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ANALYSIS OF ESG YIELD CURVE IN MEXICO

BLANCA LETICIA ROMERO MERCADO

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ASESOR:

DIANA TERRAZAS SANTAMARIA

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Abstract

This study analyzes the dynamics of the sustainable debt market in Mexico in 2024 through an examination of the yield curve, based on the strategy of the Ministry of Finance to promote sustainable finance through the issuance of ESG-compliant bonds and the adoption of newly implemented risk-free rates. To the best of our knowledge, this is the first study to address these developments.

By estimating and interpreting the shape of the yield curve during periods of monetary policy changes and market volatility, the research provides valuable insights into the ability of the sustainable yield curve to reflect economic trends and serve as a benchmark in the market. ESG bonds issued by the government and the Development Bank, key players in this market, are analyzed, with a focus on the yields of these instruments between March and October 2024.

The main findings indicate that, although the sustainable bond market in Mexico is still developing, it is sensitive not only to changes in monetary policy, such as those on March 22, August 9, and September 27, but also to new relevant market information. This behavior is particularly evident during periods of high volatility, as observed in September. The findings contribute to understanding the emerging ESG bond market in Mexico and its potential to support a resilient and transparent financial system.

Resumen

Este estudio analiza la dinámica del mercado de deuda sostenible en México en 2024 a través del examen de la curva de rendimiento, basándose en la estrategia de la Secretaría de Hacienda para impulsar las finanzas sostenibles mediante la emisión de bonos con criterios ESG y la adopción de tasas libres de riesgo recientemente implementadas. Hasta donde se tiene conocimiento, este es el primer estudio que aborda estos desarrollos.

Al estimar e interpretar la forma de la curva de rendimiento durante períodos de cambios en la política monetaria y volatilidad del mercado, la investigación proporciona información valiosa sobre la capacidad de la curva de rendimiento sostenible para reflejar las tendencias económicas

y servir como referencia en el mercado. Se analizan los bonos ESG emitidos por el gobierno y la Banca de Desarrollo, principales actores en este mercado, con un enfoque en los rendimientos de estos instrumentos entre marzo y octubre de 2024.

Los resultados principales indican que, aunque el mercado de bonos sostenibles en México aún se encuentra en desarrollo, muestra sensibilidad no solo a los cambios en la política monetaria, como los ocurridos el 22 de marzo, 9 de agosto y 27 de septiembre, sino también a nueva información relevante dentro del mercado. Este comportamiento es particularmente evidente en períodos de alta volatilidad, como se observó en septiembre. Los hallazgos contribuyen a la comprensión del mercado emergente de bonos ESG en México y su potencial para apoyar un sistema financiero resiliente y transparente.

1 Introduction

Building financial resilience is essential to address climate change and geopolitical events pressures, ensure the financial system's stability, and foster a dynamic economy capable of withstanding external shocks (OCDE, 2024). The private sector plays a critical role by adopting models that manage nature-related risks (World Wide Fund for Nature, [WWF], n.d.), though clear benchmarks led by governments are necessary to guide these efforts.

One effective way to attract public and private investment for a resilient and greener financial transition, aligned with the Sustainable Development Goals (SDGs) of the 2030 Agenda, is through the issuance of sustainable debt instruments. In emerging economies like Mexico, a robust, locally-denominated debt market is required to enhance market liquidity, deepen market participation, and foster trust among market agents (SHCP, 2024b).

Since 2020, Mexico has implemented innovative strategies to strengthen its local debt market and reduce reliance on foreign agents (SHCP, 2021b). These efforts include transitioning to risk-free rates, expanding the sustainable debt market, and developing an Overnight Interest Swap (OIS) curve, a benchmark for future issuances, including derivatives (Yorio et al., 2022). Following recommendations from international regulators like the International Organization of Securities Commissions (IOSCO) and the Financial Stability Board (FSB) (IOSCO, 2019; IOSCO, 2021), Mexico's Ministry of Finance and Public Credit (MoF) and the Central Bank of Mexico replaced the Interbank Equilibrium Interest Rate (TIIE) with the Overnight Funding Rate (TIIEF) as the primary reference rate in 2020. This transition, part of the Road to Efficiency in the Local Debt Market initiative (Banco de México, 2022b; Banco de México, 2024d; Yorio et al., 2022), included a strategy to develop a sustainable debt market supported by the publication of taxonomies and frameworks designed to align with the Sustainable Development Goals (SDGs) aimed at fostering investor confidence (SHCP, 2023a).

Expanding Mexico's sustainable market relies on the government's issuance of sustainable bonds, which are essential for developing a local sustainable yield curve. This yield curve serves as the foundation for constructing a risk-free, floating-rate curve, enabling the creation of a fixed-rate curve that enhances liquidity and pricing efficiency in both primary and secondary markets. These initiatives have attracted a diversity of institutions committed to Environmental, Social, and Governance (ESG) criteria, fostering projects that address social inequalities and combat climate change while ensuring transparency in ESG instruments (SHCP, 2024a).

The growth of Mexico's sustainable bond market is evident in its high demand and significant expansion. A standout example is the issuance of the second sovereign sustainable bond in July 2022, valued at 15 billion pesos, which attracted demand 4.4 times its amount and participation from 36 domestic investors (SHCP, 2023e; SHCP, 2022b). By 2023, ESG bond issuance had increased by 25%, reaching USD 14.7 billion and positioning Mexico as the second-largest issuer of thematic bonds in Latin America and the Caribbean, driven largely by government and Development Bank initiatives (CBI, 2023). This strong momentum underscores the importance of studying the yield curve of Mexico's sustainable bond market to better understand its dynamics, provide a benchmark for other market participants, and shape its future trajectory.

This study examines the dynamics of Mexico's sustainable debt market in 2024 by analyzing the yield curve, building on the Ministry of Finance's strategy to advance sustainable finance through ESG-integrated bond issuances and the adoption of newly implemented risk-free rates. To the best of my knowledge, this is the first study to analyze these developments. By estimating and interpreting the yield curve's shape during periods of monetary policy shifts and market volatility, the research provides valuable insights into the responsiveness of the sustainable yield curve to prevailing economic trends and its role as a benchmark.

Focusing on ESG bonds issued by the government and Development Banks—the primary players in this market, led by sovereign ESG issuances such as BONDES G—this study examines the comparative yields of these instruments from March to October 2024. Analyzing the yield curve, highlights its benchmarking role for other financial actors (Sally et al., 2019) and its capacity to reflect market expectations and economic outlooks over specified periods (Moorad, 2001). This is especially relevant in the context of recent interest rate cuts and the growing preference for sustainable investments (Yorio et al., 2022), offering a timely perspective on the evolving sustainable debt market.

The main results of this analysis indicate that, although the local sustainable bond market in

Mexico —comprising bonds referenced to the TIIEF under ESG criteria— is still in its developmental stages, it exhibits responsiveness not only to monetary policy changes, such as those on March 22, August 9, and September 27 but also to new information within this market. This behavior is particularly pronounced during high volatility, as observed in September. To the best of my knowledge, this represents the first evidence of the dynamic nature of the ESG bond market in Mexico.

The study's structure is as follows: Section 2 reviews the literature on ESG bonds and the yield curve of sustainable instruments. Section 3 discusses strategies for developing a local bond market in Mexico. Section 4 outlines the expectation theory that underpins yield curves. Section 5 describes the database used in the analysis, while Section 6 details the empirical strategy. Finally, Section 7 presents the findings and concludes with crucial insights.

2 Literature Review

Addressing climate change requires mobilizing substantial capital flows to mitigate climate risks and support adaptation projects. To attain this goal, financial instruments have been developed to channel significant funding toward tackling the most pressing challenges of climate change (Reichelt, 2010). The first green bond was issued in 2007 by multilateral institutions European Investment Bank (EIB) and World Bank with an amount of 807.2 USD million, was created to fund projects that have positive environmental or climate benefits since then the green bond market has seen exponential growth, reaching USD 1 trillion in cumulative issuance in 2020 since market inception in 2007 (Climate Bonds Initiative, 2020). The deepening of this market has been marked by an increasing diversity of issuers from various sectors, all striving to align their activities with the Sustainable Development Goals (SDGs). This shift has placed greater emphasis on the integration of Environmental, Social, and Governance (ESG) principles (Su, Lucey, and Jha, 2024; Bonds, 2017).

For emerging economies, attracting private investments of sufficient scale and duration is critical to addressing their sustainability challenges and climate vulnerabilities. Capital markets are key to channeling untapped commercial capital into financial instruments such as green, social, and sustainability-linked bonds. These instruments bridge the gap between capital markets and sustainability needs, providing access to long-term financing while allowing investors to align their financial goals with positive social and environmental outcomes, particularly vital for developing countries facing significant economic and environmental challenges (OCDE, 2024).

As reported by the Word Bank (Raquel and Ignacio, 2022), the importance of developing sustainable debt markets in emerging economies lies in addressing capital shortages and stimulating vital economic sectors. The issuance of green bonds increased in 2023, driven by the stabilization of financial markets, which allowed investors to anticipate lower inflation and central banks to ease interest rates. Economic growth in these markets exceeded expectations, with corporate earnings surpassing forecasts despite avoiding a US recession. In emerging markets, green bonds tend to outperform traditional bonds during risk periods but underperform when market sentiment is positive, which is why they are considered efficient for raising capital (IFC-Amundi, 2023).

According to estimations of the International Finance Corporations, in 2023 (IFC-Amundi, 2023) the future of the ESG bond market looks promising, with demand for sustainable instruments expected to grow, and more borrowers seeking funding for climate commitments. The sustainable market is projected to expand at an annual rate of 7.1% to 2025, driven by a slight decrease in inflation rates, growth rates surpassing those of developed markets from 2024 to 2025, and an increased focus on climate change and energy transition. This will be accompanied by a surge in Green, Social, Sustainability, and Sustainability-Linked (GSSS) [1] bond issuances, as well as sovereign encouragement in emerging economies. Sovereign institutions play a crucial role in channeling private funds into green projects by providing guidelines, creating a categorization system for sustainable finance, and aligning new taxonomies with international standards, thus simplifying risk assessments (IFC-Amundi, 2023).

[1] Collectively (GSS+ as defined by the Climate Bond Initiative those are four sustainable debt themes based on the projects, activities, and expenditures financed: green, social, sustainability, and Sustainability-Linked Bonds (CBI, 2023).

2.1 Yield Curves for ESG-Aligned Financial Instruments

The relation between future economic activity and the yield curve slope —defined as the difference between long- and short-term rates— is examined by Ibarra (2021) in the context of Mexico. Ibarra highlights one possible factor that could influence this relationship: the term premium, mentioned above. His findings indicate that the predictability incorporated in the yield curve is significant only when the term premium surpasses a critical threshold, suggesting that the effectiveness of the yield curve as an indicator series may indeed depend on prevailing market conditions. Yet, the sustainable yield curve [2] has not been studied in Mexico.

Sustainable bonds, particularly ESG bonds, warrant close study due to their sensitivity to economic shocks and the need for a deeper understanding of yield curves. Yield curves, which depict the relationship between bond yields and maturities, play a critical role in evaluating borrowing costs and investment risks. Studies suggest that green bonds may differ from conventional bonds in terms of yield, driven by factors such as market liquidity and the presence of a green premium [3] (Zerbib, 2019).

Studying the yield on sustainable bonds offers valuable insights into the market dynamics of these emerging instruments and the impact of ESG criteria on financial markets. For instance, Tomczak's research on sovereign green bonds across 13 countries reveals that green bonds tend to yield higher returns when conventional sovereign bond yields decrease. This understanding is crucial for shaping bond structuring and issuance strategies that incorporate ESG factors (Tomczak, 2024). Furthermore, some investors may prioritize social or ethical objectives over purely financial returns, indicating a preference for socially responsible investments even at the expense of suboptimal financial performance (Renneboog, Horst, and Zhang, 2008).

Nonetheless, according to (Umar, Kenourgios, and Papathanasiou, 2020), the dynamic nature of ESG markets suggests that ESG bond yield curves can display unique characteristics, especially during market turbulence periods. This study examines the equity indices of companies with strong ESG performance from 2007 to 2020, assessing their interconnectivity and poten-

[2] The yield curve based on green bonds or ESG bonds.

[3] Also known as greenium is defined as the yield differential between a green bond and an otherwise identical conventional bond (Zerbib, 2019).

tial spillover effects. Using daily closing prices of the MSCI ESG Leaders Indices [4] across ten global equity markets. The findings indicate that during periods of uncertainty, the diversification benefits of ESG investments diminish. Investors should diversify their portfolios and implement hedging strategies to mitigate risks in ESG markets and improve risk-return outcomes. Policymakers and regulators must also consider the significant risk of spillovers between ESG markets during these times.

The impact of pro-environmental preferences on bond prices, as identified by (Zerbib, 2019), further enriches the analysis of ESG bond yield curves. Zerbib highlights a slight negative premium for green bonds, suggesting that sustainability preferences are beginning to influence bond pricing. His study compares green bonds with synthetic non-green bonds issued between July 2013 and December 2017, constructing a green bond curve while integrating greenium into conventional bond curves. The results reveal a slight but noticeable premium, suggesting that green bonds can attract a broader range of investors without discouraging purchases or causing significant valuation discrepancies. However, data quality issues in Zerbib's study, such as low liquidity instruments, long-term rather than short-term greenium, and small sample size, account for discrepancies between green bond yields and the constructed curve.

Another area of interest is how sovereign sustainable curves influence corporate sustainable curves. Using a difference-in-differences (DID) approach, Cunha, Craveiro, and Rossi (2024) explore how building a sovereign ESG reference yield curve can stimulate the private ESG bond market. The study examines 430 corporate and sovereign ESG bonds issued in Latin America and the Caribbean (LAC) active in international markets. The findings show that a sovereign ESG reference curve leads to a 60% rise in corporate bond issuance and a 25% rise in ESG corporate bond issuance in foreign markets over three years. However, comprehensive studies on how ESG bond yield curves behave under various market conditions remain scarce.

The research by Liberati and Marinelli (2021) provides an estimation of ESG bond yield curves for financial and non-financial corporations, using monthly price and yield data for 250 secu-

[4] The selected indices invest in the most significant ESG markets in terms of depth and breadth, representing a substantial share of global market capitalization for 10 markets: the US, Australia, Canada, China, Europe, India, Japan, Russia, South Africa, and the UK (Umar, Kenourgios, and Papathanasiou, 2020).

rities classified as ESG and non-ESG bonds from June 2017 to March 2021 in the Euro-area. The study applies the Nelson-Siegel yield curve model to link yields with residual maturities and estimates its parameters—level, slope, and curvature—characterizing the zero-coupon bond yield curve. The findings show that the yield curve for euro-denominated ESG bonds lies below that of non-ESG bonds, indicating a negative spread. This yield spread increases over time, converging to zero for short maturities and widening as maturities lengthen.

Despite the evident positive impact and progress in integrating and promoting ESG investments, this market faces significant challenges due to *ESG washing*. This refers to instances where funding is misleadingly directed toward projects that do not truly adhere to ESG principles. The lack of universal taxonomies or frameworks for assessing ESG projects contributes to uncertainty, misunderstanding, and hesitance among investors to fully commit to ESG investments (Michela et al., 2021). These challenges result in a lack of liquidity and lower demand, ultimately leading to an underdeveloped benchmark yield curve

Despite the growing understanding of ESG investments, few studies have explored ESG instruments *"relation with sovereign yields or the components of the treasury yield curve"* (Iqbal et al., 2024). Most studies focus on developed markets, particularly within the European Union, where the sustainable bond market has been consolidating for some time (Tomczak, 2024) or focus on comparing the non-ESG curve with the ESG curve (Zerbib, 2019), (Liberati and Marinelli, 2021).

3 On the Development of a Local Bond Market

Local debt markets are a crucial component for strengthening financial stability. Acting as intermediaries in financial transactions, these markets facilitate agreements between entities with deficits and those with surpluses (Toca and Santaella Castell, 2014). Developing a robust local financial market provides governments with alternative funding sources, allowing them to reduce inflationary deficit financing and implement monetary policy effectively. Both, governments and corporations can reduce their dependence on foreign or national banking sectors (Jeanneau and Tovar, 2008). A diversified range of options for allocating savings mitigates risk.

Moreover, the transmission of monetary policy through short-term interest rates across various maturities is a crucial factor that the central bank should manage (Sidaoui, 2002). Reducing reliance on banks, utilizing a variety of financial instruments, and enhancing the effectiveness of monetary policy all contribute to maintaining the stability of the economic system.

Local bond markets provide the foundation for the yield curve and reflect a healthy state of public finances. Sovereign instruments, regarded as risk-free, are issued by the government and serve as the cornerstone of fixed-income markets, enabling the establishment of a government yield curve that acts as a benchmark for future debt issuances. A well-developed debt market offers comprehensive investment options at lower costs, aligning with the investment profiles of corporations and governments. A credible sovereign issuer complements an advanced local bond market, along with supportive policies such as monetary and fiscal consolidation, a regulatory legal framework, assurances of liquidity supply, and competitive financial markets (Toca and Santaella Castell, 2014).

Several conditions catalyze the development of a local debt market, including solid institutions and cooperation among agents, particularly in emerging economies, as evidenced by the financial crisis at the end of the 1990s. Following this crisis, Asian emerging economies faced vulnerabilities linked to currency denomination and maturity mismatches (Didier and Schmukler, 2014). A study conducted by Hardie and Rethel in 2019 [5], involving 155 interviews with policymakers and financial market participants, emphasizes the importance of strong institutions and active collaboration among various financial stakeholders. Their findings indicate that while government policies are vital, the stability and growth of debt markets are significantly influenced by the structure of domestic financial markets and the engagement of diverse stakeholders. Other studies, including those by Park (2017) and Bossu, Hillier, and Bergthaler (2020), demonstrate that the rapid expansion of local currency bond markets in emerging Asia was driven by interconnected regional incentives, alongside enhancements in macroeconomic performance, institutional strength, and sovereign credit ratings. For effective market advancement, it is essential to reinforce institutional structures.

[5](Hardie and Rethel, 2019).

Asian emerging economies have implemented several strategies to develop their local debt markets, such as establishing robust legal and tax frameworks and fostering active participation from market players. A particularly noteworthy approach, exemplified by Singapore, involved creating a yield curve to serve as a benchmark for stimulating demand for local currency sovereign bonds. This strategy enhances transparency in corporate bond pricing and improves market efficiency. By enforcing such a framework, these economies have developed practical risk management tools and extended the yield curve, mitigating risk concentration within dominant sectors (Park, 2017).

The Mexican government bond market has experienced significant growth since 1990 (Jeanneau and Verdia, 2005), resulting in a stable macroeconomic environment over recent decades, enabling the expansion of its government securities market. Key factors include reducing external vulnerabilities, liberalizing capital flows, implementing clear debt policies, reforming the pension system, developing the TIIE derivatives market, and enhancing legal certainty in financial regulations. These efforts have extended the yield curve from one year to 30 years and significantly increased the average debt maturity while creating a deep and liquid secondary market (Banco de México, 2018). However, this debt market relied on a reference rate with a high risk of manipulation, posing a threat to financial stability.

In 2020, Mexico positioned itself as a leader among emerging economies in Latin America with its innovative strategy to develop an efficient local debt market, focusing on traditional instruments while also boosting the sustainable debt market. To achieve this, the Mexican MoF has been leading a three-step plan: first, concentrating on the issuance of conventional debt instruments referenced to new risk-free benchmarks; second, encouraging the issuance of new debt instruments tied to these benchmarks while simultaneously integrating ESG criteria; and finally, focusing on the long-term issuance of the previously mentioned debt instruments, establishing an Overnight Index Swap (OIS) curve in local currency aimed at serving as a benchmark for both the derivatives and debt markets (Yorio et al., 2022).

The MoF aims to achieve this objective by boosting transactions utilizing the new risk-free benchmarks, which will lead to increased activity in the derivatives market and the development of the OIS curve in Mexican pesos to ensure accurate pricing of debt products. Consequently, the local debt market will become more efficient and dynamic, enhancing liquidity and depth, financing traditional and sustainable projects for public and private issuers, and expanding the investor base.

3.1 Mexico's transition away from vulnerable rates

Manipulations of widely used benchmarks in the financial market threaten financial stability, prompting a reformation in the calculation of financial rates globally, with Mexico actively adopting these changes. Thus, the first step of the MoF's plan to align with international reform trends was to encourage the adoption of the TIIEF while issuing sovereign floating bonds.

Interbank Offered Rates (IBORs), particularly the well-known LIBOR (London Interbank Offered Rate), served as the main benchmarks in dollars globally for various financial instruments, including derivatives, securities, loans, bonds, and deposits [6]. IBOR rates, submitted daily by a panel of banks, reflect interest rates in unsecured interbank transactions. These rates comprise a risk-free rate, a term premium, and a credit risk component associated with panel banks, serving as a reference for the average rate at which banks can obtain short-term interbank loans (Divya, 2017). The methodology used to calculate LIBOR led to manipulation and raised concerns about its long-term sustainability. Despite the widespread adoption of IBORs and the creation of liquid markets, the transaction volume used for their calculation significantly declined after the 2008 Global Financial Crisis.

In response to this manipulation, the Financial Stability Board (FSB) and the International Organization of Securities Commissions (IOSCO) recommended preventing future abuses. The proposed solution was to transition to risk-free benchmarks based on actual transactions rather than estimates (Duffie and Stein, 2015). These benchmarks aim to provide a robust representation of money market interest rates, offer a reference rate usable in a broader range of financial instruments, and serve as benchmarks for term-leading funding, as highlighted by Abrantes-Metz et al. (2019)[7].

[6](BIS, 2021).

[7]The reform of IBOR rates adopted credible overnight reference rates as risk-free rates according to established

These new benchmarks aim to address the demands of the IOSCO, FSB, and the Institute of International Finance (IIF)[8], emphasizing collaboration among governments, businesses, and regulators to tackle challenges related to fallback plans, hedging, and transition deadlines. Consequently, in Mexico, the MoF decided to cease the issuance of sovereign floating bonds referenced to the Equilibrium interest rate (TIIE), which was equivalent to the international IBORs as its calculation was based on a survey rather than the daily cost of interbank loans (Yorio et al., 2022). Instead, the MoF encourages the adoption of the new benchmark, TIIEF, while issuing a new debt instrument tied to it, known as BONDES F.

Following the international principles for new benchmarks—governance, accountability, and quality of information—the Mexican Central Bank began calculating and publishing the Funding Interbank Equilibrium Interest Rate (TIIEF) in January 2020. This rate is determined as the volume-weighted median [9] of the interest rates paid in funding transactions based on observed overnight transactions. These transactions are conducted in Mexican pesos by banks and brokerage firms through overnight repo operations with securities issued by the Federal Government, the Bank Saving Protection Institute (IPAB), and the Mexican Central Bank, using CETES, BONDES, BREMS, and IPAB securities (Banco de México, 2023a), (Secretaría de Gobernación, 2020).

Since 2021, the MoF has commenced issuing BONDES F. The strategy to promote the adoption of new floating bonds involves exchanging conventional floating bonds, known as BONDES D, issued for monetary policy purposes and substituting them with BONDES F of the same maturity (Yorio et al., 2022).

To ensure a smooth and timely transition, the entities leading the reform act vigorously. The Central Bank, through the Alternative Reference Rates Working Group in Mexico (GTTR), is

deadlines to facilitate this transition. IOSCO published the Principles of Financial Benchmarks in 2013 and set December 31, 2021, as the deadline to discontinue USD LIBOR, also encouraged establishing national working groups to guide the transition to risk-free rates IOSCO (2021), IOSCO (2019).

[8]The Institute of International Finance (Nozema, 2019).

[9]To determine the volume-weighted median, the base sample is ordered by interest rate from lowest to highest. For identical rates, the smallest amount is prioritized. Each transaction's accumulated volume is then calculated as a percentage of the total volume. The Funding TIIE is the rate of the first transaction whose accumulated volume reaches or exceeds fifty percent. This rate is expressed as an annual percentage to two decimal places (Banco de México, 2023a).

promoting the TIIEF as a replacement for the 28-day TIIE benchmark and is supporting the development of the Overnight Index Swap (OIS) curve in Mexican pesos. In collaboration with the MoF, the Mexican Central Bank has established deadlines for phasing out the traditional benchmark, aiming for a complete transition by 2025.[10] Furthermore, the Central Bank has continuously issued communications urging all market participants to use the TIIEF as a reference in new contracts while establishing the appropriate guidelines (Banco de México, 2022a).

The adoption of new reference rates has demonstrated varied progress globally. Notably, the transition from LIBOR to the Secured Overnight Financing Rate (SOFR) has been highly successful in replacing USD LIBOR, by the end of 2022 (Financial Stability Board, 2022) [11]. In contrast, the coexistence of traditional benchmarks with newer rates has posed challenges in other regions, such as Japan and the European Union, where the Tokyo Overnight Average Rate (TONA) and the Euro Short-Term Rate (ESTER) have led both reformed and traditional benchmarks continuing to exist side by side (AbrantesMetz et al., 2019).

While the effects of this transition in Mexico remain underexplored, it is crucial to consider the potential impacts on emerging economies. These nations face distinct challenges, particularly as eliminating the debt risk component in new benchmarks raises concerns about market efficiency [12], asset valuation, and investment decisions (Gök, Pirgaip, and Bouri, 2023). The shift away from IBORs could complicate matters for emerging countries like Mexico, where significant foreign ownership of the local debt, and floating-rate foreign exchange debt is prevalent (Toca and Santaella Castell, 2014).

In Mexico, challenges related to the TIIEF (Tasa de Interés Interbancaria de Equilibrio Financiero) arise from its reliance on USD-denominated transactions and limited liquidity. Foreign banks must adjust their USD balance sheets to access overnight loans in Mexican pesos and purchase sovereign bonds, highlighting the lack of a discount curve in pesos. Most im-

[10] The TIIE will be phased out for tenors of 91 and 182 days by January 2024 and for tenors of 28 days by January 2025 (Banco de México, 2022a).

[11] At the end of 2022, SOFR usage had surged from 30% to nearly 100% in USD loan references and syndicated loans (Financial Stability Board, 2022).

[12] Financial markets in which prices/rates fully reflect all available information at any point in time and do not provide for ex-ante profit opportunities are called "efficient" (Gök, Pirgaip, and Bouri, 2023).

portantly, the ongoing inflationary period may lead policymakers to adjust interest rates, which could shift investors' preferences toward floating-rate bonds. This change may expand the issuance of such bonds, altering the dynamics of the sustainable market in Mexico (Yorio et al., 2022).

3.2 Mexico's Path to Develop a Sustainable Local Debt Market

Influenced by the global development of sustainable financial markets, which aim to mobilize investments in alignment with the Sustainable Development Goals (SDGs) of the 2030 Agenda, the next step for Mexico's local debt market is to complement it with the issuance of sustainable instruments in local currency.

In 2023, the Mexican government took unprecedented action by establishing the Sustainable Finance Mobilization Strategy (SFMS), positioning itself as a leader in the Sustainable bond market (SHCP, 2023d). Given Mexico's vulnerability to the effects of climate change and the significant hurdles it faces in meeting the Sustainable Development Goals (SDGs), particularly in mitigating climate impacts and reducing socioeconomic disparities, it is essential to tackle these challenges with a focus on social and environmental justice while accelerating financing mobilization.

Mexico is also working to integrate the SDGs into its fiscal and national goals. This involves revising internal procedures within organizations such as the MoF while creating new entities like the Agenda 2030 Council and the Specialized Technical Committee on the Sustainable Development Goals (CTEODS). Since 2018, the MoF has focused on aligning the national budget with the SDGs, including issuing BONDES G, sovereign bonds linked to the ESG standards, to finance projects and expenditures to meet SDGs. The issuance of BONDES G encourages sustainable issuance in the local market and promotes the adoption of new risk-free rates, as BONDES G are referred to the TIIEF (SHCP, 2023d).

Although the issuance of thematic bonds in Mexico began in 2015 with a bond issuance by NAFIN[13], the market lacked benchmark issuances and was not yet consolidated. To address

[13] Nacional Financiera (NAFIN) is a National Credit Society, a Development Bank institution with its legal

these issues and further develop the sustainable local debt market, the issuance of sovereign debt instruments denominated in Mexican pesos, BONDES G, began in 2022 (SHCP, 2023b). BONDES G shares almost the same characteristics as BONDES F, but with the added alignment to sustainability criteria and issuance at different tenors, facilitating price discovery and integrating a premium called *greenium* [14] to incentivize debt issuance in local currency, particularly by Development Banks (UNDP, 2022). This is driven by the pressure to align with sustainable principles and a preference for floating rates (Yorio et al., 2022). Furthermore, this public investment enhances climate risk management, broadening the investor base to include those supporting innovative projects with environmental and social benefits. Sustainable investment aims to minimize fiscal risk, ensure macroeconomic stability, and protect against potential biodiversity loss and climate change (SHCP, 2023e).

The primary objective of issuing BONDES G is to attract a broader range of market participants and, ultimately, to establish a sustainable yield curve, which is the main focus of this study. Development Banks have taken the lead as pioneers in the sustainable debt market, emerging as the second-largest contributors to the issuance volumes of bonds aligned with ESG standards (CBI, 2023). Their alignment to finance SDG projects and preference for floating rates will allow them to complement the tenors of ESG sovereign bond issuances: BONDES G. While ESG sovereign bonds will be issued at longer maturities, Development Bank instruments could be issued at shorter maturities, thereby adding "market depth" to the local sustainable curve (Yorio et al., 2022).

Despite progress, Mexico's ESG sector still faces challenges, such as a lack of clarity in the regulatory framework, investor concerns about corruption and labor mismanagement, and limited ESG management among corporations (BIVA, 2022). In emerging markets, a key barrier is the lack of international recognition for green bond credit ratings, with over 80% of green bonds being unrated in 2023. Nonetheless, efforts have been made to establish social criteria and raise funds through ESG bonds. Mexico's sustainable taxonomy emphasizes expanding be-

personality and assets. Its purpose is to promote savings and investment, as well as channel financial and technical support for industrial development and, in general, for the national and regional economic development of the country.

[14] The *'greenium'*, or green premium, refers to pricing benefits based on the willingness of investors to pay extra or accept lower yields in exchange for sustainable impact (UNDP, 2022).

yond a narrow focus on climate, addressing issues like gender equality, financial inclusion, and access to healthcare and education. For example, in 2018, the National Commission for the Retirement Savings System (CONSAR) encouraged AFORES (Retirement Fund Administrators) to incorporate ESG concepts into their investment and risk analysis processes according to a report of the Institutional Stock Exchange BIVA (2022) to integrate ESG aspects into Mexican companies.

The third and final step of the MoF strategy focuses on integrating yield curves and extending maturities. As previously mentioned, BONDES F and BONDES G will be issued at different tenors, enabling the construction of a floating-rate curve. Once sufficient liquidity and maturity are achieved, this curve will serve as a benchmark for derivatives linked to the TIIEF. This process will also facilitate the creation of a fixed-rate curve with maturities of up to 10 years, derived from both floating and future rates (Yorio et al., 2022). However, this step is beyond the scope of this study.

4 Yield curve

Holding a bond entitles investors to receive interest payments at specified periods and the repayment of the principal at maturity. When comparing different bonds, investors typically assess their yields, focusing on bonds from similar issuers or those with comparable liquidity across various maturities. The primary measure of a bond's return is the yield to maturity (YTM), which represents the total return an investor can expect by holding the bond until its maturity (Cebula and Yang, 2008). This measure accounts for the bond's current market price, coupon payments, and time to maturity.

The yield curve, also known as the term structure of interest rates, is a fundamental concept in finance and economics, mainly for zero-coupon bonds (Moorad, 2001). It is a continuous function that relates interest rates to maturities across different time horizons. The yield curve plots the yields of bonds with various maturities, all sharing the same risk, liquidity, and characteristics. A yield curve is valuable for comparing yields across a broad range of bonds, visually representing these relationships. By analyzing the yield curve, agents in the market can gain insights into future short-term interest rate movements and the overall economic outlook (Mishkin and Eakins, 2012).

Analyzing yield curves is crucial because they serve as a benchmark in financial markets. Commonly, the first yield curve constructed is the yield curve for government bonds, as the sovereign curve is considered reliable due to the expectation that governments will generally meet their debt obligations. This yield curve is often referred to as the risk-free yield curve, as it reflects market conditions and supports the development of the bond market. Due to their "risk-free" nature and relatively higher liquidity, government bonds are used to benchmark other fixed-income products in the same currency denomination, hedge market positions, and assess long-term borrowing costs efficiently (Sally et al., 2019).

Once sovereign debt instruments are issued across a wide range of maturities—from short to long tenors—they establish benchmark yields for new issuers. As government bonds are regarded as risk-free debt with higher liquidity, they allow market participants to hedge against risks in other investments and promote the efficient allocation of resources. This enables issuers to price their bonds and other debt instruments based on the sovereign curve. Furthermore, portfolio managers analyze the yield curve's shape to identify points that offer higher returns (Moorad, 2001). Comparing the yield spread between sovereign and non-sovereign debt instruments also helps assess the creditworthiness of different categories of borrowers (Sally et al., 2019).

The yield of the sovereign bonds plays a role in pricing corporate bonds. As shown in the study of Bevilaqua, Hale, and Tallman (2020) for developed and emerging economies, the established relationship between the corporate and sovereign yields strengthens as sovereign debt incorporates key informational elements that help corporations price their future debt issuances. Notably, *"corporate bond yields are subject to a sovereign floor"* (Bevilaqua, Hale, and Tallman, 2020), as corporate bond yields are generally higher than sovereign yields. This relationship influences the level of corporate bond spreads and the probabilities of bond issuance.

However, the main interest in analyzing the yield curve in this study, especially its shape, lies in its ability to signal the anticipated future path of interest rates as formed by various economic agents. The yield curve naturally shows the cost of funds at various maturities, providing an overall view of financing conditions across different sectors. This means that both the shape and level of the yield curve reflect the present state of the economy and offer clues about its future direction (Moorad, 2001). Consequently, the yield curve becomes an important indicator of the economic outlook over a given period.

Among the several theories that explain the shapes of yield curves, the most widely explored are the expectations hypothesis and the liquidity preference theory, which define the relationship between the form of the yield curve and expectations formed concerning future market conditions. By applying these models, bondholders can gain insight into the prospective movement of interest rates. The unbiased expectations hypothesis, frequently examined in empirical research, states that the forward rate is an unbiased predictor of the future spot rate prevailing in the subsequent period (Moorad, 2001). Consequently, expectations of future short-term interest rates can be inferred from the current yield curve.

On the other hand, while the expectations hypothesis does not account for all possible shapes of the yield curve, it is complemented by liquidity preference theory to offer a more comprehensive analysis (Moorad, 2001). The liquidity preference theory states that the interest rate on a long-term bond will equal an average of short-term interest rates over the bond's duration plus a liquidity premium (Mishkin and Eakins, 2012). It assumes that bonds of longer maturity carry a higher default risk. Therefore, bondholders must be compensated through a premium for this added risk due to loss of liquidity compared to bonds of shorter maturity.

Thus, the yield curve, explained by the expectations hypothesis, combined with liquidity preference theory, can be graphically represented as the unbiased expectations curve plus a liquidity premium. This combination effectively illustrates the actual yield curve, capturing the nuances of interest rate expectations and the associated risks inherent in longer maturities.

When the yield curve exhibits a positive slope as maturity increases, it assumes a typical or conventional shape. According to the expectations theory, the upward-sloping yield curve (Figure 1a) signals that investors believe short-term interest rates will increase soon. In this context, long-term interest rates represent the average of expected future short-term rates. If the long-term rate is currently higher than the short-term rate, this implies that the future short-term rates, on average, are expected to increase above the current short-term rate. This increase in future rates would bring the long-term rate to a level higher than the current short-term rate, reflecting the market's expectation of rising short-term interest rates over time. Consequently, an upward-sloping curve reflects lower yields for short-term rates and higher yields for long-term rates (Mishkin and Eakins, 2012).

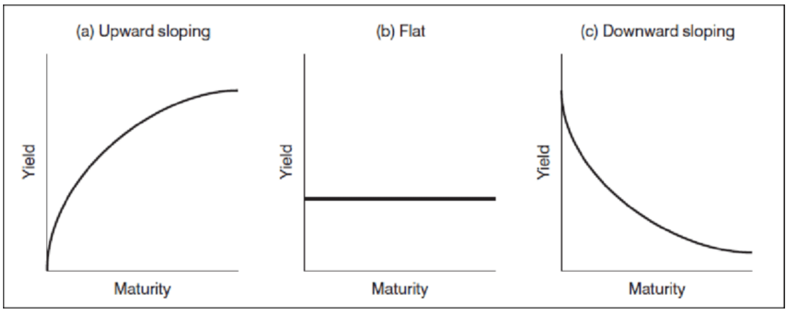

Figure 1: The shapes of the yield curve
Source: (Kettell, 2002)

When the yield curve is downward sloping (Figure 1c), sometimes referred to as an inverted curve, the expectations theory explains that yield curves become inverted when short-term rates are high (Moorad, 2001) (Figure 1). Market participants usually expect them to decline. The average of future short-term interest rates is expected to be lower than the current short-term rate, implying that short-term interest rates are expected to fall, on average, in the future.

The expectations theory also explains that interest rates on bonds with different maturities tend to move together over time. Changes in short-term rates influence market participants' expectations regarding future short-term rates. Since long-term rates are derived from the average of anticipated future short-term rates, an increase in short-term rates will lead to a rise in long-term rates, resulting in a synchronous movement between short- and long-term rates (Mishkin and Eakins, 2012).

The expectations theory indicates that only when the yield curve is flat (Figure 1b) do short-term interest rates imply that no significant changes are anticipated for the future on average.

However, the expectations theory is limited to explaining why yield curves generally slope upward, suggesting that short-term interest rates are usually expected to rise in the future, thus long-term rates would consistently exceed short-term rates only if markets consistently expect rates to increase in the future, however, this is not always true. The theory established that short-term interest rates are equally likely to fall as they are to increase, and so it will imply that the typical yield curve should be flat rather than upward-sloping. (Mishkin and Eakins, 2012). (Figure 1) The liquidity theory also postulates that upward-sloping yield curves can arise from several factors as constant liquidity premiums and steady short rates (Figure 2), declining expected short rates alongside increasing liquidity premiums (Figure 3), or upward-shifting expected short rates and rising liquidity premiums (Figure 4). (Zvi, Alex, and J., 2018). With the additional boost of a positive liquidity premium, long-term interest rates will be substantially higher than current short-term rates, resulting in a steep upward slope of the yield curve due to investors' preferences for short-term bonds.

Conversely, when short-term rates are high, market participants usually expect a decline in those rates. In such cases, long-term rates will fall below short-term rates, as the average of expected future short-term rates will be lower than current short-term rates. Consequently, despite positive liquidity premiums, the yield curve will exhibit a downward slope. (Mishkin and Eakins, 2012).

Finally, the humped shape (Figure 1) is characterized by yields reaching their peak at medium maturities before declining to lower levels for long-term periods (Moorad, 2001). The humped shape can emerge when there is a constant liquidity premium combined with declining expected short-term rates and increasing liquidity premiums (Zvi, Alex, and J., 2018) (Figure 5). Generally, the humped nature of the yield curve observed for short maturities reflects the hypothesis of the liquidity premium theory stating that long-term bonds pay a positive liquidity premium (Zvi, Alex, and J., 2018).

The yield curve is a vital economic indicator that offers important insights for investors, economists, and policymakers by reflecting expectations about economic growth and inflation (Sally et al., 2019). An inverted yield curve, where short-term rates exceed long-term rates, typically signals an impending recession, while an upward-sloping curve suggests expectations of economic expansion (Estrella and Mishkin, 1996). A rising slope indicates higher future interest rates and

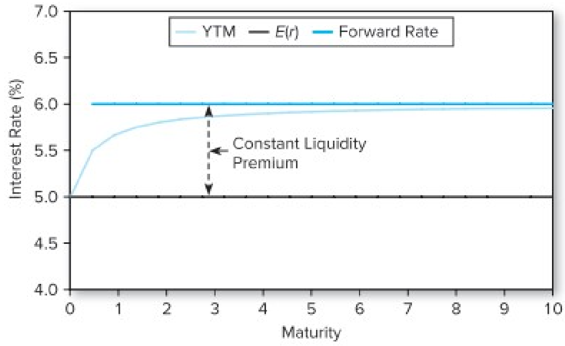

Figure 2: Constant expected short rate. Liquidity premium of 1%
Source: Zvi, Alex, and J. (2018)

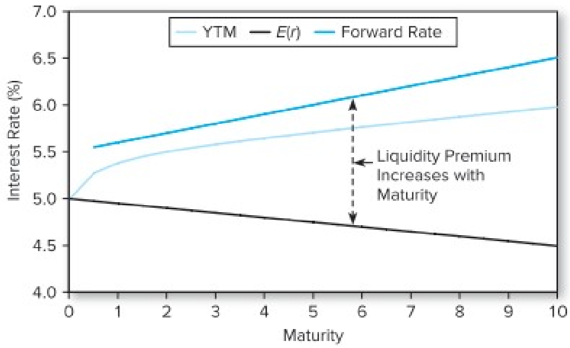

Figure 3: Yield curve with declining expected short rates and increasing liquidity premiums
Source: Zvi, Alex, and J. (2018)

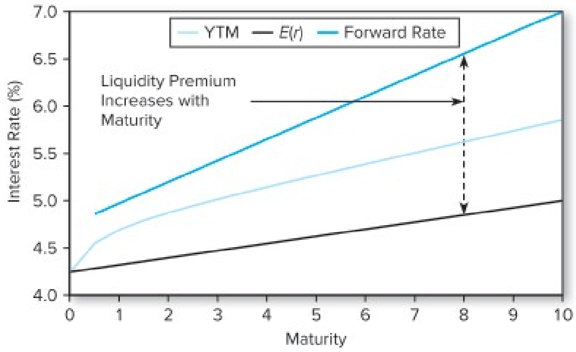

Figure 4: Yield curve with increasing expected short rates and increasing liquidity premiums
Source: (Zvi, Alex, and J., 2018)

robust growth, while a downward slope points to a potential economic slowdown and lower future rates.

Understanding the shape of the yield curve is crucial for assessing the economic outlook and forming expectations about future conditions. Research by Nelson and Siegel (1987) and Diebold and Li (2006) emphasizes the importance of breaking the curve down into three com-

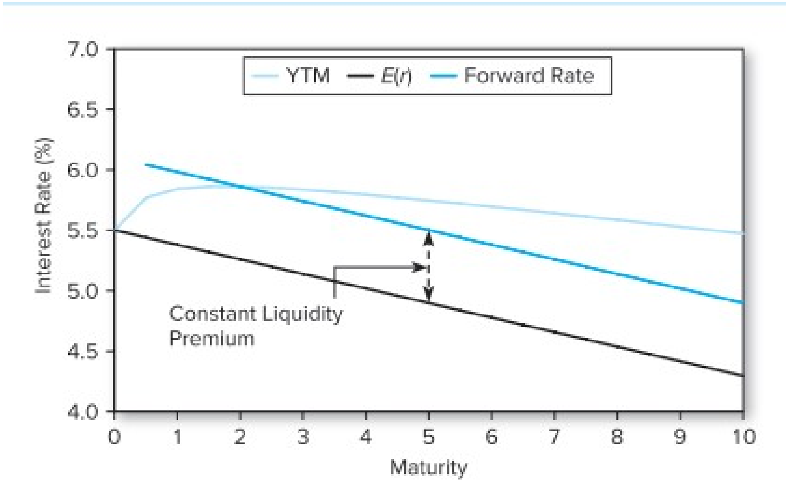

Figure 5: Humped Yield curve
Source: Zvi, Alex, and J. (2018)

ponents: level, slope, and curvature, which correspond to long-term, short-term, and medium-term rates, respectively. The level of the yield curve reflects the overall interest rate environment, with shifts driven by investor expectations about future rate changes, influencing yields across both short- and long-term horizons. The slope captures the difference between short-term and long-term bond yields, while the curvature illustrates the relationship between short-, medium-, and long-term yields to maturity, offering deeper insight into market expectations.

The yield curve also serves as a predictor of future economic conditions, influencing securities markets, especially those based on government bonds (Rudebusch, Francisco, and Williams, 2008), (Bauer and Mertens, 2018). Bond prices, which reflect broader banking sector conditions, play a key role in determining general interest rates and influence capital allocation. The speed at which bond prices adjust to new information is crucial for efficient market functioning (Sally et al., 2019).

For policymakers, the yield curve provides valuable insights into the effects of interest rate changes. For example, raising short-term rates may signal a weakening economy, potentially causing an inversion, while lowering short-term rates could lead to higher long-term rates and stimulate economic activity (Argyropoulos and Tzavalis, 2016). This helps policymakers assess how shifts in debt levels impact yields across various maturities (Moorad, 2001).

5 Data

The Mexican bond market is one of the most developed in Latin America, with USD 882.4 billion in debt securities. The domestic market includes various instruments such as Udibonos, Cetes, Bondes D, Bondes M, Bondes F, and BONDES G. Udibonos hold the largest share, accounting for 29.6% of the market, while Bondes F and BONDES G, both tied to the new risk-free rate (TIIEF), together make up 14.7% [15].

Although the issuance of BONDES F and BONDES G is crucial for Mexico's transition towards risk-free rates and the consolidation of the local currency debt market, these instruments, while sharing many features, also have distinct characteristics, as highlighted in Table 1.

BONDES F, introduced in October 2021, were the first instruments tied to the new benchmark rates. Like BONDES G, they have a face value of 100 Mexican pesos and accrue interest every 28 days. However, BONDES F are issued with terms of 1 to 5 years and were created to replace BONDES D, with their rates accruing interest in arrears.

In contrast, BONDES G, although linked to the TIIEF rate, distinguish themselves by adhering to Environmental, Social, and Governance (ESG) criteria and supporting the Sustainable Development Goals (SDGs). These bonds are expected to have longer maturities, extending up to 10 years, and aim to promote sustainable investment in Mexico. However, as of April 2024, the outstanding amount of Bondes F is over 28 times greater than that of BONDES G (Table 1). As shown in Figure 6, although the gap decreases from 28 times to 19 times by the fourth quarter of 2024, BONDES F remains significantly more liquid compared to its counterpart, BONDES G, both of which are referenced to the TIIEF.

BONDES F were designed to replace conventional bonds and encourage the adoption of TIIEF. However, this study focuses on BONDES G, as they integrate unique elements that promote the growth of the sustainable debt market while supporting the transition to new benchmarks. Key features include their issuance through syndicated auctions, which provide greater volume

[15] Retrieved from the technical description of Government securities, updated on May 3rd, 2024, by the MoF; https://www.finanzaspublicas.hacienda.gob.mx/work/models/Finanzas_Publicas/docs/ori/Espanol/guias/PPT_Government_Securities_May24.pdf.

Table 1: Main Characteristics of BONDES F, BONDES G, and Development Bank ESG Bonds

Characteristics	**BONDES F**	**BONDES G**	**Development Bank ESG Bonds**
Face Value	100 MXN	100 MXN	100 MXN
Term	1 to 5 years	1 to 6 years	3 to 4 years
Coupon Frequency	28 days	28 days	28 days
Interest Rate	Overnight Equilibrium Interbank Interest Rate (TIIE) collateralized	Overnight Equilibrium Interbank Interest Rate (TIIE) collateralized	Overnight Equilibrium Interbank Interest Rate (TIIE) collateralized + variable spread
First Issuance (Year)	2021	2022	2022
Outstanding Amount (MXN)	2,060 billion	73.4 billion	48.78 billion
Outstanding Amount (USD)	122.5 billion	4.4 billion	2.94 billion
Aligned with ESG criteria	No	Yes	Yes

Source: Ministry of Finance 2024

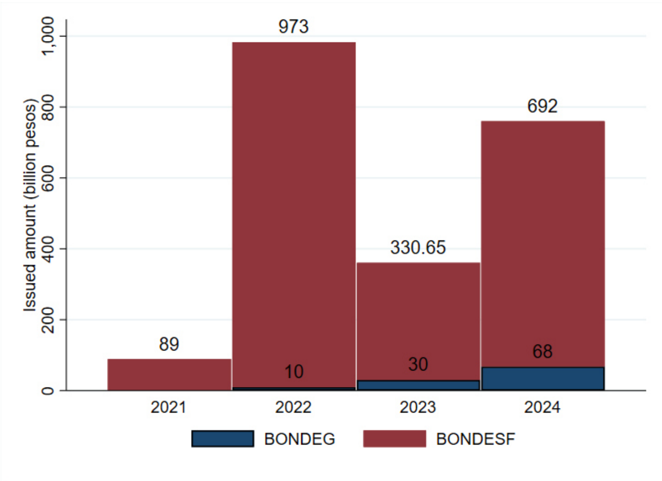

Figure 6: Issued Amount of BONDES over Time
Source: Own elaboration with data from PiP.

compared to primary auctions, their complementary role to the monetary regulation function of BONDES F, and their potential to attract a broader investor base by providing liquidity in the secondary market (Yorio et al., 2022).

This study emphasizes the pivotal role of BONDES G and Development Bank ESG bonds in advancing Mexico's sustainable debt market. BONDES G are specifically designed to align with ESG standards, while maintaining the key features of their conventional counterpart, BONDES F. Beyond these standard characteristics, BONDES G offer an added premium for issuers that adhere to sustainability criteria, focusing on sectors like health, education, economic growth, and industry. In contrast, ESG bonds issued by development banks are also referenced to the TIIEF rate, plus a spread, and are aligned with ESG principles. However, the issuance volume of these bonds remains relatively small compared to that of BONDES G.

This study aligns with the MoF's strategy to adopt risk-free rates and promote the development of a sustainable debt market. The sample includes sovereign sustainable bonds (BONDES G) and sustainable bonds issued by development and private banks. All bonds in the sample are floating-rate instruments tied to the TIIEF and issued in Mexican pesos. The data is retrieved from *Proveedor Integral de Precios* (PiP)[16] and consists of daily pricing for these financial instruments.

The data on all ESG bonds is collected from March to October 2024 and includes daily dirty price, clean price, accrued interest, nominal price, yield, and spread for 22 bonds issued at TIIEF in Mexican pesos, among which 8 are issued by sovereign entities, 11 by Development Banks, and 3 by private banks. Additionally, issuance data, such as issuance and maturity dates and issued amounts, retrieved from the placement notices, are included to examine issuance patterns and maturity timelines (Table 2).

Table 2: Descriptive Statistics

Issuer	**Issued amount in billion pesos**	**Yield**				
	Total	Median	Mean	Minimum	Maximum	Standard Deviation
Development Banks	48.78	11.25	11.17	7.738	11.57	0.33
Government	143	11.14	11.09	10.57	11.48	0.19
Private banks	22.86	11.26	11.14	10.20	11.67	0.25
Total	214.64	11.22	11.14	7.74	11.67	0.29

Note: Maturity is expressed in years, and Yield is expressed as a percentage.

The Mexican government's commitment to achieving the Sustainable Development Goals (SDGs) and promoting sustainable investment began in 2020 by issuing its first sovereign ESG bond for EUR 750 million (SHCP, 2021a). Although this bond aimed to support the SDGs, it was not yet aligned with the new benchmark rates until the issuance of BONDES G. Mexico's ongoing commitment to expanding ESG bond issuance by the government is reinforced by a robust

[16]Proveedor Integral de Precios (PiP) is a multinational corporation in official and independent assessments of financial assets in Latin America. Its products include closing price valuations, curves, databases, options tools, and customized products, including the valuation of derivative instruments and structured notes.

process for selecting eligible expenditures [17].

The MoF's strategy of issuing BONDES G proved effective in 2022, positioning floating bonds; BONDES G as the leading instrument among ESG bond issuances, with the highest share by amount (USD 2,242 million) and allocation (44.7%). The key projects supported by these issuances target SDGs related to Zero Hunger, Health & Well-Being, Quality Education, Decent Work, Economic Growth, Industry, Innovation, and Infrastructure (SDGs 2, 3, 4, 8, and 9, respectively) (SHCP, 2023e).

Since 2022, the sustainable debt market has grown by 52.54%, rising from 59 billion pesos to 90 billion pesos by Q3 2024 (Figure 7). This growth is also evident in the number of bond issuances, which increased from 9 in 2022 to 16 in 2023, with 14 already issued by 2024. A key driver of this expansion was the government's issuance of new BONDES G in 2022, which stimulated higher issuance levels from Development Banks and the private sector. Development Bank issuers, who issued only one bond in 2022, significantly increased their issuances in 2023. Although the government's issuance decreased in 2023 due to a shift toward prioritizing the fixed-rate BONO S with ESG criteria, the number of bonds issued remained consistent with 2022 levels (6 bonds). Notably, the fourth and fifth issuance of BONDES G in 2023, totaling 30 million pesos, attracted a demand of 60,535 million pesos (SHCP, 2023c).

Development Banks have become the second dominant issuers of ESG bonds, with a total issuance of 48.78 billion pesos, representing nearly 22.7% of all issues (Figure 8). This trend indicates that the strategy implemented by the MoF is delivering positive results, as initially, sovereign debt placement tied to the TIIEF was intended to promote Development Banks as issuers, given their preference for sustainable and floating-rate bonds (Yorio et al., 2022).

These ESG sovereign bonds, known as BONDES G, were issued with maturities ranging from 1 to 10 years. However, given that the sustainable market is still in its early stages, the most

[17] The process of choosing sustainable expenditures involves six filters: (i) a list of budgetary programs is compiled, (ii) programs that include productive activity are identified, (iii) those with at least one contribution to the SDGs are selected, (iv) programs with operating rules or guidelines are prioritized, and (v) ineligible assets are eliminated, followed by (vi) the exclusion of assets representing uncertain budget conditions, leading to the final selection of SDG expenditures. This process, along with a transparent methodology aligned with the development of sustainable taxonomies, has effectively encouraged non-sovereign issuers to issue ESG debt instruments (SHCP, 2022a).

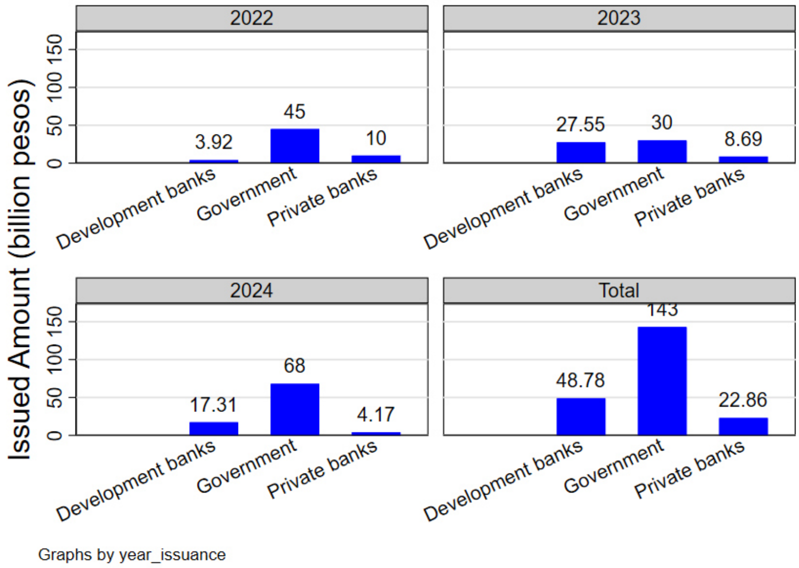

Figure 7: Issued Amount by Issuer over Time
Source: Own elaboration with data from PiP.

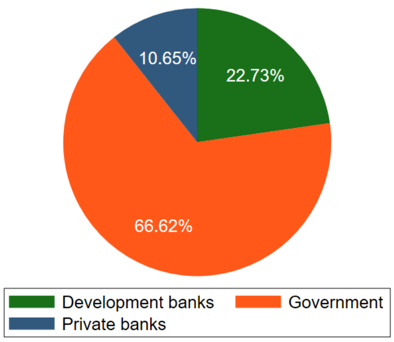

Figure 8: Distribution of Issued amount of ESG Bonds by issuer
Source: Own elaboration with data from PiP

extended maturity in the sample is 6 years, with BONDES G predominantly having a tenor of 4 years. This suggests that the current trend in sustainable bond maturities could serve as a reference curve, potentially encouraging Mexican Development Banks to issue longer durations of bonds. While local currency ESG bonds tied to the TIIEF have primarily been issued by Development Banks, their maturities are mostly limited to 2.7 years (Figure 9).

Furthermore, the yields on the ESG bonds in the analyzed sample exceed 11%. BONDES G have the lowest yields, averaging 11.09%, while Development Bank-issued bonds offer the highest yields at 11.17%. This indicates that ESG sovereign bonds may serve as a market benchmark or a minimum yield for non-sovereign securities, as sovereign issuances reflect country-specific risks. In contrast, non-sovereign instruments carry additional risks, such as company-specific factors (Figure 10).

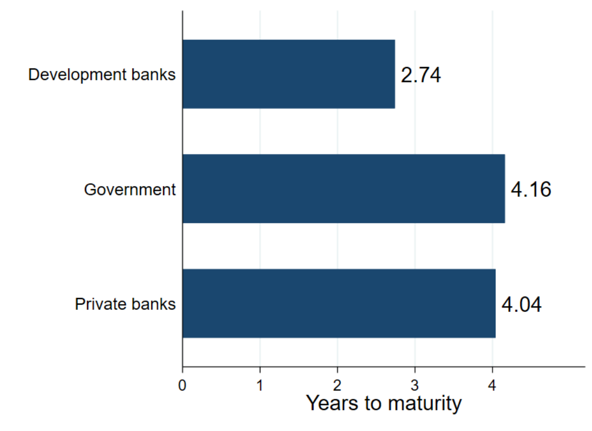

Figure 9: Average tenor by issuer
Source: Own elaboration with data from PiP.

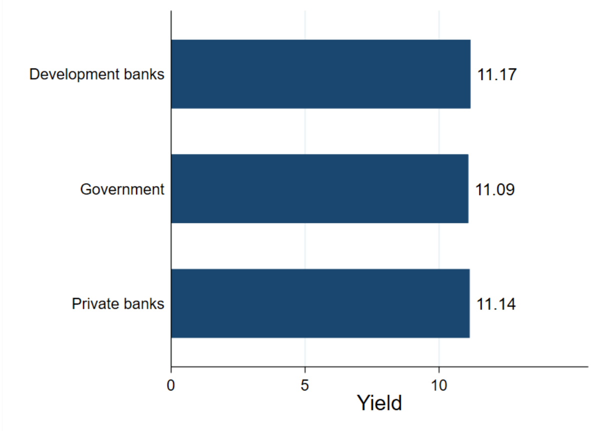

Figure 10: Average yield by issuer
Source: Own elaboration with data from PiP.

5.1 Yield Curve Dynamics

Before estimating the yield curve for ESG bonds, it is crucial to examine the yield behavior of the sample of ESG bonds during the sample period (from March 1st to October 18th, 2024). Inflation remains persistently above the Central Bank's targets, contributing to volatility in international financial markets, further exacerbated by heightened risk aversion due to escalating geopolitical tensions in the Middle East. As a result, monetary conditions are expected to remain more restrictive for a more extended period than previously anticipated, with downward pressures on economic activity and increased market volatility. In particular, the heightened perception of risk in the market is expected to lead to higher risk premiums, meaning that the yields on longer-dated bonds are likely to exceed those of shorter-term bonds due to more significant uncertainty (Ernest et al., 2024).

The first analysis focuses on the yield trend of ESG bonds issued by the government (BONDES G). Figure 11 illustrates the weighted average yield of BONDES G over the study period. For this graph, the BONDES G bonds are classified based on their maturity dates, resulting in five maturity groups: (i) bonds with maturities of 1 year to $<$ 2 years, (ii) 3 years to $<$ 4 years, (iii) 4 years to $<$ 5 years, (iv) 5 years to $<$ 6 years, and (v) 6 years or more. No bonds were issued with maturities between 2 and 3 years. The average yield for each maturity group is calculated and weighted by the number of bonds within the group. Additionally, the TIIEF (the reference rate for these bonds) and the Central Bank's target rate are shown on the same graph for comparison.

As mentioned earlier, since the rate cut is expected to last longer than initially forecast, it is essential to analyze the yield trends before and after the changes in monetary policy. These changes are indicated by the red vertical lines on the graph, which mark the dates when the Mexican Central Bank implemented rate cuts: March 22nd, August 9th, and September 27th, 2024 [18].

As shown in Figure 11, the yield of BONDES G exhibits a consistent downward trend, primarily driven by changes in monetary policy, particularly the reductions in the target rate. The reference interest rate, the Interbank Interest Rate (TIIEF), was cut three times by the Central Bank: by 25 basis points to 11% on March 22 (Banco de México, 2024a), by 25 basis points to 10.75% on August 9th (Banco de México, 2024c), and again by 25 basis points to 10.5% on September 27th (Banco de México, 2024b) in the sample. As a result, the target rate, which started at 11.25% at the beginning of the sample period, decreased to 10.5% by the end, as shown by the line for the target rate in the graph. This decline in the reference rate also influenced the TIIEF, which is subject to volatility due to its calculation based on actual overnight market transactions.

Figure 12 shows the yield spread between the bond with the more extended maturity and the bond with the shortest maturity. For BONDES G, a clear maturity premium is observed: bonds with a 6-year maturity offer a higher yield to compensate for the longer holding period than bonds maturing in one year. However, the figure also shows a discontinuity, as no BONDES G with a 1-year maturity were available for data collection between late March and early September.

Non-sovereign ESG bonds issued by Development Banks exhibit similar yield dynamics to government-issued ESG bonds (BONDES G). As shown in Figure 13, the yields on ESG bonds from Development Banks have declined over time, following the reduction in the reference rate

[18] Note that the red line marking September 2nd, 2024, does not indicate a change in monetary policy. Rather, it reflects volatility that impacted the calculation of the TIIEF1 for that day, which, in turn, affected the yields of all bonds on that date.

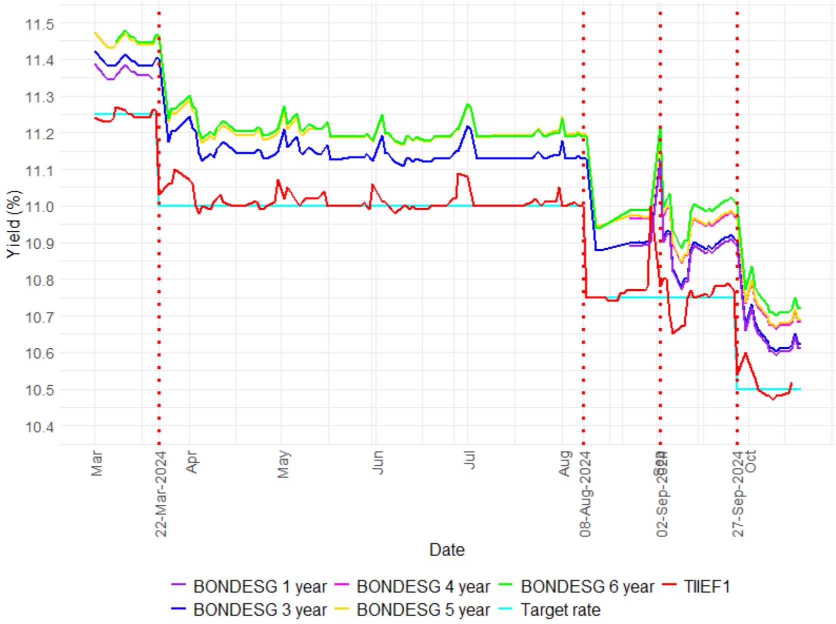

Figure 11: Yield of BONDES G

Source:Author's construction based on PIP data

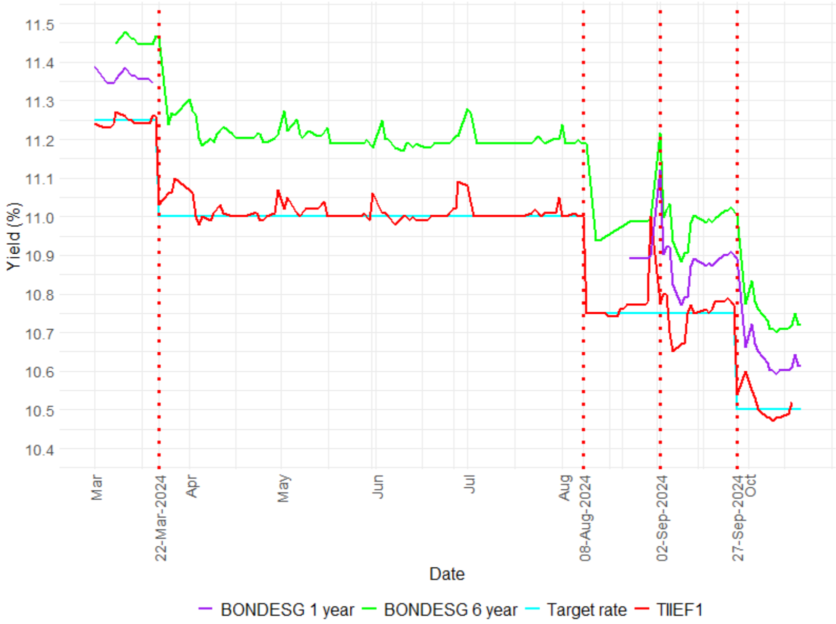

Figure 12: Yield of BONDES G (1 and 6 year maturity)

Source:Author's construction based on PIP data

(TIIEF) since the monetary policy changes in March. Although Development Banks issue ESG bonds with shorter maturities than BONDES G, their yields are, on average, higher, as seen in the descriptive statistics section; this can be attributed to the Mexican government's low fiscal deficit, which has helped maintain manageable government debt levels and preserved budgetary space to support short- and medium-term sustainability, even during the pandemic

(BANCOMEXT, 2021).

Another critical observation is that, while BONDES G exhibit a positive yield premium for longer maturities (6 years) compared to shorter ones (1 year) (Figure 11), Development Banks' ESG bonds with shorter maturities offer higher yields than their longer-maturity ESG bonds (Figure 14). This anomaly can be attributed to prevailing uncertainty in the international economic outlook. Factors such as potential shifts in monetary policy, political changes, election cycles, geopolitical tensions, and persistent inflationary pressures all influence Mexico's financial system, contributing to increased risk aversion, driven by idiosyncratic elements (Consejo de Estabilidad del Sistema Financiero, 2024), which may explain why shorter-term bonds issued by Development Banks carry higher yields than longer-term ones. This contradicts the typical upward-sloping yield curve, where longer-term bonds usually offer higher returns to compensate for the increased holding period risk.

As proxies for the slope of the yield curve, Ang and Piazzesi (2003), Fernando, Manuel, and Alberto (2008), and Diebold and Li (2006) used the difference between the yields on the longest and shortest maturity bonds in the sample. This is because short-term bonds respond quickly to immediate changes in economic conditions or monetary policy, while long-term bonds reflect expectations about the future (Sundberg, 2019). The three main factors of the yield curve—level, slope, and curvature—are widely studied as they help interpret the effects on the yield curve, even without identifying the exact economic causes behind these movements (Ang and Piazzesi, 2003).

As shown in Figure 15, the slope proxy for BONDES G reflects an increasing yield curve slope over time. The difference between the yields of the 6-year and 1-year BONDES G bonds remains positive throughout the available study period, despite some discontinuity due to previously mentioned data gaps. This indicates that for sovereign ESG bonds (BONDES G), the yield on the 6-year bond consistently exceeds that of the 1-year bond, reflecting a higher premium for longer-term holdings and resulting in a conventional yield curve shape, with greater compensation for extended maturities.

In contrast, for Development Bank ESG bonds, the difference between the yields of the 4-year

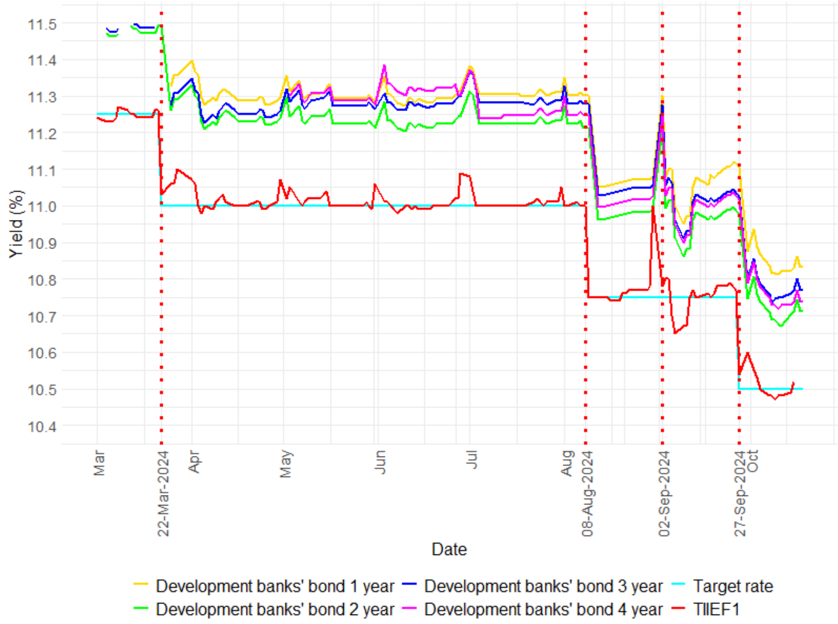

Figure 13: Yield of Development Bank ESG bonds

Source: Author's construction based on PIP data

Figure 14: Yield of Development Bank ESG bonds (1 and 4 year maturity)

Source: Author's construction based on PIP data

and 1-year bonds decreases over time and eventually turns negative, as shown in Figure 16. This suggests that, during the sample period, the yield on shorter-term Development Bank bonds (1-year) surpasses that of longer-term bonds (4-year). This trend is likely driven by a higher compensation for short-term uncertainty and high volatility, mainly due to political instability.

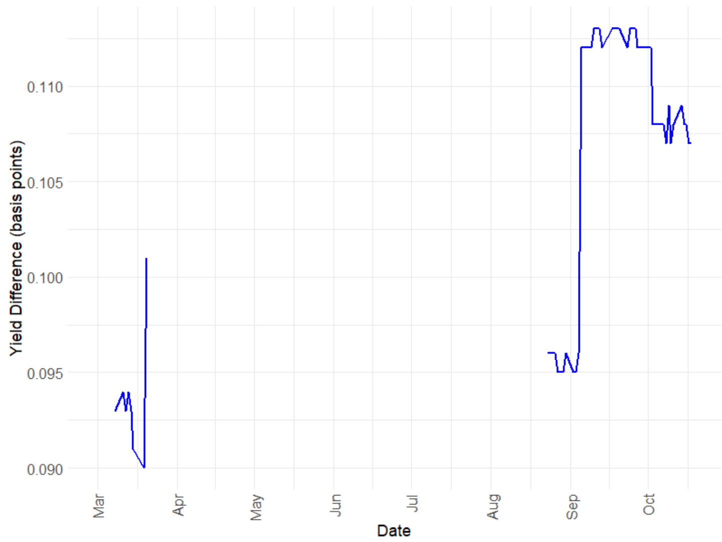

Figure 15: Difference in yield of BONDESG (1 and 6 year maturity)

Source:Author's construction based on PIP data.

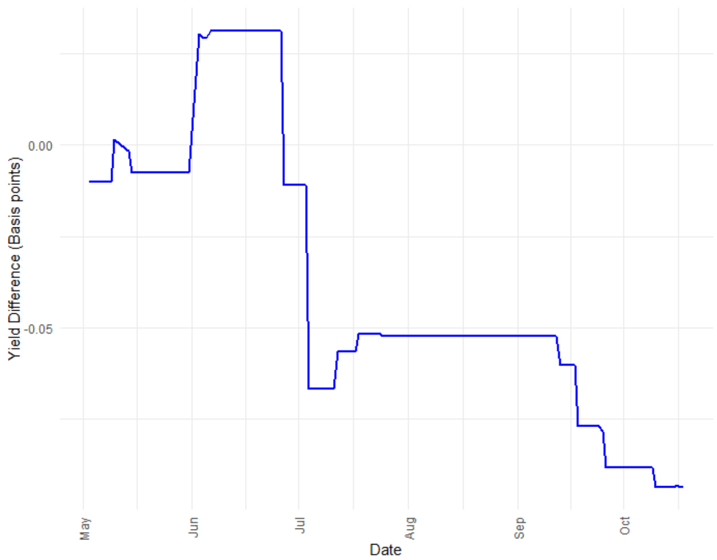

Figure 16: Difference in yield of Development Bank bonds (1 and 4 year maturity)

Source:Author's construction based on PIP data.

6 Yield Curve Estimation Methods

As previously explained, the yield curve represents bond yields across different maturities evaluated at the same credit quality. However, yield data could be only available for specific maturities, known as benchmark maturities, making it necessary to fit a smooth curve to the discrete data (Vasicek et al., 2021).

Two main approaches widely used for estimating yield curves are parametric and non-parametric. On the one hand, parametric models assume a functional form defined over the entire maturity range and estimate their parameters by minimizing the squared deviations between theoretical and observed prices or yields. The most common methods employed by central banks, such as the Bank of Chile (Alfaro, 2009), France, Belgium, and Italy (Bank for International Settlements, 2005) include those developed by Nelson and Siegel (1987) and its variant (Svensson, 1994), allow for the estimation of coefficients that contribute to the behavior of forward rates in the short, medium, and long-term, resulting in a parsimonious and flexible framework to estimate typical forms for the yield curve[19] (Camilo, 2008).

The parametric expression introduced by Nelson and Siegel (1987) is grounded in the expectations theory of the term structure of interest rates. The model is defined as follows:

$$r(m) = \beta_0 + \beta_1 \cdot \frac{1 - e^{-m/\tau_1}}{m/\tau_1} + \beta_2 \cdot \left(\frac{1 - e^{-m/\tau_1}}{m/\tau_1} - e^{-m/\tau_1} \right) \tag{1}$$

Where: *r(m)* is the yield for an instrument with maturity m, and β_0, β_1, β_2, and τ_1 are the parameters to be estimated, that correspond to the level, slope, and curvature for the yield curve, representing the long-term, short-term, and medium-term factors, respectively. The parameter β_0 represents the asymptote of the yield curve function. As the remaining maturity approaches infinity, β_0 can be interpreted as the long-term interest rate. The sum $\beta_0 + \beta_1$ represents the initial value of the curve, i.e., $f(0) = \beta_0 + \beta_1$, which is interpreted as the instantaneous interest rate. Therefore, $\beta_0 + \beta_1 > 0$ is required.

The parameter τ_1, known as the decay factor or the shape factor, controls two key aspects of the yield curve. First, it determines the steepness of the slope factor β_1 and how quickly the yield curve slope flattens as the time to maturity increases. Second, it controls the position of the hump on the yield curve. This is reflected in the exponential function e which plays a central role, as Nelson and Siegel (1987) used the Laguerre function, which is the product of an exponential decay term with a first-degree polynomial (Xe^{-x}), and generates the hump if

[19] Monotonic, humped, and S-shaped curves.

$\beta_2 > 0$ or a trough if $\beta_2 < 0$ (Annaert et al., 2012).

As mentioned above, the proxy for the slope of the yield curve is taken from the Nelson and Siegel (1987) model (1), where the loading of the curvature coefficient β_2 depends on the maturity of the instrument. As maturity (m) approaches infinity, the loading of β_2 approaches zero. Thus, β_2 is referred to as the short-term factor, and changes in β_2 correspond to changes in the yield curve's slope. This yield difference is considered a proxy for the slope, as noted in Sundberg (2019).

Although Nelson's model proposes the estimation of four parameters, one of its significant limitations is that it does not approximate all types of yield curves due to its constrained flexibility (Moorad, 2019). In contrast, the Svensson (1994) model extends the functional form of the Nelson-Siegel model, allowing for greater flexibility in fitting the curves by introducing a second "hump". This model adds two additional parameters to capture an extra effect, the second hump, thus the equation to estimate the yield is as follows:

$$r(m) = \beta_0 + \beta_1 \cdot \frac{1-e^{-m/\tau_1}}{m/\tau_1} + \beta_2 \cdot \left(\frac{1-e^{-m/\tau_1}}{m/\tau_1} - e^{-m/\tau_1} \right) + \beta_3 \cdot \left(\frac{1-e^{-m/\tau_2}}{m/\tau_2} - e^{-m/\tau_2} \right) \quad (2)$$

where β_3 is analogous to β_2 for the Nelson and Siegel (1987) model, and the additional parameters can be interpreted as determining the magnitude and direction of the second hump, while τ_2 specifies the position of the second hump or U-shaped.

Svensson (1994) suggests estimating the parameters of the zero-coupon (spot curve) by minimizing a fitting measure, such as the sum of squared errors over the spot prices. Therefore, the parameters are determined by minimizing the sum of squared differences between the observed yields and those estimated by the curve. The estimation can be conducted using maximum likelihood, non-linear least squares, or generalized method of moments. Svensson (1994) notes that while the Nelson-Siegel model often provides satisfactory fits, in cases where the interest rate structure is more complex, the Nelson-Siegel model may yield unsatisfactory adjustments, and the Svensson model tends to perform better.

On the other hand, nonparametric models for fitting the yield curve have recently gained widespread use (Camilo, 2008) because, compared to parametric functional forms, they offer more flexibility, with the curve fitting entirely dependent on the data, allowing the data to determine an appropriate function. In particular, the spline methods, which offer a polynomial interpolation method, enable the estimation of polynomial functions that ensure derivatives exist at all points (known as *knots*). For instance, cubic splines allow cubic functions to be fitted continuously and differentiable at each knot (Camilo, 2008).

A cubic spline is a function g defined on an interval $[t_1, t_k]$ with node points $t_1 < t_2 < \ldots < t_k$, if i) g is a cubic polynomial on each of the subintervals $[t_{j-1}, t_j]$ for $1 < j \leq k$, and ii) g is twice continuously differentiable over the entire interval $[t_1, t_k]$.

However, this method can present oscillations, particularly at most extended maturities that are not well explained, and for estimating forward rates, the model may become unstable, especially at the longest maturities (Waggoner, 1997). Thus, to achieve a better fit for the yield curve, rather than specifying a single function and its parameters in advance, the segments are joined smoothly at the knots (Bank for International Settlements, 2005). Thus, the flexibility of the smoothed spline depends on the number of node points.

6.1 Model Selection

In this case, the yield curve will be estimated using the yields of BONDES G and Development Bank ESG bonds, which integrate ESG criteria and TIIEF rates. Among the models discussed earlier, the best goodness-of-fit will be selected. Corporate bonds with similar characteristics are excluded from this analysis due to their relative complexity and the limited number of available observations.

The decision to focus on yields rather than prices stems from the fact that minimizing pricing errors can often lead to significant yield errors for bonds with short maturities, as prices are relatively insensitive to yield changes within this range. Therefore, the models will be estimated by minimizing yield errors (Svensson, 1994).

Since these bonds are referenced to the TIIEF, specific initial conditions—such as incorporating

TIIEF rates for maturities from 1 day to 128 days—were included to enable a complete yield curve estimation. For maturities below 1 year, money market rates (covering overnight to 128-day maturities) can be considered, with adjustments made for liquidity considerations. In this context, the TIIEF rates (the overnight reference rate). This distinction is based on the difference between the TIIEF with the longest tenor (128 days) and bonds with a 1-year tenor. Bonds exhibiting higher volatility, such as the FEFA 22S bond, should be excluded from the sample population.

The estimation process will begin with the yield curves of BONDES G and Development Bank's ESG bonds, employing the smooth spline, Nelson-Siegel, and Svensson methods for periods both before and after the monetary policy rate cut, as specified by the dates provided. Outliers, such as the previously mentioned bond, will be excluded to minimize noise and ensure accurate yield curve estimation.

To estimate the yield curve, TIIEF rates for maturities ranging from 1 to 182 days were used as initial conditions to define the curve's starting point. These rates, serving as benchmarks for bond issuances, play a critical role in market consolidation by providing a reliable reference for bond settlements. All bonds in the sample are tied to the TIIEF rate, with an additional spread applied.

In alignment with efforts to promote a robust financial system and adhere to international standards recommended by the Financial Stability Board (FSB) and the International Organization of Securities Commissions (IOSCO), the Bank of Mexico introduced the one-day Equilibrium Interbank Interest Rate (TIIE de Fondeo) in January 2020 as an internationally consistent reference rate. As a result, the Central Bank mandated the discontinuation of longer-term TIIE rates as references for new contracts starting in 2024 and short-term TIIE rates beginning in 2025 (Banco de México, 2023b).

Market conditions and expectations serve as a test for the performance of various models, particularly during periods when market participants anticipate interest rate hikes or cuts. In this context, three specific periods were chosen for analysis.

- March 19: Days before the monetary policy rate cut on March 22.
- March 27: Days after the monetary policy rate change.
- August 7: Days before the monetary policy rate cut on August 9.
- August 23: Days after the monetary policy rate change.
- September 25: Days after the monetary policy rate change on September 27.
- October 8: Days after the monetary policy rate change.

During this period, there were expectations of interest rate cuts. It encompasses the days leading up to the governing council's meeting and the days following their decision. This timeframe provides an opportunity to analyze short-term interest rate expectations and monetary policy outlooks. Additionally, the yield curve exhibits a gradual adjustment during this period.

Although the yield curve can be constructed daily, the yield values are fitted using the models proposed by Nelson and Siegel (1987), its extended version by Svensson (1994), and the widely adopted cubic splines approach. As shown in the appendices, the yield curve estimates for BONDES G and Development Bank ESG bonds were generated using the Nelson-Siegel and Svensson models, before and after the policy change. Figures 23 through 32 demonstrate that the Svensson model provides a better fit compared to the Nelson-Siegel model, which is attributed to the Svensson model's ability to capture the double-humped shape of the yield curve.

By comparing the coefficients estimated for each model (Table 9), for BONDES G, the Nelson-Siegel model produces slightly similar values for the first parameter, β_1. However, for the remaining parameters, the Svensson model more effectively accounts for the yield curve's humped structure. In contrast, spline models have more parameters, which, in theory, allow for a better fit and increased curve flexibility. This flexibility is influenced by the number and placement of the knot points (which, in this case, correspond to each bond, given the limited sample size) and the settings of the roughness penalty function. However, the relatively large number of parameters can make it challenging to demonstrate, compare, and interpret the parameter values in an economic context or with other estimation models.

An in-sample analysis was conducted to select the model. Following the methodologies of Nymand-Andersen (2018) and Waggoner (1997), this analysis calculated each model's weighted mean absolute errors (WMAE) [20], hit rates [21], and mean squared errors (MSE) based on bond maturity. Table 3 (in the appendices) shows that all models achieve a strong in-sample fit, with notably low weighted mean absolute errors. However, the model proposed by Nelson and Siegel (1987) exhibits higher WMAE values than the others. Meanwhile, the difference in WMAE values between the smooth cubic splines and the Svensson (1994) model is minimal while estimating the BONDES G yield curve and the Development Bank ESG bonds yield curve.

7 Results

When evaluating the models across different maturity segments—short, medium, and long-term rates—the statistical results indicate that both the Svensson model and smooth cubic splines perform well across all maturities. However, smooth splines demonstrate a superior fit for medium- and long-term maturities, as reflected in their lower error rates. Overall, the models exhibit strong goodness of fit, with low error values and high hit rates for maturities up to six years. Therefore, the yield curve analysis will be based on smooth spline estimations[22].

An analysis of the yield curve for BONDES G (Figures 17 and 18) reveals that the curve initially appears inverted, with short-term yields exceeding long-term yields. However, the slope is positive, as indicated by the estimated proxy. Over time, yields for longer-maturity instruments surpass those for short-term instruments, gradually transforming the curve into a more conventional upward slope. This shift aligns with the expectations theory, reflecting anticipated economic growth and rising inflation.

[20] This is a measure of the average distance between the actual yield and the estimated curve, using the inverse of the square root of duration as the weighting factor (Nymand-Andersen, 2018).

[21] The hit rate represents the percentage of observed yields that lie within a predefined spread from the curve, thus indicating that models with a higher percentage level of hit rates fit the dataset better than models with a relatively lower percentage level (Nymand-Andersen, 2018).

[22] The yield curve was estimated using all three methods; however, results for the Nelson-Siegel and Svensson models, along with the corresponding error statistics, are presented in the appendices.

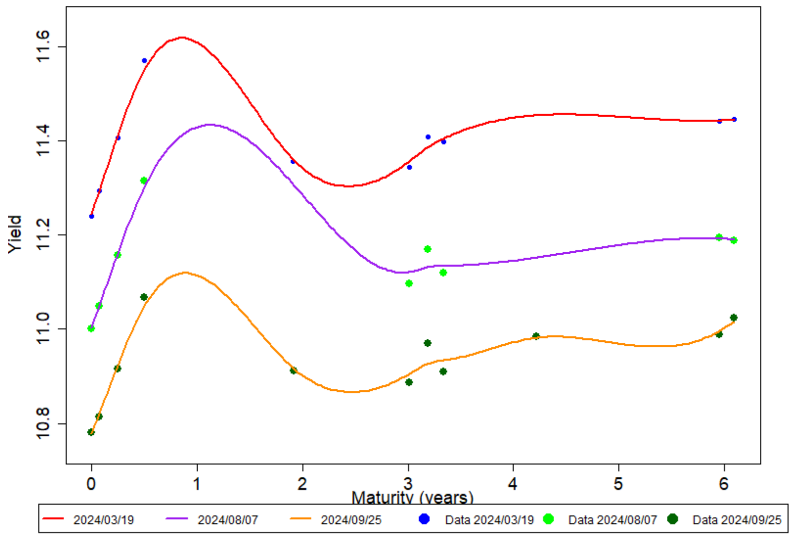

Figure 17: BONDES G Yield Curve Before Monetary Policy Adjustments

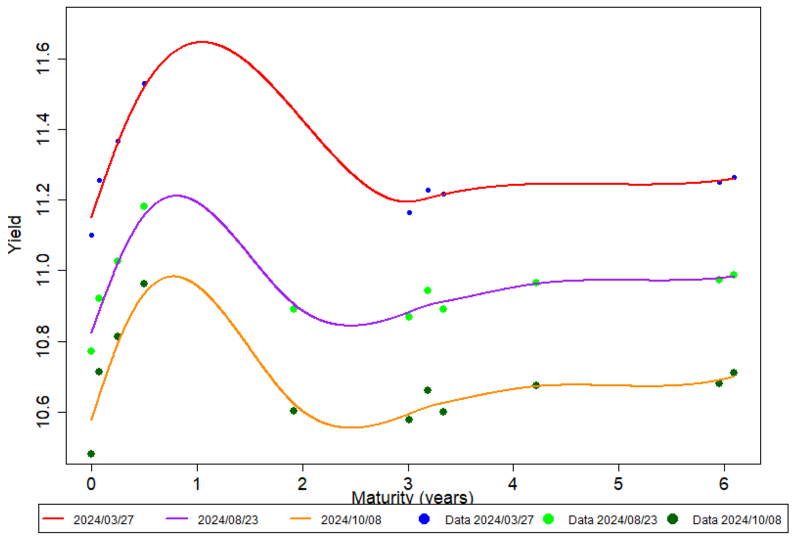

Figure 18: BONDES G Yield Curve After Monetary Policy Adjustments

Source: Author's construction based on PIP data

The inverted shape of the yield curve (with higher yields in the short-term and lower yields in the medium- and long-term) can be attributed to the current high monetary policy rates, which the central bank is gradually reducing. As a result, yields on medium-term instruments decrease, but longer-term instruments still show a positive slope due to persistent inflationary risks. Bondholders demand compensation for additional risks, such as political, environmental, and inflationary factors, in the form of a higher premium. Consequently, bonds with longer maturities offer higher yields than those with medium-term maturities, this estimation is supported by the previously discussed proxy for the yield curve's slope, which indicates a positive difference, consistent with a positive slope.

Examining the yield curves at various points before the monetary policy rate cuts (Figure 17) shows that the curves for March (2024-03-19), August (2024-08-07), and September (2024-09-25) exhibit a gradual inversion for maturities between 1 and 3 years, before the policy changes. This inversion indicates that short-term interest rates exceed long-term yields, deviating from the typical upward slope of a standard yield curve. In this case, short-term rates are expected to rise before decreasing over a 2- to 3-year horizon, reflecting growing concerns about a potential recession or default (Sally et al., 2019). As the curve adopts a more typical shape, yields for maturities beyond three years increase, indicating that longer-term bonds offer greater compensation for the additional risks associated with extended maturities.

Additionally, the overall level of the yield curve declined over time following the reference rate cuts. The estimated curve for March 19th nearly intersects with the curve for August 7th, as a BONDES G bond with a maturity of nearly 2 years matured in late March. Since the spline interpolation lacks a reference node for a 2-year maturity, the yield curves for March and August before the rate cuts are quite similar. The yield curve for BONDES G mainly serves as a reference for bonds with maturities of around two years in March and late August, when these bonds were actively traded. Outside these periods, the market lacked benchmarks and the liquidity to price instruments with maturities under two years. This proximity between the curves persisted until the new issuance of BONDES G in late August, which was incorporated into the estimation for October 8th. As a result, the similarity between the curves disappeared after the policy changes, following the government's issuance of BONDES G on August 22nd.

Following the rate cuts, the yield curve for BONDES G on the specified dates after the monetary policy adjustments is estimated (Figure 18). The yield curve remained inverted for March (2024-03-27), August (2024-08-23), and October (2024-10-08), with high short-term rates. As maturities increase, yields rise to compensate for additional risks. Furthermore, the yield curve for BONDES G shifted downward in March, August, and October after the monetary policy decisions on March 22nd, August 9th, and September 27th. This downward shift was most noticeable for short- and medium-term maturities, aligning with the Central Bank's Monetary Policy Reports (Banco de México, 2024c) and (Banco de México, 2024b), which indicated declines in the yield curve for government securities, especially in short- and medium-term maturities. This trend shows that the BONDES G yield curve, as a sovereign yield curve, serves as a tool for transmitting monetary policy information, reflecting interest rate changes that directly affect bond yields.

However, the effectiveness of a government yield curve is determined by how quickly bond prices respond to new information (Sally et al., 2019). During the sample period, especially from August 30 to September 9, the Mexican markets experienced heightened uncertainty and volatility, primarily due to political factors related to judicial reforms. During this time, the Mexican peso depreciated, and the stock market stagnated, even though economic indicators remained stable (Cristiani and Cuevas, 2024). A significant date within this period is September 2, as both BONDES G and Development Bank bonds showed higher yields across all maturities, driven by expectations of future economic conditions.

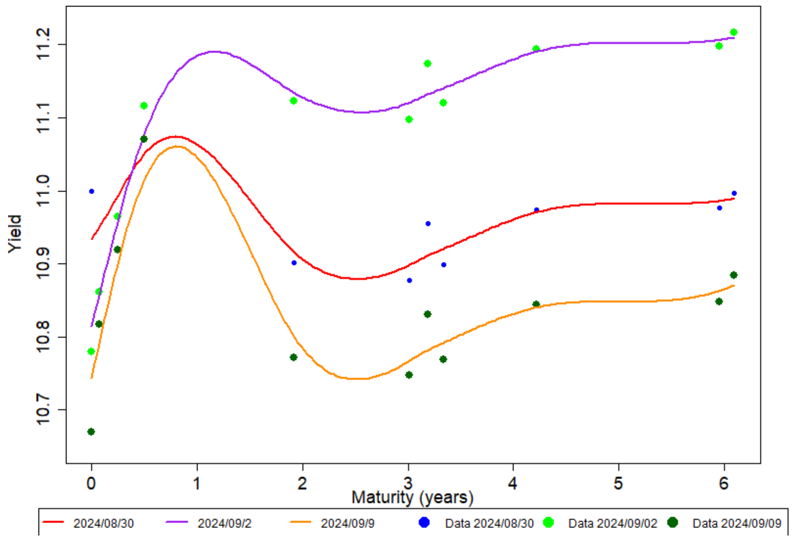

Figure 19: Yield Curve of BONDES G on September 2nd
Source: Own elaboration with data from PiP

Figure 19 shows the BONDES G yield curve before and after the yield spike on September 2nd. On August 30th, the 1-day TIIEF rose due to revised, lower economic growth projections for 2024, rather than changes in monetary policy. Since the TIIEF serves as the reference rate for the analyzed ESG bonds, these changes were expected to impact their yields, triggering a market response.

On August 30th, the 1-day TIIEF surged in response to the updated economic growth outlook, as outlined in the Central Bank's April-June quarterly report (México, 2024b). Despite this spike, market yields did not react immediately. Instead, they adjusted on the following business day: September 2nd, when yields across all maturities rose, even though the TIIEF had already stabilized near its target rate. As a result, the yield curve for August 30th shows a higher yield only for the 1-day maturity, which reflects the TIIEF spike and places it above the September 2nd curve for that maturity.

September 2 marked the peak of bond yields, as the yield curve rose for maturities beyond 1 day compared to August 30th. On this day, the Central Bank released its Survey on the Expectations of Private Sector Economic Specialists, which presented a pessimistic economic outlook for the remainder of the year. The forecast for real GDP growth was revised downward from 1.8% to 1.5% for 2024, and from 1.8% to 1.6% for 2025 (México, 2024a). While inflation expectations marginally decreased compared to the second-quarter report, markets demanded higher compensation for inflation risks. As a result, the inflation risk premium increased, driving yields higher across all maturities. Additionally, uncertainty over public policies and potential reforms led to reduced investor interest in Mexican assets, which, combined with the heightened volatility in domestic financial markets, further worsened operating conditions (México, 2024b).

By September 9th, the yield curve had fallen below both the September 2nd and August 30th curves, reflecting a decline in inflationary pressures. Inflation reached 4.99%, the lowest level in five months, according to the National Institute of Statistics and Geography (INEGI) report (INEGI, 2024), signaling a return to more stable conditions. This sequence illustrates how the BONDES G yield curve adjusts to new information. It also underscores the liquidity of ESG bonds, as their yields, while responding to changes in monetary policy, also capture broader market dynamics.

The ESG bonds issued by Development Banks display dynamics similar to those of ESG

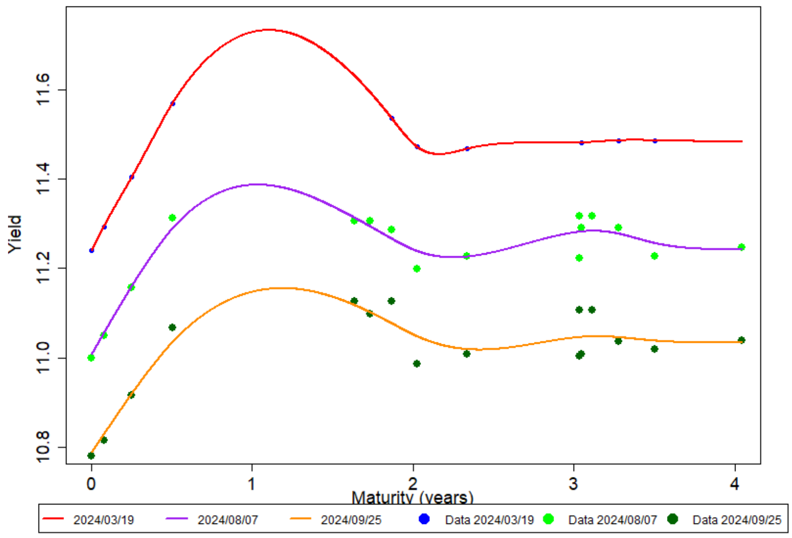

Figure 20: Yield Curve of Development Bank ESG Bonds Before Monetary Policy Adjustments
Source: Author's construction based on PIP data.

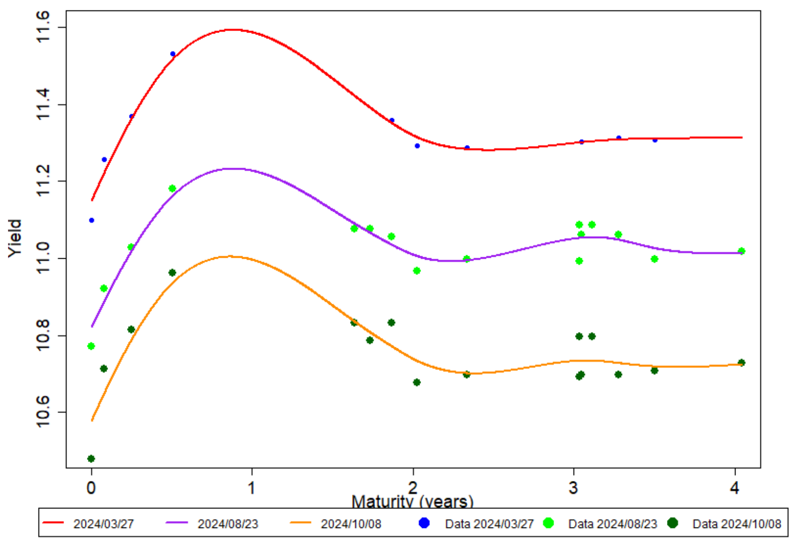

Figure 21: Yield Curve of Development Bank ESG Bonds After Monetary Policy Adjustments policy
Source: Author's construction based on PIP data.

sovereign bonds, such as BONDES G. As shown in Figure 20, the yield curve is inverted, with higher yields concentrated in the short term. Following the monetary policy changes on August 9th and September 27th, the yield curves for August 23rd and October 8th decreased compared to the March 25th levels, as shown in Figure 21. These curves all reflect a reduction in yield levels following the policy changes that began in March. Notably, yields on these bonds show a downward trend, particularly for medium-term maturities, a trend that became more pronounced after the first rate cut in March.

The yield curve for Development Bank bonds exhibits a negative slope, indicating a decrease in yield over time. This typically suggests expectations of a recession or heightened default risk. As seen in Figures 20 and 21, the yield curves for Development Bank bonds are flatter than those for sovereign bonds beyond the two-year mark. This flattening is partly driven by the negative slope indicated by the proxy, as well as the relative immaturity of the ESG Development Bank bond market compared to the more established sovereign ESG bond market, which acts as a benchmark for the former.

Notably, Development Bank ESG bonds are primarily issued with maturities exceeding three years. This trend may be influenced by the sovereign bond market, where a significant portion of bonds also share similar maturities. This alignment helps ensure sufficient liquidity for new issuances and facilitates effective pricing. Development Banks typically finance projects focused on improving efficiency and contributing to sustainable development goals (SDGs). The funds raised through these bonds are used to finance or refinance projects for no more than three fiscal years (Botton et al., 2021).

Although Development Bank bonds typically have shorter maturities than sovereign bonds, the inverted yield curve and the larger number of available data points suggest that the BONDES G yield curve can serve as a reliable benchmark for this market. Once the BONDES G curve was established, it became a reference for Development Banks as they began issuing bonds and forming their yield curves. This is evident in the fact that Development Banks have issued a larger volume of ESG bonds referenced to the TIIEF since 2022, with their yield curves showing minimal distortions and their increased number of data points enhancing liquidity, helping to create a smoother yield curve.

As previously mentioned, the efficiency of a government yield curve is measured by its ability to respond to new market information, particularly through adjustments in bond prices, which are subsequently reflected in the yields of other institutions or corporations, adjusted for their specific credit risk spreads. Market participants often use government securities as reference rates due to their hedging properties (Sally et al., 2019). In this context, estimating the yield curve for Development Bank ESG bonds as of September 2 is valuable, especially given the unusual trends observed in the TIIEF. This will help assess the extent to which the BONDES G yield curve is a benchmark for the yield on Development Bank bonds.

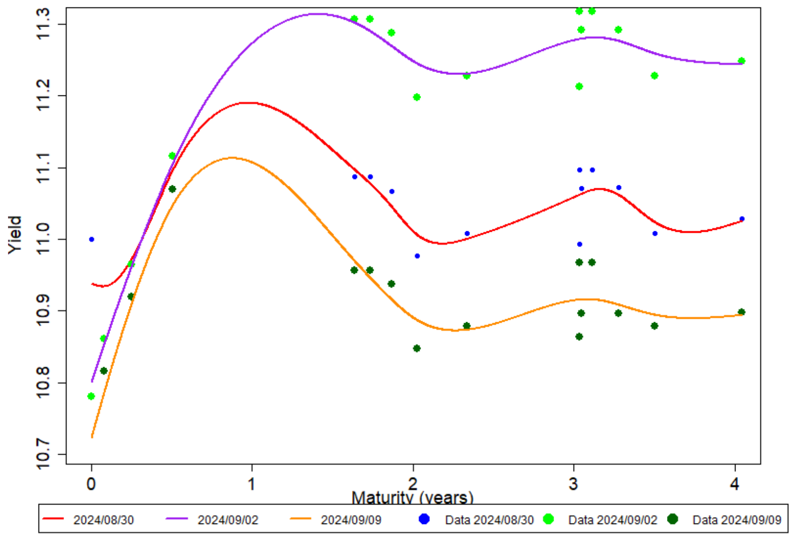

Figure 22: Yield Curve of ESG Development Banks bonds on September 2nd
Source: Own elaboration with data from PiP

Changes on BONDES G yield curve for September 2nd also applied to the yield curve of Development Bank ESG bonds (Figure 34). The increase in the 1-day TIIEF on August 30th caused the yield curve for these bonds to be higher than the September 2nd curve, but only for 1-day maturities. The delayed response in yields for bonds with maturities longer than one day became evident on September 2nd, and by September 9th, market conditions had stabilized. This highlights the efficiency of the BONDES G yield curve as a sovereign benchmark, as it quickly adjusts to new information and influences the pricing of other bond markets, including Development Bank bonds. This allows for efficient capital allocation within the market. Like the BONDES G yield curve, the Development Bank ESG curve responds to new market information driven by market volatility and monetary policies, signaling its high liquidity and reliance on the BONDES G yield curve as a reference.

To summarize, sovereign and non-sovereign yield curves have shifted downward, resulting in an inverted curve reflecting recent reference rate cuts. However, the prevailing trend suggests that the Central Bank will likely continue to reduce rates, as reference rates remain high due to the restrictive monetary policy aimed at controlling inflation. This environment makes short-term bonds in the Development Bank bonds market more attractive, while long-term yields reflect heightened uncertainty. In contrast, for BONDES G, long-term bonds present higher yields compared to short-term bonds. This uncertainty is driven by factors such as potential constitutional reforms, and external risks like climate change, and because economic activity and the financial system are directly or indirectly reliant on the services provided by biodiversity and ecosystems (Martinez-Jaramillo et al., n.d.). The increased uncertainty signals higher default risk for long-term holdings of Development Bank bonds, compared to the lower default risk of BONDES G, which are backed by the government (Banco de México, 2020).

As mentioned, during this period of economic uncertainty and high interest rates, a comparison of the Sustainable yield curve [23] with the conventional BONDES M yield curve (estimated for June 2024) reveals similar dynamics and an inverted shape. While the sustainable yield curve shifted downward as the target interest rate decreased during the sample period, the conventional bond yield curve increased across all maturities from December 2023 to June 2024. This occurred despite a slight decrease in the target interest rate, from 11.25% in December 2023 to 11% in June 2024, as Mexico's Central Bank pointed out in its June 2024 report (Ernest et al., 2024).

In both cases, the inverted shape of the yield curve can be attributed to adverse economic projections. According to the Financial Stability Report published by the Central Bank (Ernest et al., 2024), the negative slope of the conventional bond yield curve reflects investor preference for short-term bonds amid uncertainty about future monetary policy, rising risks, and an increased supply of long-term bonds. Recently, risk premiums for these bonds have increased, prompting investors to demand higher yields to compensate for the higher risk of holding long-term securities. As a result, the yield curve flattens for medium- to long-term maturities.

Furthermore, it is important to note that the conventional yield curve is based on instruments with maturities ranging from 1 month to 30 years, reflecting real interest rates. This curve shape is driven by expectations that interest rates will remain high in developed countries,

[23] Term used to generalize the yield curve for BONDES G and ESG Development Bank bonds.

delays in the anticipated start of monetary easing in the United States, and the expectation that Mexico's reference interest rate will stay restrictive for a longer period than originally forecasted. Additionally, the increase in the financing program by the Ministry of Finance and Public Credit (SHCP) and, more recently, rising risk premiums associated with these securities contribute to the curve's inverted shape.

8 Conclusion

This study focused on estimating and interpreting the yield curves of ESG bonds issued by the government (BONDESG) and Development Banks—two crucial players in the sustainable debt market. It explores the impact of the 2024 monetary policy changes and heightened market volatility, assessing their influence on market dynamics. Understanding the insights from both yield curves is crucial for evaluating their ability to reflect the current economic landscape, respond to market changes, and determine the extent to which the BONDESG yield curve is a benchmark for Development Banks. The findings reveal that, despite being relatively new, the sustainable debt market is responsive to monetary policy shifts and the latest market information. This highlights that while the market is still maturing, it demonstrates sufficient liquidity and adaptability to align with broader economic trends.

Particularly, the yield curve responses to monetary policy rate cuts in 2024 (on March 19th, August 9th, and September 27th) and market volatility (September 2nd) are analyzed using three models: Nelson-Siegel, Svensson, and smooth splines. Among these, the smooth splines method performed best, producing more accurate yield curves with lower measurement errors and higher hit rates for both bond issuers. The analysis showed that while the BONDESG yield curve exhibited an inversion, with increasing slopes at longer maturities to account for inflationary risks and uncertainty, Development Bank bonds also displayed an inverted curve. In this case, short-term bonds offered higher yields than long-term bonds, suggesting that the Development Bank yield curve has not yet normalized. The persistent inversion of both curves likely reflects economic and geopolitical uncertainties, the impact of central bank rate cuts, and elevated short-term bond yields.

Furthermore, the relevance of a yield curve lies in its ability to reflect market expectations regarding economic growth, inflation risks, and future interest rate trends. Specifically, the sovereign yield curve is crucial in transmitting valuable information about monetary policy within the financial system. Its ability to quickly adjust prices to new information enables it to serve as a benchmark not only for sovereign debt but also for Development Bank bonds, facilitating more efficient capital allocation in the market.

Importantly, despite the inverted shape of the Development Bank yield curve, the BONDES G yield curve remains a reliable benchmark, especially for Development Banks. While Development Bank bonds typically have shorter maturities, the BONDES G curve offers data points for longer maturities, helping to create a smoother overall curve. Additionally, its responsiveness to new market information, as seen on September 2, highlights how market participants rely on sovereign assets as a reference benchmark to react to economic outlooks and as hedging instruments. The substantial volume of ESG bonds issued by Development Banks under the TIIEF framework further underscores the BONDESG curve's significance as a foundational reference for this growing market.

Continuing to enhance liquidity in the sustainable yield curve for sovereign ESG bonds, particularly BONDES G, is essential for solidifying a reliable benchmark in the emerging sustainable debt market. The importance of developing this yield curve is expected to grow through 2025. According to the Parliamentary Gazette (Cámara de Diputados, 2024), the issuance of sovereign ESG bonds, especially BONDES G, will remain a key priority. Establishing reference points for shorter maturities is critical, as increased issuance of ESG sovereign debt through BONDES G could attract more market participants, including private investors, to the sustainable debt market. A well-developed sovereign yield curve provides a liquid and reliable benchmark for corporate issuers, offering favorable financing conditions and sufficient scale to support a diverse investor base. This, in turn, fosters greater ESG debt issuance across several market actors. This process will play a pivotal role in consolidating Mexico's sustainable finance model by providing investors with diverse sustainable instruments and a low-risk benchmark for future corporate issuance targeting social inequalities and climate change. In turn, this will strengthen the development of Mexico's sustainable yield curve.

However, the analysis has certain limitations. It focuses exclusively on variable interest rate bonds, excluding real-rate bonds, and is restricted to ESG bonds linked to the TIIEF, studied over a relatively short time frame. As Mexico's sustainable debt market has gained momentum since 2022 and with the strategy to promote SDG-focused projects through ESG financing expected to intensify in 2025, future research should address these gaps. Extending the study to a longer period, including real-rate bonds, and comparing the sustainable yield curve with conventional bond curves will offer deeper insights into market dynamics and the response of both curves to adverse economic trends.

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A Appendices

A.1 Nelson-Siegel model

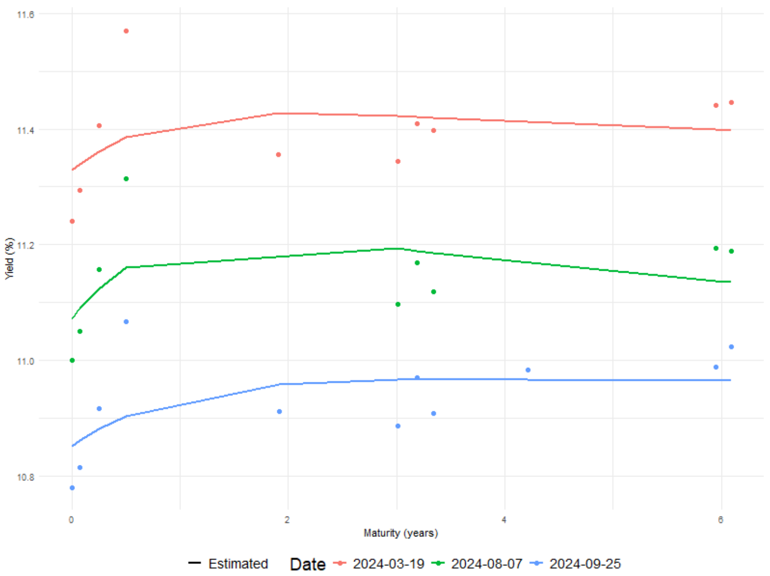

Figure 23: Nelson-Siegel Yield of BONDES G Before Monetary Policy Adjustments

Source:Proveedor integral de precios (PiP)

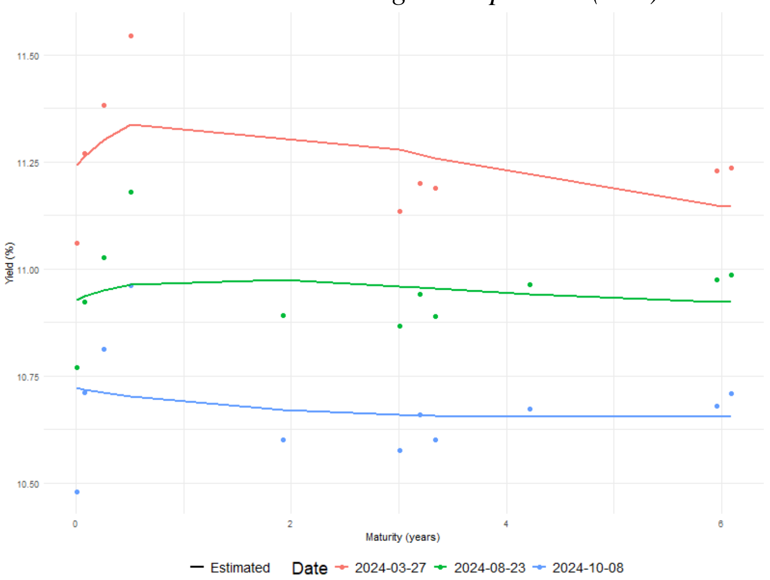

Figure 24: Nelson-Siegel Yield Curve of BONDES G After Monetary Policy Adjustments

Source:Proveedor integral de precios (PiP)

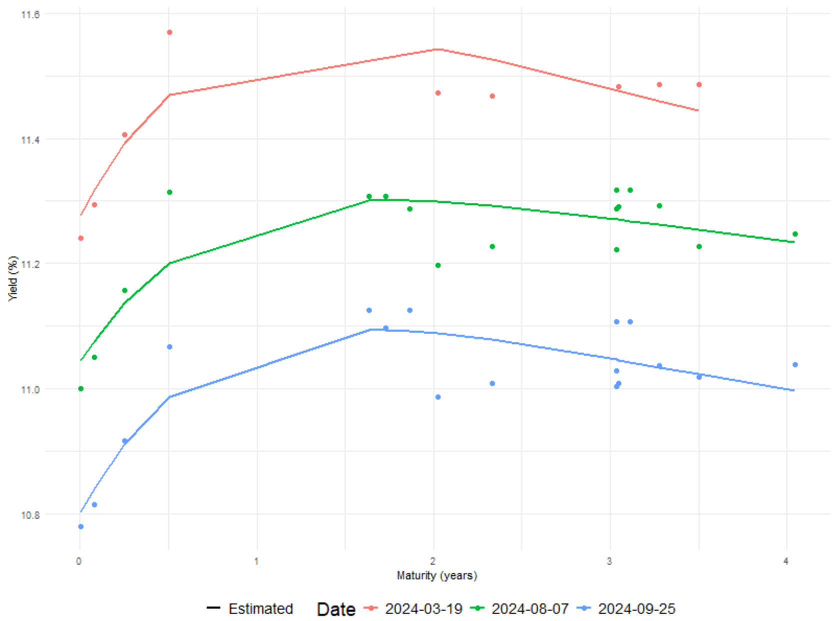

Figure 25: Nelson-Siegel Yield Curve for Development Banks Bonds Before Monetary Policy Adjustments

Source:Proveedor integral de precios (PiP)

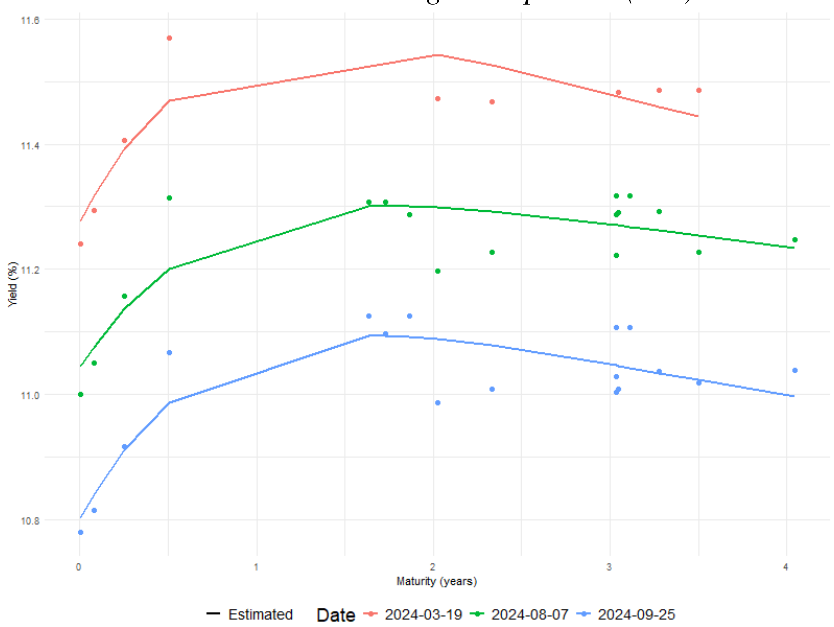

Figure 26: Nelson-Siegel Yield Curve for Development Banks Bonds After Monetary Policy Adjustments

Source:Proveedor integral de precios (PiP)

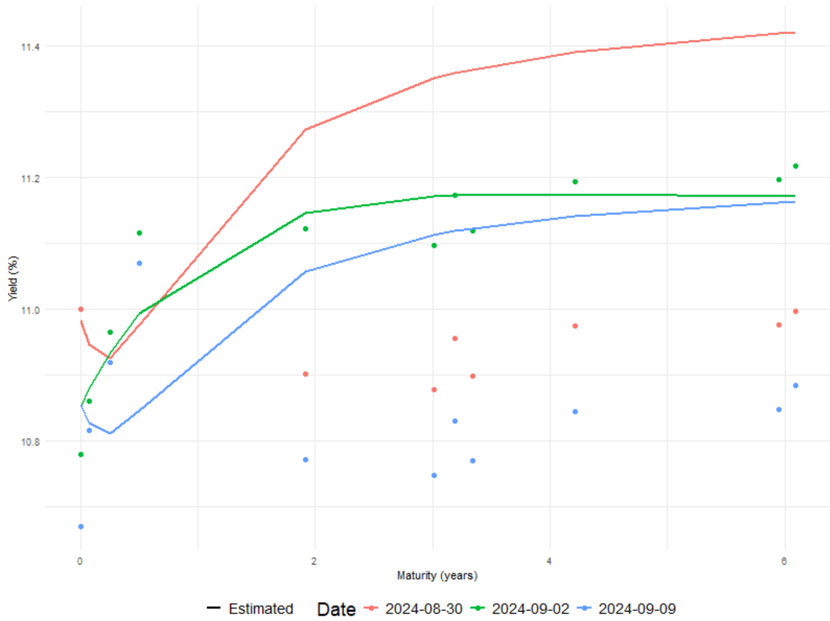

Figure 27: Nelson-Siegel Yield Curve for BONDES G on September 2

Source:Proveedor integral de precios (PiP)

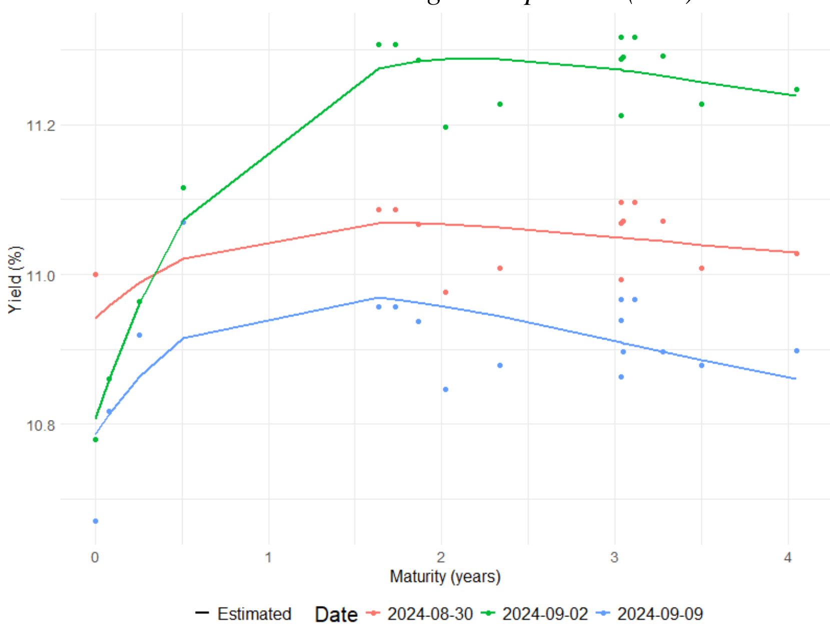

Figure 28: Nelson-Siegel Yield Curve for Development Banks Bonds on September 2

Source:Proveedor integral de precios (PiP)

A.2 Svensson model

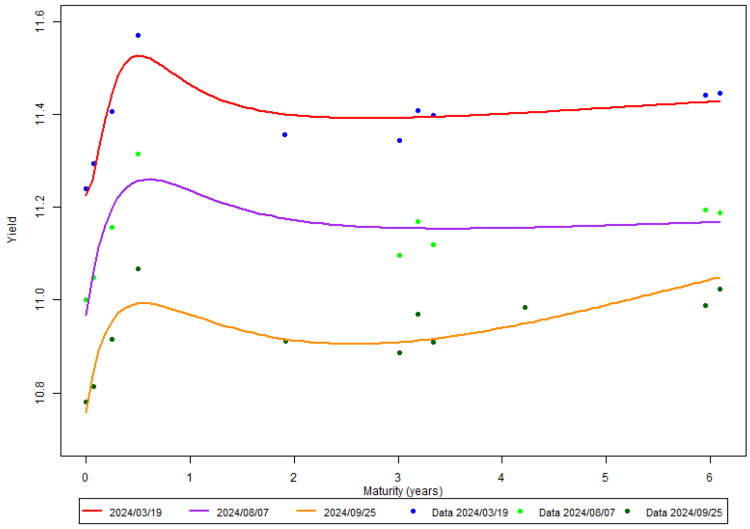

Figure 29: Svensson Yield curve of BONDES G Before Monetary Policy Adjustments

Source:Proveedor integral de precios (PiP)

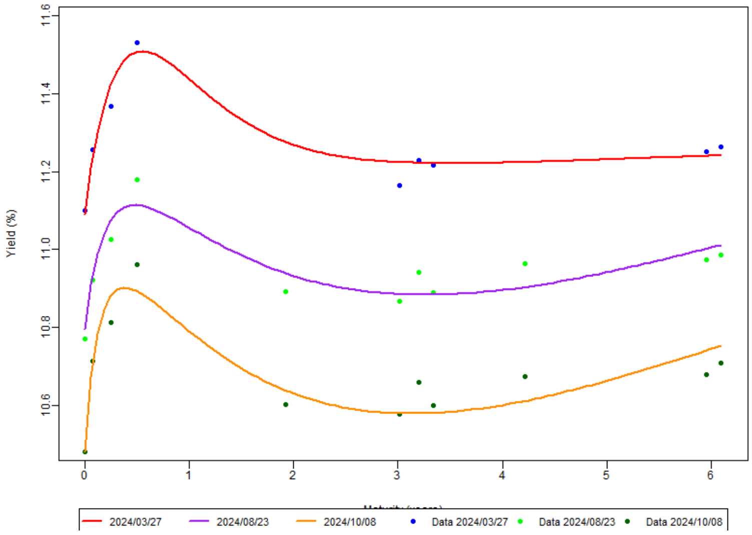

Figure 30: Svensson Yield curve of BONDES G After Monetary Policy Adjustments

Source:Proveedor integral de precios (PiP)

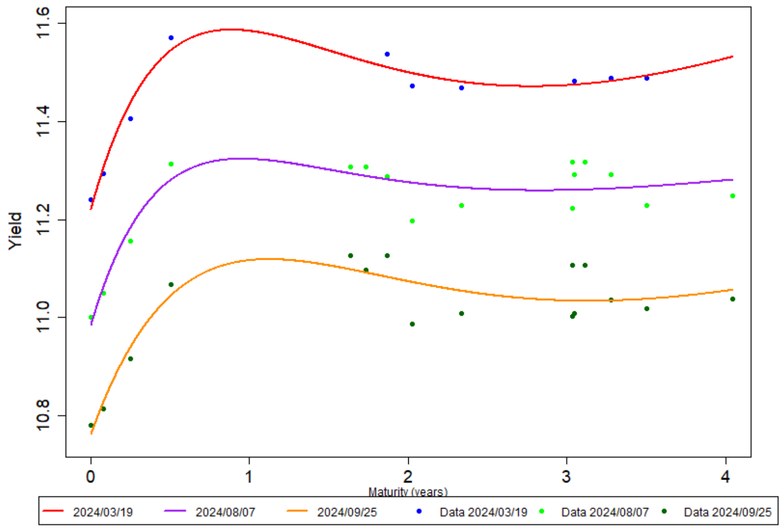

Figure 31: Svensson Yield of ESG Development Bank Bonds Before Monetary Policy Adjustments

Source:Proveedor integral de precios (PiP)

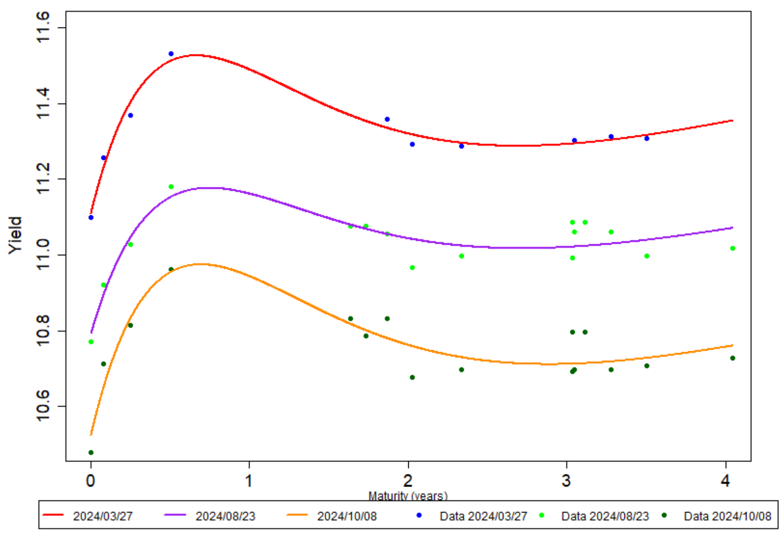

Figure 32: Svensson Yield of ESG Development Bank Bonds After Monetary Policy Adjustments

Source:Proveedor integral de precios (PiP)

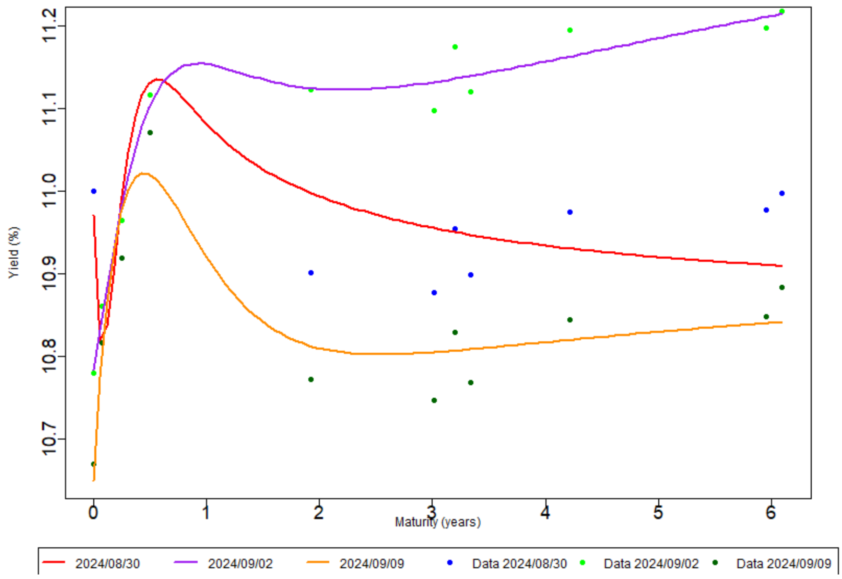

Figure 33: Svensson Yield Curve of BONDES G on September 2
Source: Own elaboration with data from PiP

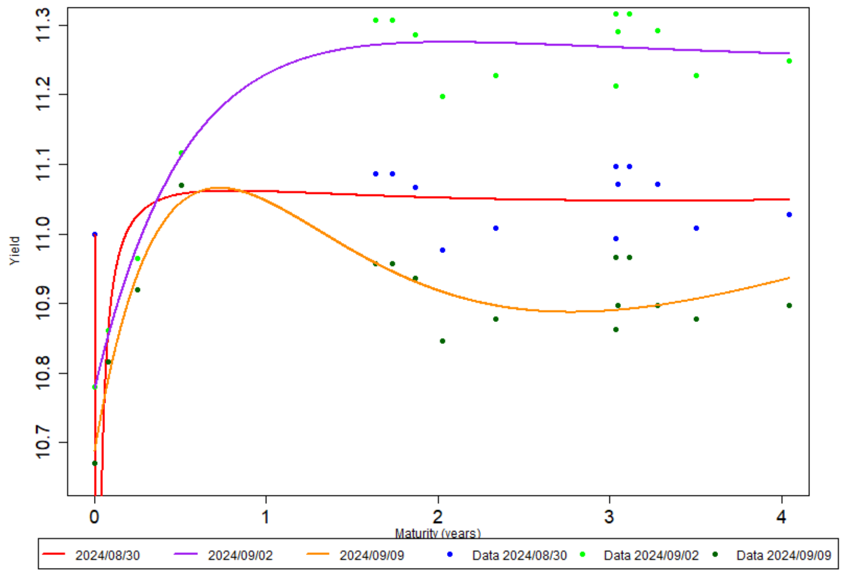

Figure 34: Svensson Yield Curve for Development Banks Bonds on September 2
Source: Own elaboration with data from PiP

A.3 Tables of measurement errors

Table 3: Error Measure by Model and Range for BONDESG bonds

Model	Maturities	MSE	WMAE	Hit Rate
Splines	0 - 1	0.01	0.08	0.4
	2 - 3	0.03	0.13	0.5
	4 - 5	0.029	0.12	0.5
	6+	0.03	0.12	0.5
Nelson-Siegel	0 - 1	0.0007	0.018	0.15
	2 - 3	42.13	6.20	0.0
	4 - 5	118.33	10.87	0.0
	6+	NA	NA	0.0
Svensson	0 - 1	0.20	0.25	0.41
	2 - 3	0.40	0.46	0.5
	4 - 5	0.95	0.68	0.5
	6+	0.845	0.65	0.5

Note: This table presents the performance of different yield curve models across various maturity ranges, highlighting their predictive accuracy for Sovereign ESG bonds: BONDESG. The table demonstrates that each of the three models produces a significantly high in-sample fit with a particularly low weighted mean absolute error and high hit rates for the Spline model.

Table 4: Error Measure by Model and Range Development Bank's ESG Bonds

Model	Maturities	MSE	WMAE	Hit Rate
Splines	0 - 1	0.018	0.1	0.43
	2 - 3	0.026	0.12	0.42
	4 - 5	0.032	0.13	0.42
Nelson-Siegel	0 - 1	0.001	0.026	0.8
	2 - 3	120.65	10.98	0.0
	4 - 5	5.23	2.13	0.0
Svensson	0 - 1	0.006	0.05	0.70
	2 - 3	0.001	0.022	0.92
	4 - 5	0.001	0.028	0.81

Note: This table presents the performance of different yield curve models across various maturity ranges, highlighting their predictive accuracy for Development Bank's ESG bonds. Notably, the Svensson and Smooth Splines models exhibit a high in-sample fit, characterized by particularly low weighted mean absolute errors and high hit rates.

A.4 Tables of parameters estimation

Table 5: Error Measure by Model and Range for BONDESG Bonds on September 2

Model	Maturities	MSE	WMAE	Hit Rate
Splines	0 - 1	0.01	0.075	0.46
	2 - 3	0.04	0.13	0.66
	4 - 5	0.04	0.12	0.66
	6+	0.03	0.11	0.66
Nelson-Siegel	0 - 1	0.01	0.10	0.00
	2 - 3	4.37	2.05	0.00
	4 - 5	121.14	11.00	0.00
	6+	NA	NA	NA
Svensson	0 - 1	0.0003	0.014	0.047
	2 - 3	0.001	0.027	0.03
	4 - 5	6.19	0.0007	1.00
	6+	NA	NA	0.50

Note: This table presents the performance of different yield curve models across various maturity ranges, highlighting their predictive accuracy for Sovereign ESG bonds: BONDESG on September 2. The table demonstrates that each of the three models produces a significantly high in-sample fit with a particularly low weighted mean absolute error and high hit rates for the Spline model.

Table 6: Error Measure by Model and Range for Development Bank's ESG Bonds on September 2

Model	Maturities	MSE	WMAE	Hit Rate
Splines	0 - 1	0.018	0.07	0.60
	2 - 3	0.045	0.13	0.58
	4 - 5	0.039	0.11	0.66
	6+	NA	NA	NA
Nelson-Siegel	0 - 1	0.001	0.022	0.047
	2 - 3	0.74	0.83	0.00
	4 - 5	NA	NA	NA
Svensson	0 - 1	0.0003	0.01	0.04
	2 - 3	0.001	0.028	0.04
	4 - 5	6.19	0.0008	1.00

Note: This table presents the performance of different yield curve models across various maturity ranges, highlighting their predictive accuracy for Development Bank's ESG bonds on September 2. Notably, the Svensson and Smooth Splines models exhibit a high in-sample fit, characterized by particularly low weighted mean absolute errors and high hit rates.

Table 7: Parameters for Nelson and Svensson Models: Pre- and Post-Policy Yield Curve Estimation of BONDES G Bonds

Model	**Policy**	**Date**	β_0	β_1	β_2	β_3	τ_1	τ_2
Nelson	Before	2024/03/19	11.35	-0.029	0.27		0.99	
		2024/08/07	11.04	0.023	0.51		0.99	
		2024/09/25	10.95	-0.10	0.16		0.99	
	After	2024/03/27	10.95	0.28	0.86		0.99	
		2024/08/23	10.86	0.05	0.26		0.99	
		2024/10/08	10.95	-0.10	0.16		0.99	
Svensson	Before	2024/03/19	12.74	-1.53	1.53	0.19	29.01	0.22
		2024/08/07	11.29	-0.30	0.63	0.88	4.35	0.37
		2024/09/25	10.93	-0.21	1.83	-0.24	1.18	0.17
	After	2024/03/27	11.30	-0.23	0.23	1.36	4.31	0.66
		2024/08/23	10.93	-0.15	2.66	-1.6	1.61	0.08
		2024/10/08	11.025	-0.58	2.18	-0.50	7.77	0.14

This table presents the estimated parameters for the BONDES G yield curve, calculated under the constraints ($\beta_0 + \beta_1 > 0$, $\tau_1 > 0$, and $\tau_2 > 0$). These parameters are associated with the levels of the long-term and short-term interest rates, as well as the slope and hump of the curve. The two additional parameters in the Svensson model provide the flexibility to introduce a second hump, enhancing the curve's adaptability.

Table 8: Parameters for Nelson and Svensson Models: Pre- and Post-Policy Yield Curve Estimation of Development Bank's ESG Bonds

Model	**Policy**	**Date**	β_0	β_1	β_2	β_3	τ_1	τ_2
Nelson	Before	2024/03/19	11.05	0.21	1.31		0.99	
		2024/08/07	11.03	0.008	0.879		0.99	
		2024/09/25	10.73	0.068	1.097		0.99	
	After	2024/03/27	10.70	0.50	1.53		0.99	
		2024/08/23	10.80	0.12	0.89		0.99	
		2024/10/08	10.30	0.34	1.20		0.99	
Svensson	Before	2024/03/19	13.14	-1.92	0.85	-4.95	0.55	1.9
		2024/08/07	11.58	-0.60	1.37	-1.62	0.55	1.21
		2024/09/25	11.93	-1.17	23.63	-24.76	1.11	1.21
	After	2024/03/27	12.01	-0.91	3.13	-4.06	0.55	1.08
		2024/08/23	11.70	-0.91	2.20	-3.17	0.55	1.21
		2024/10/08	11.49	-0.97	2.84	-3.90	0.55	1.21

This table presents the estimated parameters for the yield curve of the Development Bank's ESG bonds, calculated with the constraints ($\beta_0 + \beta_1 > 0$, $\tau_1 > 0$, and $\tau_2 > 0$). These parameters correspond to the levels of long-term and short-term interest rates, as well as the curve's slope and single hump. The additional parameters in the Svensson model enable the inclusion of a second hump, increasing the curve's flexibility and precision.

Table 9: Parameters for Nelson and Svensson Models: Yield Curve Estimation of BONDES G and Development Bank ESG Bonds on September 2

Model	**ESG Bond Type**	**Date**	β_0	β_1	β_2	β_3	τ_1	τ_2
Nelson	BONDES G	2024/08/30	11.49	-0.50	-0.91	—	0.29	—
		2024/09/02	11.15	-0.30	0.42	—	0.99	—
		2024/09/09	11.21	-0.35	-0.65	—	0.29	—
	Development Bank ESG Bonds	2024/08/30	10.91	0.023	0.36	—	0.99	—
		2024/09/02	11.01	-0.20	1.22	—	0.99	—
		2024/09/09	10.61	0.17	0.91	—	0.99	—
Svensson	BONDES G	2024/08/30	10.85	0.12	1.11	-1.19	1.37	0.122
		2024/09/02	11.49	-0.71	1.41	-0.56	3.52	0.24
		2024/09/09	10.91	-0.27	0.28	0.75	2.24	0.38
	Development Bank ESG Bonds	2024/08/30	11.12	22.87	-36.2	0.23	0.001	2.05
		2024/09/02	11.22	-0.45	0.73	-0.02	0.55	1.21
		2024/09/09	11.55	-0.87	2.23	-3.18	0.56	1.21

This table presents the estimated parameters for the BONDES G and Development Bank ESG bonds yield curve, calculated under the constraints ($\beta_0 + \beta_1 > 0$, $\tau_1 > 0$, and $\tau_2 > 0$). These parameters are associated with the levels of the long-term and short-term interest rates, as well as the slope and hump of the curve. The two additional parameters in the Svensson model provide the flexibility to introduce a second hump, enhancing the curve's adaptability.

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