European Journal of Operational Research 000 (2017) 1–20

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

From bond yield to macroeconomic instability: A parsimonious affine model

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ARTICLE INFO

Article history:
Received 14 May 2016
Accepted 19 April 2017
Available online xxx

Keywords:
Finance
Stochastic volatility model
Yield dynamics in the Eurozone
Early warning indicator
Yield forecasting

ABSTRACT

We present a hybrid Heston model with a common stochastic volatility to describe government bond yield dynamics. The model is analytically tractable and, therefore, can be efficiently estimated using the maximum likelihood approach and a specific expansion in order to cope with the curse of dimensionality. Twofold is the model contribution. First, it captures changes in the yield volatility and predict future yield values of Germany, French, Italy and Spain. The result is an early-warning indicator which anticipates phases of instability characterizing the time series investigated. Then, the model describes convergence/divergence phenomena among European government bond yields and explores the countries' reactions to a common monetary policy described through the EONIA interbank rate. We also investigate the potential of this indicator on U.S. data (treasury bills).

1. Introduction

The financial and economic crisis that started in 2007 is a clear symbol of the materialization and propagation of systemic risk.

Systemic risk and the potential ensuing contagion refer to a situation whereby the instability in a given country, market or institution is transmitted to one or more countries, markets or institutions.[1] On the one hand, the strong interaction at the micro and meso level generated the well-known knock-on effect, which culminated in the demise of Lehman Brothers. On the other hand, the same interdependence at the macro level has played a key role in exacerbating the sovereign debt problems in the Euro zone. As a consequence, macro and financial economists and market participants have all attempted to build reliable models to describe and anticipate systemic risk. Although the resulting models are very different in form and fit, they all incorporate the interactions as a key element in generating crisis and contagion. A significant part of the literature focuses on the analysis of government bond yields. These important financial instruments, in fact, reflect the interaction phenomena from different angles. First, they incorporate information on the relationship among countries and their mutual interdependence in government debt. In this regard, the literature has studied the convergence (divergence) of government bond yields in Europe and especially among the Euro Area countries.[2] In many papers this is done by attributing an important role to the fiscal/monetary policies in causing such convergence (divergence) (see, for instance, Afonso & Strauch, 2007; Manganelli & Wolswijk, 2009; Mesters, Schwaabb, & Koopman, 2014; Rault & Afonso, 2011; Walheer, 2016). Second, the yield term structure provides important information about how to evaluate a country with respect to its development over time. In this regard, the above mentioned interactions become dynamic and describe phenomena in the short, medium and long term (see, for instance, Diebold & Li, 2006; Ehrmann, Fratzscher, Gurkaynak, & Swanson, 2011; Trolle & Schwartz, 2009).

In this paper we are interested in analyzing both the first line of research, interactions among countries, and the second line, the countries' development over time via yield curves. Specifically, we propose a simple analytically tractable stochastic volatility model in continuous time which captures the yield dynamics in the Eurozone. The model is based upon an important assumption: the

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[1] Broadly speaking, we call the direct and indirect spillover effects arising from the bankruptcy, or the financial distress of a shocked organism, systemic risks. We refer the reader to the studies of Ayotte and Skeel (2009), Constancio (2012), Kaufman and Scott, (2003), Schwarcz (2008), for an accurate definition of systemic risk and its impact in the economic systems.

[2] A part of the research has focused on the determinants of yield spread between European countries and other States (see Giannone, Lenza, Pill, & Reichlin, 2011; Nickel, Rother, & Ruelke, 2011).

http://dx.doi.org/10.1016/j.ejor.2017.04.042

interest rate volatility is stochastic and common across the different yields investigated. The stochasticity of the interest rate volatility is a well-known stylized fact about interest rate (see, for example, Trolle & Schwartz, 2009). The fact that this volatility is common[3] is due to the strong political and economical ties among the countries analyzed. To sum up the model describes the dynamics of n yields which depend, each in a different way, on a common stochastic volatility described by a mean reverting process.

We deduce an integral representation formula for the transition/marginal conditional density function of the process as well as an explicit expression for its moments. Furthermore, we propose an expansion of the marginal conditional density function in powers of the volatility of volatility, and derive the first two terms of this expansion. These two terms are elementary functions and are used to obtain a closed form formula approximation for the transition probability function and the cumulative distribution function. This simple perturbation approach, applicable to several stochastic volatility models, allows us to cope with the curse of dimensionality which arises when an efficient calibration of the model is necessary. This in turn permits an efficient estimation of model parameters, yielding reliable time series of these parameters, whose analysis provides useful insights into market behavior.

Two classes of models "compete" in being able to reproduce the yield curve. The first are macroeconomic models which study how the market/government expectation of inflation and future real economic activity determine the yields. This group of models often use a reduced-form term structure where bond yields are expressed using three factors: "level", "steepness", and "curvature". Starting from the pioneering Nelson and Siegel (1987) model and its re-interpretation by Diebold and Li (2006), several reduced-form term structure models have been developed over the last ten years. These models have proven to be quite successful at capturing and forecasting the cross-sectional properties of bond yields (see Chen & Tsang, 2013; Diebold, Li, & Yue, 2008; Diebold & Rudebusch, 2013; Diebold, Rudebusch, & Aruoba, 2006b; Hautsch & Ou, 2012; Mesters et al., 2014). Moreover, they have shown that level, slope and curvature factors also capture systematic risk. The second class are financial models which study derivatives pricing and portfolio risk management. Foremost among these are the popular affine arbitrage-free term structure models (see Andersen & Benzoni, 2010; Cheredito, Filipovic, & Kimmel, 2007; Chiarella & Kwon, 2003; Collin-Dufresne, Goldstein, & Jones, 2009). This class of models focuses on fitting the term structure at a point in time to ensure good forecasts of derivatives and portfolio risk. However, in recent years, these models have employed factors capable of capturing the stochastic volatility of the interest rates. Thanks to this, these models have been able to describe and predict the bond yield term structure[4] (see Collin-Dufresne et al., 2009; Dai & Singleton, 2002; Duffee, 2002; Trolle & Schwartz, 2009).

Despite the impressive theoretical advances of the yield curve in macroeconomics and financial economics, a large gap still exists between these two classes of models. Surprisingly, little attention has been paid to analyzing the potential bidirectional feedback between the yield curve to macroeconomic dynamics. This is particularly true for financial modeling that does not consider the impact that macroeconomic policies may have on the yield curve. This paper begins to bridge this gap by formulating and estimating a yield model that integrates financial and macroeconomic factors. To this end, we introduce an affine model, which is a hybrid Heston model with a common stochastic volatility, to describe government bond yield dynamics (see Trolle & Schwartz, 2009). We estimate our stochastic volatility model on German, French, Italian and Spanish bond yields and on the OverNight Index Average (EONIA hereinafter) interbank rate from 29 March, 2004 to 3 April, 2014. The selected countries are chosen as being representative of different geographical areas of the Eurozone while the time period considered is relevant due to the presence of different economic phases. Furthermore, the introduction of the EONIA interest rate[5] allows us to analyze the effects of the monetary policy not only with respect to the investigated countries but also with respect to economic phases.

Due to its simplicity and analytical tractability, the model is able to capture changes in yield volatility and predict future yield values. Its descriptive and predictive abilities are verified not only on fixed-maturity bonds, but also on bonds with different maturities. The reason for this good performance of the model rests on two important features. First, the derivation of a closed form solution for the cumulative distribution function and explicit formulas for the moments allow us to efficiently estimate the model parameters via a maximum-likelihood-type approach[6] in line with Aït-Sahalia (2002), Chang and Chen (2011) and Li and Chen (2016). Second, the assumption of a common stochastic volatility governing the Eurozone allows us, on the one hand, to simplify the analytical treatment and, on the other hand, to understand the current interactions among the countries of this zone.

The model's good performance in reproducing the yield curve encourages us to further study the properties of the estimated parameters. The empirical and mathematical results suggest a strong correlation between the estimated volatility parameters and the instability in the government bond yields. Thus, starting from the analysis of these parameters we are able to build an early warning indicator for significant instabilities.[7] The proposed indicator identifies three bubbles that anticipate the three episodes of instability characterizing our time series: the sub-prime mortgage, the collapse of Lehman and the sovereign debt crisis. We also investigate the potential of this indicator on U.S. data (treasury bills). The results obtained confirm that the calibrated model is able to capture the peculiarity of the markets analyzed.

Having successfully validated our estimate for in-sample fitting and out-of-sample forecasting, we illustrate two other abilities of the model. First, its ability to describe the relations among European countries and, second, its ability to foresee their reactions to economic policies or shocks that occur in Eurozone.

In order to address the relationships among the countries investigated we analyze the dynamics of the specific country volatility which is one of the key model parameters. This parameter allows us to understand, not only phenomena of convergence (divergence) among countries, but also their macroeconomic (in)stability. The results of the empirical analysis indicate a strong co-movement between France and Germany on the one hand, and Italy and

[3] We also generalized the model using two volatilities: one common to all yields and responsible for the yield volatility changes, the other depends on the yield maturity and is responsible for the yield cross section. This generalized model is still analytically tractable. Its ability to simultaneously describe government bond yields with different maturities and representing different countries will be the object of future research.

[4] There are interesting contributions which combine the two groups of models. For instance, Coroneo, Nyholm, and Vidova-Koleva (2011) show that a reduced-form term structure model is compatible with arbitrage-freeness. Instead, Christensen, Diebold, and Rudebush (2011), Christensen, Lopez, and Rudebush, (2014), and Mesters et al. (2014) introduce stochastic volatilities in reduced-form term structure models.

[5] The EONIA interest rate is often seen as a proxy of European monetary policy (see Giannone et al., 2011; Lucas, Schwaabb, & Zhang, 2014; Mesters et al., 2014) .

[6] Other interesting works which estimate diffusion or jump–diffusion models via maximum likelihood based on expansions of likelihood functions (or transition densities) are, for example, Aït-Sahalia (2002), Aït-Sahalia and Kimmel (2007), Bates (2006), Christoffersen, Jacobs, and Mimouni (2010), Duffee and Stanton (2012), Filipovic, Mayerhofer, and Schneider (2013), Johannes, Polson, and Stroud (2009), Li (2013), Li, An, Chen, Lin, and Si (2016) and Yu (2007).

[7] A recent and relevant contribution presenting a different technique intended to forecast financial crises is in Huang, Kou, and Peng (2017).