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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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Are European sovereign bonds fairly priced? The role of modeling uncertainty

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Abstract

This paper examines the extent to which large swings of sovereign yields in euro area countries during the sovereign debt crisis can be attributed to fundamentals. We focus on the inherent uncertainty in bond yield models, which is often overlooked in the literature. We show that the outcomes are strongly affected by modeling choices with regard to i) the confidence bands for the model prediction, ii) the assumption whether the model coefficients are similar across countries or not, iii) the sample selection, iv) the inclusion of financial variables and v) the choice of time-varying coefficients. These choices affect the explanatory power of macro fundamentals and the extent of mispricing. We find substantial misalignment compared to fundamentals for Greek yields, in most specifications also for Portugal and Ireland, but for the other EMU countries, including Spain and Italy, the evidence is less clear cut. This calls for modesty in interpreting bond yield models and for cautiousness when using them in policymaking.

Keywords: Sovereign bond, Interest rate, Risk premium

JEL Classification: E43, E44, F34, G15

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1. Introduction

Developments of bond yields are an issue for monetary policy as its effectiveness depends on the transmission of money market rates into long-term bond yields (Coeuré, 2012). Disorderly market conditions can disturb this mechanism, if they go in tandem with excessive volatility in bond yields. Strong swings in bond yields may be due to (fair) changes in required compensation for credit risk, market volatility and liquidity tensions. However, during periods of high market turmoil, bond yields may also reflect risks associated with excessive risk aversion that is out of synch with economic fundamentals and market conditions.

Occasionally this may have been the case during extreme stress episodes in European bond markets since 2010 (Figure 1). At the peak of the crisis – summer 2012 – government bond markets were thought to be severely distorted due to unfounded fears on the part of investors of the reversibility of the euro (ECB, 2012). They took into account redenomination risk and this led to self-reinforcing upward spirals in bond yields. The disorderly market conditions threatened the singleness of ECB's monetary policy and the transmission of the policy stance to the real economy. This increased the risk of funding shortages for governments in the periphery of the euro area and for European banks that had large quantities of government bonds on their balance sheets (Allen and Moessner, 2013). At the time, several peripheral countries experienced sudden stops in external financing, which were reflected in the accumulation of large imbalances in the TARGET2 settlement system (Merler and Pisani-Ferry, 2012).

[insert Figure 1 about here]

In response to the disruptions in the monetary transmission mechanism, the ECB announced Outright Monetary Transactions (OMTs) in secondary markets for sovereign bonds in the euro area. Under appropriate conditions the OMTs are intended to be an effective backstop to avoid destructive scenarios with potentially severe challenges for price stability. The ECB does not target a specific yield level with OMTs, but considers a range of variables in planning any interventions (ECB, 2012). The level of yield ceilings is one, but there are also risk spreads, market liquidity conditions and measures of volatility to be considered. Such variables may indicate whether government bond markets are distorted and bonds mispriced.

The announcement of OMTs has arguably contributed greatly to the decline of intra-EMU bond spreads since the summer of 2012. Yet OMTs are not uncontroversial among policymakers, even within the ECB Governing Council. While some see OMTs as “probably the most successful monetary policy measure undertaken in recent times” (Draghi, 2013), others remind that money creation – which could result from the use of OMTs – has been a policy advice from Mephistopheles in Goethe’s *Faust* (Weidmann, 2012).

One important reason for these differences is the lack of consensus among policymakers on the exact nature of the fragilities on European bond markets (De Grauwe and Ji, 2013b). On one end of the spectrum, some see higher spreads as a rational reaction to increased insolvency risk due to deteriorating fundamentals (e.g., Issing, 2009). In this vision, financial support via loans from the EFSF/ESM or via ECB interventions carry large financial risks, while they also create moral hazard because the disciplining effect of financial markets is reduced (Benink and Huizinga, 2013). On the other end of the spectrum, some argue that higher spreads result from overshooting financial markets, where fear and panic can drive spreads away from fundamentals (e.g., De Grauwe and Ji, 2013a; Giavazzi et al., 2013). In this view, liquidity support is justified – possibly from the ECB as lender of last resort – especially as self-fulfilling expectations could turn liquidity problems into solvency problems (De Grauwe, 2012).

For policy makers, it is therefore very important to know whether and to what extent sovereign yields of euro countries are misaligned compared to fundamentals. The answer to this question determines whether market discipline can be relied on, or whether financial markets fail and support or interventions by the EFSF/ESM or ECB are needed. The answer is therefore not only relevant to assess the (future) policy of the ECB, but it also influences the future institutional design of EMU (Gilbert et al., 2013).

The research question of this paper is the extent to which the large swings of sovereign yields of several euro area countries since 2010 can be attributed to fundamentals, given the inherent model uncertainty. Yet a definite answer to the research question is not straightforward. Fundamental values of financial market variables are inherently uncertain. In addition, bond yields may react in a rational way to political risks, such as political ineffectiveness in member states, indecisiveness at the European level, political discussions about debt

restructuring and private sector involvement, or open speculation about the possibility of a euro-exit. Yet these aspects – including redenomination risks – are very difficult to quantify. Finally, recent research suggests that the reaction of bond yields to fundamentals is time-varying, for instance with fluctuations in global risk aversion (D’Agostino and Ehrmann, 2013). This time variability has probably been even stronger in the euro area, where bond yields hardly diverged between 1999 and 2008, but started to differ widely during the sovereign debt crisis. This unusual behavior of bond spreads poses important modeling challenges.

Rather than providing a final answer, we therefore emphasize the role of model uncertainty. This aspect is greatly underemphasized in the recently booming literature that explains bond yields from macroeconomic fundamentals. We adopt the approach taken in this literature and estimate reduced form models for bond yields. This modeling choice is motivated by the question of whether bond yields are fairly priced with respect to macroeconomic fundamentals and market conditions. The scope of this paper is to show the effect of model uncertainty when aiming at assessing whether sovereign bond yields are aligned with macroeconomic fundamentals. We do not aim at estimating the yield curve, so we refrain from estimating stochastic models, such as models that predict the yield curve of tomorrow by using today’s observed yield data (see, for instance, Nelson and Siegel, 1987).¹ We are also not looking for the dynamics of impulse responses of bond yields to developments of fundamental variables, such as studies that use Vector Autoregressive models do (see Arezki, Candelon and Sy, 2011). Finally, we are not looking for contagion or spill-over effects from one country to another, as e.g. Mink and De Haan (2013) have done (see further Section 2).

We give several examples of how modeling choices affect the extent of misalignment of sovereign bond yields that is found. Misalignment is defined as an upward (downward) trespassing by the actual yield of the upper (lower) bound of the model prediction’s confidence band. Schematically, in Figure 2, the red area is considered to be statistically significant evidence of overpricing, the green area of underpricing.² Thereby, we compare

¹ A related strand of literature incorporates macroeconomic factors into yield curve models (Hördahl et al., 2004).

² Strictly speaking, overpricing of an asset implies that the yield is lower than its fundamental level. However, for the sake of simplicity and because this paper focuses on yields instead of asset prices, with ‘overpricing’ we mean that the yield is higher than its fundamental level.

actual yields with in-sample prediction intervals, as the policy relevant research question is whether actual yields are misaligned with fundamentals, not what future yields will be.³

[insert Figure 2]

Our main conclusion is that bond yields do display large fluctuations that cannot be explained by macroeconomic fundamentals. At the same time, the extent to which bond yields are misaligned is highly uncertain, and should therefore be interpreted with great caution.

The remainder of this paper is structured as follows. Section 2 provides an overview of the empirical literature on sovereign bond yields and derives five major modeling choices. In section 3, we present our benchmark model and various alternative specifications, followed by a description of the data in Section 4. The benchmark model is estimated in Section 5 after which Section 6 shows how alternative modeling choices affect the results. Section 7 concludes.

2. Literature review

This review first summarizes the main findings of the empirical literature on sovereign yields, after which it focuses on the wide diversity in sample selection and modeling choices.

2.1 Main findings

There is an extensive and fast growing body of empirical literature on sovereign yields. The European sovereign debt crisis has clearly increased the interest in this subject. Roughly three relevant findings seem to emerge, even though there is no absolute consensus.⁴

First, the reaction of financial markets is not constant over time. Spreads were exceptionally low during the first decade of EMU (Bernoth et al., 2012; Pogoshyan, 2012; Beirne and Fratzscher, 2013; D’Agostino and Ehrmann, 2013) and only started to increase after the start

³ Ceteris paribus, confidence bands are wider for model forecasts than for model predictions.

⁴ Gilbert et al. (2013) provide a more elaborate overview of these three findings.

of the debt crisis. This was partly due to an increase in global risk aversion (Haugh et al., 2009; Caceres et al., 2010, Aizenman et al., 2011), but spreads also reacted more strongly to fiscal fundamentals (Haugh et al, 2009; Bernoth et al., 2012, Bernoth and Erdogan, 2012; Giordano et al., 2012; Beirne and Fratzscher, 2013; D’Agostino and Ehrmann, 2013).

Second, EMU member states appear more vulnerable than countries having their own currencies. Spreads in the so-called ‘periphery’ of the euro area (Greece, Ireland, Italy, Portugal and Spain) are higher than in countries with comparable fiscal fundamentals (De Grauwe and Ji, 2013a; Poghosyan, 2012; D’Agostino and Ehrmann, 2013), even if emerging economies are included in the sample (Aizenman et al., 2011). This is partly a rational reaction to specific vulnerabilities, such as the lack of the exchange rate as an adjustment mechanism and the large banking sectors with high shares of sovereign debt on their balance sheets (Pisani-Ferry, 2012). But EMU member states could also be more vulnerable to bond yield misalignment. The exceptionally high level of financial integration has made countries more sensitive to contagion (Forbes, 2012), while the single currency may have increased the elasticity of capital flows with respect to fundamentals (Lane, 2012). Finally, EMU countries do not have their own central bank that can act as a lender of last resort once the government is faced with liquidity problems (De Grauwe, 2012).

Third, several studies find evidence that financial markets have been overshooting at times, especially in the latter phase of the crisis. Spreads in the periphery of the euro zone were higher than could be explained on the basis of fiscal fundamentals. The evidence of mispricing continues to hold when other economic fundamentals are included, such as current account balances (De Grauwe and Ji, 2013a), potential growth (Poghosyan, 2012), private debt (Giordano et al., 2012) and indicators of financial sector problems (Di Cesare et al., 2012). In addition, yield spreads seem very persistent, which may imply that the mispricing is long lasting (Giordano et al., 2012; De Grauwe and Ji, 2013a) and possibly that “markets can stay irrational longer than a country can stay solvent” (Favero and Missale, 2011).

However, on closer inspection, the consensus on mispricing disappears. First, there is no consensus on whether certain model specifications include mispricing. For example, Bernoth and Erdogan (2012) and D’Agostino and Ehrmann (2013) see the stronger reaction of spreads to (fiscal) fundamentals during the crisis period as a normal phenomenon, not as misalignment. According to Giordano et al. (2012) and Beirne and Fratzscher (2013), the

stronger reaction to spreads during the crisis is a form of “wake-up call contagion”. They also tend to see this as a normal phenomenon that doesn’t imply mispricing, but Giordano et al. (2012) add “assessing whether the extent of such a “wake up” is appropriate or excessive is not straightforward and [...] outside the scope of this paper”. By contrast, Favero and Missale (2011) see their contagion measure – a weighted average of spreads in countries with comparable fundamentals – as a sign of misalignment. Second, there is no agreement on the causes. De Grauwe and Ji (2013a) emphasize self-fulfilling expectations that could lead to inherent instability. Favero and Missale (2011) and Giordano et al. (2012) point at contagion from other countries, while Di Cesare et al. (2012) see a perception of euro area break-up risk. By contrast, Steinkamp and Westermann (2012) point at the increasing share of loans with (implicit) senior credit status. Third, there is no consensus on the size and importance. While De Grauwe and Ji (2013a) find “systemic mispricing of sovereign risk”, Beirne and Fratzscher (2013) claim that “a deterioration in [...] fundamentals and [...] a sharp rise in the sensitivity of [...] markets to fundamentals are the main explanations”. For Portugal, Pogoshyan (2012) finds strong overpricing while Giordano et al. (2012) find none. More research seems to be necessary to determine the size and nature of misalignment more precisely.

2.2 Sample selection and modeling choices

Sample selection and modeling choices differ widely between the studies. In itself, this may be a reflection of the large model uncertainty. It seems plausible that modeling choices affect the size and nature of the mispricing found. This is especially the case when mispricing is defined as the size of the residuals generated by the model, or the part of the spreads that cannot be explained by the fundamentals. This approach is used in various studies (De Grauwe and Ji, 2013a; Pogoshyan, 2012; Giordano et al., 2012; Di Cesare et al., 2012; D’Agostino and Ehrmann, 2013).⁵

In this study we pay attention to a number of aspects of modeling uncertainty that deserve particular attention when addressing the central question at hand, i.e. whether sovereign yields

⁵ Other studies use various kinds of measures for contagion, such as ratings (Arezki et al, 2011; Aizenman et al., 2013; De Santis, 2013), economic news from other countries (Mink and De Haan, 2012; Zoli, 2013), some measure of spreads in other countries (Caceres et al., 2010; Favero and Missale, 2011; Metiu, 2012) and a crisis dummy to measure “wake up call” contagion (Giordano et al., 2012; Beirne and Fratzscher, 2013). However, not all of these contagion effects necessarily imply that spreads have been overshooting (see also Forbes, 2012).

can or cannot be explained by fundamentals or, in other words, whether there is over or underpricing in sovereign bond markets. Looking at the literature, five aspects of model uncertainty may be specifically relevant. These aspects are mutually dependent: the importance of choices on one aspect may depend on the choices made on the other aspects.⁶ We will see below that the modeling choices that are made in the end cannot be justified on the basis of econometric diagnostics alone. They also require a fair bit of economic judgment.

- 1) The first aspect relates to the *statistical uncertainty* with respect to the econometric estimation of any model. When standard deviations of estimated model coefficients are large, allowance should be made of the resulting uncertainty with respect to the model predictions. This is especially relevant when mispricing is defined as the part of the spreads that cannot be explained by the fundamentals. In this case, it is essential that the confidence bands of the prediction are taken into account. In several studies, such as Giordano et al. (2012) and De Grauwe and Ji (2013a), this aspect of model uncertainty is not mentioned explicitly. An exception is D'Agostino and Ehrmann (2013).
- 2) The second aspect is related to the assumptions with respect to *parameter heterogeneity* across regions or countries. There are two extremes to be found in the literature. On the one extreme, there are panel models where all parameters are assumed to be equal across all countries and, on the other extreme, country-specific models that are estimated separately for each individual country, resulting in different parameter estimates for each country. Examples of panel model studies are Bernoth et al. (2012), De Grauwe and Ji (2013a) and Poghosyan (2012) and examples for country-specific models are Arezki et al., (2011), Favero and Missale (2011) and D'Agostino and Ehrmann (2013). In between these two extremes are models that allow for parameter differences between regions or country groups, such as some of the models estimated by Beirne and Fratzscher (2013) and Aizenman et al. (2013). While the majority of studies uses panel models, only a few studies actually test whether the assumption of equal parameters across countries is justified (Arezki et al., 2011; Favero and Missale, 2011; Beirne and Fratzscher, 2013;

⁶ For example, D'Agostino and Ehrmann (2013) show that the amount of overpricing that is found becomes more sensitive to the sample period if the model does not contain time-dependent variables. By the same token, the choice of countries in the sample only matters if the estimation is done in a panel modeling setting.

D’Agostino and Ehrmann, 2013). In these studies, the assumption of parameter homogeneity across countries is generally rejected.⁷

The choices with respect to parameter heterogeneity may also affect the amount of mispricing. From an econometric perspective, homogeneity will generally be rejected because country-specific coefficients differ from each other and allowing for these differences therefore will yield a better fit. Yet, a search for mispricing doesn’t necessarily require the best fit. It may require investigating whether spreads are higher in some countries compared to spreads in other countries with comparable fundamentals, and this can be done more transparently using homogeneous coefficients. There may also be other reasons for homogeneous coefficients, such as the political desire to apply equal criteria to EMU countries when determining whether financial support is justified. At the same time, some cross-country group variation of model coefficients may sometimes be justified. For example, it is possible that government bonds in the periphery of the euro area are priced differently from those in the core.

- 3) The third aspect relates to *sample selection*, i.e., the sample period and the countries included. Both aspects differ widely in the literature. Regarding the sample period, choices range from the period since the financial crisis (Metiu, 2012; De Santis, 2013, Zoli, 2013) to the period since the start of EMU (among others, Bernoth and Erdogan, 2012; De Grauwe and Ji, 2013a; Beirne and Fratzscher, 2013) and even to the period since 1980 (Poghosyan, 2012). Regarding the countries in the sample, some studies include only one country (Di Cesare et al., 2012; Zoli, 2013), while others concentrate on EMU-countries (for example, Haugh et al., 2009; Bernoth et al., 2012). However, several studies also includes countries from outside the euro area, such as EU-countries (Aizenman et al., 2013), other advanced economies (De Grauwe and Ji, 2013a; Poghosyan, 2012; D’Agostino and Ehrmann, 2013) and emerging markets (Aizenman et al., 2011; Beirne and Fratzscher, 2013; Aizenman et al., 2013).

Sample choices may affect the extent of mispricing found, because the econometric estimation maximizes the fit of the model over the sample period (D’Agostino and

⁷ Of course, the wide-spread use of panel data models is motivated by the wish to exploit both cross-sectional and time dimensions in the data at the same time, and does hardly ever follow from purely statistical grounds.

Ehrmann, 2013) and (in case of a panel) the countries included in the sample. To determine possible misalignment, it is therefore important that yields in the sample are more or less “normal” on average. This normality is difficult to tell, given the time variation in the spreads and the cross-country differences. For example, estimation over the crisis period might be biased because spreads were relatively high during that period. On the other hand, estimation over the EMU-period might be influenced by the exceptionally low intra-EMU spreads before the crisis. In fact, the few studies that acknowledge that intra-EMU spreads were too low in the pre-crisis period include either data from before the start of EMU (Bernoth et al., 2012; D’Agostino and Ehrmann, 2013), countries outside EMU (Beirne and Fratzscher, 2013) or both (Poghosyan, 2012).

- 4) The fourth aspect is related to the incorporation of *financial market indicators* in the model. Many studies add some financial market indicators to the explanatory variables to account for market conditions affecting sovereign yields. The choice of financial market variables varies considerably, but two groups can be distinguished. One group of variables represents changes in global risk aversion on financial markets. Usually one global variable is included into the model, which ranges from the VIX index (see for example Giordano et al., 2012; Beirne and Fratzscher, 2013; Aizenman et al., 2012; D’Agostino and Ehrmann, 2013), to US corporate bond spreads (Haugh et al., 2009; Favero and Missale, 2011; Bernoth and Erdogan, 2012), and the TED spread (Aizenman et al., 2011). Another group of financial market variables aims at representing more structural characteristics of the bond markets of individual countries, in terms of market depth and liquidity. Usually a country-specific variable is included, which varies from an indicator of market size (Haugh et al., 2009; Bernoth et al., 2012; D’Agostino and Ehrmann, 2013) to bid-ask spreads (Bernoth and Erdogan, 2012; Giordano, Pericoli and Tommasino, 2012).

The inclusion of financial market variables in a model for sovereign yields could also affect the amount of mispricing found. Financial market variables allow yield spreads to display variation over time (global risk aversion) and across countries (liquidity) that is not explained by macroeconomic fundamentals alone. To some extent this seems to be perfectly justified, since these financial market variables reflect volatility and liquidity risks that are and should be priced in the market. On the other hand, market sentiments may be overly optimistic or pessimistic and therefore the cause of under or overpricing.

Many claim that global risk aversion was too low before the crisis, while it may have been too high during the most intense phase of the crisis. Likewise, bid-ask spreads could be affected when sovereign yields are under pressure.

- 5) The final modeling choice is how to deal with the apparent *time variability* in the reaction of yield spreads. In many studies, some form of time variability of the parameters is allowed for. On the one extreme, the coefficients are allowed to change continuously over a certain horizon (D'Agostino and Ehrmann, 2013; Bernoth and Erdogan, 2012). On the other, coefficients are assumed to remain constant throughout the whole sample period (Poghosyan, 2012; Steinkamp and Westermann, 2012). In between these two extremes, many studies allow for a structural break in several coefficients, for example, due to the financial crisis or the sovereign debt crisis (e.g., Bernoth et al., 2012; Giordano et al., 2012; Beirne and Fratzscher, 2013). Others allow for non-linearities by interacting some variables with risk indicators (Haugh et al., 2009) or adding squared terms of fiscal fundamentals (Bernoth et al., 2012; De Grauwe and Ji, 2013a; Di Cesare et al., 2012). Finally, some studies deal with time variability by incorporating some kind of contagion measure, such as spreads in other countries (Favero and Missale, 2011) or credit ratings (Arezki, 2011; Aizenman et al., 2013).

The amount of mispricing found will also depend on whether and how time-variability is incorporated. The inclusion of time-variability allows for higher coefficients in the period of the sovereign debt crisis, which implies that a larger part of the yield spreads is explained by macroeconomic fundamentals. The specific method of time-variability also seems to matter. While the incorporation of a crisis dummy only allows coefficients to differ between the crisis and the pre-crisis period, the incorporation of time-varying coefficients also allows for some variation within the crisis period. This may be justified to some extent, as the course of the crisis also varies, for instance, under the influence of political developments. However, too much time variation in the coefficients increases the chance that actual misalignment is interpreted as being related to fundamentals. There clearly is a trade-off here, which may be hard to determine exactly: D'Agostino and Ehrmann (2013) allow for some time-variation, but also find mispricing.

Our contribution is that we show how several of the above-mentioned aspects of modeling uncertainty affect the results with respect to the extent of mispricing that is to be found.

3. The benchmark model and some variants

In this Section, we first present our benchmark model, and subsequently several alternative specifications that represent modeling uncertainty.

3.1 The benchmark model

Based on the preferred habitat theory of the yield curve (Modigliani and Shiller, 1973), we assume that sovereign yields (r_{it}) consist of three components: a risk-free component (rf_{it}), a risk premium (rp_{it}) and a residual term (e_{it}):

$$r_{it} = rf_{it} + rp_{it} + e_{it} \quad (1)$$

where i denotes the country and t the time period. The risk premium not only compensates for inflation and credit risks, but also for volatility and liquidity risks. The first two risk factors are determined by expectations with respect to the macro-economic fundamentals of a country, the last two by a country's financial market conditions, i.e. liquidity and volatility, for which investors are compensated by the risk premium.

The macro-economic fundamentals, reflecting a country's earning capacity and credit worthiness, include real gdp growth (gdp), inflation (cpi), the government debt ratio ($debt$) and the current account ratio (car). These variables are used in most models that explain sovereign bond yields from macroeconomic fundamentals (see Section 2). When available, we use expectations of market participants for these macro-economic fundamentals (consensus forecasts), because expectations affect market rates in the first place.⁸ By using consensus forecasts we follow D'Agostino and Ehrmann (2013), who were the first to use such data for

⁸ Following D'Agostino and Ehrmann (2013), we use the debt ratio as explanatory variable and not the government deficit itself. For our sample including smaller countries, consensus forecast data for the latter variable are not always available.

the modeling of sovereign yields; they do this for the G7 countries. The advantages of the consensus forecasts are that, unlike official public forecasts, these have a monthly frequency and reflect the predictions of financial market participants. We will use consensus forecasts for the G7 plus 10 more countries.

For the financial market conditions we use a latent variable (fin), capturing both the volatility and liquidity of government bond markets in individual countries. These factors partly determine the efficiency of the pricing process and thereby the extent to which yields fairly reflect macroeconomic fundamentals. We also interact the financial market conditions variable with the government debt ($debt \times fin$), assuming that when financial markets are nervous, market participants are more alert with respect to the countries' credit worthiness than they are under normal market conditions (see for instance Haugh et al., 2009). In other words, we assume that some degree of non-linearity of the relation between credit worthiness and sovereign yields may be driven by market conditions. The *benchmark* model reads:

$$r_{it} = \alpha_{0i} + \alpha_1 rf_{it} + \alpha_2 cpi_{it} + \alpha_3 gdp_{it} + \alpha_4 debt_{it} + \alpha_6 debt_{it} \times fin_{it} + \alpha_7 car_{it} + \alpha_8 fin_{it} + e_{it} \quad (2)$$

Our priors are: $\alpha_1, \alpha_2, \alpha_4, \alpha_6, \alpha_8 \geq 0$ and $\alpha_3, \alpha_7 \leq 0$. We do not restrict α_1 to be equal to 1, as our proxy for the risk-free rate is the swap rate for the euro area and hence not a country-specific rate, with a maturity of 2 years (10 year maturities are not available). Therefore, the proxy is an imperfect measure for the risk-free rate and the coefficient is expected to be close to but not necessarily equal to 1.

The residual (e_{it}) reflects the effect of market sentiments unrelated to macro-economic and financial market conditions, as in, for example, De Grauwe and Ji (2013a), Pogoshyan (2012) and D'Agostino and Ehrmann (2013). Market sentiments can be excessively pessimistic or optimistic and generate under or overpricing of the interest rate, respectively.

In order to assess whether misalignment of yields has occurred during the crisis, we estimate model (2) and compare the model predictions, including the predictions' 95% confidence bands, with the actual bond rates.

3.2 Alternative specifications

We also specify several alternative specifications and propose an alternative sample selection. Our aim is to show how modeling uncertainties may affect the extent of misalignment of bond yields to be found. We consider the five sources of model uncertainty which have been discussed in Section 2.2.

Model uncertainty 1: The use and calculation of confidence bands for the model prediction is a source of model uncertainty.

The search for over or underpricing of sovereign yields essentially implies looking for an omitted variable bias in the regression results. In the present case, the omitted variable could be irrational market optimism or pessimism, which is typically hard to measure. Contagion could be such a variable, too. Omission of such variables may result in the residuals being consecutively positive or negative, respectively, depending on whether there is excessive pessimism or optimism in the sovereign bond market. Hence, when there is over or underpricing, by definition, there should be positive or negative autocorrelation of the residuals. OLS estimates for model coefficients in the presence of autocorrelation are unbiased. However, they no longer have the minimum variance property, making confidence intervals and hypothesis tests based on t and F distributions unreliable. Computed variances and standard errors of forecasts may be inaccurate when autocorrelation is not accounted for. Therefore, we report standard errors which are robust to clustering, autocorrelation and heteroskedasticity.⁹

In order to show the effect of neglecting the effect of autocorrelation on the standard errors, we also calculate prediction confidence bands using non-robust (OLS) standard errors.

⁹ Using standard notation, the OLS variance estimator is $Var_{OLS} = \frac{1}{N-k} \sum_{i=1}^N e_i^2 \cdot (X'X)^{-1}$, whereas the robust cluster variance estimator is $Var_{cluster} = (X'X)^{-1} \cdot \sum_{j=1}^{n_c} u_j' u_j \cdot (X'X)^{-1}$, where $u_j = \sum_{i \in J_{cluster}} e_i x_i$ and n_c is the total number of clusters, e_i is the residual for the i th observation and x_i is a row vector of predictors including the constant. For simplicity, the multiplier (which is close to 1) has been omitted for the formula for $Var_{cluster}$. For more information on robust standard errors in panel regressions, see e.g. Hoechle (2007).

Model uncertainty 2: The choice of common versus country-specific coefficients is a source of model uncertainty.

Model (2), our benchmark model, is a fixed effects panel model. The intercept α_{0i} is country specific; the latter represent the so-called ‘fixed effects’ allowing for time-invariant differences in interest rates between countries. The coefficients of the explanatory variables are assumed to be equal across countries, as are their marginal effects. Our assumption behind this modeling framework is that investors assess country risks in a portfolio context and use similar norms towards the issuing countries, like rating agencies do (as discussed in Section 2.2). Hence, our benchmark model adopts the approach of testing countries equally. Because the pooling assumption is strong, we also test heterogeneity of some of the coefficients across regions or country groups (as in Beirne and Fratzscher, 2013), using a region or country group dummy D_g :

$$r_{it} = \alpha_{0i} + \alpha_1 rf_{it} + \alpha_2 cpi_{it} + \alpha_3 cpi_{it} \cdot D_g + \alpha_4 gdp_{it} + \alpha_5 gdp_{it} \cdot D_g + \alpha_6 debt_{it} + \alpha_7 debt_{it} \cdot D_g + \alpha_8 debt_{it} \times fin_{it} + \alpha_9 debt_{it} \times fin_{it} \cdot D_g + \alpha_{10} car_{it} + \alpha_{11} car_{it} \cdot D_g + \alpha_{12} fin_{it} + \alpha_{13} fin_{it} \cdot D_g + e_{it} \quad (3)$$

We also estimate models separately for each country, thus allowing all coefficients to differ between all countries (as in for instance D’Agostino and Ehrmann, 2013):

$$r_{it} = \alpha_{0i} + \alpha_{1i} rf_{it} + \alpha_{2i} cpi_{it} + \alpha_{3i} gdp_{it} + \alpha_{4i} debt_{it} + \alpha_{6i} debt_{it} \times fin_{it} + \alpha_{7i} car_{it} + \alpha_{8i} fin_{it} + e_{it} \quad (4)$$

The main advantage of panel data models is that both time and cross-sectional information in the data are exploited. Another important advantage of panel data models as opposed to country-specific models, which is specifically relevant for the research question at hand, is that the residuals do not have to add up to zero for each country, which is the case in country-specific models by construction. In other words, while country-specific models force overpricing and underpricing for a country to cancel out, panel data models allow countries to exhibit more overpricing than underpricing or vice versa during the sample period.

Model uncertainty 3: The sample selection is a source of model uncertainty.

As the selection of countries is important, we select a relatively representative group of 17 advanced economies. Not only 11 euro area countries, but also 6 non-euro area countries are selected. The latter group consists both EU and non-EU countries. More information follows in the Data Section. For our sample period (January 2007 – February 2013) we have data with a relatively high (monthly) frequency which allows us to capture the developments in financial markets. The period comprises three pre-crisis years and three crisis years. To show the effects of sample selection on the findings, we estimate our models for the whole sample and for sub-samples.

Model uncertainty 4: The choice of including or excluding financial market variables is a source of model uncertainty.

In our benchmark model, financial market conditions (fin) are included. The reason is that our theoretical model assumes that the risk premium also contains a premium for market volatility and liquidity. One could question whether this is justified. Often, in times of stress on financial markets, liquidity is extremely low and volatility high, so that implicitly part of the mispricing is added as an explanatory variable. Therefore, we also estimate the fixed effects panel model excluding fin and $debt \times fin$ among the explanatory variables (as in De Grauwe and Ji, 2013a, and Poghosyan, 2012):

$$r_{it} = \alpha_{0i} + \alpha_1 rf_{it} + \alpha_2 cpi_{it} + \alpha_3 gdp_{it} + \alpha_4 debt_{it} + \alpha_5 car_{it} + e_{it} \quad (5)$$

Model uncertainty 5: The choice of fixed versus time-varying coefficients is a source of model uncertainty

In benchmark model (2), the coefficients are fixed throughout the whole sample period, as in Poghosyan (2012) and Steinkamp and Westermann (2012). However, it is conceivable that the relationship is not constant through time. Hence, following, for instance, Bernoth et al. (2012), Giordano et al. (2012) and Beirne and Fratzscher (2013), we also estimate the model

interacting with a dummy variable D_c distinguishing the crisis period from the pre-crisis period, which is set to start from January 2010 onwards.

$$r_{it} = \alpha_{0i} + \alpha_1 rf_{it} + \alpha_2 cpi_{it} + \alpha_3 cpi_{it} \cdot D_c + \alpha_4 gdp_{it} + \alpha_5 gdp_{it} \cdot D_c + \alpha_6 debt_{it} + \alpha_7 debt_{it} \cdot D_c + \alpha_8 debt_{it} \times fin_{it} + \alpha_9 debt_{it} \times fin_{it} \cdot D_c + \alpha_{10} car_{it} + \alpha_{11} car_{it} \cdot D_c + \alpha_{12} fin_{it} + \alpha_{13} fin_{it} \cdot D_c + e_{it} \quad (6)$$

In the empirical section, we will illustrate how these sources of model uncertainty affect the extent of over and underpricing that is to be found. But first, we discuss the data.

4. Data

Our dataset contains 17 countries, of which 11 euro countries and 6 non-euro countries (for comparison purposes).¹⁰ The data frequency is monthly and the sample period is January 2007 to February 2013. The panel data set is highly balanced. The relatively late start of the sample period is due to the availability of consensus forecast data for non-G7 countries.

The dependent variable is the 10 year sovereign bond yield (*yield_10*).

For the macroeconomic variables we use consensus forecasts, which are available for each month m of a particular year for the current year y and the next year $y+1$. Following Dovern et al. (2012) and D'Agostino and Ehrmann (2013), we derive average forecasts for the coming 12 months. This acknowledges that interest rates reflect market expectations about future developments. If F_m^y is the consensus forecast in month m for the current year y , and F_m^{y+1} is the consensus forecast for $y+1$, then the weighted average for the next 12 months is defined

as: $\frac{F_m^y \cdot (12 - m) + F_m^{y+1} \cdot m}{12}$, with $m = 1, \dots, 12$.

The market conditions variable is the principal factor of two financial variables: volatility and liquidity. Liquidity is measured as the monthly average of daily bid-ask spreads, volatility is the monthly average of the daily differences between the highest and lowest bond price. For

¹⁰ The 11 euro countries are Austria, Belgium, Germany, Finland, France, Greece, Ireland, Italy, the Netherlands, Portugal and Spain. The 6 non-euro countries are Canada, Japan, Sweden, Switzerland, the United Kingdom and the United States.

the risk-free rate (rf_{it}) we use the swap rate (euro overnight index for euro area countries; US and UK swap rates for the US and the UK, respectively). We take the principal factor of these two highly correlated variables (within correlation is 0.80) to reduce the number of explanatory variables in our regression models and to have one composite indicator of financial market conditions reflecting both liquidity and volatility.

Appendix A gives the definitions and sources of all variables. Table 1 presents summary statistics. Table 2 reports the correlation matrix for the panel-demeaned variables, i.e. the variables minus the means by country. The reason for showing correlations for panel-demeaned variables is that the panel models assume fixed country effects, so that the relevant variable to look at is the variables after removing the panel means. Most right-hand side variables are not strongly correlated (correlations are lower than 0.45), with a few exceptions. We will test whether multicollinearity is a problem for our benchmark regression model.

[insert Tables 1 and 2]

The outcomes of an unit root test suggested by Levin et al. (2002) show that, when suppressing panel-specific means, the presence of a unit root in all panels can be rejected for all variables except *debt* (Appendix B).

5. Results for the benchmark model

The results of the benchmark model (2) for *yield_10* are presented in the first column of Table 3. The model fit is quite high (within $R^2 = 0.68$). The (robust) standard errors indicate that *rf*, *gdp* and *debt* are statistically significant and their coefficients have the expected signs. The other variables, *cpi*, *fin x debt*, *fin* and *car* are not significant.¹¹ Our measure *fin* is not used in the rest of the literature, which makes it difficult to compare results. The insignificance of *car* is also found by De Grauwe and Ji (2013a) and Beirne and Fratzscher (2012), while D'Agostino and Ehrmann (2013) do find significant results. Our variable *cpi* is not used in many studies, but Poghosyan (2012) finds a significant effect.

¹¹ Multicollinearity does not seem to be a problem; the highest value for the Variance Inflation Factor is 3.75.

[insert Table 3]

Using these estimates, Figure C1 in Appendix C plots the actual versus the predicted yields for all 17 countries, including the 95 per cent confidence intervals for the predictions which are based on the robust standard errors.¹² For the sake of clarity, Figure 3 shows the same actual-prediction plots for a selection of five ‘periphery’ countries.

[insert Figure 3]

Figure 3 suggests that there has not been consistent and massive mispricing of yields throughout the whole of the periphery of the Eurozone. Instead, there has been some mispricing during certain periods since the sovereign crisis started in 2010. The greatest mispricing seems to have occurred for Greece and Ireland during the second half of 2011. To a lesser degree some mispricing is also discernible in this period for Portugal, while Spain has displayed some misalignment in the summer of 2012. Because the upward spikes in the yields of Italy remain below the confidence bands’ upper bound, the model estimates do not give significant evidence of overpricing of sovereign yields for this country.¹³ According to the model, some mispricing was also present in Belgium, France, the UK, the US and Canada (Figure C1 in Appendix C). Somewhat surprisingly, our model also finds underpricing in some cases. For Greece and Ireland, some underpricing is discernible at the end of the sample period (2012-2013), after the introduction of the OMTs. In the UK, the US and Canada, also some underpricing was present in the last two years of the sample. This could reflect the effect of unconventional monetary policy on long-term interest rates.

Focusing on overpricing, the first column of Table 4 reports the extent to which sovereign yields are higher than the fundamental value according to our benchmark model, defined as the actual yield minus the upper boundary of the 95% confidence interval for the model prediction, if positive (negative differences are set to zero). Panel A reports the mean values of the overpricing during the crisis period, in percentage points, Panel B reports the maximum

¹² The standard errors on which the confidence bands are based are robust for the presence of autocorrelation and heteroskedasticity. The Wooldridge test rejects the null hypothesis of no first-order autocorrelation in the panel data (F-value = 389.4, p-value < 1%). The modified Wald test also rejects the null of no country-wise heteroskedasticity in the fixed effects regression ($\text{Chi}^2 = 17630$; $p < 1\%$).

¹³ The width of the confidence bands change over time due to the adjustment of the robust standard errors for heteroskedasticity. The width of the confidence bands may also differ between countries due to different degrees of intra-country correlation of the residuals for which the robust standard errors have been adjusted.

values during the crisis period, and Panel C gives the number of months of overpricing during the crisis period. The sovereign debt crisis started at the end of 2009, when rumours suggested that Greece could no longer finance its debt burden. Therefore, the crisis period is set to January 2010 until the end of the sample period.

[insert Table 4 about here]

Mean overpricing was most substantial in Greece (5.6 percentage points), followed by much more modest mean overpricing in Ireland (0.8) and Portugal (0.6), and no mean overpricing in Spain and Italy (see Table 4, Panel A, column 0). Greece also had the highest maximum overpricing (12.1), compared to much smaller values in Ireland (1.6) and Portugal (1.5) and almost no overpricing in Spain and Italy (see Panel B). However, the number of months of overpricing was average for Greece (7) compared to Belgium (19), Canada (19) and United States (12) (see Panel C).

Table 3 does not report estimates for the fixed effects α_{0i} in model (2). Usually, these are not very interesting. However, in this particular case they reveal interesting information. As explained in Section 3, fixed effects represent time-invariant country effects which are related to some unobserved structural country-specific characteristic(s). We report the estimates for the fixed effects in Figure 4, together with their 95% confidence bands.¹⁴ The 17th country dummy, which due to the alphabetic order turns out to be for the United States, is omitted for collinearity reasons. The fixed effects have been centred, so that they can be interpreted as deviations from the mean.

Japan stands out with a strongly negative fixed effect of several percentage points. Technically, this compensates for the fact that Japan's debt ratio is the highest in the sample while Japan's sovereign yield is relatively low. Economically, this may reflect the relatively large domestic investor base for Japan's sovereign debt, which mostly results from the accumulation of pension savings coupled with a strong home bias (Andritzky, 2012). A similar story – i.e. a relatively high debt ratio and a large domestically held share of government debt – could explain the also quite sizeable negative fixed effect for Italy. By contrast, quite sizeable positive fixed effects are found for Ireland and Spain, but more

¹⁴ The Wald test rejects the null that all fixed effects are jointly equal to zero (F-value = 8.03, p-value = 0.000).

surprisingly, also for Sweden and Finland. A possible explanation for Sweden and Finland may be that these countries had relative low debt ratios and relatively good growth prospects over the sample period, which may not be fully reflected in the level of long-term yields. A similar story may hold to some extent for Spain and Ireland. These countries grew fast and had very low debt ratios before the crisis (Gilbert et al., 2013). Their deterioration in economic fundamentals since then is among the strongest in the sample.

[insert Figure 4]

Figure 5 plots the explanatory variables' contributions to the predictions of model (2) of the sovereign yields for the periphery countries (for all countries, see Appendix C, Figure C2). Note that these contributions have been calculated by means of the point-estimates for the coefficients; hence, they do not take the coefficients' standard errors into account. Consequently, their patterns through time are more reliable than their absolute values. We suppress the contributions of the fixed effects (and the intercept) because they are constant in time, as we have just shown (Figure 4).

Overall, there has been a declining trend in the contribution of the risk-free rate (rf), especially between 2008 and 2009. This probably reflects the effect of large-scale conventional and unconventional monetary policy easing since the start of the financial crisis in 2008. By contrast, growth prospects (gdp) had a positive contribution to yields during the deep 2009 recession in many countries. This effect faded when global growth prospects recovered, but especially euro area countries have experienced an increase of interest rates due to lower growth prospects in 2011 and 2012. For Greece, Ireland and Portugal, bad market conditions (fin) also had a temporary upward effect since the start of the debt crisis in 2010, while Spain and Italy have experienced this to a smaller extent in 2011 and 2012. Finally, the contribution of debt ratios has risen in many countries, except for Sweden and Switzerland.¹⁵

As the increase in government debt after the crisis differs quite substantially between countries, so does the upward effect on interest rates. It ranges from roughly around 100 basis

¹⁵ The calculated contributions may be biased if the estimated coefficients suffer from biases resulting from endogeneity of the explanatory variables. We performed separate exogeneity tests on the explanatory variables. For both gdp and rf , the Davidson-MacKinnon test failed to reject the null of exogeneity. Hence, for these variables with the overall greatest contributions to the explanation of the yields, endogeneity bias does not seem to be a problem. For $debt$ and fin , however, the tests rejected the null of exogeneity, so that the contributions of these variables may suffer from some endogeneity bias.

points in countries like Austria, Belgium, Germany and Canada to around 400 basis points for Spain and Portugal, and 800 basis points in Ireland. For Greece, the combined effect of the increase in debt and the interaction of the debt ratio with the financial market condition variable resulted in an increase of the yield by $(500 + 700 =) 1200$ basis points; on top of that came the effect of financial market stress itself amounting to 800 basis points and the contribution of worsening growth prospects (+400). In line with Beirne and Fratzscher (2013) we find that the deterioration of macroeconomic fundamentals such as growth and government debt explain a significant part of the increase in yields in the euro area.¹⁶

[insert Figure 4]

6. Results for alternative specifications

In this Section we present the results of some alternative modeling choices and sample selections, reflecting the five modeling uncertainties discussed in Sections 2 and 3.

6.1 *The calculation of confidence bands for the model prediction (Model uncertainty 1)*

We use standard errors which are robust to both autocorrelation and heteroskedasticity. If non-robust (OLS) standard errors would have been used for the calculation of the confidence bands, the latter would have been much narrower but misleading (as discussed in Section 3.2). Most of the recent empirical literature does not seem to use any confidence bands at all, with the exception of D’Agostino and Ehrmann (2013), who use “68% posterior error bands of the fitted spreads obtained from the bayesian time-varying parameter models”. With narrower confidence bands, over and underpricing would have turned out to be much greater, sometimes by up to several percentage points. Hence, with non-robust standard errors, we would have found mispricing more often, in more countries, and in greater magnitudes than with robust standard errors.

¹⁶ It should be noted that according to our model the increase in government debt would also lead to substantially higher bond yields in the UK, the US and Japan.

This is indeed apparent from Figure 6 (or, for all countries, Appendix C, Figure C3), where the confidence bands have been based on non-robust standard errors and are therefore much narrower compared to the ones in Figure 3. Table 4 (comparing column 1 to 0) indeed gives somewhat higher mean overpricing for several countries (Panel A), but especially higher maximum overpricing for many countries (Panel B) and overpricing in more months (Panel C). However, as mentioned in Section 3.2, without adjusting standard errors for autocorrelation and heteroskedasticity, the confidence intervals of the predictions are unreliable and therefore the measurement of the extent of over and underpricing misleading.

[insert Figure 6]

6.2 *Coefficients varying across countries (Model uncertainty 2)*

In benchmark model (2), coefficients are assumed to be equal across countries.¹⁷ Therefore, we show results of regressions performed *separately* for individual countries, i.e. model (4). For reasons of space, we do not report the regression output for the 17 countries (these are available from the authors); instead we show the prediction plots in Figure 7 for our selection of four countries (for all countries, see Appendix C, Figure C4). Comparing Figure 7 with Figure 3, the predictions of the individual country models follow the actual yields more closely than the panel models. Also, the confidence bands (which are both based on robust standard errors) for the country-specific models are narrower than for the panel model. This makes sense, as the model better takes into account differences between countries and therefore improves the overall fit. The country model is more flexible as cross-country variability of all coefficients is allowed.

According to the country-specific estimates, there is evidence of some misalignment for all countries. Generally, the amount of mispricing is smaller than in the benchmark model, which is in line with our expectations. However, there are exceptions for a number of countries, including Spain and Italy (Table 4). This is because the model follows actual rates more closely on the one hand, but at the same time reduces the confidence bands on the other hand. In any case, it is clear that the use of country-specific coefficients does not remove mispricing

¹⁷ Obviously, the Wald test rejects equality of all coefficients across all countries ($F = 47.79$, $p = 0.000$).

altogether. This is in line with the findings of D'Agostino and Ehrmann (2013), who also find mispricing in country-specific estimations.

[insert Figure 7]

6.3 *Using a sub-sample consisting of euro countries (Model uncertainty 3)*

We select a sub-sample consisting of euro countries only. Hence, we drop the non-euro countries from our sample. Thereby, we differentiate between the so-called periphery countries (Ireland, Italy, Portugal, Spain and Greece) and the non-periphery countries, via interaction with a periphery dummy; D_g in model (3) is the periphery dummy. The results (second column of Table 3) suggest that inflationary expectations have opposite effects on yields in both groups of euro countries: the expectation of one percentage point more inflation has an effect of 80 basis points in the periphery countries, while the effect is -45 basis points in the other euro countries. A possible explanation for the different sign of the inflation effects is that rising inflation in periphery countries is detrimental for their competitive position (which, in turn, is a main determinant of debt sustainability). In non-periphery countries the effect of inflation will to a large extent be reflected in the risk-free rate. The debt ratio has a borderline significant effect of +0.10 on yields in the periphery, while no significant effect is found for the non-periphery euro countries. This confirms the results of Aizenman et al. (2011), Poghosyan (2012) and De Grauwe and Ji, (2013a), who find that yields in the euro area's periphery are higher than in other countries with comparable macroeconomic fundamentals. Financial conditions have a significant effect on yields in the periphery, but not outside. A possible explanation is that the peripheral countries have experienced larger fluctuations in volatility and liquidity in sovereign bond markets than the other euro area countries.

The extent of overpricing is much lower according to this model in comparison to both previous models. Only Greece shows substantial mean overpricing (3.5 percentage points) during four months and Ireland shows mean overpricing (0.2) but only during one month (Table 4, column 3, Panels A and C). Two factors explain the lower extent of overpricing. The first factor is the exclusion of countries outside the euro area with their own currency. The second is the fact that we allow markets to react stronger to fundamentals in periphery

countries. It underlines how sensitive the extent of overpricing is to the selection of countries in the sample. Of course it can be debated whether the higher coefficients in the periphery should be seen as fair or rather as a sign of mispricing.

6.4 *Financial market conditions (Model uncertainty 4)*

To test for the effect of excluding the financial conditions variable on the estimates, we have estimated model (5). The estimation without any financial variables is also done by Poghosyan (2012) and De Grauwe and Ji (2013a). The results (third column of Table 3) for our sample of 17 countries show that R^2 falls to 0.37 after dropping our variable for financial market conditions; hence, the exclusion of financial conditions clearly reduces the overall fit of the model. As a consequence, the predictions also follow the actual yields less closely than in the benchmark model including *fin* (Figure 8 for the periphery or Appendix C, Figure C5 for all countries). This is in line with expectations. However, the exclusion of the financial market variable does not completely change the picture for overpricing. The model does find a larger extent of overpricing than our benchmark model for a number of countries, including Greece, Ireland and Italy (Figure 8 and Table 4, column 4). Both mean and maximum overpricing are substantial in Greece and to a lesser extent Ireland, while Italy displays more limited overpricing. However, somewhat surprisingly, the extent of overpricing is reduced compared to our benchmark model substantially in Portugal and, to some extent, in Spain. Again, this is probably because the effect of a generally lower fit on the one hand is compensated by the effect of wider confidence bands on the other. In any case, an important question remains to what extent financial variables like liquidity should be considered as a fundamental.

[insert Figure 8]

6.5 *Time variability of the coefficients (Model uncertainty 5)*

The benchmark model assumes that all coefficients are constant over time. To relax this assumption to some extent, we estimate model (6) interacting all variables with a crisis dummy variable which has value 1 from January 2010 onwards and 0 before. In this way, we

can see whether and how the relationship has changed because of the European sovereign debt crisis. This approach has also been followed by Giordano et al. (2012) and Beirne and Fratzscher (2013).

From the estimation results (fourth column of Table 3) it can be seen that notably the importance of *gdp* has increased significantly during the crisis (at the 5% significance level). The prospect of one percentage point more growth has an effect of -95 basis points on bond yields during the crisis, compared to -43 before. The coefficient for *debt* has also increased somewhat in the crisis period. Our results confirm previous findings that markets pay closer attention to macroeconomic fundamentals during the crisis, which can be seen as a form of wake-up call contagion (Giordano et al., 2012; Beirne and Fratzscher, 2013). Interestingly, our results suggest that during the crisis markets are particularly worried about the effect of lower economic growth on debt sustainability, which confirms results of Cottarelli and Jaramillo (2012).

According to this model variant the extent of overpricing is reduced in comparison to the benchmark model for Greece and Portugal, in line with our expectations. However, it increases the extent of overpricing in Ireland and, to a lesser extent, Spain. In general, the model shows that overpricing is substantial in Greece and Ireland but not in any of the other euro countries in the sample (Table 4, column 5). Surprisingly, this model also suggests some overpricing in the US and Canada.

6.6 *Summary*

Table 4 summarizes the extent of misalignment for all six models presented above. It is clear that the extent of overpricing depends on the modeling choice. The case of Greece is unambiguous: all models suggest mispricing, on average within a range of 300 to 700 basis points. Also for Ireland, all models indicate overpricing, on average within a range of 20 to 100 basis points. For Portugal, four out of six models indicate mispricing, ranging from 40 to 120 basis points. For Belgium, it ranges from 20 to 60 basis points. For Italy and Spain, mean mispricing does not exceed 30 basis points, which is in fact the range found for most countries.

7. Conclusions

Our results do not point to consistent and massive mispricing throughout the whole of the periphery of the Eurozone. A significant part of the increase in yields can be explained by the deterioration of macroeconomic fundamentals like growth and government debt, while financial variables also played a role in some countries. However, our results do show that sovereign yields cannot be fully explained by macroeconomic fundamentals alone. This applies in particular to the countries in the periphery of the euro area. In all model specifications, we find periods of substantial misalignment of Greece bond yields. Most specifications also indicate some periods of mispricing for Portugal, Ireland, and Belgium. For the other EMU countries, including Spain and Italy, the evidence of mispricing is less strong.

We also find that sovereign yields react more strongly to economic growth prospects during the sovereign crisis (starting January 2010) than before. Within the euro area group of countries, sovereign yields of the countries in the periphery are found to react more strongly to market conditions than non-periphery countries.

At the same time, modeling uncertainty makes it impossible to determine precisely the extent of misalignment. We show that the extent of overpricing that is found is affected by modeling choices, in particular with regard to i) the use and calculation of confidence bands for the model prediction, ii) the sample selection, iii) the assumption whether the model coefficients are similar across countries or not, iv) the inclusion of financial variables, and v) the assumption of fixed or time-varying coefficients.

Unfortunately, it is difficult to determine the relative merit of the various specifications. It cannot be determined on the basis of econometric diagnostics alone, because a search for possible mispricing does not necessarily require the best econometric fit of the model. The choice for a specific specification therefore also requires economic judgment, and this will by definition always remain subject to debate. Econometric models cannot fully solve the fundamental uncertainty about the fairness of bond yields.

This has a number of consequences. First, our findings call for modesty in interpreting the outcomes of specific model specifications. More awareness seems necessary on how the specific modeling choices affect the extent of mispricing, and a final verdict should preferably be made on the basis of a number of different specifications. Second, our results call for cautiousness in using estimates of bond yield models in policy making. As models cannot determine mispricing precisely, decisions about possible interventions should always be based on a broad set of information criteria, ranging from model output to expert judgment and market evidence. Finally, more research is necessary to determine the causes and nature of mispricing more precisely, in particular with regards to perceptions of political developments and monetary policy decisions.

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Figures

Figure 1. Government bond yields

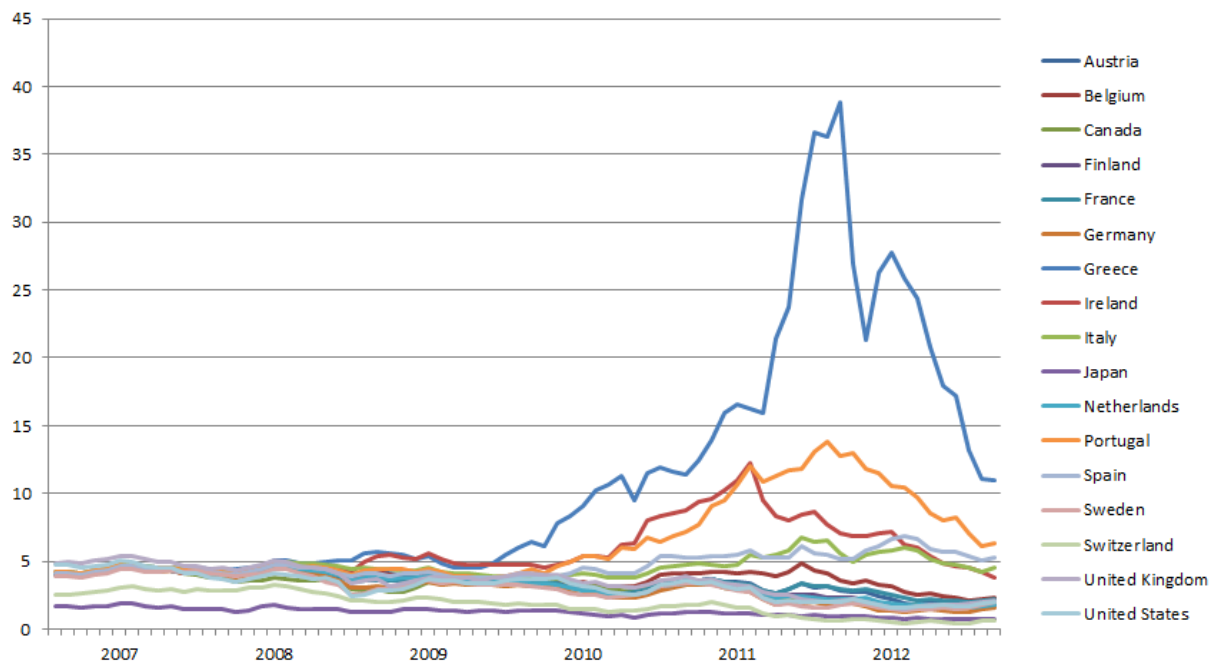


Figure 2. Overpricing and underpricing

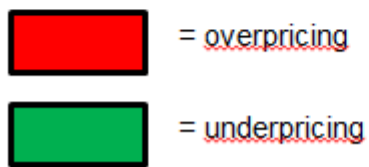
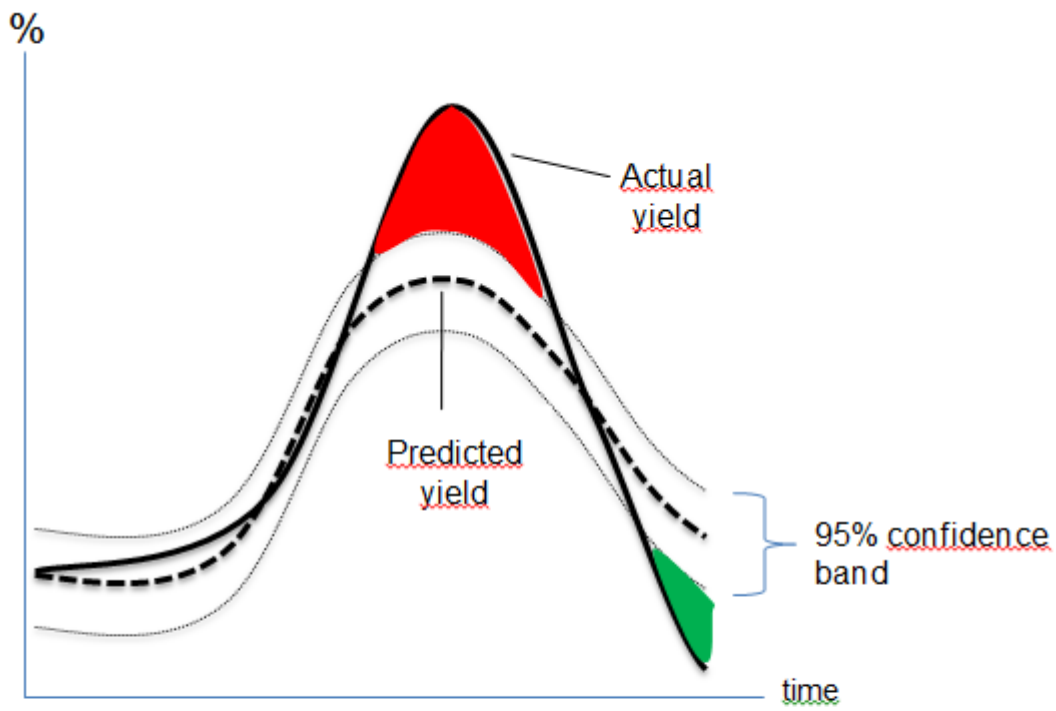


Figure 3. Benchmark model (2), robust standard errors

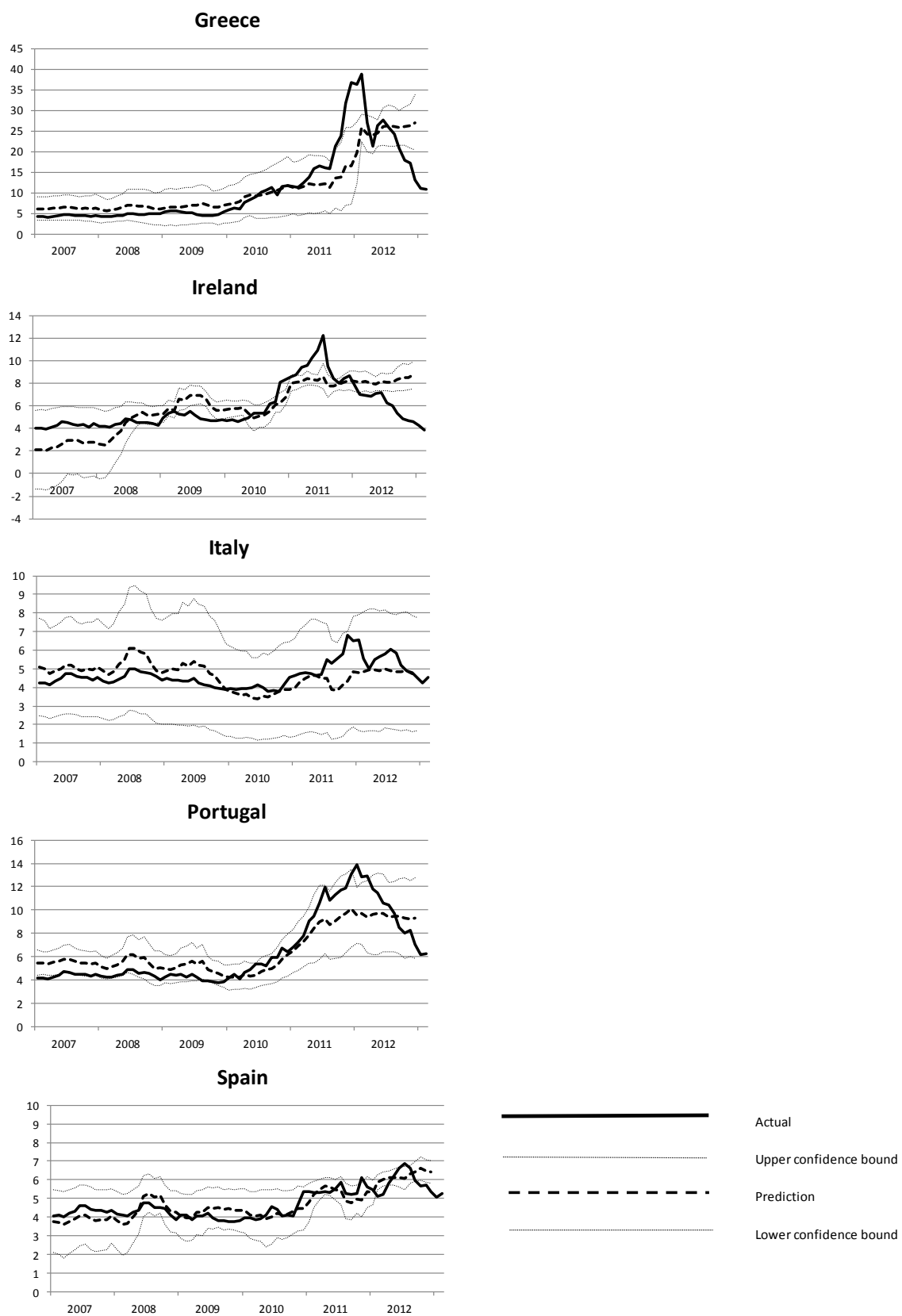
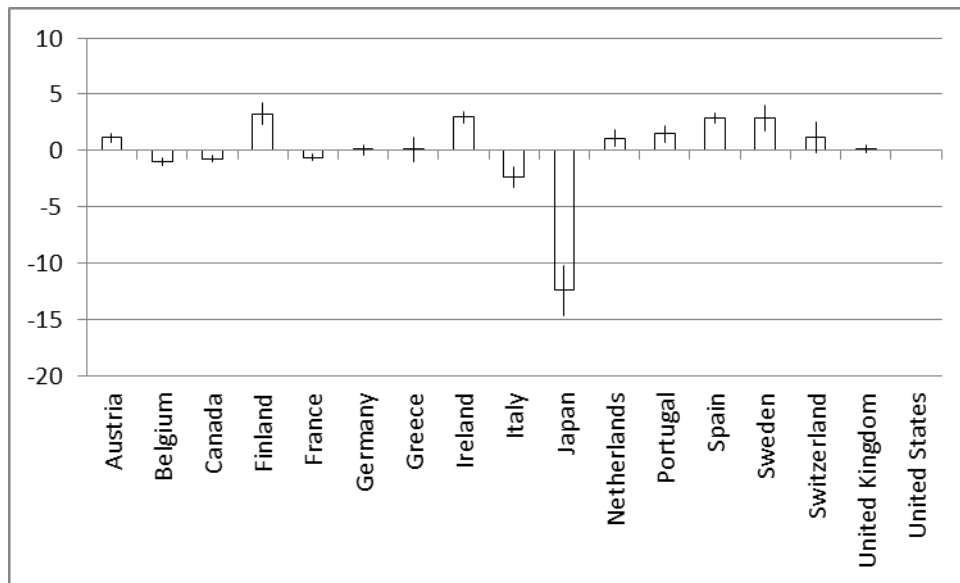
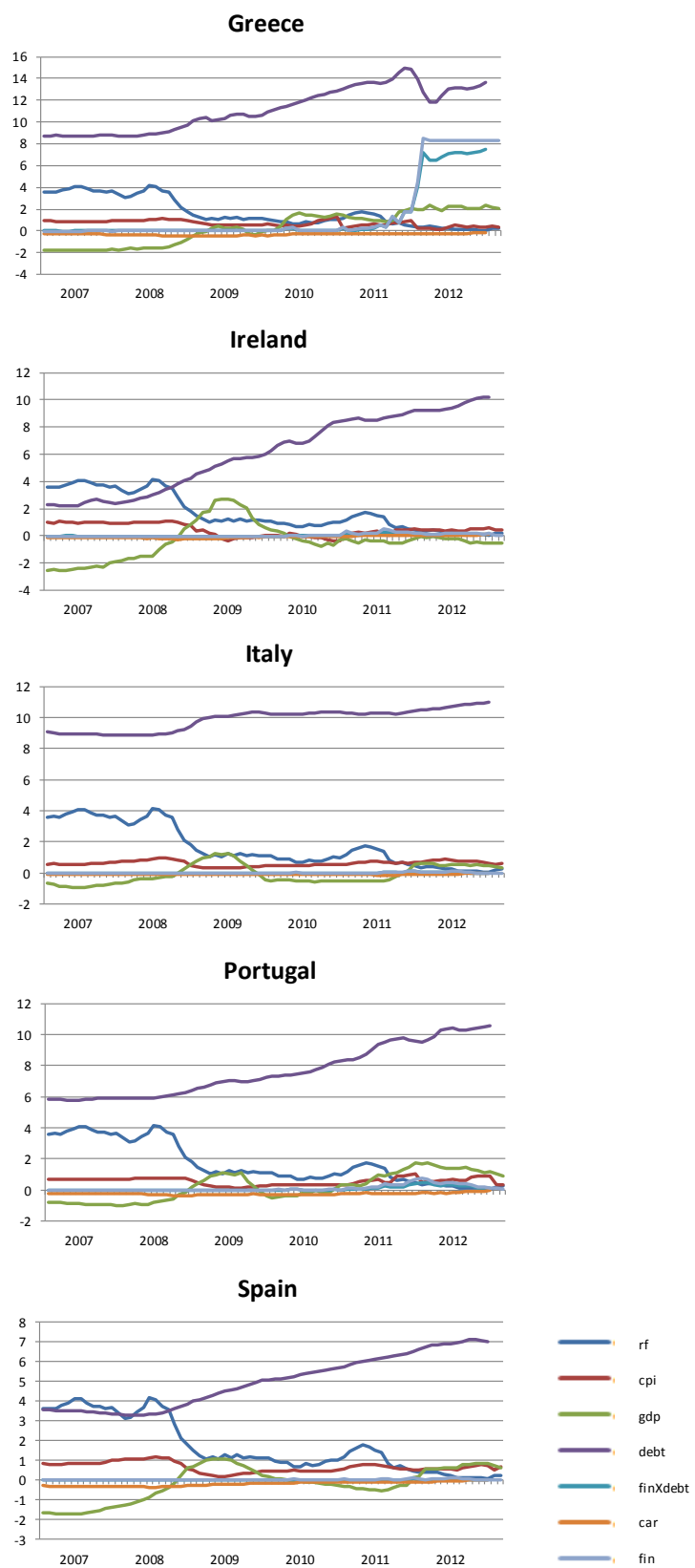


Figure 4.
Fixed effects, model (2)



Explanatory note: Bars represent the fixed effects, vertical lines the 95% confidence intervals. Fixed effects have been centred, so that they represent deviations from the sample mean.

Figure 5. Benchmark model (2), contributions to predicted yields



Explanatory note: The contributions should be accumulated to get their total contribution to the predicted yield. Contributions of the constant and of the fixed country effects are not shown.

Figure 6. Benchmark model (2), non-robust standard errors

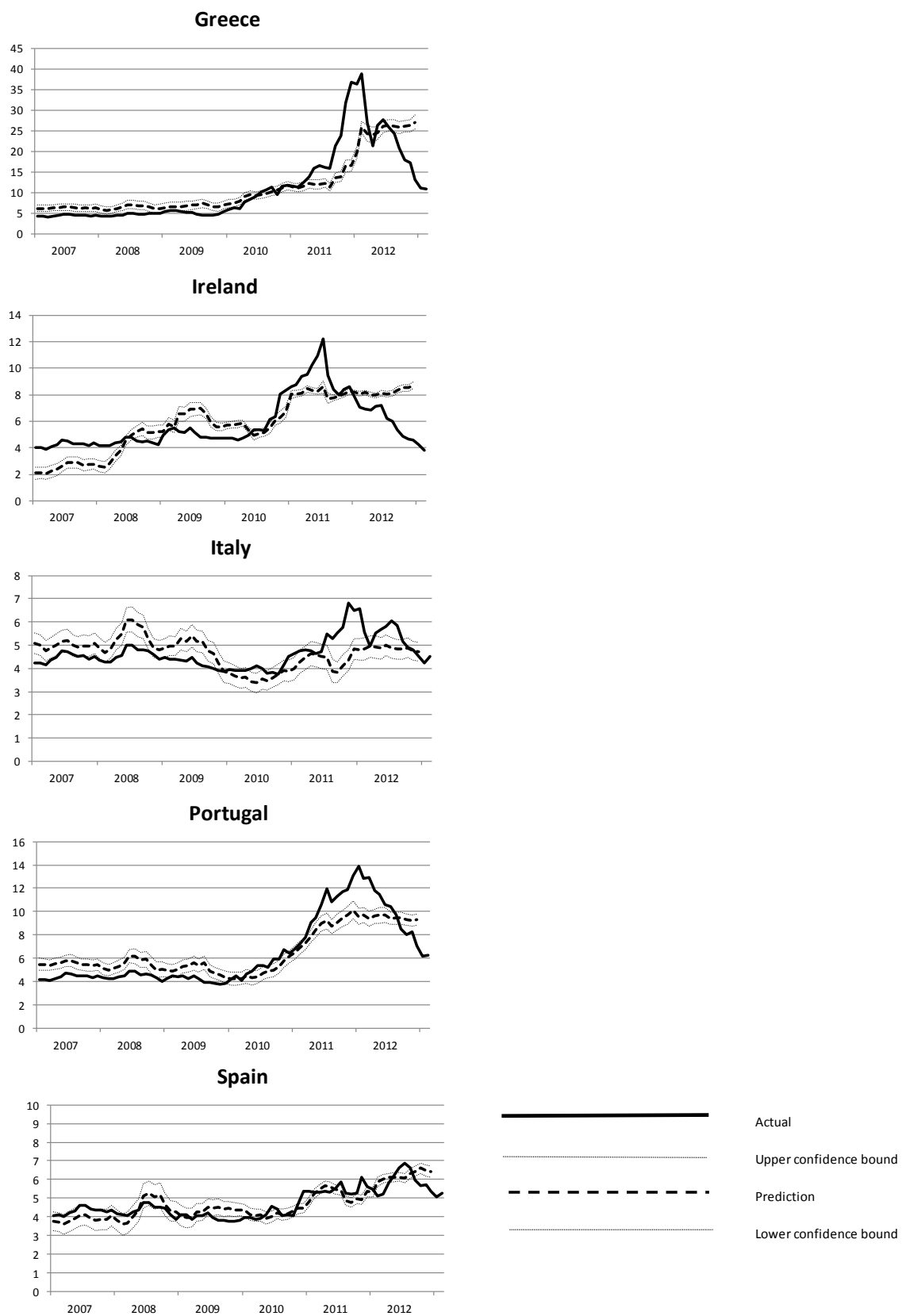


Figure 7. Country-specific estimation, model (4)

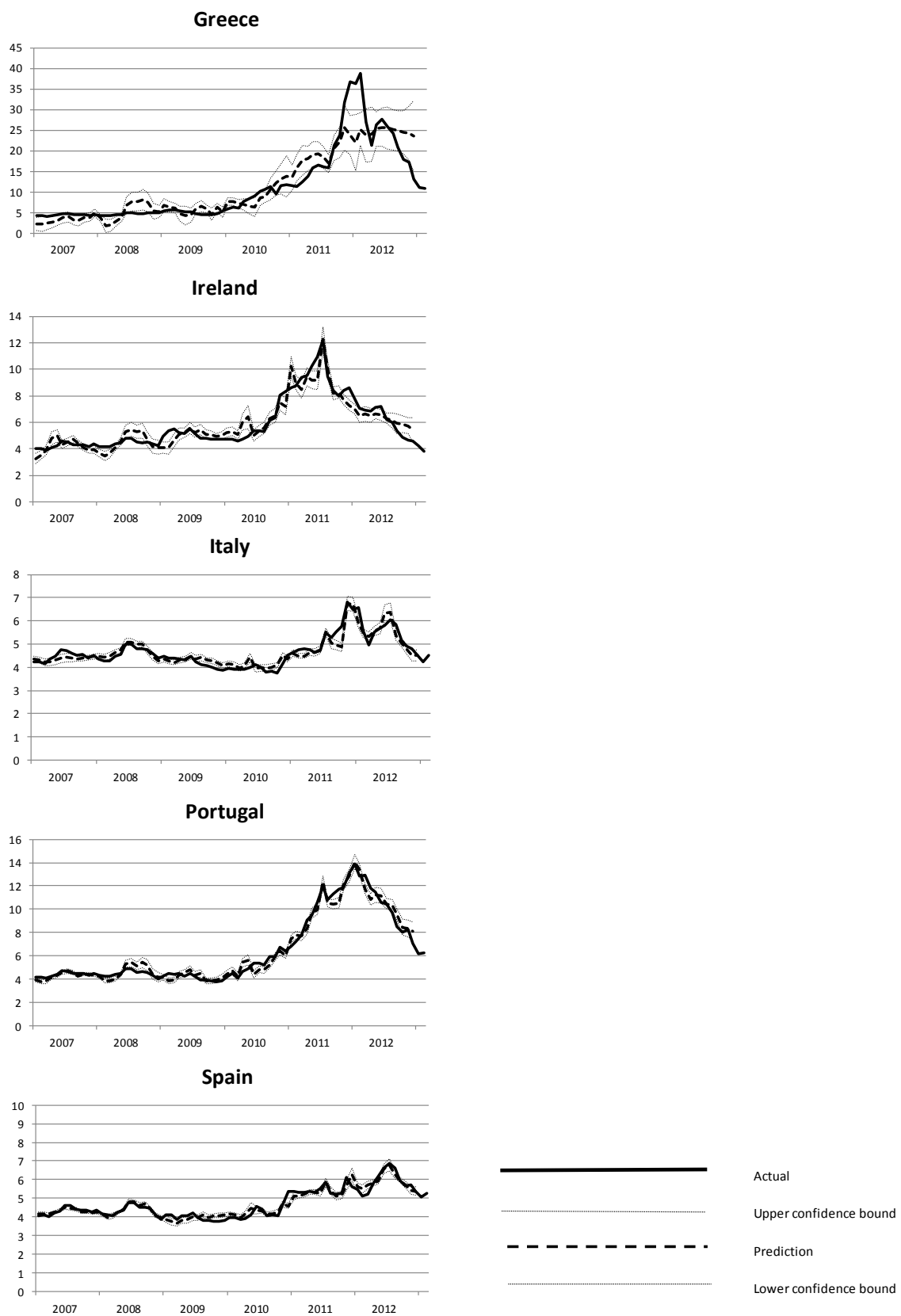
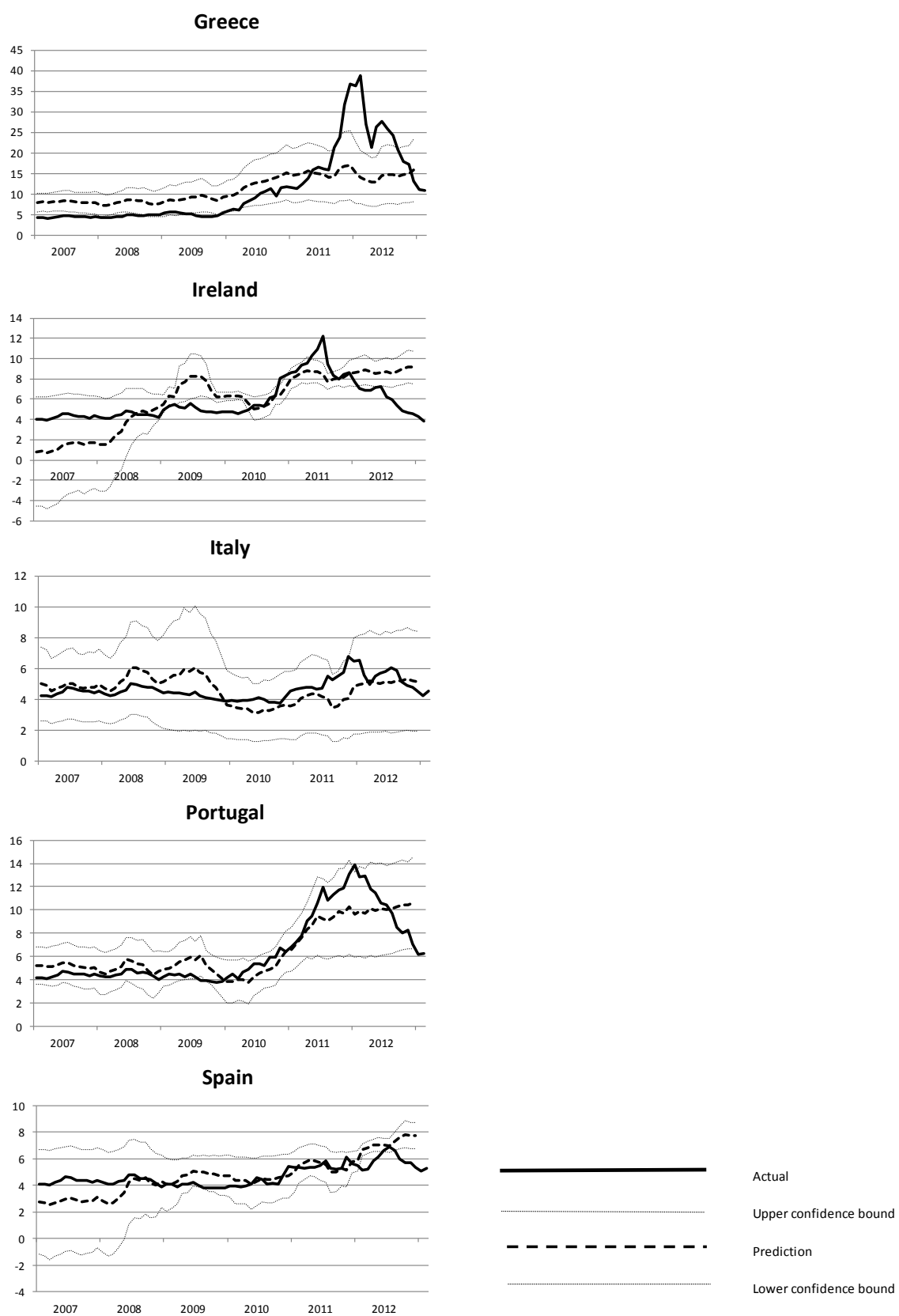


Figure 8. Excluding the financial market variable, model (5), robust standard errors



Tables

Table 1. Summary statistics

	<i>Mean</i>	<i>Median</i>	<i>Standard deviation</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Number of obs.</i>
<i>yield 10</i>	4.072	3.769	3.254	0.439	38.832	1258
<i>rf</i>	1.800	1.218	1.609	0.076	6.283	1258
<i>cpi</i>	1.741	1.810	0.940	-1.290	4.420	1258
<i>gdp</i>	0.975	1.395	1.679	-5.270	4.990	1258
<i>debt</i>	87.321	80.110	43.143	26.089	249.866	1224
<i>fin</i>	0.376	-0.290	3.546	-0.674	32.951	1258
<i>car</i>	0.265	-0.383	5.626	-14.243	15.497	1224

Explanatory note. *Yield 10* = yield on 10 year government bond, *rf* = risk free rate, *cpi* = expected inflation rate, *gdp* = expected real gdp growth, *debt* = expected debt ratio, *fin* = financial market conditions, *car* = expected current account ratio. Variable definitions are given in Appendix A.

Table 2. Correlation coefficients, panel demeaned variables

	<i>yield 10</i>	<i>rf</i>	<i>cpi</i>	<i>gdp</i>	<i>debt</i>	<i>fin</i>	<i>car</i>
<i>rf</i>	0.003						
<i>cpi</i>	-0.106	0.364					
<i>gdp</i>	-0.347	0.507	0.540				
<i>debt</i>	0.317	-0.723	-0.278	-0.404			
<i>fin</i>	0.652	-0.137	-0.168	-0.297	0.204		
<i>car</i>	-0.319	-0.009	-0.042	-0.041	0.367	0.193	

Explanatory note. For variable names, see Table 1. Variable definitions are given in Appendix A.

Table 3. Estimation results. Dependent variable is yield on 10 year government bond

	Model (2), Benchmark model	Model (3) for euro countries, interacted with periphery dummy	Model (5), i.e. excluding financial conditions	Model (6), interacted with crisis dummy
	(1)	(2)	(3)	(4)
Risk free rate	0.894*** (0.238)	0.887** (0.327)	0.959*** (0.268)	0.930*** (0.228)
Inflation expectations	0.310 (0.184)		0.293** (0.144)	
x Dummy = 0		-0.408*** (0.074)		0.146 (0.137)
x Dummy = 1		0.821*** (0.165)		-0.034 (0.118)
Growth expectations	-0.517** (0.191)		-0.772** (0.335)	
x Dummy = 0		-0.117 (0.085)		-0.425*** (0.115)
x Dummy = 1		-0.532*** (0.144)		-0.953*** (0.283)
Debt forecast	0.083** (0.033)		0.091** (0.033)	
x Dummy = 0		0.057 (0.051)		0.050** (0.022)
x Dummy = 1		0.136** (0.051)		0.064** (0.027)
Financial conditions x Debt forecast	0.0003 (0.001)			
x Dummy = 0		0.013** (0.004)		-0.029** (0.012)
x Dummy = 1		0.0004 (0.0004)		0.0005 (0.0009)
Current account forecast	0.035 (0.076)		0.158 (0.098)	
x Dummy = 0		-0.108 (0.061)		-0.046 (0.124)
x Dummy = 1		-0.219 (0.158)		-0.093 (0.105)
Financial conditions	0.051 (0.190)			
x Dummy = 0		-0.076 (0.272)		1.707** (0.813)
x Dummy = 1		0.026 (0.070)		0.002 (0.157)
R ² - within	0.628	0.710	0.369	0.667
Number of observations	1224	792	1224	1224
Number of countries	17	11	17	17
Explanatory note. Fixed country effects included (not reported). Robust standard errors within parentheses. ***, **, * denote p-values less than or equal to 1%, 5%, 10%, respectively. For model (3) and (6), coefficients are reported for subsamples for which the interacted dummy variable is equal to 0 and 1, respectively. Variable definitions are given in Appendix A.				

Table 4. Overpricing during crisis period, percentage points

	Benchmark model (2): robust standard errors	Model (2) with OLS standard errors	Model (4): Country specific	Subsample: model (3) for euro countries with periphery dummy	Model (5): excluding financial conditions variable	Model (6) Crisis dummy
Model uncertainty	(0)	(1)	(2)	(3)	(4)	(5)
<i>Panel A. Mean values</i>						
Austria	0.0	0.3	0.2	0.0	0.0	0.0
Belgium	0.3	0.4	0.2	0.0	0.6	0.2
Canada	0.4	0.6	0.3	.	0.2	0.5
Finland	0.0	0.2	0.2	0.0	0.0	0.0
France	0.2	0.3	0.1	0.0	0.0	0.0
Germany	0.0	0.3	0.1	0.0	0.0	0.0
Greece	5.6	3.8	3.2	3.5	7.2	5.7
Ireland	0.8	0.9	0.3	0.2	1.0	0.9
Italy	0.0	0.3	0.3	0.0	0.2	0.0
Japan	0.0	0.1	0.0	.	0.0	0.0
Netherlands	0.0	0.4	0.1	0.0	0.0	0.0
Portugal	0.6	1.2	0.4	0.0	0.6	0.0
Spain	0.1	0.3	0.2	0.0	0.0	0.1
Sweden	0.0	0.2	0.3	.	0.0	0.0
Switzerland	0.0	0.1	0.1	.	0.0	0.0
United Kingdom	0.3	0.3	0.3	.	0.0	0.3
United States	0.4	0.6	0.1	.	0.0	0.6

Table 4 Continued.

	Benchmark model (2): robust standard errors	Model (2) with OLS standard errors	Model (4): Country specific	Subsample: model (3) for euro countries with periphery dummy	Model (5): excluding financial conditions variable	Model (6) Crisis dummy
Model uncertainty	(0)	(1)	(2)	(3)	(4)	(5)
<i>Panel B. Maximum values</i>						
Austria	0.0	0.6	0.4	0.0	0.0	0.0
Belgium	0.8	0.9	0.5	0.0	1.3	0.6
Canada	0.9	1.1	0.6	.	0.4	1.0
Finland	0.0	0.3	0.5	0.0	0.0	0.0
France	0.3	0.4	0.3	0.0	0.0	0.0
Germany	0.0	0.7	0.2	0.0	0.0	0.0
Greece	12.1	18.3	8.0	5.9	18.2	10.9
Ireland	1.5	1.9	1.0	0.2	2.7	2.0
Italy	0.0	1.0	0.7	0.0	0.1	0.0
Japan	0.0	0.1	0.1	.	0.0	0.0
Netherlands	0.0	0.6	0.2	0.0	0.0	0.0
Portugal	1.6	3.7	0.7	0.0	0.6	0.0
Spain	0.2	0.8	0.7	0.0	0.0	0.4
Sweden	0.0	0.8	0.5	.	0.0	0.0
Switzerland	0.0	0.2	0.1	.	0.0	0.0
United Kingdom	0.4	0.6	0.7	.	0.0	0.5
United States	0.8	1.0	0.3	.	0.0	1.0

Table 4 Continued.

	Benchmark model (2): robust standard errors	Model (2) with OLS standard errors	Model (4): Country specific	Subsample: model (3) for euro countries with periphery dummy	Model (5): excluding financial conditions variable	Model (6) Crisis dummy
Model uncertainty	(0)	(1)	(2)	(3)	(4)	(5)
<i>Panel B. Number of months</i>						
Austria	0	17	14	0	0	0
Belgium	19	25	11	0	23	14
Canada	19	19	11	.	10	17
Finland	0	9	14	0	0	0
France	7	8	11	0	0	0
Germany	0	15	12	0	0	0
Greece	7	22	5	4	11	6
Ireland	6	11	8	1	6	8
Italy	0	21	8	0	1	0
Japan	0	6	13	.	0	0
Netherlands	0	7	11	0	0	0
Portugal	5	21	11	0	1	0
Spain	4	11	8	0	0	5
Sweden	0	11	9	.	0	0
Switzerland	0	8	7	.	0	0
United Kingdom	4	8	12	.	0	13
United States	12	13	8	.	0	13
Explanatory note: Overpricing = Actual yield minus upper confidence bound for prediction, if positive. Negative differences have been set to zero. The crisis period is from January 2010 onwards.						

Appendix A. Data definitions and sources

<i>Variable name</i>	<i>Description</i>	<i>Definition</i>	<i>Sources</i>
<i>yield_10</i>	Yield on 10 year government bonds	Monthly average	Datastream
<i>rf</i>	Euro overnight index swap rate	Monthly average	Datastream
<i>cpi</i>	Inflation rate, consensus forecast	Monthly, weighted average for next 12 months ^a	Consensus Economics
<i>gdp</i>	Real GDP growth rate, consensus forecast	Monthly, weighted average for next 12 months ^a	Consensus Economics
<i>debt</i>	Debt ratio, expected	Debt ratio minus <i>bal</i> ; debt ratio seasonally adjusted and interpolated from quarterly figures ^b	OECD, Consensus Economics
<i>bal</i>	Budget balance, % GDP, consensus forecast	Monthly, weighted average for next 12 months ^a	Consensus Economics
<i>fin</i>	Financial market conditions. Principal component ^c of high-low and bid-ask spreads ^d	Monthly average	Own calculations based on Datastream
<i>car</i>	Current account ratio, consensus forecast	Monthly, weighted average for next 12 months ^a	Consensus Economics

^a If F_m^y is the consensus forecast made in month m for the current year y , and F_m^{y+1} is the consensus forecast for the coming year $y+1$, then the weighted average for the next 12

months is defined as: $\frac{F_m^y \cdot (12 - m) + F_m^{y+1} \cdot m}{12}$, with $m = 1, \dots, 12$.

^b If *bal* consensus forecasts were not available, actual figures have been used.

^c The principle component is equal to $-0.718 + 5.020 \cdot \text{high-low spread} + 2.893 \cdot \text{bid-ask spread}$, and is therefore an indicator of illiquidity and volatility.

^d For Greece, bid-ask spreads are not available for the most of the sample period. Therefore, *Fin* for Greece has been based on the high-low spread; for this country, the high-low spread since April 2012 has been kept constant on the level of March 2012 as data were not available. For several countries, there were only a small number of missing values for high-low and bid-ask spreads that have been interpolated.

Appendix B. Levin, Lin and Chu (2002) unit root tests

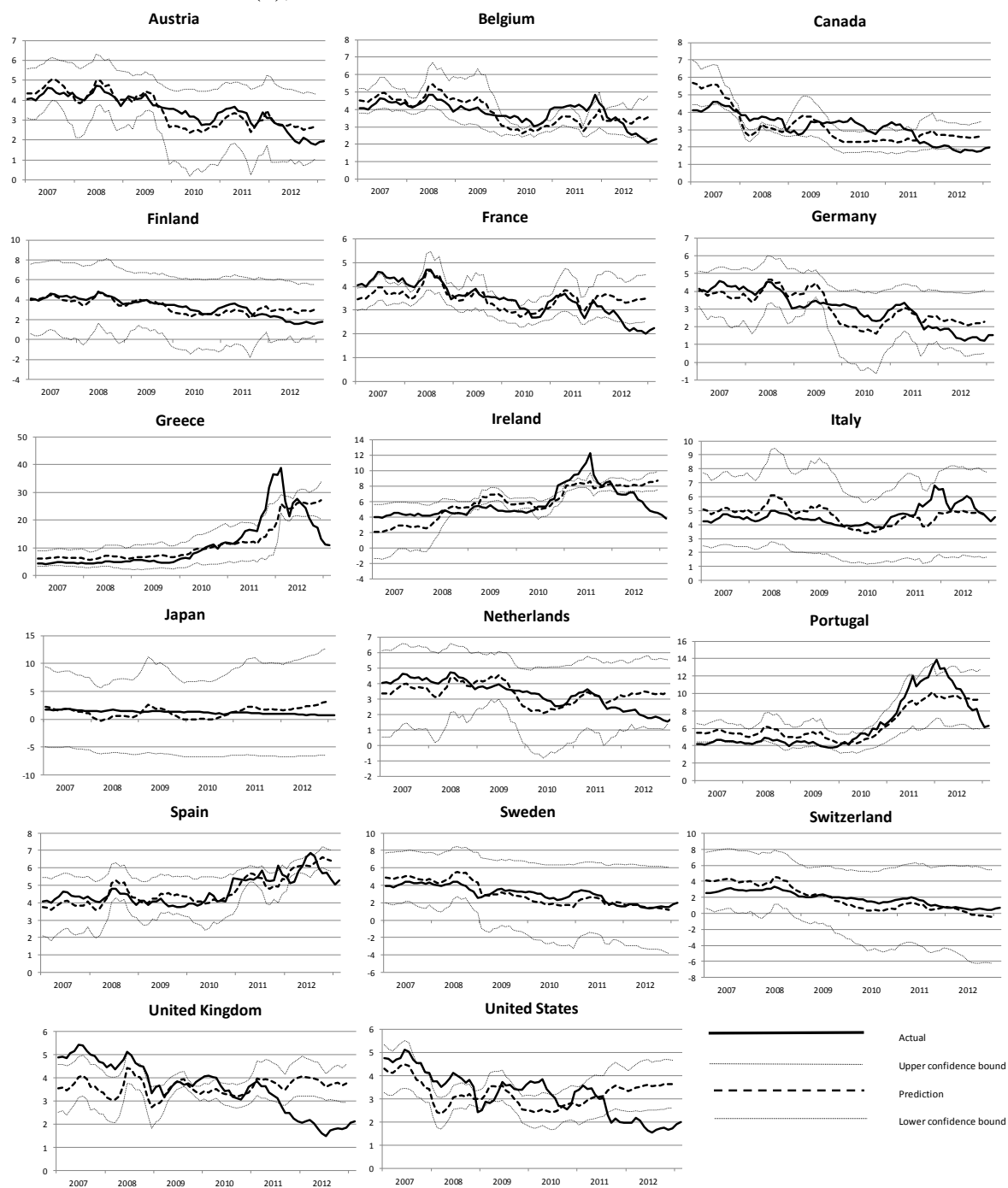
Ho: Panels contain unit roots						
Ha: Panels are stationary						
Panel means:	Included		Included		Not included	
Time trend:	Not included		Included		Not included	
<i>Variable</i>	<i>Adjusted t</i>	<i>p-Value</i>	<i>Adjusted t</i>	<i>p-Value</i>	<i>Adjusted t</i>	<i>p-Value</i>
<i>yield_10</i>	-0.509	0.305	-2.547	0.005	-4.116	0.000
<i>rf</i>	-4.550	0.000	-3.265	0.001	-8.187	0.000
<i>cpi</i>	-2.561	0.005	-1.652	0.049	-2.581	0.005
<i>gdp</i>	-3.100	0.001	-1.929	0.026	-6.924	0.000
<i>debt</i>	-3.438	0.000	-4.790	0.000	2.353	0.990
<i>fin</i>	-2.134	0.016	-3.540	0.000	-2.827	0.002
<i>car</i>	1.929	0.973	1.064	0.856	-2.830	0.002

ADF regressions: 1 lag; Common AR parameter.

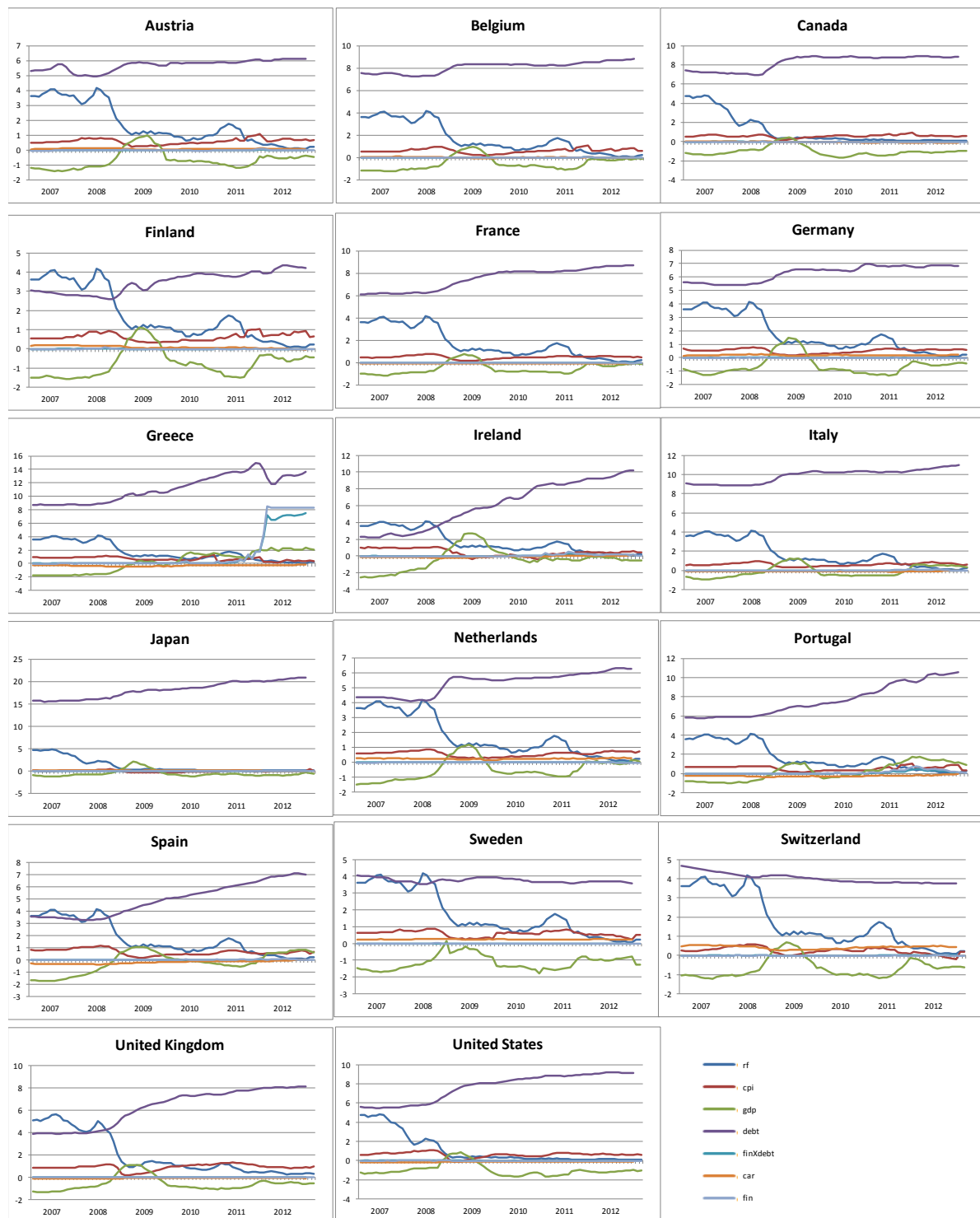
LR variance: Bartlett kernel, 13 lags average (chosen by LLC)

Appendix C. Figures for all 17 countries

C1. Benchmark model (2), robust standard errors

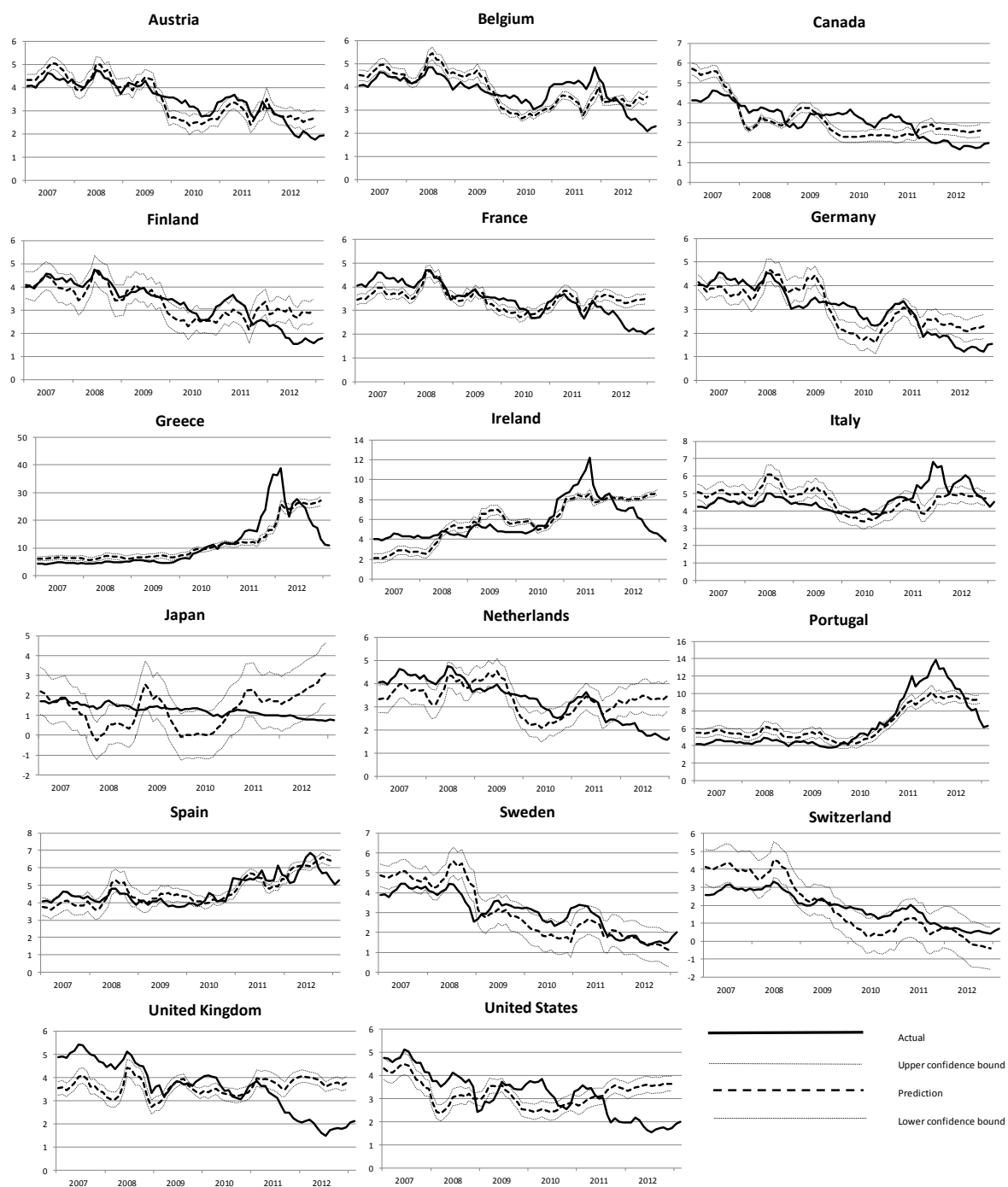


C2. Benchmark model (2), contributions to predicted yields

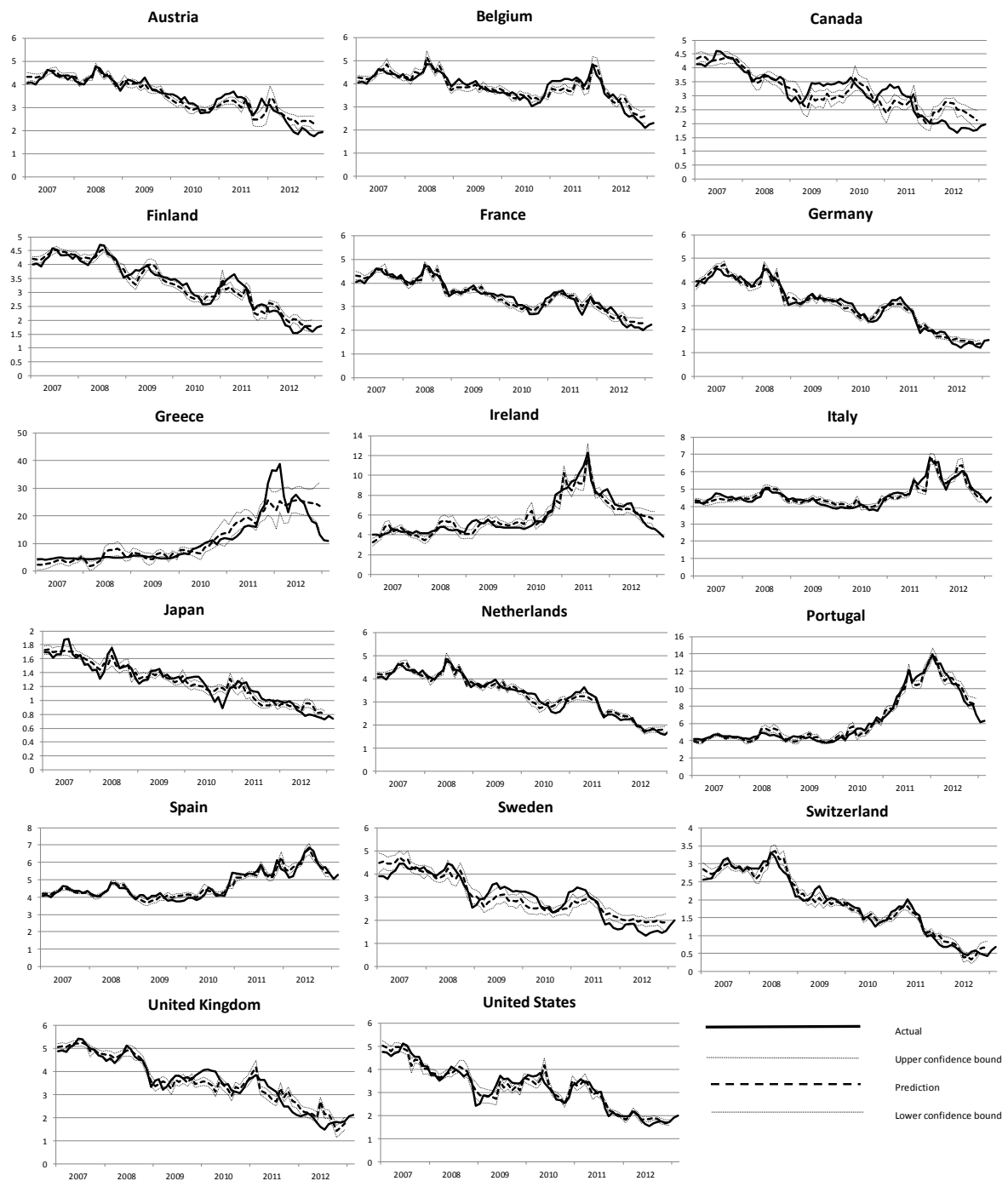


Explanatory note: The contributions should be accumulated to get their total contribution to the predicted yield. Contributions of the constant and of the fixed country effects are not shown.

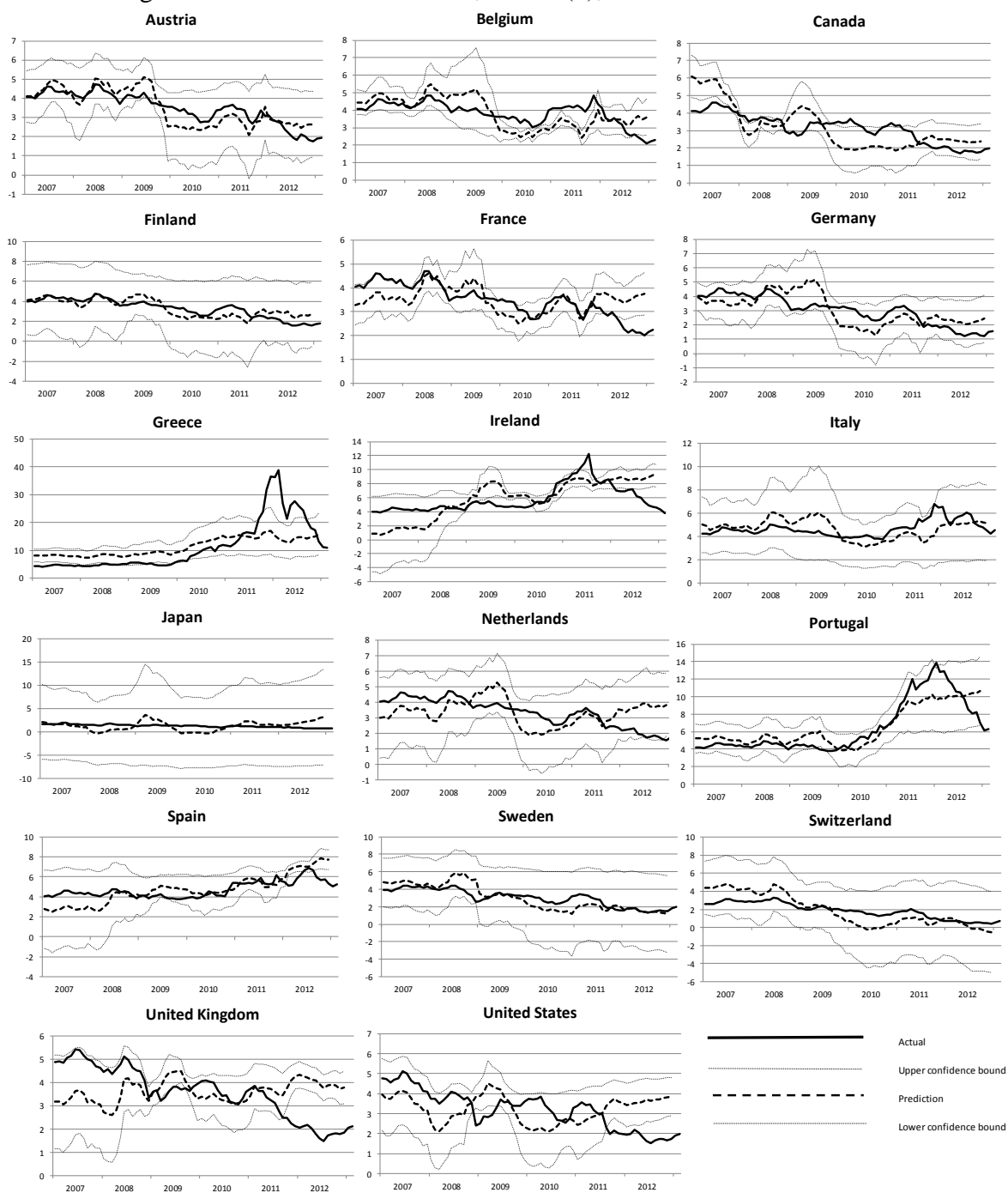
C3. Benchmark model (2), non-robust standard errors



C4. Country-specific estimation, model (4)



C5. Excluding the financial market variable, model (5), robust standard errors



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