}^*)\left(\frac{1+v'(B_{01})+(B_{01}-\overline{B_{01}})v''(B_{01})}{\sigma\pi_0} - \frac{1}{\pi}\right)\right] = 0. \quad (8)$$

This first-order condition can be rewritten further as:

$$[1 + v'(B_{01}) + (B_{01} - \overline{B_{01}})v''(B_{01})] \left[ 1 + Cov_0 \left( \frac{u'(G_{2g})}{E_0[u'(G_{2g})]}, \frac{\pi}{\pi_0} \right) \right] = \sigma. \quad (9)$$

Because  $\sigma < 1$ , for a positive solution to  $v'(B_{01})$ , we need that  $Cov_0 \left( \frac{u'(G_{2g})}{E_0[u'(G_{2g})]}, \frac{\pi}{\pi_0} \right) < \sigma - 1 < 0$ .

Using a first-order Taylor approximation of  $u'(G_{2g})$  around the point  $\pi = \pi_0$  and assuming CARA utility, i.e.  $u(x) = -\exp(-ax)$ , the Appendix shows that we can write the first-order condition (9) as:

$$[1 + v'(B_{01}) + (B_{01} - \overline{B_{01}})v''(B_{01})] \left[ 1 - \alpha Var_0(\pi) \left( \frac{G'_{2g}(\pi_0)}{\pi_0} \right) \right] = \sigma. \quad (10)$$

The Appendix also shows that

$$\frac{G'_{2g}(\pi_0)}{\pi_0} = \frac{1}{\pi_0} \frac{1}{(1+\pi_0)^2} \left[ \bar{y} + B_{01} - \overline{B_{02}} + \frac{(1+v'(B_{01}))(B_{01} - \overline{B_{01}})}{\sigma \pi_0} \right] > 0. \quad (11)$$

Hence, for (10) to have a solution, we will from now on assume that

$$\alpha Var_0(\pi) \left( \frac{\bar{y} + \overline{B_{01}} - \overline{B_{02}}}{\pi_0(1+\pi_0)^2} \right) < 1.$$

In other words, the variance of the repayment probability and the CARA coefficient are assumed to be not too high.

Finally, the Appendix also shows that the second-order condition is fulfilled under weak assumptions. In particular, 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. In the sequel, we maintain this assumption.<sup>6</sup>

## 2.3 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  $\sigma$ .
- A reduction in expected fiscal revenue through a fall in the expected likelihood  $\pi_0$  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.

In the empirical analysis below, we characterize the yield curve by its level and its slope. The level is defined as the average between the short-term and the long-term yield, i.e. as  $\left(\frac{1}{P_{01}} + \sqrt{\frac{1}{P_{02}}}\right)/2$ , while the spread or slope is defined as the long-term minus the short-term yield, i.e. as:

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

where the second equality is obtained using the first-order condition (10) evaluated at  $\overline{B_{01}} = B_{01}^*$ . A sufficient, but by no means necessary, condition for the spread to be positive is that  $\pi_0 < \sigma$ . A higher variance in the repayment probability and a higher coefficient of absolute risk aversion on the side of the government both raise the spread.

Our first proposition deals with an increase in investor risk aversion:

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<sup>6</sup> Hence, when doing the comparative statics, we will always differentiate with respect to  $B_{01}$  first, after which we impose  $\overline{B_{01}} = B_{01}^*$ .

Proposition 1: *An increase in the risk aversion of international investors, i.e. a reduction in  $\sigma$ , leads in period 0 to:*

- (i) an upward shift in the level of the yield curve,*
- (ii) an ambiguous effect on the slope of the yield curve, and*
- (iii) a shortening of the maturity structure, i.e. a higher  $B_{01}^*$  and a lower  $B_{02}^*$ .*

Regarding Part (i), the upward shift in the yield curve level follows directly from falling prices  $P_{01}$  and  $P_{02}$  of both short- and long-term bonds. In turn, the effect on  $P_{01}$  follows immediately from (4) and the effect on  $P_{02}$  follows immediately from (6). Regarding Part (ii), we are not able to establish an unambiguous effect of  $\sigma$  on the slope of the yield curve. While an increase in risk aversion has a direct positive effect on the slope, there is an opposite negative effect resulting from a shortening of the maturity structure. The Appendix demonstrates Part (iii) by differentiating (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.

Next, we have the effect of a reduction in expected fiscal revenue. This is modelled by a reduction in the expected probability  $\pi_0$  of a good state, i.e. of debt repayment, in period 2:

Proposition 2: *A reduction in the expected probability of repayment  $\pi_0$  leads in period 0 to:*

- (i) an ambiguous effect on the level of the yield curve,*
- (ii) an increase in the slope of the yield curve, and*
- (iii) a lengthening of the maturity structure, i.e. a lower  $B_{01}^*$  and a higher  $B_{02}^*$ .*

Part (i) of Proposition 2 follows immediately from the reduction in the short-term bond yield, because  $P_{01}$  rises, and the increase in the long-term bond yield, because  $P_{02}$  falls. The effects on  $P_{01}$  and  $P_{02}$

follow immediately from (4) and (6). Finally, since the effects on the short-term and the long-term yields go into opposite directions, we are unable to establish an unambiguous effect on the yield curve level (Part (ii)). The Appendix demonstrates Part (iii) by differentiating (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 only issuing short-term debt, because of the roll-over risk in period 1. A reduction of  $\pi_0$  makes the government less wealthy, which, with constant absolute risk aversion, increases its relative risk aversion. A given variance of the actual repayment probability around  $\pi_0$  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 government utility.

Finally, there is the effect of an increase in the demand for the liquidity services of short debt:

**Proposition 3:** *Assume that  $v(B_{01}) = \gamma f(B_{01})$ , where  $\gamma$  is a positive constant. An increase in  $\gamma$  leads to:*

- (i) a downward shift in the level of the yield curve,*
- (ii) an increase in the slope of the yield curve, and*
- (iii) a shortening of the maturity structure, i.e. a higher  $B_{01}^*$  and a lower  $B_{02}^*$ .*

To prove Parts (i) and (ii), start by differentiating (4), which yields  $\frac{dP_{01}}{d\gamma} = f'(B_{01}^*) + \gamma f''(B_{01}^*) \frac{dB_{01}^*}{d\gamma}$ .

The Appendix shows that  $\gamma f''(B_{01}^*) \frac{dB_{01}^*}{d\gamma} > -\frac{1}{2}f'(B_{01}^*)$ , hence  $P_{01}$  rises and the short-term bond yield falls. By (6),  $P_{02}$  remains unchanged and, hence, the long-term yield remains unaltered. Parts (i) and (ii) now follow immediately. The Appendix demonstrates Part (iii) by differentiating (10) and evaluating at  $\overline{B_{01}} = B_{01}^*$ .

We summarize the effects of Propositions 1—3 in the following table:

Effect of risk factor on	LEVEL	SLOPE	WAM
Increase in the investors'	+	?	-

risk aversion			
Reduction in expected probability of repayment	?	+	+
Increase in preference for liquidity services	-	+	-

### 3. Data sources and description

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, which reports for each auction its 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:

$$WAM_t = \frac{\sum_{m=2}^{50} m \cdot AUC_{m,t}}{\sum_{m=2}^{50} AUC_{m,t}}, \quad (12)$$

where  $\sum_{m=2}^{50} AUC_{m,t}$  denotes the volume of maturity- $m$  debt auctioned in period  $t$ , which we set to be quarterly. Constructing monthly measures for the WAM is possible, but due to the fact that public debt issuance occurs relatively infrequently we construct the WAM only at the quarterly frequency. The range for  $m$  results from the fact that we exclude bill issuance with a maturity up to and including 1 year,<sup>7</sup> and from the fact that 50 years is the longest maturity for which bonds were issued in our time sample. 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 cyclicity in tax

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<sup>7</sup> For Spain the shortest maturity we include in calculating the WAM is 18 months.

revenues and financial sector support, which are outside the scope of our model.<sup>8</sup> 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.<sup>9</sup>

Figure 1 shows the WAM of the newly-issued debt. The figure suggests that even with quarterly data there is quite a bit of “noise”. This should not be surprising. Very long-term debt, such as 30-year debt, is issued only infrequently, while it obviously has quite a substantial impact on the WAM when it occurs. The figure also suggests the possible presence of seasonality.

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 2 shows the 1-year secondary market yield and the spread between 10-year and 1-year secondary market yields.

We collect data on variables that we deploy to proxy for the fundamental shocks hitting the economy. Motivated by Bekaert *et al.* (2013) and Groen and Peck (2014), for example, our primary proxy for the investors’ risk aversion is the VSTOXX, which measures the implied volatility of near-term EuroStoxx 50 options.<sup>10,11</sup> It is downloaded from Thomson Reuters Datastream. As an alternative for the VSTOXX, we use (minus) the “PVS” (“price volatile stocks”) measure developed by Pflueger *et al.* (2018). It measures the macroeconomic risk appetite as the stock market value of low-volatility stocks minus that of high-volatility stocks. An increase in risk-aversion causes high-volatility stocks

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<sup>8</sup> 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. Indeed, including bills would cause erratic and rather volatile patterns in the WAM.

<sup>9</sup> 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).

<sup>10</sup> The VSTOXX is the Euro Stoxx 50 Volatility Index. The Euro Stoxx 50 is the most closely followed equity index of the Eurozone – see <https://www.macoption.com/vstoxx/>.

<sup>11</sup> Bekaert *et al.* (2013) decompose the Chicago Board of Exchange VIX, which is essentially the U.S. counterpart of the VSTOXX, into a risk aversion component and an uncertainty component (based on stock market volatility).

to fall in price relative to low-volatility stocks, hence produces a rise in the PVS.<sup>12</sup> The PVS measure is only available up to the second quarter of 2016, hence the sample is shortened by one-and-a-half years. Our primary proxy for repayment risk is the 5-year credit default spread (CDS), which we obtain from Bloomberg. The 5-years CDS is the maturity for which the longest series is available. Moreover, it serves as a compromise between the 1- and 10-year maturities used for the yield curve. As our secondary repayment risk variable we collect from Datastream the Oxford Economics credit rating index constructed out of sovereign credit ratings from the three major credit rating agencies, Fitch, Moody's and Standard & Poor's. Credit rating agencies assess the risk of non-repayment of the outstanding debt, and investors closely watch their ratings. We invert the original index, which ranges from 0 to 20, such that a value of 0 corresponds to the highest possible rating level and is assigned to a country that has an AAA rating from all three credit rating agencies. Hence, an increase in the index corresponds to a deterioration of the credit rating. Our preference for the CDS rather than the credit rating index is driven by the former being forward-looking and continuous, while changes in the latter are discrete and often based on information that has already found its way into the prices.<sup>13</sup> Our final shock source is the demand for the liquidity services of short debt, for which our primary proxy is the 10-year KfW-Bund spread. This is the difference between the Kreditanstalt für Wiederaufbau (KfW) loan rate and the rate on German public debt of the same maturity. The series for the KfW-Bund spread was kindly made available by Roberto de Santis. However, since it starts at the beginning of 2006, we append it to the KfW-Bund spread (multiplying the latter by the ratio of the two series at the date at which they are appended) that for the period before 2006 we construct from the KfW-swap spread and the Bund-swap spread for Germany. Both series were kindly provided by UBS Delta. Because KfW loans are guaranteed by the German government, their 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. Conceptually, the short-term safety premium arises from the money-like properties of short-term government debt, such as its extreme safety and its use as collateral in

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<sup>12</sup> We define the PVS as the negative of that in Pflueger et al. (2018). This is for convenience, because this way an increase in the degree of risk aversion causes a movement of the VSTOXX and the PVS into the same direction and, hence allows for easier comparison.

<sup>13</sup> See, for example, Afonso et al. (2011) on the determinants of credit ratings.

financial transactions and by banks as liquid assets to back short-term liabilities. Finally, following Krishnamurthy and Vissing-Jorgensen (2012), our secondary proxy for the demand for the liquidity services of short debt is the spread between the BBB and AAA Merrill Lynch euro-area corporate bond indices with a maturity from 1 to 3 years,<sup>14</sup> which we download from Datastream.

Figure 3 plots the aforementioned variables. The VSTOXX peaks during periods commonly seen as turbulent, in particular the second half of 2008 and the end of 2011, while the PVS reaches its highest point towards the end of 2008. The 5-year CDS tends to peak during the second half of 2011 and in 2012. Credit ratings are relatively close until mid-2010, when the euro-area sovereign debt crisis starts to erupt and they start to diverge more widely. The credit rating downgrades tend to be less concentrated than the increases in the CDS spreads. The KfW-Bund spread reaches particularly high values towards the end of 2008 and the first half of 2009 and in the second half of 2011 and in 2012. These periods also roughly correspond to those in which the BBB - AAA euro-area corporate bond spread is at its largest. Table A.1 in the Additional Appendix reports the correlations of the variables reported in Figure 3. All the correlations are positive and in many instances quite high.

## 4. Empirical results

To relate our paper to the literature that explores the relationship between the maturity structure and the yield curve, and see if its main findings are confirmed with the data obtained from debt auctions, we start our empirical analysis with the estimation of the relationship between the WAM and the yield curve for the euro area countries in our sample. Such a reduced-form regression cannot serve as a formal test of the above propositions, because the theory treats the WAM and the yield curve as endogenous and, unlike in the regression, the WAM and the yield curve level and slope will all change simultaneously in response to the underlying shocks. However, the regression could serve as an initial step to gauge the potential relevance of the theory by exploring whether the signs of the

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<sup>14</sup> 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 the 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.

coefficient estimates correspond to those predicted by the propositions. In particular, Proposition 1 predicts a negative relationship between the WAM and level of the yield curve, while Proposition 3 predicts a positive relationship. Further, Proposition 3 predicts a negative relationship between the WAM and the yield curve slope, while Proposition 2 predicts a positive relationship.

Next, using a panel VAR analysis we explore how the underlying shock sources affect the properties of the yield curve and the average maturity of new debt issues, thereby providing direct evidence on the hypotheses derived above. The VAR structure is motivated by the fact that the shocks we consider may need time to propagate into the yield curve and the maturity structure, while there may also be feedback effects among the endogenous variables. We close the empirical analysis with a variance decomposition in order to assess the relative importance of the different shock sources in explaining the fluctuations in the yield curve and the weighted average maturity of new debt issues.

#### 4.1 The relationship between the WAM and the yield curve

In our theoretical model, the risk-free rate for all maturities is zero. In reality, the short-term risk-free rate is determined by monetary policy, while the long-term risk-free rate is determined by the expectations of future short-term risk-free rates plus inflation risk premia. As these elements are not present in our theoretical model, we amend our empirical set-up to incorporate a non-zero risk-free rate. For the risk-free rate we take the overnight index swap (OIS). We define  $OIS_{1t}$  and  $OIS_{10,t}$  as the 1-year, respectively 10-year, risk-free rate, and  $Y_{1,i,t}$  and  $Y_{10,i,t}$  as the 1-year, respectively 10-year, yield on country- $i$  public debt. Using these definitions, we further define:

- The “level” of the risk-free rate:

$$OIS\_LEVEL_t = (OIS_{1t} + OIS_{10,t})/2.$$

- The “slope” of the risk-free rate:

$$OIS\_SLOPE_t = OIS_{10,t} - OIS_{1,t}.$$



- The “level” of the yield curve of country  $i$  in our sample:

$$Y\_LEVEL_{it} = \frac{(Y_{1i,t} - OIS_{1t}) + (Y_{10,it} - OIS_{10,t})}{2} = \frac{Y_{1i,t} + Y_{10,it}}{2} - OIS\_LEVEL_t.$$

- The “slope” of the yield curve of a country in our sample:

$$Y\_SLOPE_{it} = Y_{10,it} - Y_{1,it} - OIS\_SLOPE_t.$$

The baseline regression equation for the relationship between the WAM and the yield curve, controlling for the level of the risk-free rate, reads:

$$WAM_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^S D_{j,t} + \beta_1 Y\_LEVEL_{i,t} + \beta_2 Y\_SLOPE_{i,t} + \gamma OIS\_LEVEL_t + \varepsilon_{i,t} \quad (13)$$

where  $c_i$  is a constant,  $\delta_i t$  a time trend,  $D_{j,t}$  a dummy for season  $j$ , and  $\varepsilon_{it}$  a disturbance term. We estimate this equation at the quarterly frequency using OLS with Newey-West adjusted standard errors in the country regressions to correct for potential serial correlation and heteroscedasticity in the error terms and panel-corrected standard errors (PCSE) with cross-section weights to take care of cross-sectional heteroscedasticity.<sup>15</sup> We always use *beginning-of-quarter* values for yields, so  $Y\_LEVEL_{i,t}$ ,  $Y\_SLOPE_{i,t}$  and  $OIS\_LEVEL_t$  refer to values at the *beginning* of quarter  $t$ , while the  $WAM_{i,t}$  always measures the weighted average maturity of new issues *during* quarter  $t$ . This way we avoid feedback effects from the dependent variable to the explanatory variables. We include quarter 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. We estimate equation (13) at the country level and as a panel with country fixed-effects and country-specific time trends. The latter

<sup>15</sup> For the panel regressions Newey-West correction is not available in Eviews. The standard errors under the corrections that are available for panel estimation are all very similar. Estimation at the individual country level yields Newey-West standard errors that are even lower than the non-corrected standard errors. Finally, the various available tests show no evidence of cross-sectional dependency.

allow to account for potential country-specific trends in the weighted average maturity of new debt issuances.

Baseline regression (13) thus links the WAM to the level and the slope of the yield curve (in deviation from the level, respectively slope, of the risk-free rate), while controlling for the level of the risk-free rate itself (as in Gagnon et al., 2011). The advantage this formulation is that in our regression the coefficient on the level measures the impact of a parallel shift in the yield curve, while the coefficient on the slope measures the effect of an increase in the slope, keeping the average of the yields constant.

The following table reports the theoretically expected signs of the regression coefficients, conditional on the shock that is at play:

<b>Predicted sign of regression coefficient due to risk factor</b>	<b>LEVEL</b>	<b>SLOPE</b>
Increase in investors' risk aversion	-	?
Reduction in expected probability of repayment	?	+
Increase in preference for monetary services	+	-

Table 1 reports the estimates of (13) for the full sample period. For all the countries the coefficient on the level is negative, while that on the slope is negative in half of the cases and positive in the other half. The fact that the individual country estimates for the level are of identical sign, is an argument to estimate the model also as a panel. The differences in the signs of the slope coefficients motivate us to also estimate the model for sub-panels of countries. We consider Germany, The Netherlands, France and Belgium (GNFB) as a separate group and Italy and Spain (IS) as a separate group. The rationale behind the split into these two sub-groups 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 1. For both the full panel and the two sub-panels the estimates of the coefficient on the yield curve level are highly significantly negative. The estimates of the coefficient on the yield curve slope are also negative for the full panel and the two sub-panels, although the estimate is insignificant for the core group. The negative estimates for the

yield curve slope are in line with what the literature tends to find.<sup>16</sup> The coefficient estimates are also significant in economic terms. For example, based on the full-panel estimates the effect of a one-percentage point upward shift in the yield curve is associated with a reduction in the WAM by about 1 year, while an increase in the spread between the 10- and the 1-year yield by one percentage point is also associated with a reduction in the WAM by about 1 year. These magnitudes may seem rather large. However, one needs to realize that the effects of changes in the yield curve on the maturity structure of the full debt stock can only be relatively 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. Finally, we observe that the estimate of the coefficient on the level of the OIS is negative for the full panel and the two sub-panels, although it is not significant for the Italy-Spain sub-panel. We also estimate the model adding the slope of the OIS on the right-hand side of (13). To save space, the numbers are not reported here, but this variable is never significant in the (sub-) panels, while the signs and significance of the coefficients on the yield curve variables remain unchanged. This is also the case for the (post-) crisis sample estimates discussed below.

The negative coefficient of the yield curve level is consistent with the prediction of Proposition 1 that fluctuations in investor risk aversion generate a negative association between the WAM and the yield curve level, but runs counter to Proposition 3's prediction of fluctuations in the demand for the liquidity services of short debt driving a positive association between the WAM and the yield curve level. By contrast, the negative coefficient on the slope of the yield curve is consistent with Proposition 3, but at odds with Proposition 2 that fluctuations in expected repayment risk produce a positive association between the WAM and the yield curve slope.

We also estimate our baseline regression (13) for the (post-) crisis sub-sample 1 July 2007 to 31 December 2017. For the (sub-) panels the signs of the coefficients on the yield curve level and the slope are in all but one case identical to those for the full sample period. However, only the

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<sup>16</sup> For example, see Arellano and Ramanarayanan (2012), Broner et al. (2013), Bai et al. (2015) and Perez (2017).

coefficients on the yield curve level are always negative, while significance seems to become weaker in any case. This may not be surprising as fewer observations are available.

## 4.2 Panel vector auto regression estimates

The previous subsection provides strong evidence of a negative relationship between the WAM and the level of the yield curve and weaker evidence of a negative relationship between the WAM and the slope of the yield curve. The former would suggest a relatively important role for the presence of shocks to risk-aversion, while the latter would suggest a relatively important role for liquidity-preference shocks. However, because the theoretical model treats the WAM and the yield curve as endogenous, while, moreover, different shocks can hit the economy simultaneously, these estimates cannot immediately be used to test the validity of Propositions 1 – 3. In this subsection we set up a panel VAR in which the WAM, the level and the slope of the yield curve feature as endogenous variables, while shocks originate from variables that proxy for risk aversion, the expected probability of repayment and the demand for the liquidity services of short debt. By using a panel VAR, we also create the possibility that shocks may feed only gradually into the economy. This subsection is closed with a variance decomposition, which allows us to gauge the relative importance of the various shock sources.

Concretely, the baseline panel VAR is set up as follows. The variables to proxy for the shocks to risk aversion, expected repayment risk and the demand for the liquidity services of short debt are, respectively, changes in the VSTOXX, the 5-year CDS and the 10-year KfW-Bund spread. As exogenous variables we always include  $OIS\_LEVEL_t$ , its first lag, seasonal dummies, country-specific fixed effects and country-specific trends. We use a Cholesky identification scheme, in which we enter the shock first. The ensuing ordering of the other variables is irrelevant for the impact of the exogenous shock on the level, the slope and the WAM. We confine ourselves to a quarterly panel. Hence, the vector of endogenous variables in the VAR is  $[SHOCK_{it}, Y\_LEVEL_{it}, Y\_SLOPE_{it}, WAM_{it}]'$ , where  $SHOCK_{it}$  can be the VSTOXX (variable name:  $VSTOXX_t$ ), the 5-year CDS (variable name:  $CDS_{it}$ ) and the 10-year KfW-Bund spread (variable name:  $KfW_t$ ). Under the baseline, we always include one lag of the vector of endogenous variables.

#### 4.2.1. Full sample panel VAR estimation

The size of the shock is always a one-unit rise in the case of the VSTOXX and a one-percentage point rise in the case of the CDS and the KfW-Bund spread. To put the shock sizes into perspective, the full-sample standard-deviation of the VSTOXX is 9.5, while the full-sample standard deviations of the CDS and the KfW-Bund spread are 0.94 and 0.18 percentage points, respectively.

A positive risk-aversion shock as proxied for by an increase in the VSTOXX raises both the level (in line with Proposition 1) and the slope of the yield curve (see Figure 4). The level jumps on impact, while the slope takes a quarter to become significant. Also in line with Proposition 1, and in line with the estimates in the previous subsection, the WAM falls. The responses have some, though not a major economic significance: a one standard deviation shock in the VSTOXX would raise the level of the yield curve by about 7 basis points and the yield difference between 10- and 1-year debt by about 5 basis points. The WAM would fall by about a quarter of a year.

Figure 5 exhibits the impulse responses following a reduction in the expected repayment probability as captured by an increase in the CDS. Both the level and slope of the yield curve exhibit a very strong and highly significant increase. The former jumps on impact, while the latter takes a quarter to become significant. The WAM responds with a highly significant fall after one quarter. While the effect on the yield curve slope is in line with Proposition 2, the effect on the WAM contradicts this proposition. The responses are also economically meaningful: the impact response of the yield curve level following a one standard-deviation CDS increase is about 0.6 percentage points, while the yield difference between 10- and 1-year debt rises by 0.3 percentage points at its peak. The maximum fall in the WAM is about 0.8 year over the response horizon.

Finally, Figure 6 shows the impulse responses to an increase in the demand for the liquidity services of short debt as captured by a positive shock to the KfW-Bund spread. The response pattern is similar to that for the CDS shock. Both the level and the slope of the yield curve exhibit a strong and highly-significant positive response, while the WAM decreases. Again the level jumps on impact, while the slope and the WAM take a quarter to become significant. The level response contradicts Proposition 3, but the responses of the slope and the WAM are in line with this proposition. Again, the sizes of the responses to a one standard-deviation increase in the KfW-Bund spread are

quantitatively non-negligible with an increase in the yield curve level of about 0.2 percentage points on impact and a maximum increase in the slope of about 0.15 percentage points. The peak response of the WAM is a fall by half a year, about double the effect of a one standard-deviation shock to the CDS.

In summary, the results offer support for the theoretical predictions of an increase in investors' risk aversion, but contradict some of the predictions of an increase in the government's probability of repayment and the investors' preference for liquidity services.

#### **4.2.2. Panel VAR estimates for country groups**

Above we distinguished sub-panels for the groups of the core and periphery countries. Hence, our next step is to also distinguish these groups in our panel VAR analysis. Figures 7- 9 show the results. Overall, the results are similar for the two country groups and similar to those for the full sample. However, we generally see that the significance of the estimates weakens somewhat, which is not surprising, because the number of observations in each country group is smaller than was the case for the full country sample. An increase in the VSTOXX raises the yield curve level significantly for both country groups, although the response is somewhat slower for the core. The slope also increases significantly, with a similar pattern for both groups. With some delay the WAM still falls significantly for the core, but it essentially stays unaltered for the periphery. An increase in the 5-year CDS produces significant increases in the level and slope of the yield curve and a significant decrease in the WAM for both country groups. The level effect is larger for the periphery, while the slope effect is slightly larger for the core. Finally, an increase in the KfW-Bund spread also generates significant rises in the level and slope of the yield curve for both country groups and a significant reduction in the WAM. Most remarkable is the difference in magnitude of the level responses between the two country groups. The peak increase for the core is about 0.4 percentage points, while that for the periphery is about 2.3 percentage points. This clearly demonstrates the periphery suffers in particular from a reduction in market liquidity.

#### 4.2.3. Panel VAR estimates for the crisis sample

In this subsection we estimate the baseline panel VAR specification for the crisis sub-sample period 2007Q3 – 2017Q4. The estimates are found in the Additional Appendix, in Figures A.1 – A.3. Due to the shorter sample period, the significance of the results slightly weakens, although qualitatively speaking they are still very similar to those for the full sample. A positive shock to the VSTOXX has on impact a significantly positive effect on the yield curve level as well as a significantly positive effect on the yield curve slope after one quarter. However, the WAM no longer responds significantly, although we still detect a fall in the WAM that becomes very close to significance. Regarding a positive shock to the CDS, we still observe highly significant positive responses in the yield curve level and slope, and a highly significant fall in the WAM, with magnitudes all in line with those for the full sample estimates. Finally, a positive shock to the KfW-Bund spread also produces positive effects to the yield curve level and slope and a negative effect on the WAM, with magnitudes again in line with those for the full sample.

#### 4.2.4. Other robustness of panel VAR estimates

As a further robustness to the baseline regression, we re-estimate the panel VAR with a different proxy for each individual shock. The results are reported in the Additional Appendix. Replacing the VSTOXX with the PVS measure, the responses remain qualitatively largely consistent with the original ones (Figure A.4). The yield curve level does not respond, but the slope rises after one quarter, and, in line with Proposition 1, the WAM becomes significantly negative after one quarter. The responses to a negative credit rating shock are very similar to those for a positive CDS shock (Figure A.5), while the responses to a positive shock to the BBB – AAA spread closely resemble those following a positive shock to the KfW-Bund spread (Figure A.6).<sup>17</sup> Overall, the responses to the alternative proxies to our shock variables are qualitatively consistent with the original responses.

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<sup>17</sup> As an alternative to the 10-year KfW-Bund spread, we also estimate the baseline panel-VAR with the 3-year KfW-Bund spread (the shortest non-artificially constructed maturity available) kindly made available via UBS Delta and with the spread between the one-year German bond yield and the one-year swap rate, which are both effectively free from default risk, but differ in terms of liquidity. Both variants produce results qualitatively identical to those for the 10-year KfW-Bund spread. The variant with the 3-year KfW-Bund spread yields results that are quantitatively very similar, while the other variant yields results that are slightly weaker in terms of their negative effect on the WAM.

Our final robustness check is based on including four lags, instead of one, of the vector of endogenous variables in the panel-VAR. The results are shown in Figures A.7 – A.9 in the Additional Appendix. While the confidence bands tend to get wider, because of the larger number of parameters estimated, the results remain qualitatively very much in line with the baseline results.

#### 4.2.5. Relative importance of the shocks: variance decomposition

The final step in our analysis is to explore the relative importance of the different sources of shocks (risk aversion, the expected probability of repayment and the demand for the liquidity services of short debt). To this end, we now re-estimate the panel VAR with all shocks included simultaneously. The ordering is  $[VSTOXX_t, KfW_t, CDS_{it}, Y\_LEVEL_{it}, Y\_SLOPE_{it}, WAM_{it}]'$ . This ordering is motivated by the presumed degree of “exogeneity”. We order the  $VSTOXX_t$  first, because a within-period feedback to the  $VSTOXX_t$  is relatively unlikely, as it is based on the pan-European stock market and as this market is at most partially integrated with the European bond markets. That is, the sets of traders differ between those markets and, hence, capital does not flow perfectly from one market to the other. We order the KfW Bund-spread second. Even though it measures the difference between two German variables, we consider it of relevance for the entire Eurozone bond market. The CDS spread, which is a country-specific variable, is ordered third. With the expanded system, the impulse responses are very similar those we obtained before. They are found in Figure A.10 in the Additional Appendix.

Tables 2, 3 and 4 report the forecast error variance decomposition of the yield curve level, its slope and the WAM, respectively. To the yield curve level the main contributor after one quarter is the CDS with about 52%, followed by the level itself with 38%. The  $VSTOXX$  contributes about 9% and the KfW-Bund spread less than 2%. Over longer horizons, the importance of the CDS increases even further to reach almost 75% after 10 quarters at the cost of a shrinkage in the importance of the level. The  $VSTOXX$  and the KfW-Bund spread remain roughly stable. The influences of the slope and the WAM are essentially negligible. Turning to the decomposition of the slope, we see that, at the one-quarter horizon, by far the most important factor is the slope itself with 86% of the total contribution, followed by the level with 13% contribution and the other variables with negligible



contributions. At longer horizons, the contribution of the slope quickly falls in favor of the CDS, which after 10 quarters contributes about 40%, roughly the same as the contribution of the slope itself. The VSTOXX and the KfW-Bund spread also gain in importance, together making up about 10% after 10 quarters. Finally, turning to the forecast error variance decomposition of the WAM, the by far largest contribution after one quarter comes from the WAM itself with more than 99%. Over time, the contribution of the WAM shrinks, but it remains by far the largest factor with almost 90% after 10 quarters. It is followed by the CDS which gains in importance over time and which contributes almost 6% after 10 quarters. The VSTOXX gets to slightly less than half of this at this horizon, while the KfW-Bund spread, the level and the slope stay at around 1 percent or even less than that.

So, overall, of the different shock sources, the CDS has by far the largest effect on the impulse responses. This may not be too surprising in view of the fact that the CDS is a country-specific variables, while the VSTOXX is a common variable and the KfW-Bund spread is a common variable for all countries other than Germany.

## 5. Concluding remarks

The recent euro-area debt crisis has brought public debt management to the forefront of the media and the public debate, 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 into the direction preferred by the Treasury than that of the full stock of outstanding debt, of which the maturity structure is only a slow-moving variable.

We started by 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. Univariate regressions exhibited a strong negative relationship between the weighted average maturity of new debt and the level of the yield

curve, as well as a weaker negative relationship between the weighted average maturity and the yield curve slope. This was followed by a panel VAR analysis that showed that positive shocks to risk aversion, the expected probability of non-repayment and the demand for the liquidity services of short debt all raise the level and the slope of the yield curve, while reducing the weighted average maturity of new debt. These effects tend to be highly statistically significant as well as economically significant. The responses following a positive shock to risk aversion are consistent with our theory, while the responses induced by a reduction in the expected repayment probability and an increase in the demand for the liquidity services of short debt are partially in line with our theory. Using a forecast error variance decomposition, we observe that generally the most important shock source driving the responses is a change in expected repayment probability, especially in the longer run.

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## Appendix

### Derivation of (10) starting from (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 (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 (9) and assume CARA utility, i.e.  $u(x) = -\exp(-\alpha x)$ . The result follows immediately.

### Proof of (11)

Take (7) 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,

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

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

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

## Second-order condition

We differentiate the left-hand side of (8) with respect to  $B_{01}$ . Applying  $B_{01} = \bar{B}_{01}$ , this yields:

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

Since  $\frac{dG_{2g}^*}{dB_{01}} > 0$ , a sufficient, but by no means necessary, condition is that  $\pi > \sigma\pi_0/(1+v'(\bar{B}_{01}))$ ,

hence, if  $\pi$  is bounded from below at a not too low value.

## Intermediate results

Differentiating (11) with respect to  $B_{01}$  and then imposing  $B_{01} = \bar{B}_{01}$  yields:

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

Hence,

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

Further, differentiating (10) and imposing  $B_{01} = \bar{B}_{01}$  yields:

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

$$\frac{1}{\pi_0} \frac{dG'_{2g}(\pi_0)}{d\gamma} = 0,$$

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

### The effect of $\sigma$

Differentiating (10) and evaluating at  $B_{01} = \overline{B_{01}}$  yields:

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

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

### The effect of $\pi_0$

Differentiating (10) and evaluating at  $B_{01} = \overline{B_{01}}$  yields

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

$$[1 + v'(\overline{B_{01}})] \alpha Var_0(\pi) \frac{(1+3\pi_0)(\bar{y} + \overline{B_{01}} - \overline{B_{02}})}{\pi_0^2(1+\pi_0)^3} d\pi_0 = 0.$$

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 $\gamma$

Let  $v'(B_{01}) = \gamma f'(B_{01})$  and differentiate (10) with respect to  $\gamma$ :



$$\left\{ \left[ \frac{\sigma}{1+v'(\overline{B}_{01})} \right] 2\gamma f''(\overline{B}_{01}) - [1 + v'(\overline{B}_{01})] \alpha \text{Var}_0(\pi) \left[ \frac{1+\sigma\pi_0+v'(\overline{B}_{01})}{\sigma(\pi_0(1+\pi_0))^2} \right] \right\} dB_{01} + \left[ \frac{\sigma}{1+v'(\overline{B}_{01})} \right] f'(\overline{B}_{01}) d\gamma =$$

0,

or

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

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

## Tables

Table 1: WAM and yield curve

$WAM_{i,t} = c_i + \delta_i t + \mu \sum_{j=1}^S D_{j,t} + \beta_1 Y\_LEVEL_{i,t-1} + \beta_2 Y\_SLOPE_{i,t-1} + \gamma OIS\_LEVEL_{t-1} + \varepsilon_{i,t}$									
	Germany	Netherlands	France	Belgium	Italy	Spain	Panel	Panel GNFB	Panel IS
(a) Full sample period: January 1, 1999 – December 31, 2017									
$\beta_1$	-1.95**	-1.43	-5.82***	-7.29***	-0.73***	-0.94***	-1.01***	-3.90***	-0.85***
$\beta_2$	0.18	-2.90	0.34	2.76**	-0.45	-1.10*	-1.03**	-0.079	-0.86**
$\gamma$	-0.28**	0.24	-0.40**	-1.39*	-0.52***	0.023	-0.36**	-0.53**	-0.25
Adj. R <sup>2</sup>	0.34	0.029	0.32	0.19	0.19	0.31	0.33	0.33	0.39
Obs.	76	76	76	75	76	76	455	303	152
(b) Crisis period: July 1, 2007 – December 31, 2017									
$\beta_1$	-0.50	-4.82	-7.06***	-4.21**	-0.90***	-0.82**	-0.93***	-2.54*	-0.88***
$\beta_2$	0.80*	-1.76	1.10*	2.27*	-0.24	-1.38*	-0.56	0.42	-0.84*
$\gamma$	0.17	-1.23	-0.53	-0.47	-0.65***	-0.18	-0.20	-0.24	-0.39
Adj. R <sup>2</sup>	0.22	-0.025	0.57	0.43	0.27	0.44	0.53	0.55	0.43
Obs.	42	42	42	42	42	42	252	168	84

Notes: Estimation method is Ordinary Least Squares (OLS) with Newey-West adjusted standard errors at the country level and OLS with panel-corrected standard errors with cross-section weights for the panels. 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 formed by Germany, Netherlands, France and Belgium, and “Panel IS” is the sub-panel formed by Italy and Spain.

Table 2: Forecast error variance decomposition of yield curve level at various horizons

Period	VSTOXX	KFW	CDS	Y_LEVEL	Y_SLOPE	WAM
1	8.67 (3.11)	1.84 (1.38)	51.78 (3.85)	37.72 (3.32)	0.00 (0.00)	0.00 (0.00)
2	9.20 (3.31)	1.80 (1.43)	60.72 (3.85)	27.62 (2.91)	0.015 (0.21)	0.64 (0.77)
5	9.45 (3.93)	1.59 (1.63)	72.68 (4.23)	15.77 (2.16)	0.035 (0.43)	0.47 (0.74)
10	8.66 (4.13)	1.20 (1.52)	74.32 (4.76)	15.21 (3.24)	0.24 (0.70)	0.36 (0.58)
15	8.29 (4.13)	1.12 (1.46)	73.78 (5.19)	16.09 (4.02)	0.35 (0.80)	0.37 (0.56)

Note: the entries in the table report the contributions in percent of the total. The numbers in brackets report the corresponding standard errors.

Table 3: Forecast error variance decomposition of yield curve slope at various horizons

Period	VSTOXX	KFW	CDS	Y_LEVEL	Y_SLOPE	WAM
1	0.03 (0.45)	0.06 (0.49)	0.31 (0.76)	13.10 (3.36)	86.50 (3.48)	0.00 (0.00)
2	1.43 (1.17)	2.11 (1.09)	5.97 (1.61)	11.05 (2.99)	79.44 (3.36)	0.00 (0.40)
5	6.02 (2.61)	4.28 (2.08)	28.95 (4.51)	8.41 (2.44)	52.32 (4.31)	0.02 (0.34)
10	6.93 (3.21)	3.42 (1.96)	40.65 (5.84)	10.53 (3.54)	38.41 (4.92)	0.05 (0.36)
15	6.74 (3.29)	3.20 (1.86)	42.32 (6.49)	11.75 (4.24)	35.91 (5.40)	0.08 (0.39)

Note: see notes to Table 2.

Table 4: Forecast error variance decomposition of the WAM at various horizons

Period	VSTOXX	KFW	CDS	Y_LEVEL	Y_SLOPE	WAM
1	0.65 (1.03)	0.00 (0.47)	0.15 (0.65)	0.01 (0.48)	0.04 (0.46)	99.15 (1.49)
2	1.20 (1.17)	0.49 (0.69)	0.42 (0.74)	0.36 (0.72)	0.51 (0.80)	97.03 (1.67)
5	2.27 (1.47)	1.09 (0.98)	2.87 (1.64)	0.45 (0.85)	0.57 (0.85)	92.74 (2.46)
10	2.72 (1.58)	1.134 (1.01)	5.88 (2.66)	0.94 (0.89)	0.57 (0.81)	88.75 (3.62)
15	2.75 (1.59)	1.12 (0.99)	6.68 (3.04)	1.27 (1.05)	0.58 (0.80)	87.60 (4.13)

Note: see notes to Table 2.

## Figures

Figure 1: Weighted average maturity of bond issues at quarterly frequency

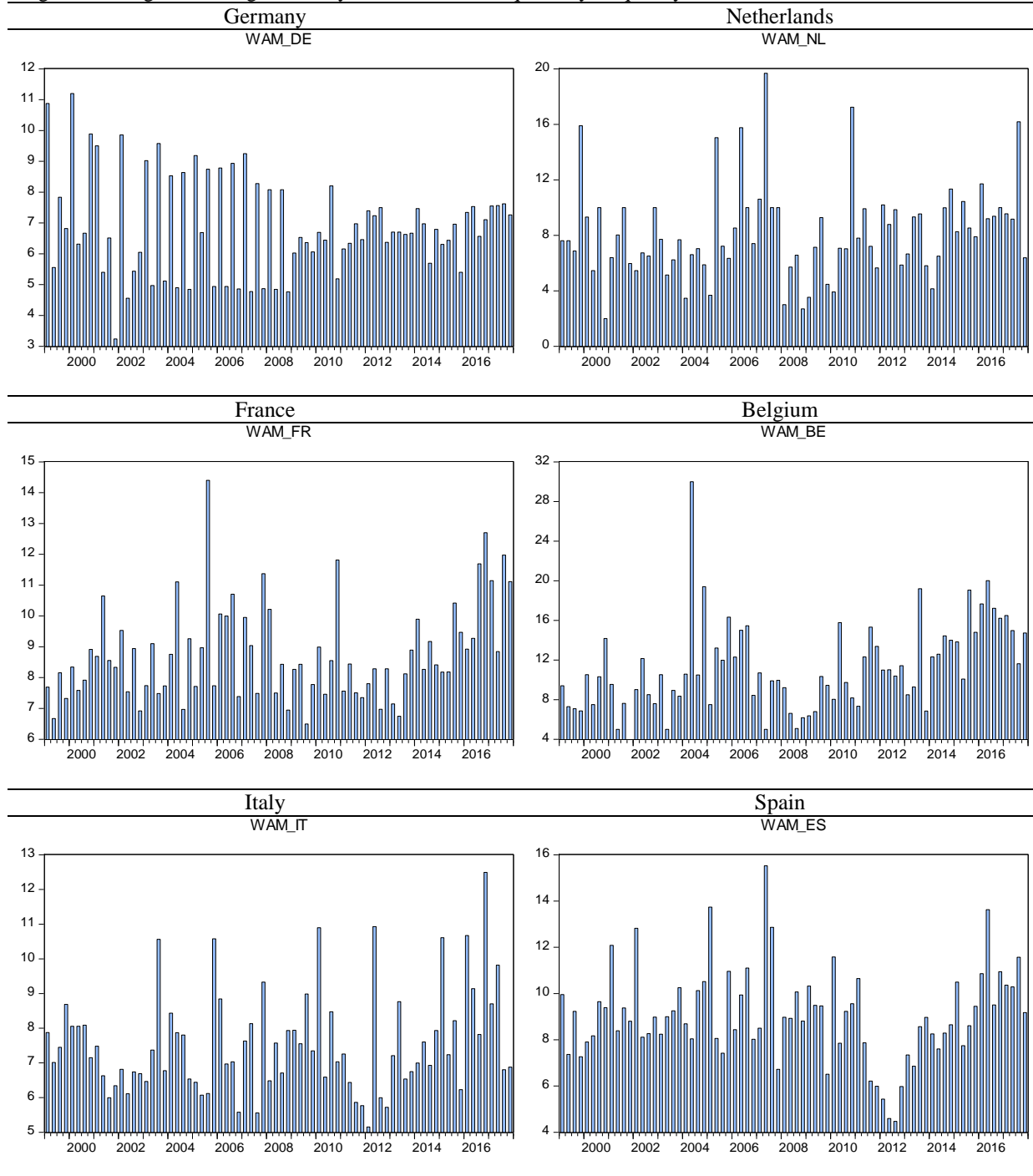
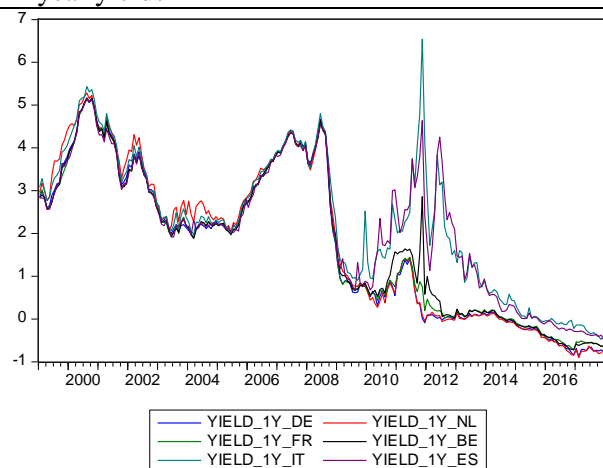


Figure 2: Secondary market yields

1-year yields



Spread between 10-year and 1-year yields

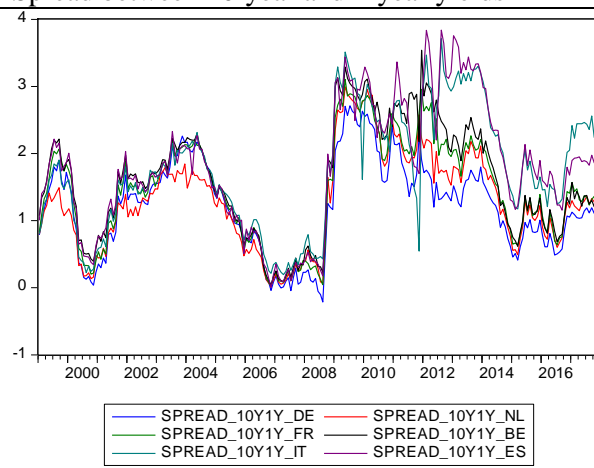
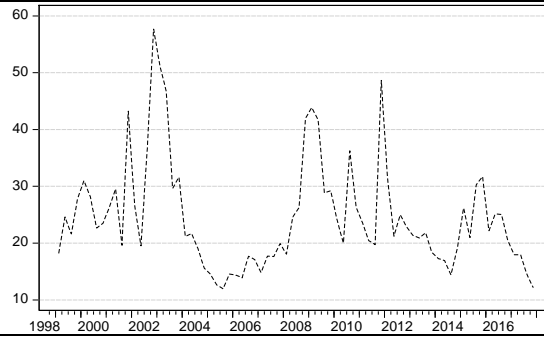
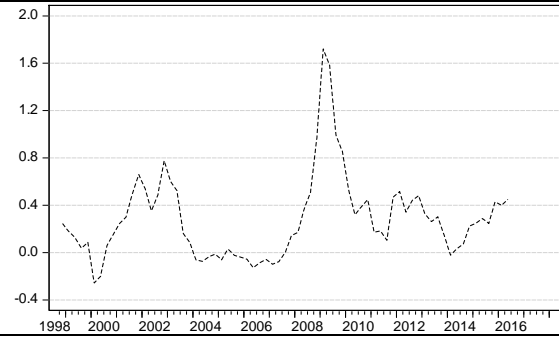


Figure 3: Variables proxying for the shocks

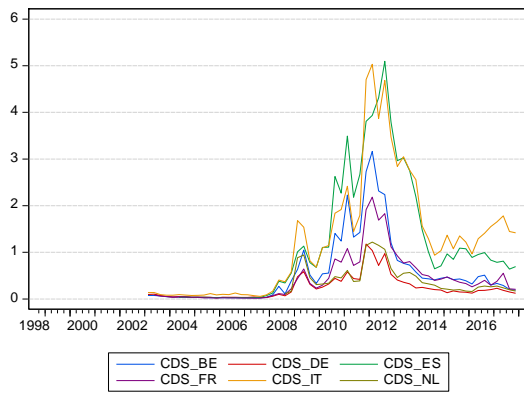
VSTOXX



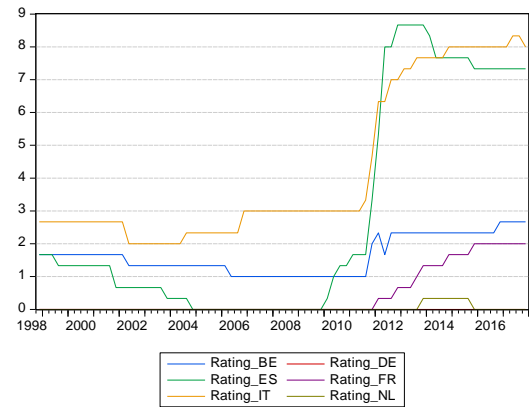
PVS



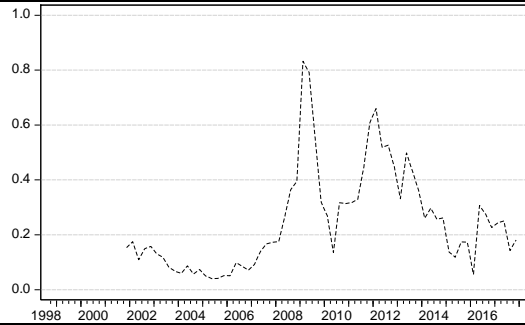
CDS



Rating



KfW



Corporate bond spread

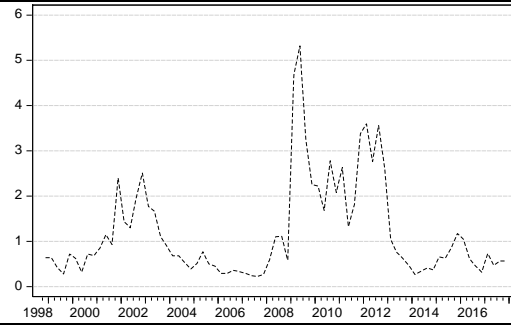


Figure 4: Impulse response to an increase in the VSTOXX

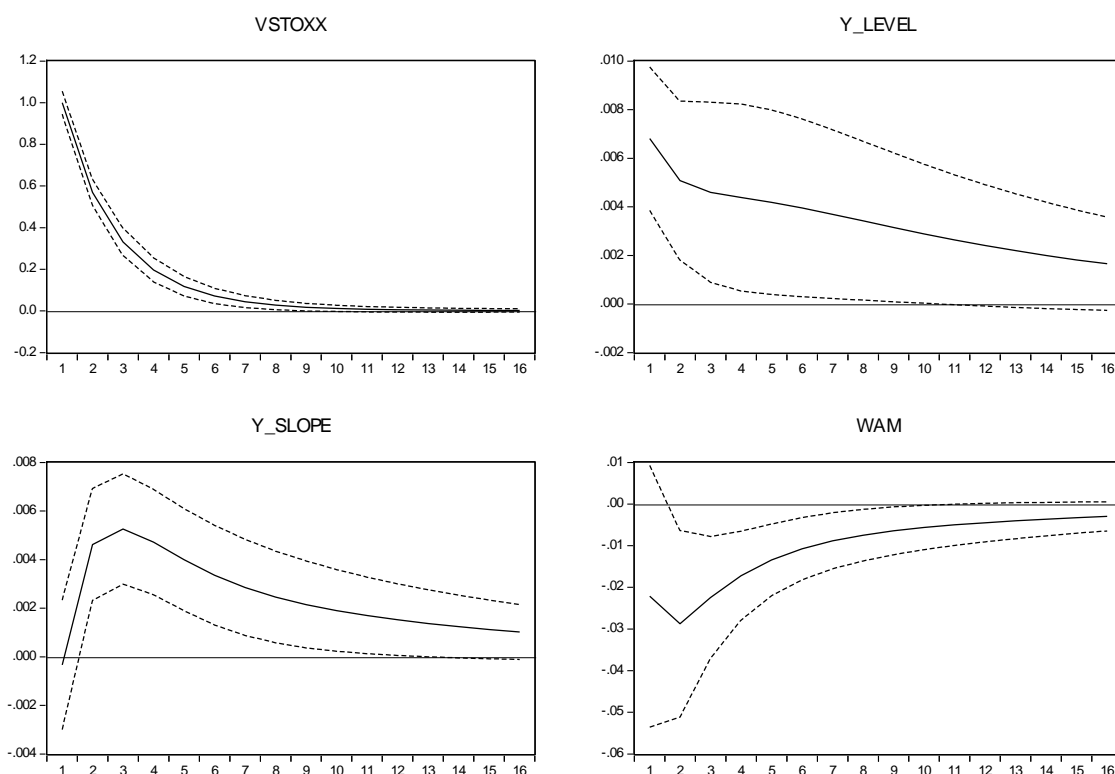


Figure 5: Impulse responses to an increase in the 5-year CDS

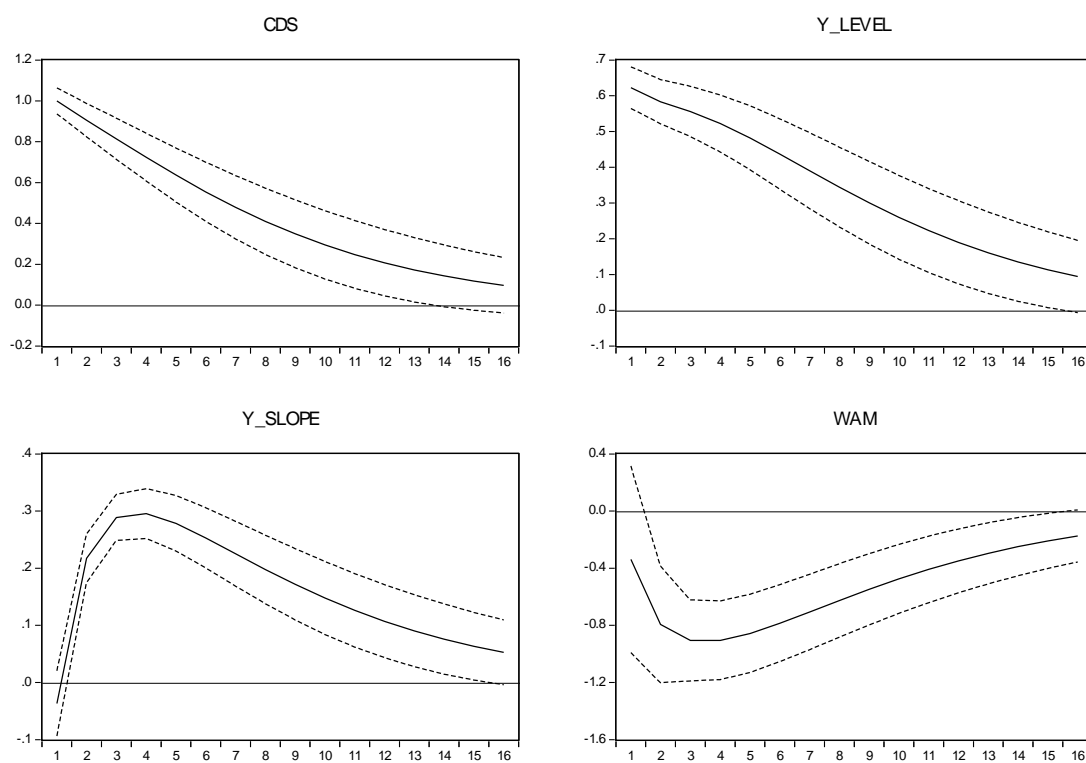


Figure 6: Impulse responses to a positive liquidity preference shock

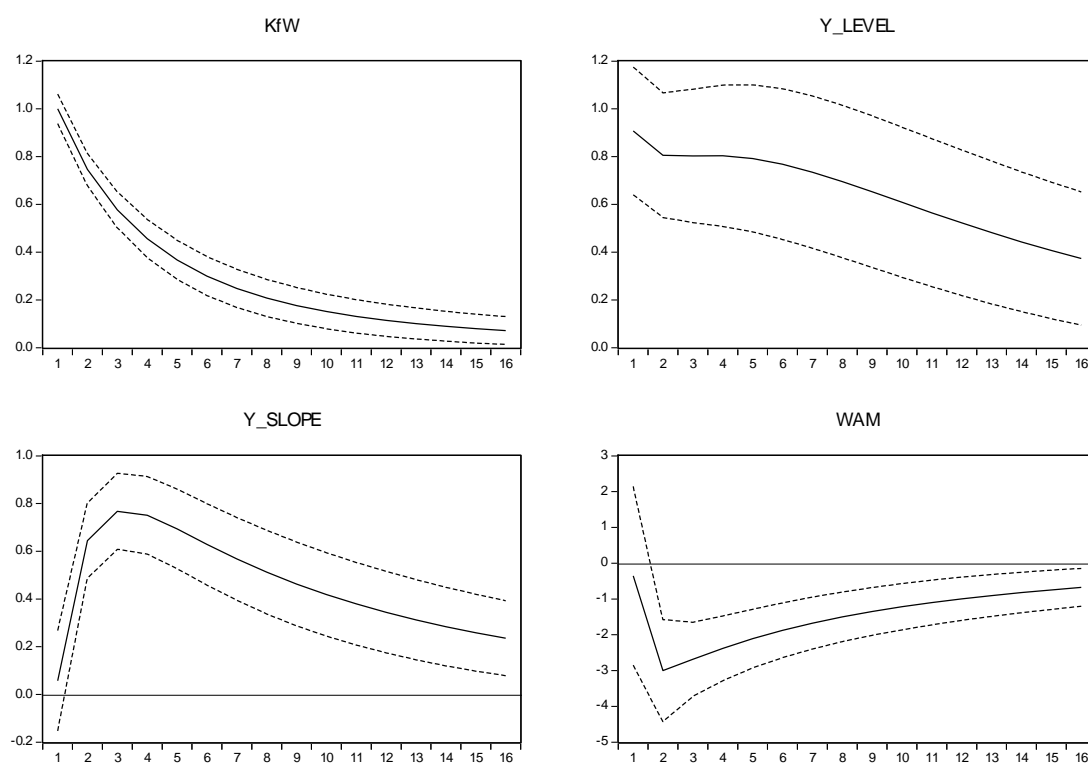


Figure 7: Impulse response to an increase in the VSTOXX – country groups

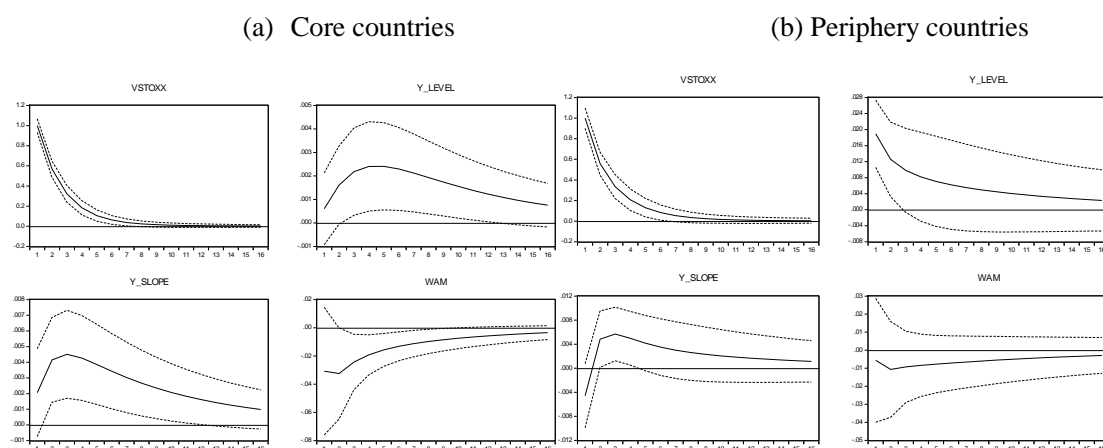


Figure 8: Impulse responses to an increase in the 5-year CDS – country groups

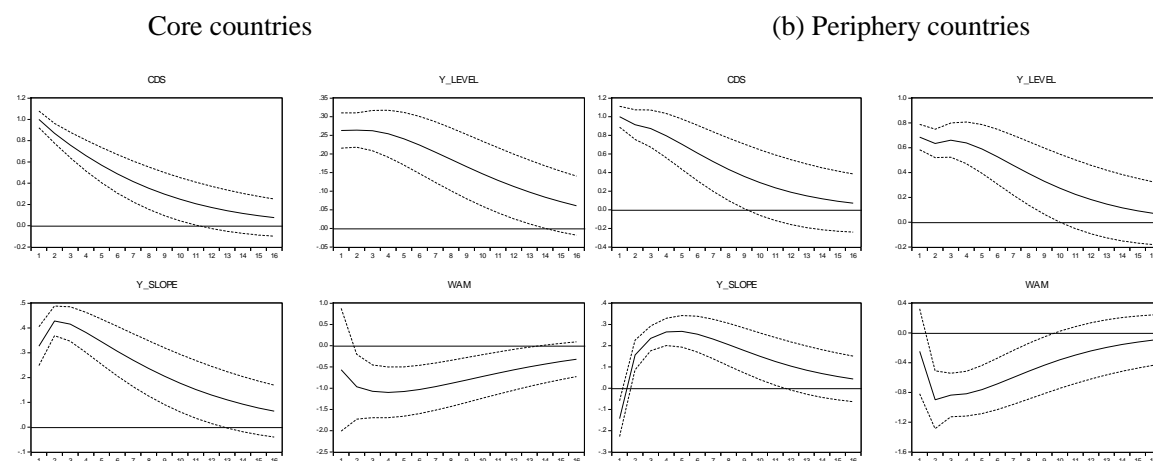
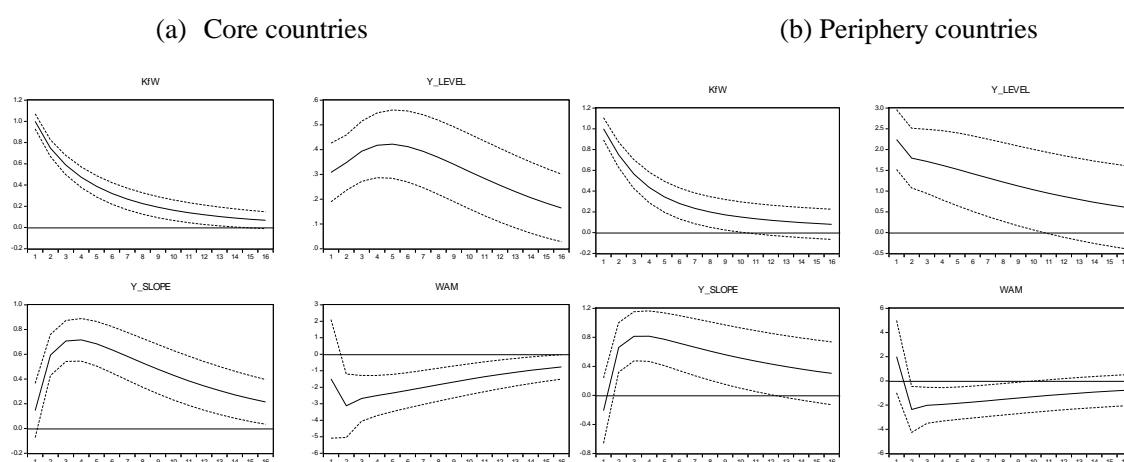


Figure 9: Impulse responses to a positive liquidity preference shock – country groups





## Additional appendix

### Correlations

Table A.1: Correlations between variables								
	VSTOXX	KfW	CDS_BE	CDS_DE	CDS_ES	CDS_FR	CDS_IT	CDS_NL
VSTOXX	1							
KfW	0.59	1						
CDS_BE	0.34	0.55	1					
CDS_DE	0.44	0.69	0.94	1				
CDS_ES	0.12	0.46	0.87	0.83	1			
CDS_FR	0.25	0.54	0.95	0.94	0.92	1		
CDS_IT	0.16	0.51	0.84	0.87	0.91	0.95	1	
CDS_NL	0.44	0.81	0.85	0.94	0.78	0.88	0.84	1

*Notes:* Correlations at quarterly frequency.

## Impulse responses for (post-) crisis

Figure A.1: Impulse response to an increase in the VSTOXX – (post-) crisis sample

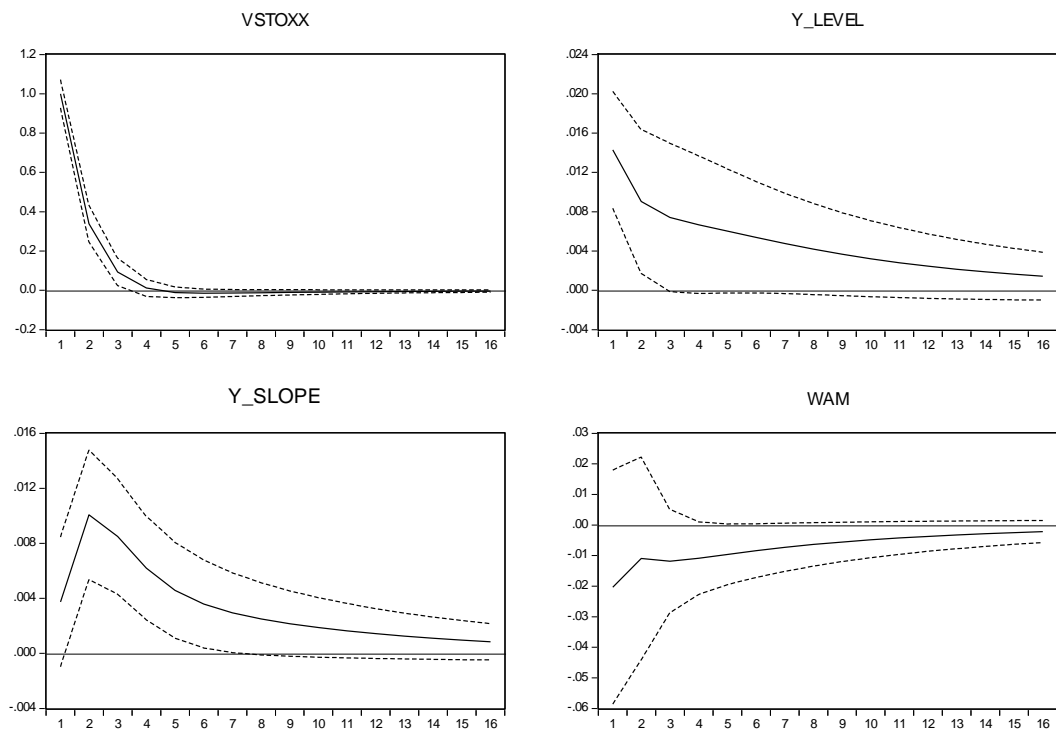


Figure A.2: Impulse responses to an increase in the 5-year CDS – (post-) crisis sample

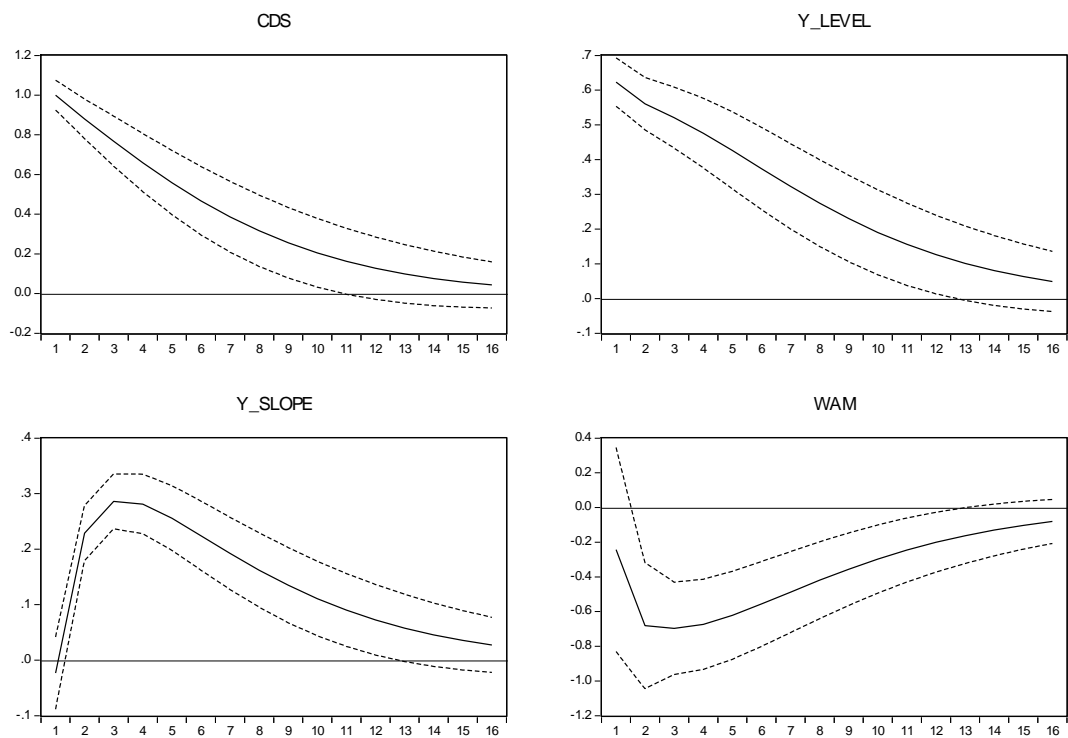
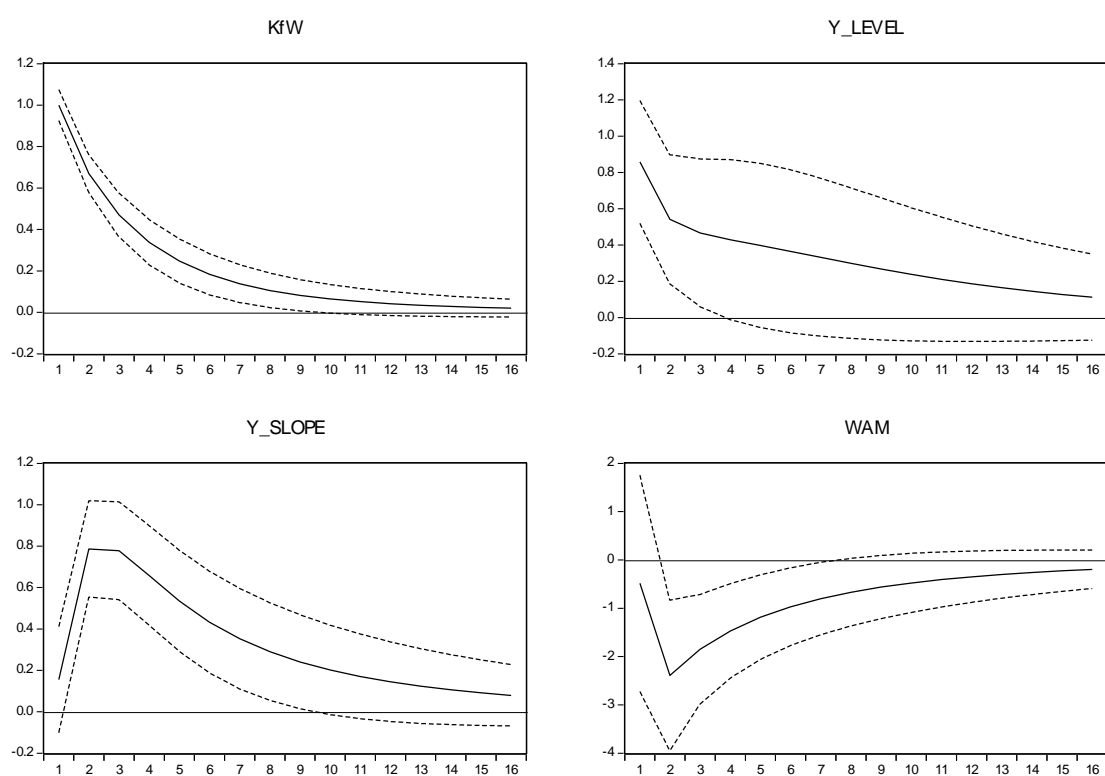


Figure A.3: Impulse responses to a positive liquidity preference shock – (post-) crisis sample



## Impulse responses with alternative shock variables

Figure A.4: Impulse response to an increase in the PVS

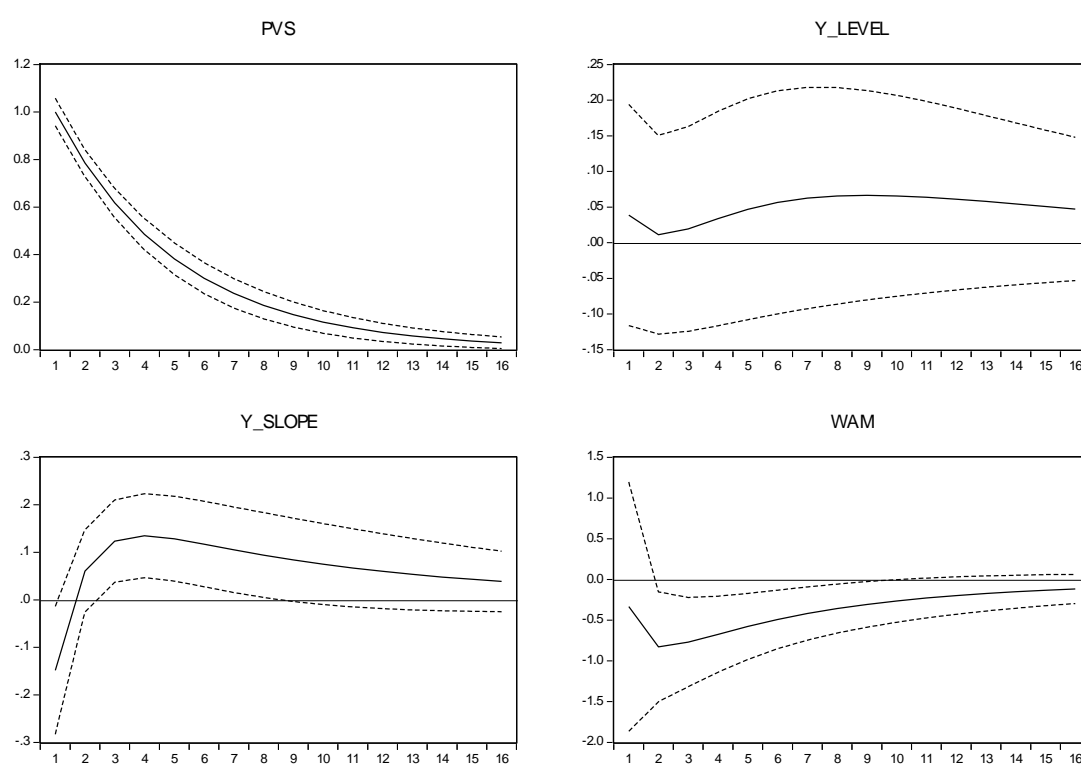


Figure A.5: Impulse responses to an increase in the credit rating

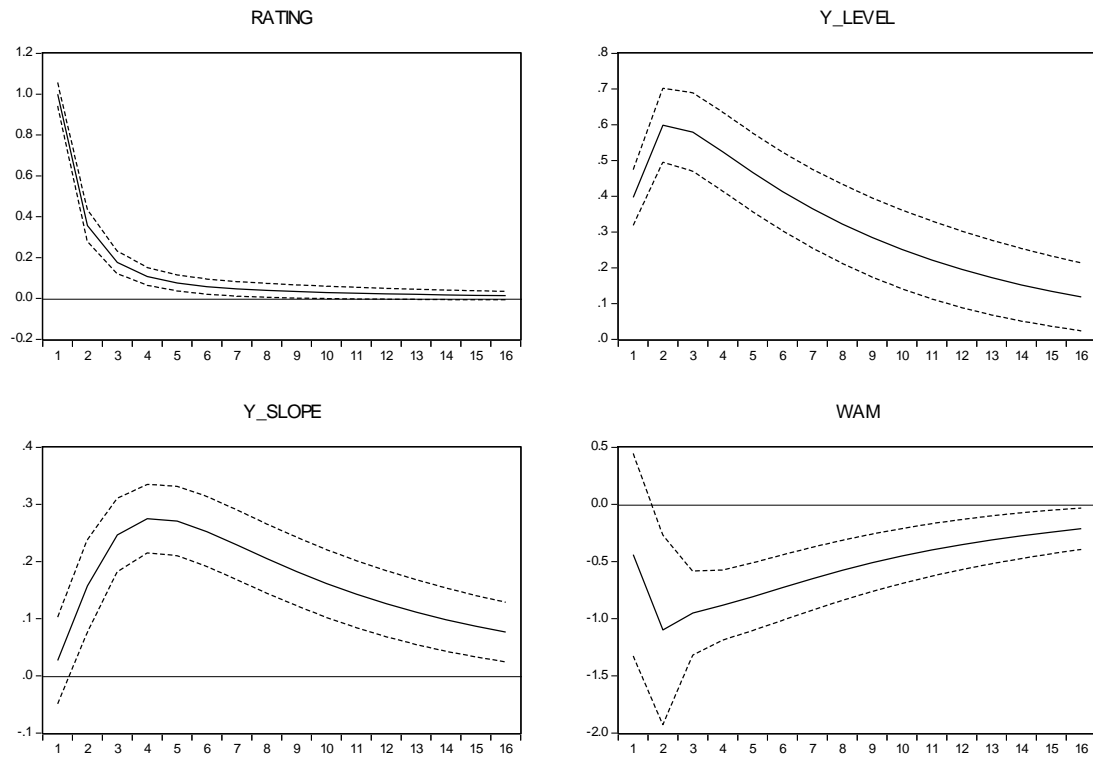


Figure A.6: Impulse response to a change in the BBB – AAA corporate bond spread

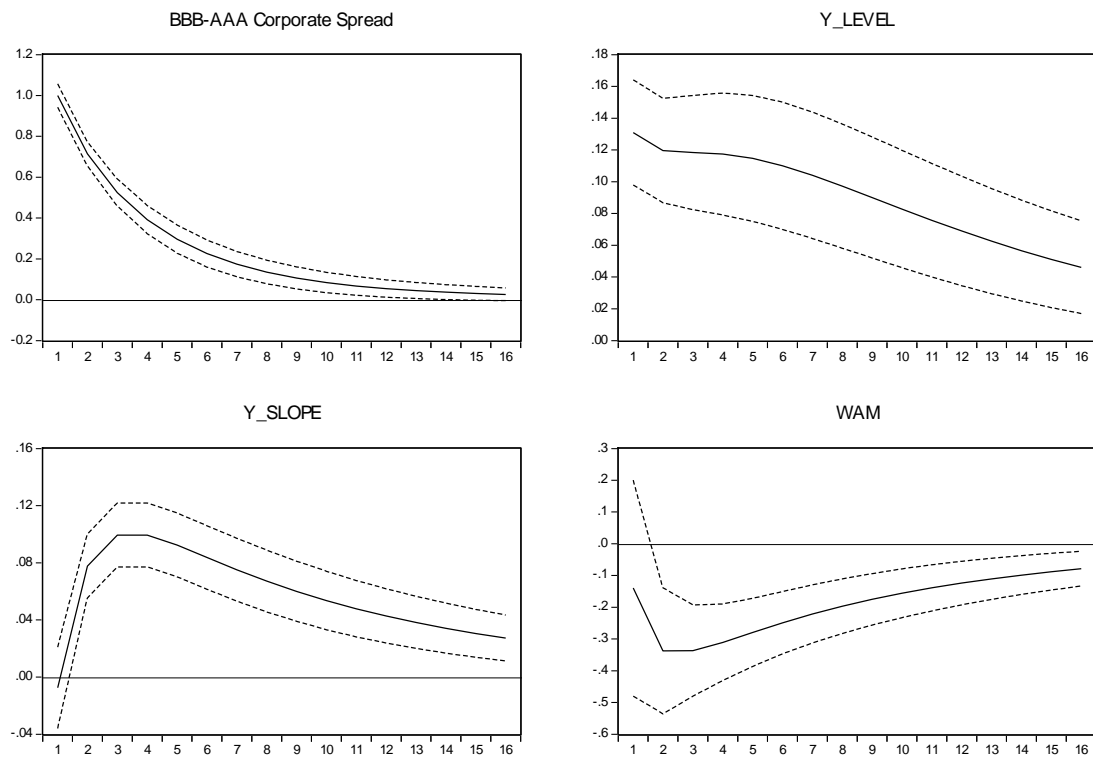


Figure A.7: Impulse response to an increase in the VSTOXX – four lags

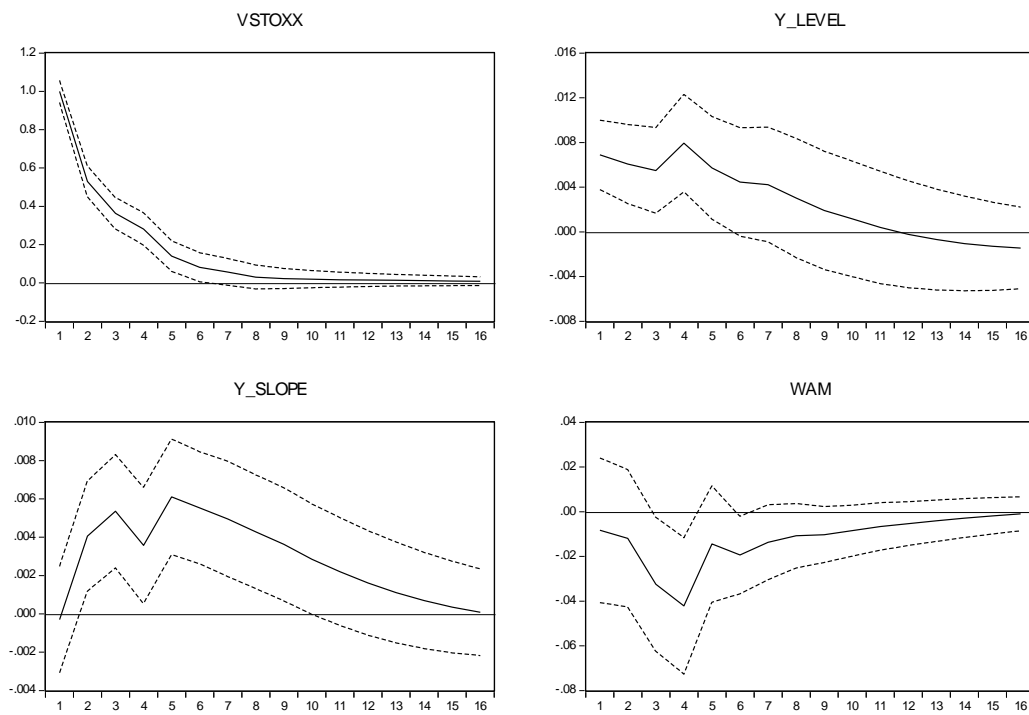


Figure A.8: Impulse responses to an increase in the 5-year CDS – four lags

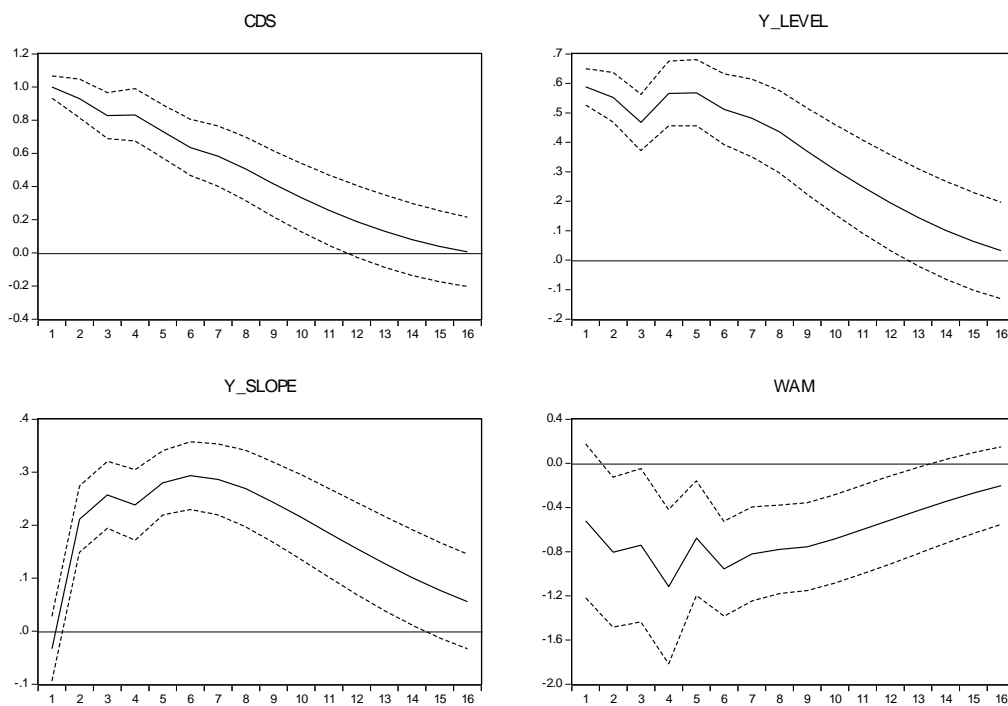


Figure A.9: Impulse response to a change in the KfW-Bund spread – four lags

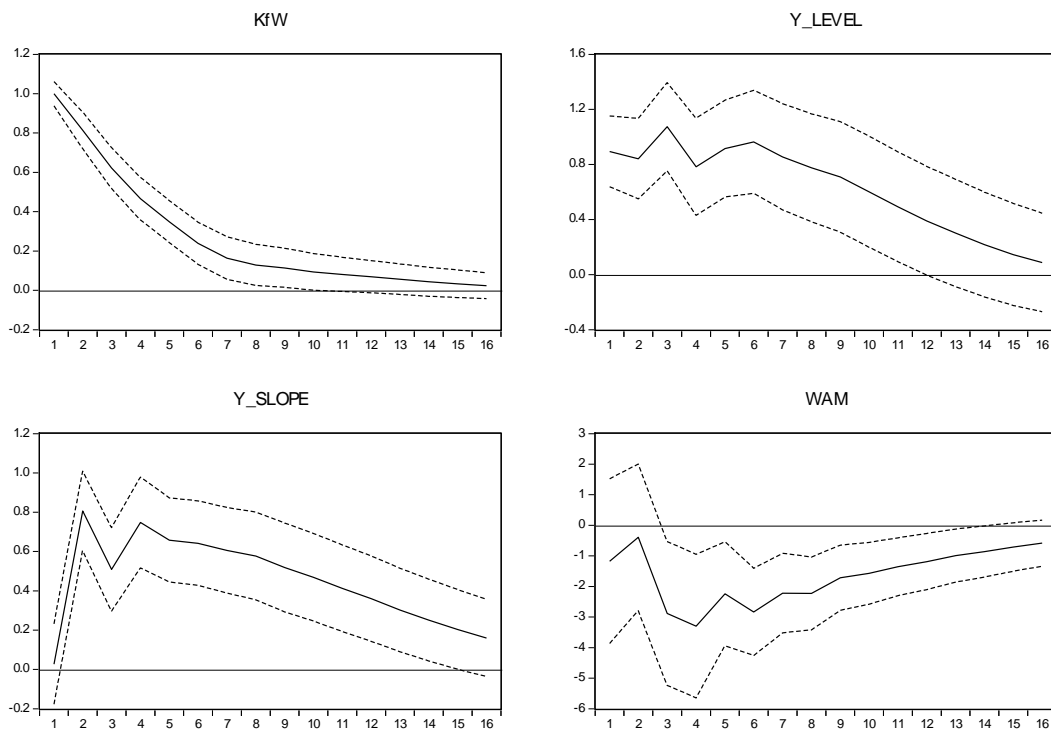


Figure A.10: Impulse responses for variance decomposition

