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Markov-switching variance models and structural changes underlying Japanese bond yields: An inquiry into non-linear dynamics

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A B S T R A C T

This study employs a Markov-switching variance method to model structural changes in Japan's long-term government bond data and reveals three state classifications according to time-varying influences from various factors on bond yields. It examines three internal factors—Japan's short-term interest rate, its inflation rate and stock returns—and one external factor—yields on the US long-term government bond. The results of this study highlight the non-linear nature of Japanese bond yields over approximately the past three decades.

1. Introduction

This note seeks a well-formulated econometric representation of the dynamics of Japan's long-term government bond yield over approximately the past thirty years. A Markov-switching variance approach is adopted for the purpose of accounting for various structural changes observed in the bond yield data. In this Introductory section, an impetus is given for the empirical study of Japan's long-term bond yield, together with a summary of the study's significant aspects.

Extensive empirical literature has examined long-term government bond yields from various perspectives of economics and finance. It is noteworthy, in particular, that US long-term bond rates did not rise during an era of increases in the Federal funds rate around 2004, a phenomenon that the then-chairman of the Federal Reserve Board Alan Greenspan called “conundrum” (see Greenspan, 2005). Understanding the behaviour of long-term bond yields is considered to be critical for assessing the transmission of monetary policy. It is, therefore, no surprise that Greenspan's observation on the US long-term bond rates sparked numerous studies of US and Eurozone economies (see Backus and Wright, 2007; Bandholz et al., 2009 and references therein). Recent studies examine the low yields that have persisted in Europe and the US for a decade or longer.

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Japan is seen as a precursor of these developed economies in that it started to experience the lowering of bond rates as early as the mid-1990s after the asset-price bubble burst. See Mosk (2007, chap. 11) for further details of Japan's economic bubble. Therefore, understanding Japan's long-term bond rate movements is deemed to be useful for policy-makers not only in Japan, but also in various other regions facing stagnant long-term interest rates. This study advances such an understanding by estimating a well-formulated econometric model for the time series data of a newly-issued 10-year government bond yield—a representative long-term interest rate in Japan's overall bond market. Japan's 10-year bond yield is one constituent in the leading index for the business cycle compiled by the Japanese Cabinet Office. In addition, its yield data are considered to useful in predicting the yen's fluctuations against major currencies. Thus, modelling Japan's long-term bond yield may assist economic forecasting. These are the foundations for the empirical investigation pursued in this study.

This study employs a Markov-switching method introduced by Hamilton (1989, 1990) to obtain an informative econometric model of Japan's bond yield data. See Ang and Bekaert (2002), Taylor (2004), Frőmmel et al. (2005), De Grauwe and Vansteenkiste (2007) and Schwartz (2012), *inter alia*, for the validity of this method in modelling time series data for various economic and financial variables. Following Turner et al. (1989), this study assigns importance to switching variance characteristics in evaluating conceivable structural changes in the data. See also Kim et al. (1998) and Bhar and Hamori (2003) for examples of switching variance specifications.

This study starts with a tentative regime-switching analysis of the bond yield data to provide a basis for further investigation. It then presents a formal Markov-switching econometric analysis of various factors affecting the behaviour of Japan's long-term bond yield. This Markov-switching analysis illuminates the non-linear dynamic characteristics underlying the data, producing a more accurate understanding of Japan's bond yield behaviour during approximately the past thirty years.

Let us recall that short-term interest rates are generally under the control of a monetary authority. This study confirms a strong linkage between Japan's long-term bond yield and its benchmark short-term rate, except for a deflationary period during which the short-term rate reached a zero-bound. In addition, Japan's stock market exerts some nonlinear collateral effects on its bond market, according to the Markov-switching regression results in this study. Alongside these internal factors, this study examines the US long-term bond yield as an external factor and demonstrates that its influences on Japan's bond yield are also regime-dependent. It is, therefore, important to take account of time-varying influences from all of these factors in order to comprehend and predict movements in Japanese bond yields. Earlier research into Japanese interest rates uses non-linear econometrics (see Kuo and Enders, 2004; Kagraoka and Moussa, 2013, *inter alia*). However, few empirical researchers explicitly examine the regime-switching characteristics of Japan's long-term bond yield. This study's quantitative findings, therefore, illuminate the Japanese government bond market over approximately the past three decades.

This study proceeds as follows. Section 2 reviews Markov-switching variance models employed in this study. Section 3 analyses the time series data of Japan's government bond rate in detail using the Markov-switching models. Section 4 concludes. All quantitative and graphic analyses are conducted using *OxMetrics* (Doornik, 2013a).

2. Review of Markov-switching variance models

Primary references for this review of Markov-switching methodology are Hamilton (1994, chap. 14) and Doornik (2013a, 2013b). Let s_t denote an unobservable random variable representing a state or regime at time t and hold an integer from 0 to $N-1$, that is $s_t \in \{0, \ldots, N-1\}$. This variable is subject to an N-state Markov chain defined as

$$p_{j|i} = \mathbf{Pr}(s_{t+1} = j | s_t = i), \quad \text{for } i, j = 0, \ldots, N-1,$$

where $p_{j|i}$ is called the transition probability that state j follows state i. Note that a series of transition probabilities falls within the constraints of $\sum_{j=0}^{N-1} p_{j|i} = 1$ and $p_{j|i} \geq 0$ for $i, j = 0, \cdots, N-1$. A representative Markov-switching variance model for an observed variable y_t is then given as

$$y_t = \mathbf{x}_t' \boldsymbol{\alpha} + \mathbf{z}_t' \boldsymbol{\beta}(s_t) + \sigma(s_t)\varepsilon_t, \quad \text{for } t = 1, \ldots T, \tag{1}$$

where $\mathbf{x}_t$ is a k-dimensional vector of lagged and contemporaneous explanatory variables with a vector of fixed parameters $\boldsymbol{\alpha}$, and $\mathbf{z}_t$ is a l-dimensional vector of lagged and contemporaneous explanatory variables with a vector of state-dependent parameters $\boldsymbol{\beta}(s_t)$. The innovation term ε_t is assumed to follow independent and identical normal distributions with zero mean and unit variance, that is $\varepsilon_t \sim IN[0, 1]$, so that $\sigma(s_t)\varepsilon_t$ has switching variance. Both intercepts and observed autoregressive terms such as $y_{t-1}, y_{t-2}, \ldots$ may be contained in $\mathbf{x}_t$ and $\mathbf{z}_t$, while other explanatory variables are assumed to be weakly exogenous (see Engle et al., 1983) for the parameters in (1).

Let $\boldsymbol{\theta}$ represent a vector of all the unknown parameters in (1). The parameter vector $\boldsymbol{\theta}$ can be estimated in a maximum likelihood framework subject to the constraints on transition probabilities. See the above references for further details of evaluating the likelihood function and estimating the unknown parameters. In addition, let Ω_t^1 denote a vector consisting of the observed variables in (1) while their initial values are fixed. Using an algorithm developed by Kim (1994), one is able to calculate the probabilities $\mathbf{Pr}(s_t = j | \Omega_T^1, \hat{\boldsymbol{\theta}})$ of a state being labelled as j for $j = 0, \ldots, N-1$, given information on the observed series up to the end point T and on the parameter estimates $\hat{\boldsymbol{\theta}}$. These probabilities, called smoothed probabilities, have time-varying