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Article

Yield Curve Modeling and Business Implications: Evidence from Coupon-Bearing Government Bonds in Vietnam

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Abstract

This paper examines the empirical performance of the Nelson–Siegel (NS) and Nelson–Siegel–Svensson (NSS) models in estimating the term structure of interest rates from coupon-bearing government bonds in Vietnam. Using a comprehensive dataset covering more than 2,900 trading days and 77,000 bond observations on the Hanoi Stock Exchange, we implement a one-step estimation approach that directly fits model-implied prices to observed bond prices. Model performance is evaluated in terms of yield curve fitting, bond pricing accuracy, and stability over time. The results reveal a clear trade-off between parsimony and flexibility. The NS model delivers lower pricing errors, more stable parameter estimates, and stronger overall fit, making it a reliable benchmark for routine monitoring. In contrast, the NSS specification provides greater flexibility in capturing complex yield curve shapes, particularly during periods of market stress, but at the cost of higher volatility and weaker pricing performance. Beyond methodological insights, the estimated yield curves offer economically meaningful signals for business conditions in Vietnam, as interest rate dynamics influence firms' cost of capital, investment decisions, and sectoral performance.

Keywords: coupon; bond; term structure; yield curve

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1. Introduction

The term structure of interest rates, commonly represented by the yield curve, is central to both academic research and practical financial applications. By reflecting market expectations of future rates, risk premia, and macroeconomic conditions, the yield curve provides the foundation for monetary policy, fixed-income pricing, and interest rate risk management.

Research on the term structure has generally evolved along two main directions. The first is the fitting approach, which approximates observed yields with a smooth curve using either parametric or non-parametric functions. This line of work is most relevant when the objective is to extract discount factors directly from bond data for applications such as risk management and valuation. Several methods have been proposed within this tradition. While the bootstrap technique generates exact zero-coupon yields, it is highly sensitive to data irregularities and often produces instability at short maturities (Cortazar et al., 2017). To address these shortcomings, parsimonious parametric models, most notably Nelson and Siegel (1987) and its extension by Svensson (1995), have become widely adopted for their ability to capture the level, slope, and curvature of the yield curve. Subsequent contributions, including Diebold and Li (2006) and Christensen et al. (2011), demonstrated that these models not only fit cross-sectional bond data but also generate meaningful dynamics for forecasting and policy analysis.

The second strand is stochastic modeling, which treats yields or forward rates as random processes free of arbitrage. This approach is especially suited for building risk scenarios and pricing derivatives, since it reflects the distribution of potential future interest rate paths, and is closely linked to affine term structure models.

This study follows the fitting tradition. The objective is to construct a reliable yield curve that can be used to discount bond cash flows and analyze market dynamics in Vietnam. In this context, accuracy in fitting observed data is more critical than generating future rate scenarios. The Svensson specification, in particular, provides a transparent and flexible tool for summarizing the cross-section of yields, even though stochastic models remain indispensable in derivative pricing.

Despite substantial progress in the literature, challenges persist in applying parametric models to coupon-bearing bonds. These include ensuring stability at short maturities, minimizing fitting errors across maturities, and preserving non-negativity of implied yields (Cortazar et al., 2017). For advanced markets, Andreasen et al. (2019) proposed a one-step estimation framework that reduces measurement error by calibrating parameters directly from observed coupon bond prices, thereby improving upon conventional two-step methods. However, systematic applications to developing markets remain scarce. In Vietnam, the government bond market has grown rapidly since the early 2010s, alongside the emergence of municipal and government-guaranteed instruments. While these markets play an increasingly important role in public finance and monetary operations, few studies have employed contemporary parametric models to estimate the full-term structure.

This research seeks to fill that gap. Using government, municipal, and government-guaranteed bonds from the Hanoi Stock Exchange over the period January 2013 to August 2025, the study applies both the Nelson-Siegel and Nelson-Siegel-Svensson specifications. The goals are twofold: (i) to construct a consistent term structure of interest rates from observed coupon-bearing bonds; and (ii) to evaluate the comparative performance of the NS and NSS frameworks in fitting yields across bond classes and maturities.

The remainder of the paper is structured as follows. Section 2 reviews the existing literature. Section 3 describes the methodology and model specifications. Section 4 outlines the dataset and summary statistics. Section 5 presents the empirical results and compares model performance. Section 6 concludes with policy implications and directions for future research.

2. Literature Review

Research on the term structure of interest rates has developed along two approaches: fitting methods and stochastic dynamic models. Three types of fitting methods, bootstrapping, parametric, and non-parametric, are used to create the yield curve from observed bond data at a specific moment in time. These methods are frequently used for bond valuation, market monitoring, and cash flow discounting (McCulloch, 1971; Bank for International Settlements, 2005). Additionally, they often serve as the first step in stochastic models, where dynamic specifications are derived from estimated zero-coupon or forward rates. In contrast, stochastic dynamic models describe how interest rates move over time, embedding equilibrium or no-arbitrage restrictions to capture risk premia, monetary policy, and derivative pricing (Vasicek, 1977; Cox et al., 1985; Duffie & Kan, 1996). To put it briefly, stochastic models guarantee consistency over time, while fitting techniques provide accuracy and usability in the cross-section; therefore, they are complementary rather than interchangeable.

The bootstrap approach constructs zero-coupon yields by sequentially stripping cash flows from coupon bonds, ensuring that the instruments used are exactly priced (Bliss, 1996; Bolder & Streliski, 1999). Because of its simplicity and transparency, it has become a standard in early empirical applications (Fabozzi, 2005). However, it is highly sensitive to maturity coverage, liquidity, and instrument selection, which frequently results in noisy or unstable segments when data is sparse. (Bliss, 1996; Bolder & Streliski, 1999). Within the class of fitting methods, parametric models have attracted many attention because they strike a balance between flexibility and interpretability. The Nelson-Siegel model (Nelson and Siegel, 1987) parsimoniously represents the yield curve through three factors, level, slope, and curvature, that carry intuitive economic meaning. The Nelson-Siegel model is appreciated for its interpretability, robustness, and ease of estimation, which explains why it has been widely applied by central banks (Diebold & Li, 2006; Bolder & Streliski, 1999). However, the model has certain limitations as well, such as limited flexibility at very long maturities (European Central Bank,

2008) and the inability to guarantee no-arbitrage conditions (Christensen et al., 2011). In order to improve fit, especially at the long end of the yield curve, Svensson (1995) suggested an extension that adds a second curvature factor. However, this flexibility comes at the expense of more unstable parameter estimates and the possibility of overfitting (European Central Bank, 2008). Additionally, central banks have improved estimation techniques by reducing bond price errors instead of yield deviations. For example, while the Bank of Canada uses Macaulay-duration weights to keep long-maturity bonds from dominating estimation (Bolder & Streliski, 2004), the Banque de France applies a maximum likelihood approach with duration-weighted price errors (European Central Bank, 2008). Despite their popularity, many applications still rely on synthetic zero-coupon curves bootstrapped from coupon bonds, which can lead to biases and measurement errors (Bliss, 1997; Gürkaynak et al., 2007).

A common limitation of this literature is the reliance on a two-step process: constructing zero-coupon yields from coupon bonds and then fitting parametric models to the synthetic series (Cortazar et al., 2017). Despite being computationally efficient, this method often produces smoothing biases and blurs price signals (Fontaine & Garcia, 2012; Steeley, 2008). Direct estimation based on observed bond prices is supported by more recent research. A one-step method that directly applies an arbitrage-free Svensson model to coupon-bearing bonds is put forth by Andreasen et al. (2019). Their results show smaller pricing errors and more accurate parameters when compared to the two-step process. Furthermore, simulations show that even small errors in synthetic zero-coupon yields can distort risk-neutral dynamics, whereas direct fitting avoids these problems. Supporting this view, Pancost (2017) finds that predictable pricing errors in coupon bonds contain information about excess returns, while Fontaine and Garcia (2012) show that avoiding synthetic zero-coupon yields during estimation improves the capture of liquidity premia.

An alternative line of research focuses on non-parametric approaches. These approaches balance fit and smoothness using spline-based or smoothing techniques rather than assuming a fixed functional form. McCulloch (1971, 1975) pioneered spline-based discount function estimation, after that Fisher, Nychka, and Zervos (1995) introduced cubic splines with an explicit smoothness penalty. Extending these ideas, Tanggaard (1997) applied penalized least squares with natural cubic splines to coupon bond prices. Linton et al. (2001) took a different route, using kernel smoothing estimators for discount and forward curves. More recently, Liu and Wu (2021) advanced adaptive bandwidth kernel smoothing to balance global smoothness with local variation. Other innovations include monotone convex interpolation that ensures economically consistent forward curves (Hagan & West, 2006) and exact smooth estimators that enforce shape restrictions and no-arbitrage conditions (Filipović & Willems, 2018). These collections of works show how flexible non-parametric approaches are at capturing market irregularities, but they also draw attention to persistent issues with interpretability, high computational demands, and instability in sparse maturity segments.

The advantages of fitting models directly to coupon-bearing bonds, whereas earlier studies of the term structure mainly relied on synthetic zero-coupon yields. One-step approaches such as Andreasen et al. (2019) reduce pricing errors, provide more accurate parameter estimates, and lessen biases associated with the use of synthetic zero-coupon data. Building on this work, our study applies the parametric one-step fitting framework of Andreasen et al. (2019) directly to coupon-bearing bonds. The unique circumstances of the Vietnamese market, where zero-coupon instruments are limited and illiquid, served as the impetus for this decision. Our method circumvents these data limitations while maintaining the interpretability of the Nelson-Siegel models by taking advantage of the entire panel of coupon bond prices, providing a more solid basis for empirical research and insights focused on policy.

3. Methodology

In this study, we apply a one-step estimation method. The yield curve will be constructed directly from coupon-bearing bond. The empirical analysis is based on a parametric representation of the term structure of interest rates using the Nelson-Siegel and Nelson-Siegel-Svensson models. These models are widely applied in both academia and practice owing to their ability to provide flexible yet interpretable descriptions of yield curves.

3.1. Yield Curve Models

The Nelson-Siegel (NS) specification expresses the continuously compounded yield for a bond with maturity τ as a function of three latent factors:

$$y_t(\tau) = \beta_{0,t} + \frac{1-e^{-\lambda\tau}}{\lambda\tau}\beta_{1,t} + \left(\frac{1-e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\right)\beta_{2,t} \quad (1)$$

where $y_t(\tau)$: the yield at time t with maturity τ, β_0 represents the level of the yield curve, β_1 the slope, β_2 the curvature, and λ controls the exponential decay rate. The model parsimoniously captures the main stylized facts of yield curves: long-term levels, short-end slopes, and medium-term humps. The Nelson-Siegel-Svensson (NSS) specification extends the NS model by introducing an additional curvature term, which improves flexibility in fitting medium- to long-term maturities:

$$y_t(\tau) = \beta_{0,t} + \frac{1-e^{-\lambda_1\tau}}{\lambda_1\tau}\beta_{1,t} + \left(\frac{1-e^{-\lambda_1\tau}}{\lambda_1\tau} - e^{-\lambda_1\tau}\right)\beta_{2,t} + \left(\frac{1-e^{-\lambda_2\tau}}{\lambda_2\tau} - e^{-\lambda_2\tau}\right)\beta_{3,t} \quad (2)$$

Here, β_3 and λ_2 provide additional flexibility to account for more complex curve shapes. While this improves fit, it also introduces estimation challenges and increases sensitivity to noise in the data.

3.2. Estimation Procedure

Bond prices are computed as the present value of future cash flows (coupon payments and redemption value) discounted by the term structure implied by the candidate yield curve. Let $P_t^i(\tau, C)$ denote the price at time t of the ith coupon bond, which matures at time t + τ and pays the coupon C annually at time t_j. In the absence of arbitrage, the clean price of this coupon bond equals the present value of all remaining payments:

$$P_t^i(\tau, C) = C(t_1 - t)P_t^{zc}(t_1 - t) + \sum_{j=2}^{N} C P_t^{zc}(t_j - t) + P_t^{zc}(t_N - t) \quad (3)$$

with $t < t_1 < \cdots < t_N = \tau$. The price of the zero-coupon bond with maturity τ (namely discount factor), $P_t^{zc}(\tau)$ is calculated by:

$$P_t^{zc}(\tau) = e^{-y_t(\tau)\tau} \quad (4)$$

where $y_t(\tau)$ is the yield at time t with the maturity τ. To estimate parameters, we minimize the difference between market prices and model-implied prices. The baseline loss function is a weighted mean squared error, where weights are proportional to bond durations to account for sensitivity to discounting.
Specifically, the objective function is the weighted sum of squared errors:

$$\min_{\psi} \sum_{i=1}^{n_{i,t}} w_i (P_t^{Data,i} - \widehat{P_t^i(\psi)})^2 \quad (5)$$

Where $P_t^{Data,i}$ denotes the observed market price of bond i, $P_t^i(\psi)$ is the fitted price implied by the yield curve model with parameter set ψ, and w_i weights based on Macaulay duration to account for interest rate sensitivity. Numerical optimization is performed separately for each trade date to obtain time series of parameter estimates.

Parameter estimation is implemented using the optim routine in R to minimize the weighted sum of squared pricing errors. For the NS specification, the initial parameter vector is set to (0.05, −0.02, 0.01, 2), corresponding to economically plausible values for the level, slope, curvature, and decay parameters. For the NSS specification, the initial vector is set to (0.05, −0.02, 0.01, 0.005, 2, 5), allowing for an additional curvature factor and decay parameter. Optimization is conducted separately for each trade date, and convergence is verified before parameter estimates are retained for subsequent analysis. The parameters vector ψ depends on the chosen specification: for NS, it is $(\beta_0, \beta_1, \beta_2, \lambda)$ or NSS, and $(\beta_0, \beta_1, \beta_2, \beta_3, \lambda_1, \lambda_2)$. Parameters are estimated for each observation date t by minimizing the objective function among all bonds traded on that date $(n_{i,t})$.

3.3. Model Evaluation

Model performance is evaluated along two complementary dimensions. First, yield curve fitting accuracy is assessed by comparing model-implied yields with those derived from coupon-bearing bonds. Second, bond pricing accuracy is measured by the deviation between observed and fitted bond prices. Error metrics include mean absolute error (MAE), mean absolute percentage error (MAPE), root mean squared error (RMSE), and the coefficient of determination (R^2). In addition, residual diagnostics and robustness checks across maturity buckets and time are used to evaluate stability and economic interpretability. These error metrics are defined as:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|P_t^{Data,i} - \widehat{P_t^{\iota}(\psi)}\right| \quad (6)$$

$$MPAE = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{P_t^{Data,i} - \widehat{P_t^{\iota}(\psi)}}{P_t^{Data,i}}\right| \quad (7)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_t^{Data,i} - \widehat{P_t^{\iota}(\psi)})^2} \quad (8)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(P_t^{Data,i} - \widehat{P_t^{\iota}(\psi)})^2}{\sum_{i=1}^{n}(P_t^{Data,i} - \overline{P_t^{Data,\iota}})^2} \quad (9)$$

where $\overline{P_t^{Data,\iota}}$ is the mean observed market prices. Lower values of MAE, MAPE and RMSE indicate that the estimated curve tracks the market data more closely, while high R^2 captures the overall goodness-of-fit.

4. Results

4.1. Data Preparation

We construct our dataset from a panel of coupon-bearing government bonds. For each bond, the dataset records the trade date, coupon rate, maturity, payment structure, par value, and observed market price. To ensure internal consistency, bonds exhibiting implausible characteristics, such as market prices exceeding the present value of discounted cash flows, are excluded. Furthermore, trade dates with fewer than eight available bonds are removed to preserve sufficient cross-sectional variation for yield curve estimation. For each bond, yield-to-maturity (YTM) and Macaulay duration are computed as model-free diagnostics and weighting factors during estimation. The final dataset contains 2,905 trade dates, with an average of 26 bonds per date. Maturities range from 2 to 30 years, with an average coupon rate of 5.5% and a mean price of 111,373.

Table 1. Statistics for coupon bearing - bond data.

Number of trade date	Mean number of bond	Min maturity	Max maturity	Mean Coupon rate	Mean prices
2,905	26	2	30	0.055	111,373

Figure 1 depicts the distribution of bond maturities in the dataset. The maturity structure is far from uniform, with distinct clusters around short- to medium-term horizons. A large proportion of bonds are concentrated within the 2 – 12 years range, with notable peaks around 5 years and 10 years. By contrast, bonds with very short maturities (<2 years) or very long maturities (>20 years) are relatively scarce. This uneven distribution reflects the issuance practices of government securities, which typically favor benchmark maturities in the medium range. The relative scarcity of long-dated bonds may reduce the precision of model estimation in the far end of the yield curve, while the dense concentration in the 5 - 10 years segment ensures stronger identification of medium-term dynamics.

Table 2. Bond observations by maturity bucket.

Maturity bucket	Number of observations	Percentage (%)	Average coupon rate
< 3 years	17,967	23.2	0.071
3–7 years	22,623	29.2	0.059
7–15 years	30,934	40.0	0.044
> 15 years	5,904	7.63	0.057
Total	77,428	100	0.055

Table 2 highlights the uneven maturity distribution of the Vietnamese government bond market. Most observations are concentrated in medium-term maturities, particularly between three and fifteen years, while long-dated securities remain relatively scarce. This pattern is consistent with the maturity distribution shown in Figure 1 and helps explain the higher estimation uncertainty observed in the long end of the yield curve.

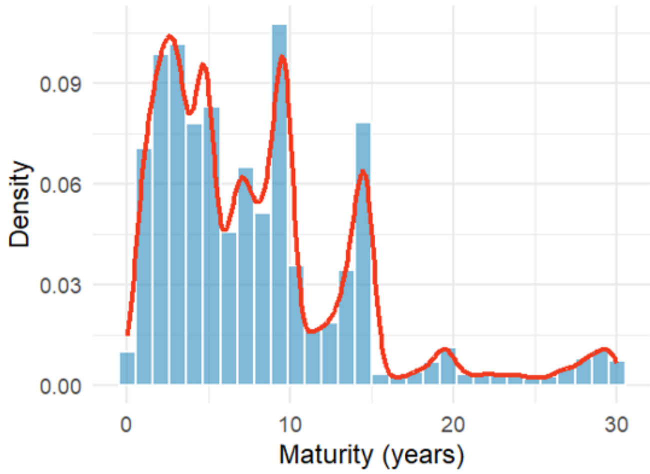

Figure 1. Bond maturity distribution.

Figure 2 presents the relationship between time-to-maturity and yield-to-maturity (YTM) across all bonds in the dataset. The majority of observations are concentrated at relatively low yield levels, reflecting the prevailing low-interest-rate environment during much of the sample period. Short-term securities display a wide dispersion of yields, with several outliers exceeding 40%, which may be attributed to illiquidity or transient market stress.

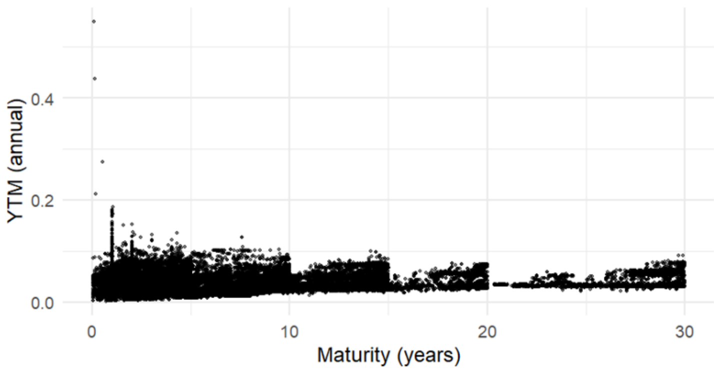

Figure 2. Time-to-maturity against yield-to-maturity.

Beyond the very short end, yields remain relatively flat across maturities, indicating the absence of a strong term premium in much of the sample. Nevertheless, moderate heterogeneity is observed in medium- and long-term maturities, where yields cluster around different bands, suggesting variation in issuance periods and coupon structures. Overall, the figure highlights that while short-term yields exhibit substantial volatility, the medium- to long-term segment of the yield curve is comparatively stable, providing a suitable foundation for model-based curve fitting.

4.2. Parameter Estimation

The parameters of the NS and NSS models are estimated using observed bond prices across the full sample. Each parameter is associated with an economically meaningful interpretation: the level factor (β_0) captures the long-run component of interest rates; the slope factor (β_1) reflects the relative behavior of short- and long-term yields; the curvature factors (β_2, β_3) govern the shape of the medium-term segment; and the decay parameters (λ_1, λ_2) determine the speed at which slope and curvature effects diminish. Summary statistics (Tables 3 and 4) demonstrate that the NSS specification consistently achieves a lower mean squared error (MSE) than the NS model, underscoring its superior flexibility.

Table 3. Estimated parameters of Nelson–Siegel across sample period.

Statistics	β_0	β_1	β_2	λ	MSE
Mean	0.05927	-0.03456	-0.017331	0.4759	15,752
Median	0.05625	-0.03399	-0.012849	0.4840	13,985.3
Min	0.01804	-0.22369	-0.539849	0.1077	296.4
Max	0.27892	0.77676	0.150848	5.1301	63,816.9

Table 4. Estimated parameters of Svensson models across sample period.

Statistics	β_0	β_1	β_2	β_3	λ_1	λ_2	MSE
Mean	0.05287	0.03202	-0.12531	0.014072	1.865	5.107	28,891.6
Median	0.05110	-0.01827	-0.04672	0.003783	1.825	5.099	18,033.1
Min	0.01740	-0.10657	-1.00000	-0.455539	0.420	2.557	263.4
Max	0.16091	0.84329	0.15762	0.589182	3.236	7.133	407,670.4

Figure 3 displays the evolution of the estimated beta parameters from the NS and NSS models over time. The level factor (β_0) remains relatively stable and close to zero throughout the sample, with only minor fluctuations, indicating persistent long-term interest rate expectations. By contrast, the slope factor (β_1) exhibits substantial variation, particularly in the NSS specification, which captures pronounced changes in short-term yield conditions during periods of market volatility. The curvature factor (β_2) shows negative values for much of the sample, with stronger fluctuations under the NSS model, reflecting its greater flexibility in capturing medium-term dynamics. Meanwhile, β_3, which is unique to the NSS specification, introduces an additional degree of curvature that remains centered around zero but displays notable variation during certain episodes, highlighting its role in improving fit in the intermediate maturities.

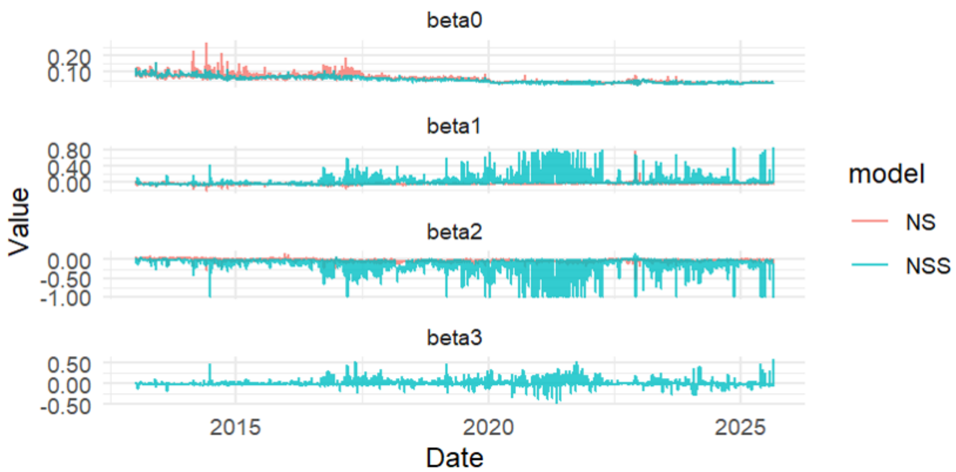

Figure 3. Line plot of betas over time.

The evolution of the decay parameters in the NS and NSS models are presented in Figure 4. The NS specification includes a single λ parameter, which remains relatively stable across the sample, with only a few spikes around periods of market stress. This stability reflects the parsimonious structure of the NS model, where the speed of exponential decay in the factor loadings is fixed through time with limited flexibility. In contrast, the NSS specification introduces two decay parameters, λ_1 and λ_2, which exhibit richer dynamics. λ_1 fluctuates within a relatively narrow band around values close to 2, suggesting consistent adjustment speeds in the medium-term segment of the yield curve. Meanwhile, λ_2 varies more widely, particularly during episodes of market turbulence, highlighting its role in capturing additional curvature and improving the model's ability to fit medium- to long-term maturities. Taken together, the plots show that while the NS model constrains decay dynamics through a single stable parameter, the NSS framework employs multiple decay terms to flexibly accommodate shifts in yield curve shapes, especially in volatile environments.

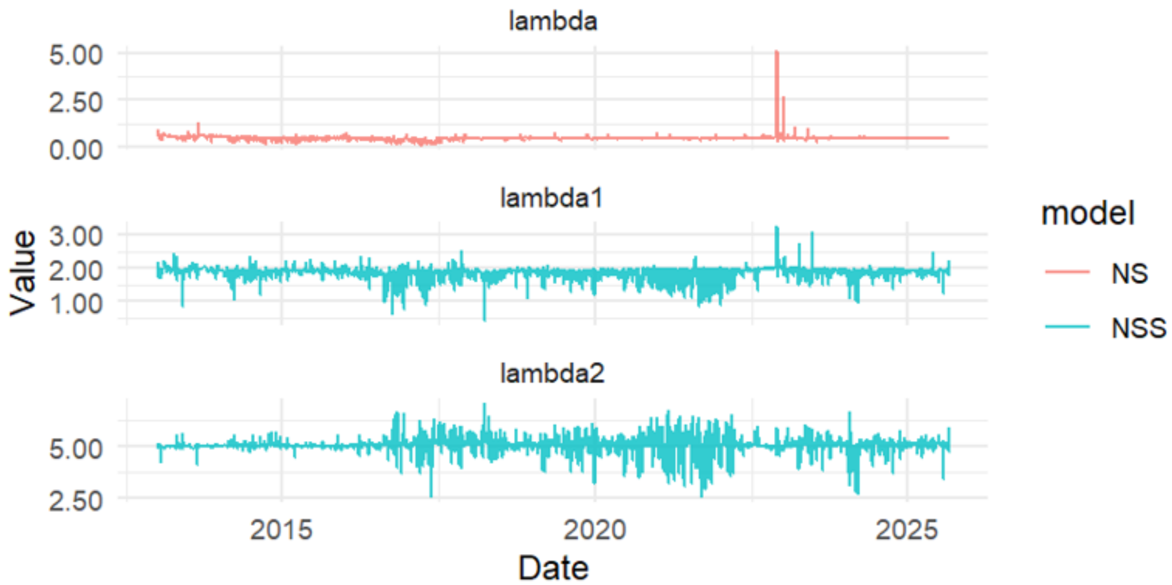

Figure 4. Line plot of lambdas over time.

Beyond their role in yield curve estimation, the factor dynamics also provide economically meaningful information regarding evolving market expectations and financial conditions. In the Nelson–Siegel framework, the level factor (β_0) is commonly associated with long-run interest rate expectations and the overall stance of financial conditions. The relatively stable behavior of β_0 throughout the sample suggests that long-term expectations remained broadly anchored despite episodes of market turbulence. By contrast, the slope factor (β_1) exhibits more pronounced fluctuations, reflecting changes in liquidity conditions, monetary policy expectations, and the relative movement of short- and long-term interest rates. Such fluctuations became more visible during periods of heightened uncertainty, indicating shifts in market perceptions regarding future economic conditions.

The curvature factors (β_2 in the NS model and $\beta_2 - \beta_3$ in the NSS model) provide additional insight into medium-term expectations. Larger movements in these parameters typically correspond to changes in the shape of the yield curve associated with uncertainty about economic growth, inflation, and financial market conditions. In particular, the stronger volatility observed during 2020–2023 coincides with several episodes of elevated uncertainty, including the COVID-19 pandemic, subsequent policy interventions, global monetary tightening, and turbulence in Vietnam's corporate bond and real-estate markets. During these periods, the NSS specification displays substantially larger fluctuations in both curvature and decay parameters, suggesting that medium-term expectations became less stable and more heterogeneous across maturities. These results indicate that the estimated factors contain economically relevant information beyond curve fitting and may serve as useful indicators of changing market expectations over time.

The joint examination of beta and lambda parameters highlights the fundamental trade-off between stability and flexibility across the two model families. The NS specification yields relatively smooth and stable trajectories for both the factor loadings (β_0, β_2) and the single decay parameter λ, underscoring its parsimony and interpretability. By contrast, the NSS model introduces an additional curvature factor (β_3) and two decay parameters (λ_1, λ_2), which display greater variability over time. This added complexity enables the NSS framework to better accommodate shifts in short- and medium-term dynamics, particularly during periods of heightened market stress. Overall, these results confirm that while NS provides robustness and transparency, the NSS specification delivers enhanced adaptability in capturing diverse yield curve shapes.

The parameter dynamics also provide useful insights into several periods of heightened market uncertainty during the sample period. A first notable episode occurred during 2020-2021, when the COVID-19 pandemic triggered substantial disruptions to economic activity and prompted both monetary and fiscal policy interventions. During this period, the NSS curvature parameters exhibited noticeably larger fluctuations, indicating increased uncertainty regarding medium- and long-term interest rate expectations. The additional curvature factor allowed the NSS specification to capture localized distortions in the yield curve that emerged as investors reassessed growth prospects and liquidity conditions.

A second period of elevated volatility can be observed during 2022-2023, coinciding with global monetary tightening, rising inflationary pressures, and turbulence in Vietnam's corporate bond and real-estate markets. Figures 3 and 4 show that both the curvature parameters and decay parameters of the NSS model became more volatile during this period. These movements suggest a greater degree of heterogeneity in market expectations across maturities and reflect changing perceptions of credit and liquidity risks. The NSS specification was able to accommodate these irregular yield curve shapes more effectively than the NS model due to its additional curvature component.

More generally, episodes characterized by abrupt policy adjustments, liquidity pressures, or shifts in market sentiment tend to generate temporary humps and distortions in the term structure. The behavior of the NSS parameters during these periods supports the view that the model provides valuable additional flexibility under stressed market conditions, even though this flexibility does not necessarily translate into lower overall bond-pricing errors.

4.3. Yield Curve Fitting

An important step in evaluating the empirical performance of the NS and NSS frameworks is to assess how well the estimated curves reproduce yields implied by market prices of coupon-bearing bonds. While the analysis of parameter dynamics provides insights into the flexibility and stability of the two models, their practical relevance ultimately depends on the ability to fit bond-implied yields across maturities and under varying market conditions. This subsection therefore compares fitted yield curves obtained from the NS and NSS specifications with yields derived from coupon-bearing bonds, with particular attention to differences in performance across trade dates characterized by varying levels of bond availability.

Figure 5 compares market yield curves with the fitted curves from the NS and NSS models for three representative trade dates selected according to the distribution of daily pricing errors. Specifically, for a given model (e.g., NSS), trade dates are ranked by their root mean squared error (RMSE) computed from bond pricing deviations, and three dates are chosen: the date with the lowest RMSE (best fit), the highest RMSE (worst fit), and the median RMSE. This selection strategy allows us to illustrate model performance under favorable, typical, and challenging estimation conditions. On the best-fitting date (lowest RMSE), both models closely replicate the observed term structure. The fitted curves align tightly with market-implied yields across maturities, indicating that the parametric structure is sufficiently flexible to capture prevailing yield dynamics when pricing errors are minimal. On the worst-fitting date (highest RMSE), discrepancies between model-implied and market yields become more pronounced. Deviations are particularly visible in segments where the yield curve exhibits local irregularities or sharper curvature. In such cases, the NSS specification tends to track medium- and long-term maturities more closely due to its additional curvature factor, although pricing dispersion remains evident. For the median-RMSE date, both models capture the overall level and slope of the yield curve with moderate accuracy. The NSS model again demonstrates marginal improvements in fitting medium- and long-term segments, while the NS model provides a smoother but slightly less flexible approximation.

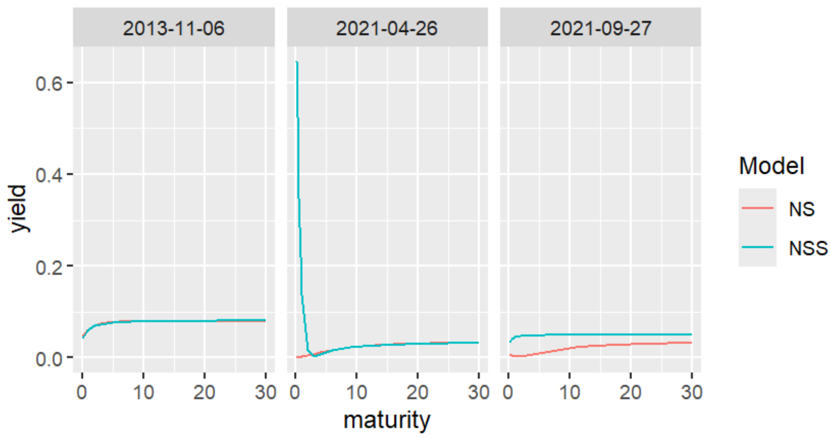

Figure 5. Market yield curve vs. Fitted yield curves for selected trade dates.

Average fitted curves with 5% - 95% confidence bands (Figure 6) further highlight the enhanced precision of the NSS model. From an economic perspective, upward-sloping curves typically signal expectations of future growth and stable inflation, whereas flat or inverted curves are frequently regarded as predictors of recessions. Hump-shaped curves are often indicative of liquidity shocks or targeted interventions. By incorporating an additional curvature factor, the NSS specification is better suited to reflect such complex yield curve dynamics.

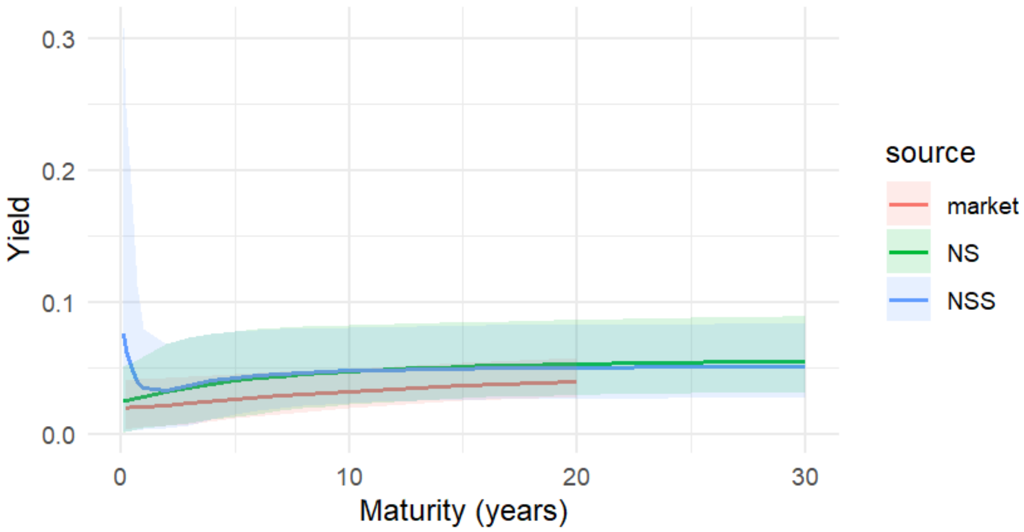

Figure 6. Average yield curve with 5% - 95% bands.

The analysis of selected trade dates in Figure 5 underscores that both the NS and NSS models are capable of replicating the general shape of the market yield curve, with accuracy improving as the cross-sectional richness of bond data increases. Nevertheless, yield curve fitting alone provides only an indirect assessment of model performance, since policymakers and market participants are ultimately concerned with how well the models reproduce observed bond prices. To address this, Figures 6 and 7 extend the evaluation by comparing fitted bond prices implied by the estimated curves with actual market prices across representative and full-sample trade dates, thereby offering a more stringent test of model accuracy at the security level.

In summary, the comparison of fitted yield curves across different trade dates shows that both models are capable of capturing the general shape of the bond-implied term structure, with the NSS specification offering marginal improvements, particularly when richer cross-sectional information is available. However, yield curve fitting alone provides only an indirect measure of model accuracy. Since market participants and policymakers are ultimately concerned with how well the models reproduce actual bond prices, the next step is to evaluate model performance at the security level by comparing fitted bond prices against observed market prices.

4.4. Bond Pricing

The comparison of yield curves in the previous section provides an initial indication of model fit, but the ultimate test lies in how well the NS and NSS specifications reproduce observed bond prices. Figures 5 and 7 together highlight this connection: on dates with flat or smooth yield curves, both models deliver accurate pricing, whereas periods characterized by sharp short-term distortions or stronger curvature expose their limitations. In particular, the NSS model tends to capture irregular yield patterns more flexibly, but often at the cost of greater dispersion in pricing errors. The following analysis therefore examines model performance systematically across bonds and trade dates, focusing on the distribution of pricing deviations and formal error metrics.

Figure 7 compares fitted and market bond prices for the same three trade dates examined in Figure 5. On the best-fitting date, where the RMSE is lowest, both models display close alignment with the 45-degree benchmark line, indicating minimal pricing deviations. The clustering of observations around the diagonal suggests that the models are able to replicate market prices very accurately when pricing errors are small. On the worst-fitting date, corresponding to the highest RMSE, pricing deviations become more pronounced. The scatter plots reveal a wider dispersion around the benchmark line, reflecting the difficulty of reproducing market prices under more irregular yield curve conditions. In this case, the NSS model tends to capture certain nonlinearities more flexibly, but this flexibility also leads to greater variability in fitted prices. By contrast, the NS model produces a more concentrated pattern of observations but may exhibit systematic bias in some maturity segments.

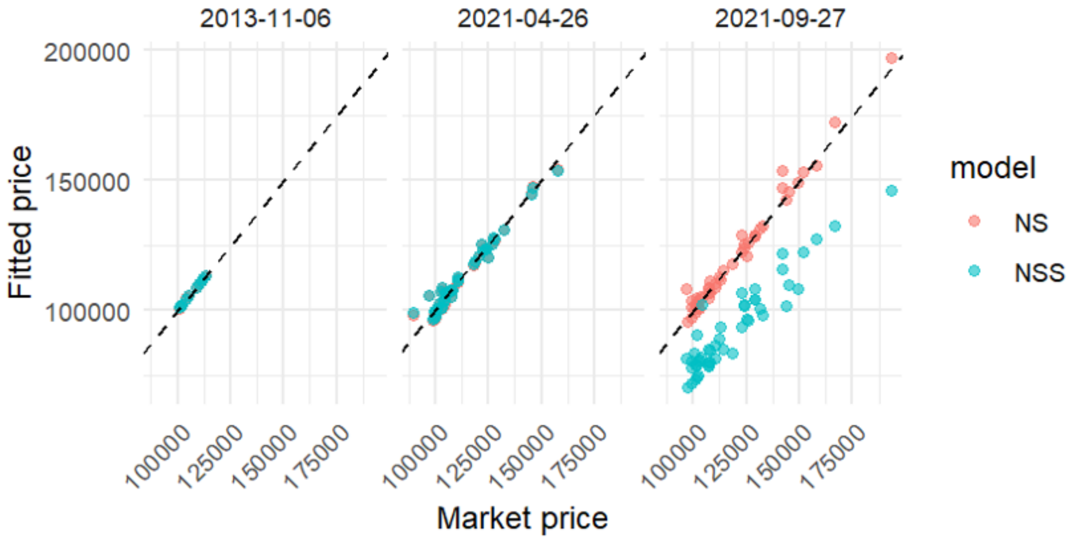

Figure 7. Fitted prices vs. Market prices by models for selected dates.

For the median-RMSE date, both models replicate bond prices with moderate accuracy. The NS specification produces relatively stable fits across bonds, while the NSS model demonstrates somewhat better alignment in medium- and long-term maturities due to its additional curvature component. Taken together, the figure illustrates that bond pricing accuracy depends not only on the functional flexibility of the model but also on the prevailing market conditions reflected in the cross-sectional structure of bond prices. The NS model offers greater stability and lower dispersion in fitted prices across most situations, whereas the NSS model can better accommodate complex yield curve shapes when market conditions deviate from standard patterns.

Figure 7 extends the analysis by comparing fitted and market prices across the full sample of trade dates. The scatter plots reveal that, while both the NS and NSS models capture the broad relationship between fitted and observed bond prices, important differences emerge in the distribution of residuals. The NS model produces a more compact clustering around the 45-degree line, reflecting greater stability in pricing accuracy across the sample. By contrast, the NSS model shows wider dispersion, particularly at medium- and long-term maturities, consistent with the additional variability introduced by its extra curvature factor.

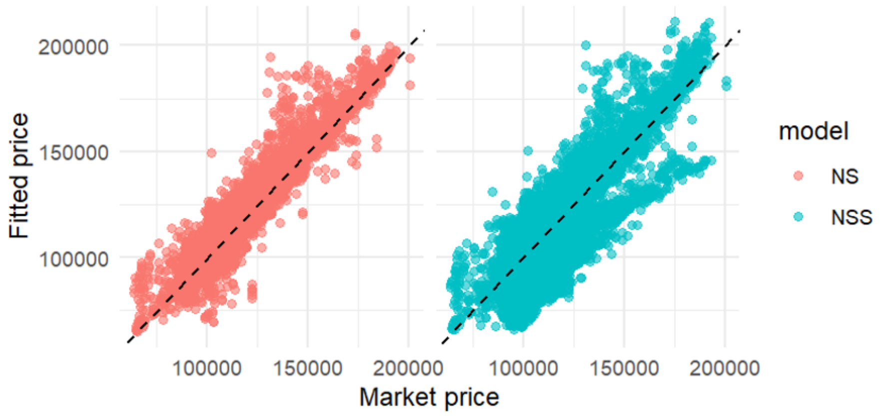

Figure 8. Fitted prices vs. Market prices by models for all dates.

Despite this increased volatility, the NSS model provides a closer fit in certain periods of heightened market stress, where complex yield curve shapes are better captured by its richer specification. Overall, the evidence suggests that the NS model is more reliable for consistent pricing accuracy, whereas the NSS model can offer advantages in episodes of structural shifts or irregular term structure dynamics.

Table 5. Model performance by both models across sample.

Metric	Nelson–Siegel	Nelson–Siegel–Svensson
N	77,428	77,428
MAE Price	1,496	2,699
MAPE Price	1.36	2.42
RMSE Price	2,493	3,919
R^2 Price	0.89	0.73

Table 5 summarizes the main error metrics across the full sample. The results confirm that the NS model consistently achieves lower mean absolute error (MAE), mean absolute percentage error (MAPE), and root mean squared error (RMSE) compared to the NSS model. Specifically, the NS specification reduces the average absolute pricing error by almost half relative to the NSS framework (MAE of 1,496 versus 2,699), while the MAPE values further indicate that proportional pricing deviations are systematically smaller. The RMSE values reinforce this pattern, highlighting that extreme pricing errors are also more effectively contained under the NS model. In addition, the higher R^2 value of 0.89 versus 0.73 demonstrates the stronger explanatory power of the NS specification.

These results corroborate the visual evidence from Figures 5 and 7, emphasizing that although the NSS model provides additional flexibility in capturing yield curve shapes, such flexibility does not necessarily translate into improved bond-level pricing performance. On the contrary, the parsimonious NS model proves to be more robust across a wide range of trade dates, particularly in terms of minimizing systematic and extreme deviations. Figure 9 complements the summary statistics in Table 5 by disaggregating pricing residuals across maturity buckets. For short-term maturities (less than three years), both models achieve tight clustering around zero, confirming that short-dated bonds are priced accurately. As maturities increase, residual dispersion widens considerably. In the medium-term segment (5-20 years), the magnitude of residuals becomes noticeably larger, suggesting increasing model difficulty in accurately pricing bonds with longer horizons. For these buckets, the NS model shows slightly higher median residuals, while the NSS model demonstrates somewhat tighter clustering, although both exhibit significant outliers.

In the long-term segment (20 - 30 years and beyond 30 years), residual variability is most pronounced. Here, the NSS model tends to reduce bias relative to the NS model, with median residuals closer to zero. Nonetheless, extreme pricing errors are observed in both specifications, reflecting the greater challenges of fitting very long maturities. The evidence indicates that both models perform satisfactorily for short maturities, but differences emerge as maturities extend. The NSS model provides marginal improvements in median accuracy at longer horizons, whereas the NS model exhibits slightly less volatility in the intermediate buckets. These results highlight the inherent trade-off between model flexibility and stability across the term structure.

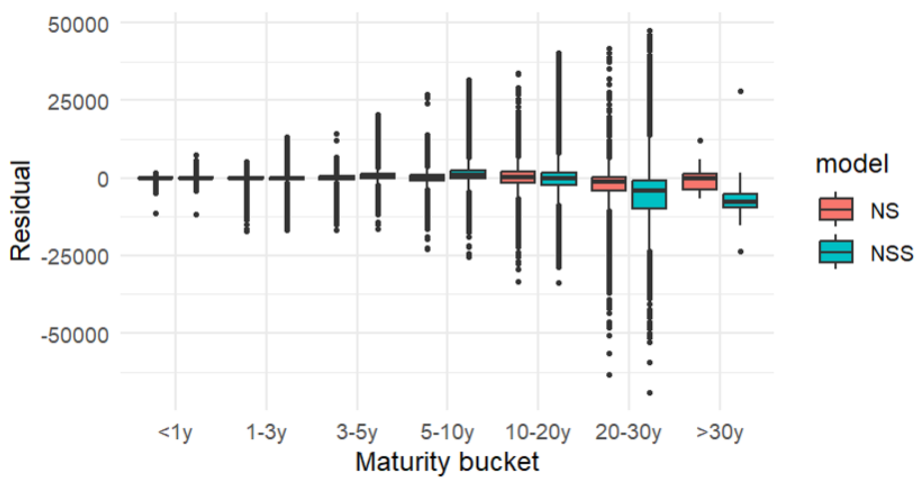

Figure 9. Residual by maturity bucket by models.

Figure 10 presents the overall distribution of pricing residuals for the NS and NSS models. Both distributions are centered tightly around zero, indicating that neither specification introduces systematic bias in bond pricing. However, the NS model exhibits a more concentrated distribution with thinner tails, reflecting greater stability and fewer extreme deviations. In contrast, the NSS model displays a wider spread of residuals, consistent with the higher error measures reported in Table 5 and the greater variability observed across maturity buckets.

These results confirm that while both models are unbiased in expectation, the NS specification provides more robust and consistent bond-level pricing performance, whereas the additional flexibility of the NSS model comes at the cost of increased volatility in pricing errors. Taken together, the evidence from Figures 7-10 and Table 5 highlights the relative strengths and weaknesses of the NS and NSS specifications in reproducing bond prices. Both models adequately capture market prices when the yield curve is smooth or when only short-dated maturities are considered. However, differences become more apparent at longer horizons and during periods of yield curve distortion. The NS model delivers consistently lower error metrics, a tighter distribution of residuals, and greater stability across the full sample, underscoring its robustness as a parsimonious framework. By contrast, the NSS model provides marginal improvements in fitting medium- and long-term maturities, but at the expense of wider dispersion in errors and reduced overall stability.

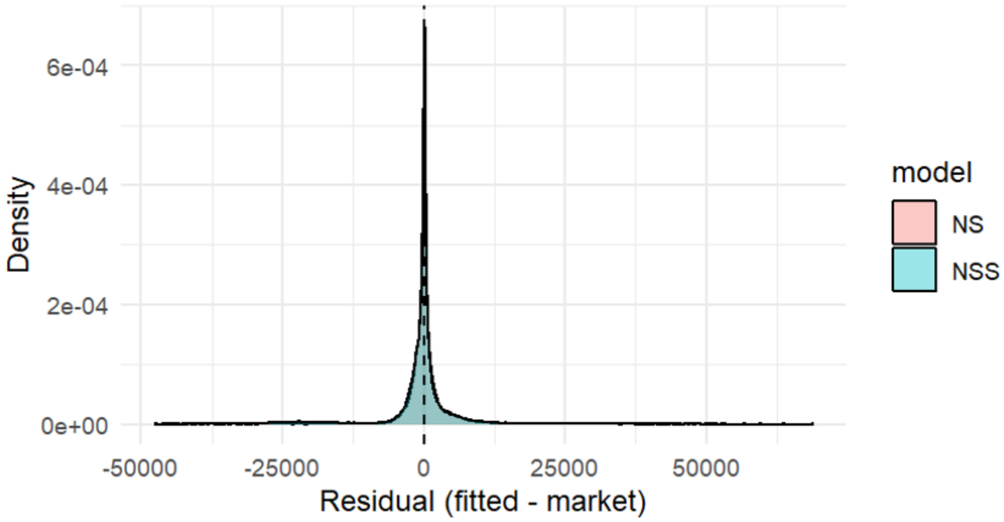

Figure 10. Distribution of pricing residuals by models.

These findings suggest that, although the NSS specification offers greater flexibility in capturing complex yield curve shapes, the NS model remains more reliable for bond-level pricing accuracy in most circumstances. The next section therefore turns to an assessment of robustness across time, examining how model performance evolves over the more than 2,900 trade dates included in the sample.

4.5. Robustness across Time

While cross-sectional results provide valuable insights into model performance at the bond and maturity levels, it is equally important to assess how these findings hold over time. Yield curve dynamics are influenced by evolving macroeconomic conditions, shifts in monetary policy, and episodes of market stress, all of which can alter model accuracy. To capture this dimension, we evaluate the stability of the NS and NSS specifications across more than 2,900 trade dates. The analysis focuses on the time series of error measures, such as the mean absolute percentage error (MAPE), in order to identify whether differences in performance are persistent or concentrated in particular market regimes.

Figure 11 reports the time series of MAPE for both specifications. The results demonstrate a clear difference in stability: the NS model consistently achieves low error levels with limited fluctuations, whereas the NSS model exhibits pronounced spikes and high volatility in error dynamics. Periods of elevated MAPE for the NSS specification coincide with episodes of market turbulence and irregular yield curve shapes, particularly during and after 2020, when short-term distortions and policy interventions were more frequent.

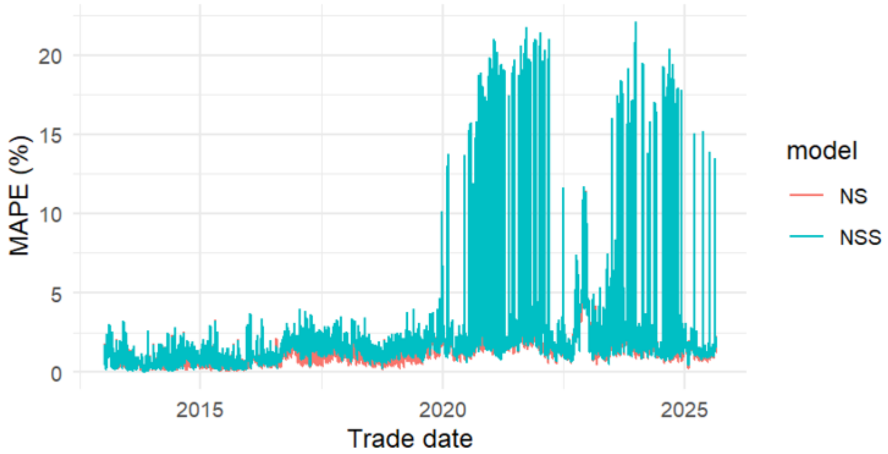

Figure 11. MAPE over time by models.

These findings underscore the trade-off between parsimony and flexibility. The NS model provides stable and reliable performance across time, reinforcing its suitability for routine monitoring and policy analysis. By contrast, the NSS model's greater sensitivity allows it to capture abrupt market shifts, but this comes at the cost of larger and more volatile errors during periods of instability. The time-series evidence therefore confirms the broader conclusion that the NS model is more robust overall, while the NSS specification may be advantageous only in environments where yield curve dynamics deviate significantly from standard shapes.

4.6. Summary of Empirical Results

The empirical analysis demonstrates that both NS and NSS frameworks are effective in summarizing the information embedded in coupon-bearing bond prices, though their relative strengths differ across contexts. The NS specification, with its parsimonious structure, provides greater stability, lower pricing errors, and stronger explanatory power across the full sample. Its robustness and interpretability make it particularly suitable for routine monitoring and policy applications. By contrast, the NSS model offers enhanced flexibility in capturing complex yield curve shapes and additional curvature at medium and long maturities, yet this comes at the cost of higher volatility in parameter estimates and less consistent bond pricing performance.

Overall, the results highlight a fundamental trade-off between robustness and flexibility. The NS model emerges as the more reliable benchmark under normal market conditions, while the NSS specification proves valuable in periods of structural shifts or irregular yield curve dynamics. These findings underscore the importance of model choice depending on the analytical objective, and they provide a foundation for the broader discussion on the practical implications of yield curve modeling.

5. Discussion

The empirical results presented in the previous section provide a comprehensive comparison between the NS and NSS models in the context of Vietnam's government bond market. Beyond the evaluation of statistical fit and pricing accuracy, these findings carry broader implications for financial interpretation, economic signaling, and practical applications. This section therefore extends the analysis by situating the results within a wider economic and institutional context.

A central result emerging from Figures 5-11 and Table 5 is the clear trade-off between parsimony and flexibility. The NS model consistently produces lower pricing errors, as evidenced by its superior MAE, MAPE, and RMSE values in Table 5, alongside a higher coefficient of determination. This performance is reinforced by the tighter clustering of residuals in Figures 8 and 10 and the lower volatility of pricing errors over time in Figure 11. These patterns indicate that the NS specification offers a stable and reliable representation of the term structure under typical market conditions.

In contrast, the NSS model demonstrates greater flexibility in capturing irregular yield curve shapes, particularly in medium- and long-term maturities. As illustrated in Figure 5, the NSS specification is better able to track localized curvature during high-RMSE periods, when the yield curve deviates from standard shapes. However, this flexibility comes at the cost of increased dispersion in pricing errors, as shown in Figures 7 and 8, and greater instability over time, as reflected in Figure 11. The additional curvature factor and decay parameter introduce sensitivity to noise, which can lead to overfitting in relatively illiquid segments of the market. An interesting finding is that the greater flexibility of the NSS specification does not translate into superior bond-pricing performance. Despite its ability to capture more complex yield curve shapes, the NSS model exhibits substantially higher pricing errors than the NS model, as reported in Table 5. Two factors may explain this result.

First, the maturity distribution of Vietnamese government bonds is uneven. As shown in Figure 1, most observations are concentrated in medium-term maturities, while relatively few bonds are available at the long end of the curve. Under such conditions, the additional curvature factor introduced by the NSS specification may be weakly identified because limited information is available to estimate the second hump-shaped component accurately. This can lead to greater parameter instability, particularly for the additional curvature and decay parameters. Evidence of this behavior can be observed in Figures 3 and 4, where the NSS parameters display considerably larger fluctuations than those of the NS model.

Second, the NSS specification involves a more complex optimization problem. Compared with the NS model, the NSS framework requires the estimation of an additional curvature factor and a second decay parameter, increasing the nonlinearity of the objective function and strengthening interactions among parameters. Consequently, multiple parameter combinations may generate similar yield curve shapes, making the estimation procedure more sensitive to local optima and numerical instability, especially during periods of lower market liquidity.

Furthermore, a better fit of the yield curve does not necessarily imply more accurate bond pricing. Because coupon-bearing bond prices depend on the discounted value of all future cash flows, relatively small variations in estimated long-term yields may translate into larger pricing deviations. Therefore, the additional flexibility of the NSS model may improve the fit of specific maturity segments while simultaneously generating higher bond-level pricing errors. This result suggests that the lower pricing accuracy of the NSS specification reflects the practical challenges of estimating a highly flexible model in an emerging market characterized by uneven maturity coverage and varying liquidity conditions rather than a failure to capture the general shape of the yield curve.

These findings highlight an important methodological implication: model performance cannot be assessed solely in terms of flexibility or goodness-of-fit in specific segments of the curve. Instead, the overall reliability of a model depends on its ability to balance accuracy, stability, and interpretability across different market conditions. In the Vietnamese context, where bond market liquidity varies across maturities and trading days, this balance becomes particularly relevant. The NS model's parsimonious structure appears better suited to such environments, while the NSS model may provide additional insights during periods of market stress or structural change. Importantly, the implications of these results extend beyond model selection. The yield curve is a fundamental input into a wide range of financial and economic decisions, and the choice of modeling framework influences how market signals are interpreted. The following subsections therefore explore how the empirical findings translate into implications for business activities and policy frameworks in Vietnam.

5.1. Business Implications in the Vietnamese Context

The estimated yield curves derived from the NS and NSS models provide more than a statistical description of bond market data; they also serve as key indicators of financial conditions that directly influence business activities. In Vietnam, where financial markets are still developing and bank-based financing remains dominant, the transmission from interest rate dynamics to corporate decision-making is particularly pronounced.

A primary channel operates through the cost of capital. As demonstrated in Figures 5 and 6, both models capture the general level of interest rates across maturities, which form the benchmark for pricing loans and corporate bonds. However, the greater stability of the NS model, reflected in its narrower confidence bands and lower pricing errors in Table 5, implies that it provides a more consistent reference for discounting future cash flows. For firms evaluating long-term investment projects, such consistency reduces uncertainty and supports more reliable capital budgeting decisions.

At the same time, variations in the shape of the yield curve convey information about expected economic conditions. The comparison of yield curves across different RMSE scenarios in Figure 5 illustrates how smooth, upward-sloping curves are associated with stable market environments, while irregular or highly curved structures emerge during periods of uncertainty. Businesses interpret these signals when forming expectations about demand, inflation, and financing conditions. In expansionary environments, firms in sectors such as manufacturing, retail, and construction are more likely to increase investment and production. Conversely, during periods characterized by distorted or unstable yield curves, firms may adopt more cautious strategies, postponing expansion or reducing exposure to long-term commitments.

Sectoral differences further amplify these effects. The maturity-dependent residual patterns shown in Figure 9 indicate that short-term interest rates are estimated with relatively high precision, whereas longer maturities exhibit greater variability. This distinction has important implications across industries. Firms relying on short-term financing, such as those managing working capital or inventory cycles, benefit from relatively predictable borrowing conditions. In contrast, capital-intensive sectors—including real estate, infrastructure, and energy—are more exposed to uncertainty in long-term rates. For these sectors, even small deviations in yield curve estimates can significantly affect project valuation and risk assessment.

The comparison of pricing performance in Figures 7 and 8 also provides insight into how financial uncertainty is transmitted to businesses. The tighter clustering of NS-based fitted prices suggests a more stable valuation framework, which is conducive to consistent financial planning. By contrast, the wider dispersion associated with the NSS model reflects environments in which market signals are less stable, potentially complicating investment decisions and increasing perceived risk. Such conditions are particularly relevant in emerging markets like Vietnam, where liquidity constraints and market segmentation can amplify the impact of financial volatility.

In addition to debt markets, the yield curve interacts with equity markets to influence business performance. Changes in interest rates affect stock valuations through discount rate adjustments and expectations of future earnings. Periods characterized by stable yield curves, as effectively captured by the NS model, tend to support predictable financial environments in which firms can access capital more easily. Conversely, periods of heightened volatility, which the NSS model is better able to capture, often coincide with fluctuations in equity prices and tighter financial conditions, affecting firms' ability to raise funds and expand operations. The empirical results underscore the role of the yield curve as a transmission mechanism linking financial markets to real economic activity. By providing accurate and interpretable estimates of interest rate dynamics, the NS and NSS models contribute to a better understanding of how financial conditions shape business decisions across sectors in Vietnam.

5.2. Policy Implications and Market Development

Beyond firm-level effects, the findings of this study also carry important implications for policymakers and the development of financial markets in Vietnam. The choice of yield curve model influences not only analytical outcomes but also the design of benchmarks, regulatory frameworks, and monetary policy tools. A key implication relates to the construction of benchmark yield curves. The superior stability and lower pricing errors of the NS model, as documented in Table 5 and Figures 8-11, suggest that it is well suited for use as an official reference curve in policy and market applications. A stable benchmark yield curve is essential for pricing government securities, valuing financial instruments, and guiding monetary policy decisions. In contrast, while the NSS model provides additional flexibility, its higher volatility may limit its suitability as a primary benchmark, although it remains useful for supplementary analysis during periods of market stress.

The results also highlight the importance of market structure in shaping model performance. As shown in Figure 1 and reflected in the residual patterns of Figure 9, the Vietnamese bond market exhibits uneven maturity distribution and limited liquidity at longer maturities. These characteristics contribute to estimation challenges, particularly for more complex models such as NSS. From a policy perspective, this suggests the need to strengthen market depth and standardize issuance across maturities. Expanding the supply of long-term government bonds and improving secondary market liquidity would enhance the reliability of yield curve estimation and support more efficient pricing across financial instruments.

Monetary policy transmission represents another critical dimension. The yield curve encapsulates market expectations of future interest rates and inflation, making it a valuable tool for central banks. The stable dynamics of the NS model, as evidenced by the relatively smooth evolution of error metrics in Figure 11, indicate that it can serve as a reliable indicator for monitoring financial conditions and assessing policy effectiveness. Meanwhile, the sensitivity of the NSS model to market fluctuations may provide early signals of stress or structural changes, complementing traditional policy indicators.

The development of the corporate bond market further reinforces the relevance of accurate yield curve modeling. In Vietnam, corporate bonds have become an increasingly important source of financing, particularly for sectors such as real estate and infrastructure. Government bond yields serve as the foundation for pricing these instruments, and inaccuracies in the benchmark curve can propagate through the financial system. The more consistent pricing performance of the NS model therefore supports more reliable valuation and risk assessment in the corporate bond market.

Finally, the findings emphasize the importance of data quality and transparency. Reliable yield curve estimation depends on the availability of accurate and liquid market data. Enhancing reporting standards, improving data accessibility, and promoting market transparency would contribute to more robust model estimation and better-informed policy decisions.

6. Conclusions

This study has examined the empirical performance of the Nelson–Siegel and Nelson–Siegel–Svensson models in estimating the term structure of interest rates from coupon-bearing government bonds in Vietnam. Using a large and comprehensive dataset, the analysis has evaluated model performance across multiple dimensions, including yield curve fitting, bond pricing accuracy, and robustness over time. The results consistently demonstrate that the NS model provides a more stable and reliable representation of the yield curve. Its lower pricing errors, tighter residual distributions, and consistent performance across time highlight its suitability as a benchmark model for practical applications. In contrast, the NSS specification offers greater flexibility in capturing complex yield curve shapes, particularly during periods of market stress, but at the cost of increased volatility and less consistent pricing accuracy. Taken together, these findings point to a fundamental trade-off between robustness and flexibility in yield curve modeling. Rather than viewing the two models as competing alternatives, they should be considered complementary tools, each suited to different analytical objectives and market conditions. More broadly, the study contributes to the understanding of yield curve modeling in emerging markets, where data limitations and market structure play a significant role in shaping model performance. By applying a one-step estimation approach directly to coupon-bearing bonds, the analysis provides a framework that is both practical and adaptable to similar contexts. Future research may extend this work by incorporating macroeconomic variables such as inflation, GDP growth, exchange rates, and policy rates into dynamic term-structure models, thereby providing deeper insights into the interaction between financial markets and economic conditions. In addition, the proposed framework may support a wider range of applications in risk management, stress testing, and asset-liability management. As Vietnam's fixed-income market continues to mature, the estimated yield curves may also serve as a foundation for the valuation of interest-rate-sensitive instruments and derivative products, further enhancing the practical relevance of term structure modeling.

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