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Dynamic estimation of an interest rate structure in Colombia. Empirical analysis using the Kalman filter

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ABSTRACT

The official estimation for the term structure model in Colombia is based on the Nelson and Siegel (1987) development which is widely accepted and used. This estimation is based on the curve fitting with available data, only for one day ahead, making difficult to estimate the future zero-coupon yield curve. Taking into account the importance of having an estimation of the term structure for the valuation of financial assets in the Colombian market, this research proposes a methodology to estimate in a dynamic form the parameters of interest rates in the Nelson and Siegel Model. This required the use of the re-parameterization proposed by Diebold and Li (2006), which determines the shape of the term structure through latent factors such as level, slope and curvature. This paper aims to show the dynamic estimation of the term structure of interest rate using the Kalman filter methodology framed in State - space. Results show that predictions are successful for more than one period in the future.

Dinámica de una estructura de tipos de interés en Colombia. Análisis empírico utilizando el filtro de Kalman

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RESUMEN

La estimación oficial para el modelo de estructura de plazos en Colombia se basa en el modelo desarrollado por Nelson y Siegel (1987), ampliamente aceptado y utilizado. Dicha estimación se basa en la curva adecuada a los datos disponibles, únicamente a un día vista, lo que dificulta la estimación de la curva de rendimiento de los cupones cero futuros. Teniendo en cuenta la importancia de disponer de una estimación de la estructura de plazos para la valoración de los activos financieros en el mercado colombiano, esta investigación propone una metodología para estimar, de manera dinámica, los parámetros de los tipos de interés dentro del modelo de Nelson y Siegel. Esto requirió el uso de la reparametrización propuesta por Diebold y Li (2006), que determina la forma de la estructura de los plazos mediante factores latentes tales como nivel, pendiente y curvatura. Este documento trata de mostrar la estimación dinámica de la estructura de plazos de los tipos de interés, utilizando la metodología del filtro de Kalman que se enmarca dentro del espacio del Estado. Los resultados reflejan que las predicciones son exitosas para más de un período a futuro.

1. Introduction

Asset pricing strategies are of extreme importance for portfolio managers whose structures admit fixed assets; therefore, estimation, management and forecasting of the term structure of interest rates of the market, that could be national, industrial or sectorial, in which they operate become essential.

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Forecasting, regardless of its nature, is crucial in the investment portfolio management for the achievement of desired results and management of the involved risk. So, having a methodology that permits to forecast the term structure of interest rates, taking into account those models that regulators ask market agents to respect, is of extreme relevance.

As for the Colombian market, the official interest rate model adopted by regulators is the one proposed in 1987 by Charles R. Nelson and Andrew F. Siegel, in order to value the market prices and to construct diverse financial products as well as derivatives connected to the interest rate. This methodology presents benefits such as the simplicity of estimation, generalized use by academicians and practitioners and its adjustment to real interest rates in the market. However, the process of parameter estimation, given that the variables are not dependent upon time, impedes its future estimation and, also its calculation requires to be contrasted with the observed values in the market performance curve.

In 2006, Francis X. Diebold and Canlin Li in their paper "Forecasting the term structure of government bond yields" interpret the parameters of the Nelson and Siegel Model (1987) as latent factors of level, slope and curvature of the term structure of the interest rate. This reparametrization allows using a set of recursive equations as the ones established in the Kalman filter in order to obtain the possible form and future level of the curve of interest rates for Colombia.

This paper is divided in five sections. The first one is this introduction; the second describes the theoretical framework. The third presents the used methodology in the research. The fourth details the obtained results from the model, and finally conclusions are shown.

2. Theoretical framework

Our research goal is centered in the forecasting of the form of the term structure of interest rates for Colombia; the paper focuses on the interest rates and forecasting models.

2.1. Stochastic models

In the field of forecasting models of the term structure, the most recognized works in academic literature are Black, Derman, and Toy (1990), Cox, Ingersoll, and Ross (1985), Oldrich and Vasicek (1977), and Ho and Lee (1986).

The Black, Derman, and Toy (1990) model of short rates assumes a lognormal distribution in order to eliminate possible negative rates. A drawback of this model is the possibility to find a closed-form solution that allows the construction of the tree, which is obtained in the term structure, to be based on the forward rates and the volatility process and, not using a forward induction process. This takes the structure of volatilities as an input, and entails a reversion process to the mean. The assumptions used in the model are: changes in the bonds yields are perfectly correlated, the expected yield is the same for all the assets in the same period, there are no taxes or transaction costs and, the distribution of short rates is lognormal. As a result, this model obtains future short term rates consistent with the term structure used as an input.

Cox, Ingersoll, and Ross (1985) is well known as CIR. This model is based on the scheme of a productive process for an economy in which each individual must decide whether to consume or to invest a limited capital, and money could be loaned. The equilibrium is achieved when the interest rate reaches the point in which no individual could feel the need to borrow money, known as the equilibrium market price. The model explains the movements in the interest rate in terms of individual preferences. The short rate assumes the risk in the productive process of the economy, and this determines the complete term structure and, therefore the valuation of the interest rate contingent claim. The long term must be compensated by a premium. The model entails a reversion process to the mean and, is lognormal given the interest rate volatility is positively related to the interest rate level. The great drawback is that the model does not provide an adequate estimation of the long term structure.

The work of Oldrich and Vasicek (1977) is an equilibrium model in conditions of no arbitrage, through the determination of a parabolic differential equation that characterizes the price of a zero-coupon bond. It is a model in continuous time with reversion to the mean in an efficient market, in which the instantaneous spot rate follows a continuous process of Markov and the price of a discount bond only depends on the spot rate during its established term. The assumptions consider that the variance is constant and shows closed solutions as a result.

Ho and Lee (1986) is a model based on the assumption that the no arbitrage of the interest rate, which does not consider market frictions, transactions costs or taxes, works in a discrete and finite time. Ho and Lee (1986) model the uncertain behavior of the term structure of interest rates through the construction of a binomial tree and, obtain as a result an interest rate structure with a perfect adjustment to the forward rate structure that is used as initial input.

2.2. Nelson and Siegel model (1987)

The Nelson and Siegel model (1987) provides a methodology of parametric estimation of a yield curve that adjusts to the market observations and concentrates in the evolution of the instantaneous forward rate. This is a non-polynomial model that aims to eliminate irregular jumps in the interest rate structure, that is, the theoretical yield curve. The main benefit is its simplicity and, therefore its generalized use by academicians and market practitioners. In the Colombian case, the curve constructed under this model's methodology is used as a reference curve to value fixed assets given market prices, among many other applications.

The model has various assumptions. It concentrates on the evolution of the instantaneous forward rate, which dynamic can be modeled by a second-order ordinary differential equation solution, particularly with equal and real roots. The ordinary differential equation can present different forms: monotone, concave, S-shape, as to mention the most common and it is not an general equilibrium model, which means that has no economic interpretation of the agent behavior in their markets.

Considering that the Nelson and Siegel model solution is reached by a second-order ordinary differential equation solution with equal and real roots, the Nelson and Siegel function for instantaneous forward rates with maturation in t is represented as:

$$f(t) = \beta_0 + \beta_1 \exp\left(-t/\tau\right) + \beta_2 \cdot \frac{t}{\tau} \cdot \exp\left(-t/\tau\right)$$

The previous equation can take different forms depending on the parameters' values. One of those forms that can be observed is the monotone, S-shape or concave. Finally, if the previous forward rate equations is integrated, the spot rate (s(t)) is obtained:

$$s(t) = \beta_0 + \left(\beta_1 + \beta_2\right)\left[\frac{1 - \exp\left(-t/\tau\right)}{\left(t/\tau\right)}\right] - \beta_2 \exp\left(-t/\tau\right) \quad (1)$$

Given that (β_0 β_1 β_2 τ) are the parameters to be estimated in the model:

β0 is the contribution of the long term component, and it never tends to zero.

β1 is the contribution of the short term component, as it increases t rapidly tends to zero.