The US Treasury Funding Advantage Since 1860*

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Abstract

We provide the first consistent historical estimate of US Treasury funding advantage, as measured by term structures of yield spreads between comparable highest-grade US corporate bonds and Treasurys. We construct a new dataset with monthly prices, cash-flows, and ratings for US corporate bonds over 1860-2024. We adjust yield curve estimation techniques to account for tax treatments and embedded options. Existing index-based spreads have mismeasured US funding advantage on long-term bonds in the post-WWI period, particularly during high inflation episodes. An asset pricing model for US funding advantage finds that standard risk factors, not quantity changes, explain most variation in spreads.

JEL classification: E31, E43, G12, N21, N41

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1 Introduction

Many researchers have argued that the US government enjoys a funding advantage: it can issue bonds at lower interest rates than the private sector, even when the private sector issues bonds that promise the same cash flow sequence. This matters because it allows the government to sell debt that is not necessarily backed by future fiscal surpluses (a "non-pecuniary" or "service flow" source of financing). In this paper, we revisit and expand the historical evidence on US funding advantage, as measured by the spread between the yields on the highest-grade US corporate bonds and Treasurys. In doing so, we uncover new statistical properties of US funding advantage and show that many established "facts" reflect mismeasurement rather than underlying economic relationships.

Formally, we estimate zero-coupon yield curves for highest-grade corporate and government bonds that promise consistent pecuniary payouts and then compute US government funding advantage as the corporate-to-government yield spread. This necessitates resolving two main difficulties: (i) detailed bond-level price data for corporate bonds prior to the 1970s has not previously been collected, and (ii) public and private sector coupon-bearing bonds differ in their "characteristics", which distort observed prices but do not necessarily reflect the government's funding advantage. To overcome the first difficulty, we construct a new micro-level dataset with historical corporate bond price, coupon, and maturity information from 1860-2024 that matches our existing datasets for Treasurys. This involves the digitization of records from historical newspapers, business magazines, and company financial reports. For bonds maturing after 1909, we use Moody's credit ratings to classify default risk while for earlier periods we use Macaulay (1938) to identify the highest quality issuers. With some abuse of terminology, we refer to the yield spread estimated using Macaulay (1938)'s highest-grade bonds and Moody's AAA bonds as the AAA Corporate-Treasury spread.

To address the second challenge, we make adjustments to the estimated bond pricing formulas to ensure like-for-like comparison between private and public sector bonds. One set of adjustments relates to differential tax treatment. From 1913-1941 Treasurys were typically exempt from Federal income taxation while corporate bonds were not. After 1941, Federal income tax exemptions were removed but tax distortions none-the-less appeared because capital gains received favorable tax treatment compared to capital losses and coupon payments. There are important periods (e.g. 1955-1985) during which these capital gains distortions were large and, on average, affected Treasurys and corporate bonds differently. Another set of adjustments relates to differential option values. Between 1918 and 1971, the Treasury issued a subclass of government bonds, known as "flower bonds", which could be redeemed to pay the bondholder's federal estate taxes upon their death at par value rather than market value. This meant that flower bonds essentially provided a tax concession and a put option, through the early redemption, that became more valuable during periods of high inflation when bond prices fell well below par value. That is, they provided a hedge against inflation risk. In addition, some Treasurys and most corporate bonds included call options. All of these tax and option features bias standard yield curve estimation techniques. We resolve this by parameterizing implicit tax and option distortions to adjust bond cash flows. We then jointly estimate the distortions and zero-coupon yields by adopting and extending the non-parametric approach from Filipović et al. (2022), which is chosen because it achieves strong out-of-sample performance. Our approach identifies the tax and option distortion parameters by exploiting the cross-sectional variation in tax treatments and option moneyness across our sample.

Our new estimates allow us to infer a collection of stylized facts about relative government debt prices and funding advantage. First, our long time series allows us to identify low frequency movements in US government funding advantage that coincide with large changes to financial sector regulation and the Federal Reserve's large-scale bond purchase programs. The US government gained a funding advantage well before Bretton Woods and global dollar dominance with the introduction of the 1862-65 National Banking Acts that allowed banks to create money so long as they backed the money with holdings of government debt (referred to as a "circulation" privilege). The US government's funding advantage on long-maturity debt generally stayed high at around 1.5% throughout the National Banking Era (1865-1920) before dropping sharply to around 0.5% in 1920 following the elimination of the National Bank circulation privilege. It then followed a downward trend until the mid 1980s before reversing course and increasing back up to around 0.5% in the 2000s. Quantitative easing during World War II led to an increase in the funding advantage at short maturities while quantitative easing after the 2007-09 financial crisis led to an increase at long maturities.

Second, we find that existing work has exaggerated the size of US funding advantage, particularly during the 1970s and 1980s when inflation risk was high. The most commonly used existing measure for the US funding advantage on long-maturity securities is the spread between the Moody's AAA corporate yield index and the Fed's long-term bond index (which we refer to as the "index-based spread"). This spread was used by Krishnamurthy and Vissing-Jorgensen (2012) and has subsequently been adopted by many other papers. The indices compute the average yield-to-maturity across bonds with a wide range of characteristics which leads to large distortions to the spread in the 1920s, 1940s, and 1960-80s. The high inflation period in 1970-80s offers a particularly revealing contrast: the funding advantage reaches its maximum value in the late 1970s using the index-based spread ($\sim 2\%$), while it reaches its lowest value in the late 1970s using our estimates ($\sim 0\%$). A key reason for the discrepancy is that the index-based measure includes yields-to-maturity on many flower bonds and the flower put option became particularly valuable when bond prices dropped below par during the high inflation period of the 1970s-80s. So the index-based spread is effectively a comparison between the average yield-to-maturity on nominal, callable corporate bonds and the average yield-to-maturity on Treasurys with a put option against inflation risk that traded like "real bonds". We conclude that a large portion of the 1970's variation in the existing index-based AAA Corporate-Treasury series is attributable to the (negative) inflation risk premia on flower bonds instead of a heightened funding advantage on regular US Treasurys.

In Section 6, we use our new corporate and Treasury yield curve estimates to study how US funding advantage is priced. We revisit the recent literature arguing that a debt-to-GDP factor combined with independent demand shocks can forecast a large fraction of movements in the AAA Corporate-Treasury spread on long-maturity bonds (e.g. Krishnamurthy and Vissing-Jorgensen (2012) and subsequent papers). That is, debt "quantity" changes can forecast "spread" changes. We use our new series for the AAA Corporate-Treasury spread term structure to replicate and extend the regressions in the literature. In particular, we estimate spread-quantity correlations within particular maturity bins and using aggregate government debt. Our analysis shows that, within the different maturity bins, debt-to-GDP increases forecast large spread declines for bonds with maturity less than 1 year, small spread declines for bonds with maturity between 1-10 years, and no significant spread decline for maturities greater than 10 years. In addition, aggregate debt-to-GDP is not a significant factor for explaining spread changes across our full sample from 1860-2024 once we control for regulatory regimes and volatility. These heterogeneous relationships suggest a more complicated, maturity specific connection between quantities and spreads than has been modeled by the literature.

To better understand how the government funding advantage is priced, we estimate a richer factor asset pricing model that forecasts spreads with principal components of the yield curves and government debt obligations while respecting no-arbitrage across time. Being able to fit this model highlights the value of having estimated the term structure of government funding advantage: we can use asset pricing tools to understand corporate-to-government bond spreads. Our model finds that quantities explain little of the variation in spreads (approximately 5-10%), reinforcing the findings from the regressions. Instead, the variation is primarily explained by the same risk factors that appear in standard bond asset pricing models. This suggests that the non-pecuniary benefit of US Treasurys is well explained by standard asset pricing.

Finally, in Section 7 we return to the government budget constraint and show that the

US government's funding advantage has significantly contributed to its overall financing. We first calculate the "ex-ante" backing of government debt obligations that comes from the future non-pecuniary benefits of government debt. In the nineteenth century, non-pecuniary backing was approximately 1.5% of GDP while in the twentieth century it was approximately 2% of GDP with peaks of 7% during World War II and 5% during the Global Financial Crisis. We then calculate the "ex-post" fraction of total government revenue that has historically come from the non-pecuniary benefit of government debt (through the funding spread on new issuance and the revaluation of the premium on the stock of outstanding debt). This shows that funding advantage was costly to establish at the end of the Civil War: the government absorbed capital losses when Treasurys started to trade at a premium. However, it reaped significant benefits in the twentieth century when it was able to use its funding advantage to finance crises. During WWI over 20% of the US government's revenue came from its funding advantage while during the Depression, the Financial Crisis and COVID the contributions were 15%, 8%, and 7% of total revenue respectively.

Related literature: Our work extends studies on historical yield spreads (e.g. Fair and Malkiel (1971), Cook and Hendershott (1978), Krishnamurthy and Vissing-Jorgensen (2012), Nagel (2016), Choi et al. (2022),Cieslak et al. (2024)). Relative to the literature, we collect new primary data and show how to adjust for tax and option treatments. Unlike some of these papers, we do not attempt to estimate the spread between Treasury yields and the expectation of the household SDF, which is sometimes referred to as the convenience yield. Instead, we only focus on the funding advantage of the US government relative to the private sector. For the modern period, there exist other high-quality estimates of the convenience yield on US government debt (e.g., see van Binsbergen et al. (2022), Koijen and Yogo (2020)), however, data limitations render them infeasible for our long time series.

Technically, our work is related to two literatures on yield curve estimation. The first estimates zero-coupon yield curves using combinations of the law of one price and some restrictions on the shape of the yield curve (e.g. Fama and Bliss (1987), Nelson and Siegel (1987), Cecchetti (1988), Svensson (1995), Diebold and Li (2006), Gürkaynak et al. (2007), Liu and Wu (2021), Filipović et al. (2022)). We adopt and adapt the Kernel Ridge regression approach proposed by Filipović et al. (2022) to handle bond heterogeneity because it is calibrated to achieve strong out-of-sample performance. Our tax and option adjustments are related to a second literature that attempts to account for tax advantages and option features in yield calculations (e.g. Robichek and Niebuhr (1970), Colin and Bayer (1970), McCulloch (1975), Cook (1977), Cook and Hendershott (1978), Duffee (1996), Duffee (1998), Elton et al. (2001)). Our contributions are: showing how to estimate implicit tax effects rather than inserting individually chosen tax rates, relaxing the assumption in the literature that bonds are held to maturity, and integrating this literature with modern yield curve estimation.

More broadly, our work is part of a literature attempting to connect historical time series for asset prices to government financing costs (e.g. Payne et al. (2025), Jiang et al. (2022), Chen et al. (2022)) We also complement the historical literature aimed at extending historical financial time series further back in time (e.g. Homer and Sylla (2004), Goetzmann et al. (2001), Reinhart and Rogoff (2009), Jordà et al. (2019), Schmelzing (2020), Officer and Williamson (2021), and Carlson et al. (2022)). Like Ghaderi et al. (2025), we focus on extending the available US historical corporate bond data.

The paper is structured as follows. Section 2 explains our conceptual framework. Section 3 examines our dataset, and details the institutional features driving bond heterogeneity that our yield curve estimates must account for. Section 4 summarizes our statistical methodology. Section 5 presents our estimate of the AAA Corporate-Treasury spreads. Section 6 constructs an asset pricing model for the US funding advantage. Section 7 calculates the historical contribution of convenience revenue. Section 8 concludes.

2 Conceptual Framework

In this section we define our notion of government funding advantage using a stylized model and explain how it relates to the government budget constraint. We then discuss the difficulties involved with attempting to use bond data to estimate the yield curves required to calculate funding advantage.

2.1 Defining Government Funding Advantage

Consider a discrete time, infinite horizon economy with time indexed by $t \in \{0, 1, \ldots\}$. The economy contains a representative private sector investor and a government.

The government issues bonds with different cash-flow profiles none of which are subject to default risk. Let $\mathcal{N}_t$ denote the set of government bonds outstanding at time t. Each bond $i \in \mathcal{N}_t$ promises a sequence of coupons $\{cp_{t,i}^{(j)}\}_{j=1}^{\infty}$ and principal payments $\{pr_{t,i}^{(j)}\}_{j=1}^{\infty}$, combined into the cash-flow stream $\mathsf{c}_{t,i} := \{c_{t,i}^{(j)}\}_{j=1}^{\infty}$ with $c_{t,i}^{(j)} := cp_{t,i}^{(j)} + pr_{t,i}^{(j)}$ denoting period-t promises of j-period-ahead dollars. These coupon-bearing bonds trade at prices $p_{t,i}$ and are in positive net supply $B_{t,i}$, where $B_{t,i}$ is the total amount (face value) of newly issued and outstanding bond i in period t. We assume the law of one price holds so that:

$$p_{t,i} = \sum_{j=1}^{\infty} q_t^{(j)} c_{t,i}^{(j)}, \qquad \forall i \in \mathcal{N}_t, \forall t \geq 0, \tag{2.1}$$

where $q_t^{(j)}$ denotes the price of a government promise to one dollar at time $t+j$ with $q_t^{(0)} = 1$. We call the sequence $\mathsf{q}_t := \{q_t^{(j)}\}_{j=0}^{\infty}$ the government's *discount function*. We also assume that the private sector issues bonds with a companion discount function $\widetilde{\mathsf{q}}_t := \{q_t^{(j)}\}_{j=0}^{\infty}$. We summarize this setup with the assumption below:

Assumption 1 (Law of One Price)**.** Within each period t, there is a common discount function q_t pricing all government bonds and a common discount function $\widetilde{\mathsf{q}}_t$ pricing all high-grade corporate bonds.

The basic premise of this paper is that when a private corporation issues default-free debt that matches the cash-flow profile of government bonds, they may face a different discount function $\widetilde{\mathsf{q}}_t \leq \mathsf{q}_t$. This means that the government can potentially sell a bond at a higher price than the private sector, even when the bond promises the same cash flow stream $\mathsf{c}_{t,i}$ and the same default risk. We refer to the difference $\mathsf{q}_t - \widetilde{\mathsf{q}}_t$ as the *premium* on government debt and refer to the *government's funding advantage* as the term structure of highest-grade corporate to Treasury yield spreads:

$$\chi_t^{(j)} := \frac{1}{j} \log\left(q_t^{(j)}\right) - \frac{1}{j} \log\left(\widetilde{q}_t^{(j)}\right), \qquad \forall j \geq 1, \quad \text{with} \quad \chi_t^{(0)} = 0.$$

A common explanation for such a spread is because the representative investor receives a non-pecuniary benefit from holding government debt due to higher liquidity, differential regulation, market segmentation, or other reasons unrelated to the bond's cash-flow stream. Following the literature, we characterize this non-pecuniary benefit by imposing that the elements of q_t and $\widetilde{\mathsf{q}}_t$ solve the investor Euler equations $\forall j \geq 1$:

$$q_t^{(j)} = \mathbb{E}_t\left[\xi_{t,t+1}\Omega_{t,t+1}q_{t+1}^{(j-1)}\right], \quad \widetilde{q}_t^{(j)} = \mathbb{E}_t\left[\xi_{t,t+1}\widetilde{q}_{t+1}^{(j-1)}\right], \quad \text{with} \quad q_t^{(0)} = \widetilde{q}_t^{(0)} = 1, \tag{2.2}$$

where $\xi_{t,t+1}$ is the marginal investor's stochastic discount factor (SDF) and $\Omega_{t,t+1}$ is a government debt specific wedge capturing the non-pecuniary benefit of government debt.

2.2 Connection to the Government's Budget Constraint

We can use the government's discount function to set up the government's intertemporal budget constraint. Using the law of one price (2.1), we can express the period-t market value of the government debt portfolio in the following (equivalent) forms:

$$\sum_{i\in\mathcal{N}_t} p_{t,i}B_{t,i} = \sum_{i\in\mathcal{N}_t}\sum_{j=1}^{\infty} q_t^{(j)} c_{t,i}^{(j)} B_{t,i} = \sum_{j=1}^{\infty} q_t^{(j)} \sum_{i\in\mathcal{N}_t} c_{t,i}^{(j)} B_{t,i} =: \sum_{j=1}^{\infty} q_t^{(j)} b_t^{(j)},$$

where the last expression defines $b_t^{(j)} := \sum_{i\in\mathcal{N}_t} c_{t,i}^{(j)} B_{t,i}$ as the number of $t+j$ dollars that the government has at time t promised to deliver. We call the sequence $\mathsf{b}_t := \{b_t^{(j)}\}_{j\geq 1}$ the *zero-coupon equivalent* government debt portfolio. Each period t, the government enters with a stock of promised payments b_{t-1}, spends g_t, raises taxes τ_t and finances the resulting deficit/surplus by "restructuring" its debt portfolio in the form of new issues of zero-coupon bonds b_t. It follows that the period t government budget constraint can be written as

$$b_{t-1}^{(1)} + g_t - \tau_t = \sum_{j=1}^{\infty} q_t^{(j)} \left(b_t^{(j)} - b_{t-1}^{(j+1)} \right)$$

that is, period-t interest payments, $b_{t-1}^{(1)}$, and primary deficit, $(g_t - \tau_t)$, must be funded by refinancing the government debt portfolio at market prices $\{q_t^{(j)}\}_{j\geq 1}$. This implies the government's borrowing costs can be fully characterized by the discount function q_t.

We can now express the government's budget constraint in terms of its funding advantage. Iterating the government budget constraint forward gives the lifetime budget constraint under the private sector's stochastic discount factor (see Appendix A):

$$\begin{aligned}
\sum_{j=1}^{\infty} q_t^{(j-1)} b_{t-1}^{(j)} = {} & \underbrace{\mathbb{E}_t\left[\sum_{s=0}^{\infty} \xi_{t,t+s}\left(\tau_{t+s} - g_{t+s}\right)\right]}_{(i)} + \underbrace{\sum_{j=1}^{\infty}\left(q_t^{(j)} - \tilde{q}_t^{(j)}\right) b_{t-1}^{(j+1)}}_{(ii)} \\
& + \underbrace{\mathbb{E}_t\left[\sum_{s=0}^{\infty} \xi_{t,t+s} \underbrace{\left\{\sum_{j=1}^{\infty}\left(q_{t+s}^{(j)} - \tilde{q}_{t+s}^{(j)}\right)\left(b_{t+s}^{(j)} - b_{t-1+s}^{(j+1)}\right)\right\}}_{\text{non-pecuniary revenue in period } t+s}\right]}_{(iii)}. \qquad (2.3)
\end{aligned}$$

This equation implies that the market value of outstanding debt (including interest payments) can be written as the sum of three components: (i) the present discounted value of future primary surpluses, (ii) a term associated with the premium on the *stock* of existing long-term government debt, and (iii) the present discounted value of the "non-pecuniary revenue" the government earns from being able to issue *new* debt more cheaply than the private sector. The second term would disappear if the government only issued one-period debt. Evidently, holding all else equal, the fraction of the market value of government debt which is unbacked by future surpluses, i.e., the last two terms on the right-hand-side of (2.3), is an increasing function of $\{\chi_t^{(j)}\}_{j\geq 1}$. In the special case of $\mathsf{q}_t = \widetilde{\mathsf{q}}_t$, we obtain the result that current debt must be fully backed by future primary surpluses.

From this discussion, we can see the importance of defining government funding advantage by comparing discount functions on government and corporate bonds that are subject to the same tax treatment and do not have options. In particular, tax exemptions on government bonds can give rise to an observed spread but only because they decrease future tax revenues. In this sense, they don't contribute to the portion of government debt that is truly unbacked by future surpluses.

2.3 Estimation Challenges with Heterogeneous Bonds

The goal of this paper is to estimate the term structure of the US government's funding advantage since 1860 by estimating the time series for the discount functions q_t and $\widetilde{\mathsf{q}}_t$. The main difficulty is that commensurate private and public sector zero-coupon bonds are not traded in large numbers. This means that the discount functions, q_t and $\widetilde{\mathsf{q}}_t$, must be inferred from a sample of traded bonds with heterogeneous bond characteristics.

In the finance literature, two approaches have been used to estimate bond yield curves. The first approach (e.g. Homer (1968) and Salomon Brothers (1988)) addresses the widespread heterogeneity in bond markets by partitioning outstanding securities into well-defined subclasses based on characteristics such as maturity, coupon rate, callability, and tax treatment and computes average yields-to-maturity for each subclass of like-for-like bonds. The main advantage of this approach is that, in some cases, it allows for the isolation of price effects associated with non-standard bond features, such as the call deferment period. Its drawback is that it restricts analysis to the small set of traded maturities rather than estimating discount functions at all maturities.

The second approach, (e.g. Diebold and Li (2006), Gürkaynak et al. (2007), Liu and Wu (2021), Filipović et al. (2022)), seeks to overcome this limitation by interpolating across non-traded maturities to estimate the entire discount function. Specifically, this literature aims to estimate a smooth discount function, $\mathsf{q} \in \mathcal{Q}$, from a suitably chosen set of functions $\mathcal{Q}$. The objective is to ensure that implied bond prices—given by the law of one price condition as in Equation (2.1)—closely match observed market prices, with any residuals being regarded as noise. A key prerequisite for the validity of the second approach is the existence of a homogeneous sample of regular bonds, for which it can be reasonably assumed that price differences arise solely from variations in coupon rates and maturity. Naturally, this approach imposes strict selection criteria—for example, excluding all bonds with embedded options—

and primarily focuses on the past few decades, characterized by "regular and predictable" US Treasury issuance. As we show in Section 3, applying similar selection criteria throughout our long sample leaves us with too few bonds to undertake yield curve estimation.

To overcome these difficulties, this paper bridges the gap between these two traditions by incorporating bond heterogeneity into the estimation of discount functions. When bonds differ in characteristics beyond their promised cash flows—such as tax exemptions or option-like features—the law of one price (Assumption 1) necessitates the inclusion of distortions in the pricing formula (2.1) that capture the price effects associated with specific bond attributes. For government bonds, they generalize the bond pricing formula as:[1]

$$p_{t,i} = \underbrace{\sum_{j=1}^{\infty} q_t^{(j)} z_i^{(j)}(\theta_t, p_{t,i}) c_{t,i}^{(j)}}_{\text{tax-adjusted fundamental value}} + \underbrace{v_i(\theta_t, p_{t,i})}_{\text{option value}} \tag{2.4}$$

where $\mathsf{z}_i(\theta_t, p_{t,i}) := \{z_i^{(j)}(\theta_t, p_{t,i})\}_{j\geq 1}$ represents tax distortions, such that the first term on the right hand side of (2.4) represents the bond's "fundamental value", while $v_i(\theta_t, p_{t,i})$ can be thought of as the value of embedded options. These distortions can depend on a set of parameters capturing bond characteristics, θ_t, and potentially on the bond's price. We define $\mathsf{z}_{t,i}$ to capture the bond and maturity specific effects of tax distortions, measured relative to a *reference discount function* q_t that is common across all bonds. We choose the reference discount function to be the function that would be inferred from tax-unadjusted cash-flows if the sample included bonds with homogeneous tax treatments (i.e. when the tax distortions are independent of i and j; see Appendix E.1 for a formal definition). This is the same discount function that the modern yield curve estimation literature attempts to estimate (e.g. Gürkaynak et al. (2007)).

At this level of generality, the crucial point to recognize is that, in the presence of bond heterogeneity, estimating discount functions without accounting for such pricing distortions can introduce significant bias.[2] Using (2.1) instead of (2.4) effectively forces the estimator to treat all price differentials as arbitrage to be eliminated, even though some observed price discrepancies stem from valuable tax advantages and option features. By contrast, the pricing formula (2.4) introduces discounting factors, composed of a common component q_t and bond-specific components $\mathsf{z}_{t,i}$ and $v_{t,i}$, that can explain price differentials. Imposing structure on the bond-specific components—guided by tax legislation and option pricing theory—enables us to leverage a heterogeneous bond sample to estimate the equilibrium q_t

[1] A similar expression holds for high-grade corporate bonds with discount function $\widetilde{\mathsf{q}}_t$.

[2] The issue is analogous to the *omitted variable bias*: if, at a given period t, the distortions $\mathsf{z}_{t,i}$ and $v_{t,i}$ correlate with the bond price, $p_{t,i}$, omitting them leads to biased estimates of q_t.

as the common component without the influence of tax effects and option-like features. In Section 3, we examine the historical context and institutional details to identify important tax effects and embedded options that the distortions $(\mathsf{z}_{t,i}, v_{t,i})$ can represent.

3 Data and Institutional Details

In this section, we discuss our new bond dataset, which overcomes a major practical challenge with estimating government funding advantage: detailed bond-level price data for high-grade corporate bonds has not previously been collected before the 1970s. We then describe the heterogeneous characteristics of the bonds in our sample, highlighting how these characteristics create challenges for measuring the government funding advantage.

3.1 Our Dataset

High-grade Corporate Bonds: We construct a new historical dataset of US corporate bonds covering the period 1840–2024, providing monthly data on trading prices, cash flows, and bond characteristics such as maturity, credit rating, and callability. The dataset integrates several existing databases with hand-collected prices and bond characteristics from historical newspapers, business magazines, and corporate financial statements. For the early period, we gather prices primarily from the *New York Times (1851–1973)*, *Commercial & Financial Chronicle* (1886–1963) and *Barron's Magazine* (1942–1973). Credit ratings and bond characteristics are primarily obtained from *Moody's Manuals*, published since 1900. From 1974 onward, we rely on the *Lehman Brothers Fixed Income Database* (1974–1997) and the *Merrill Lynch Bond Index Database* (1998–2024). Appendix C.1 provides details on the corporate bond data sources and construction.

We limit our sample to the period 1860–2024 to have sufficient price observations and focus on highest-grade corporate bonds to minimize default risk. To classify bonds as highest-grade, we primarily rely on annual Moody's credit ratings, which became available in 1909, and restrict our sample to AAA-rated bonds. For bonds maturing before 1909, we follow Macaulay (1938) in identifying highest-quality issuers, relying on the selection of railroad companies included in his highest-grade railroad bond yield index. Additional details on bond selection and credit ratings are provided in Appendix C.1.3.

US Government Bonds: Our dataset on US Treasury debt combines the comprehensive monthly panel of prices and quantities for all Treasurys from 1790–1925 constructed by Hall et al. (2018) and utilized in Payne et al. (2025), with the CRSP Treasury Database (1925-

2024). We exclude the Treasury Inflation-Protected Securities (TIPS) from our sample, but we keep bonds with varying tax exemptions and bonds with embedded call and put options. Appendix C.2 provides further details on the construction of the Treasury bond sample.

3.2 Bond Characteristics with Price Effects

In this section we highlight five key bond features that create pricing differences between otherwise "equivalent" corporate and government bonds unrelated to funding advantage: tax exemptions, low coupon rates, estate tax treatments ("flower bonds"), callability and exchange privilege. Table 1 summarizes the characteristics, necessary adjustments to the pricing formula (2.4), and the periods of greatest relevance.

Feature	**Summary**	**Sample**	**Effect on Yield**	**Period**
Tax Exemption	Reduced federal income tax rate on interest income	Gov	$y \downarrow p \uparrow$	1917–41
Low Coupon	Income mainly from capital gains with low tax rate	Both	$y \downarrow p \uparrow$	1955–85
Flower Bond	Valued at par for estate taxes upon death	Gov	$y \downarrow p \uparrow$	1970s
Call Option	Issuer has the right to refinance at call price	Both	$y \uparrow p \downarrow$	'30s,'90s
Exchange Privilege	At maturity exchangeable for new issue premium bond	Gov	$y \downarrow p \uparrow$	1930s

Table 1: Bond Characteristics with Price Effects

3.2.1 Tax Advantages

Tax exemptions on US Treasurys: Before the introduction of US federal income taxation in 1913, neither corporate nor government bonds were subject to taxes.[3] Since then, income earned by both corporations and individuals from long-term securities holdings has been subject to two types of taxes.[4] Coupon payments are taxed at the relevant (holder-specific) marginal income tax rate τ^{inc}. In addition, capital gains are taxed at the long-term capital

[3] The Sixteenth Amendment to the Constitution was announced on February 25, 1913 and the new Federal income-tax law in pursuance of this amendment was enacted on October 3, 1913.

[4] In addition, since 1916, all bonds were subject to estate taxes except for the so called flower bonds, shown by the light shaded areas in Figure 1.

gains tax rate τ^{cg} while capital losses can be deducted against ordinary income and are thus valued at the ordinary income tax rate τ^{inc}.

From WWI in 1918 to WWII in 1941, the Treasury issued both fully and partially tax-exempt bonds. While fully-taxable bonds were subject to normal income taxes and surtaxes (e.g. war and excess profits taxes), partially tax-exempt bonds were only subject to surtaxes and tax-exempt bonds were not subject to either income taxes or surtaxes.[5] Over this period, the gap between tax rates τ^{inc} and τ^{pte} was around 3%.

Figure 1 depicts the share of outstanding marketable Treasury bonds and notes (excluding T-Bills and Certificates of Indebtedness) classified by tax-treatment for the sub-period 1900-2024. From the introduction of income taxation 1913 until WWII in 1941, US federal government bonds were (either partially or fully) exempt from federal income taxes while corporate bonds were fully taxable. This created an obvious tax advantage for US Treasurys.

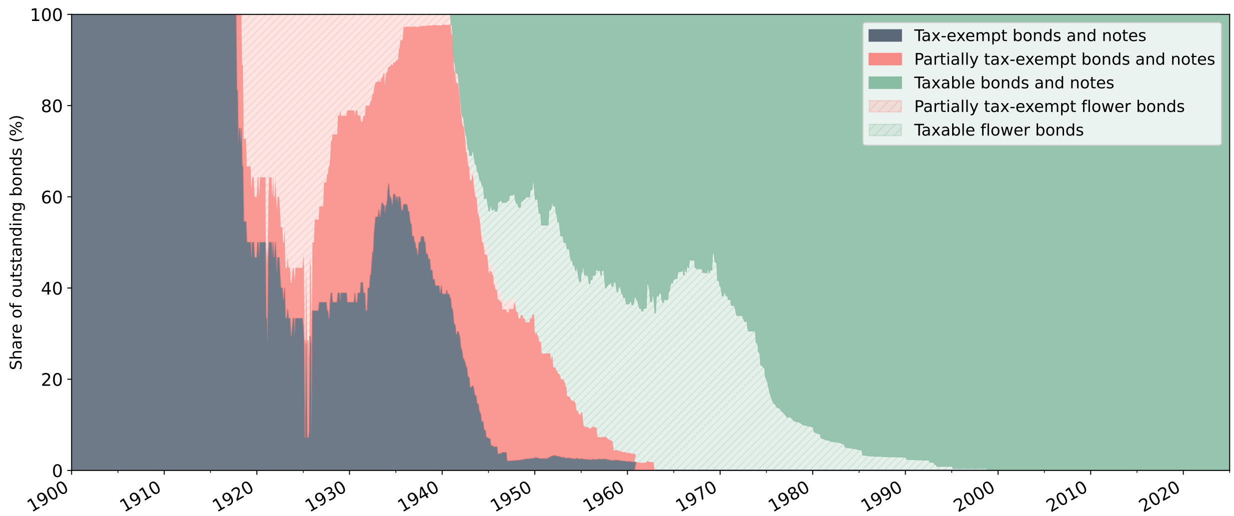

Figure 1: Share of Outstanding Treasury Bonds and Notes with Tax Exemptions.

Notes: Excluding T-Bills and Certificates of Indebtedness. Different colors represent the tax treatment of each issue.

We can gauge the approximate price impact of this exemption by analyzing the early 1940s, a period during which taxable, partially tax-exempt, and fully tax-exempt bonds were traded concurrently. The middle panel of Figure 2 illustrates the yields-to-maturity across various maturity horizons for taxable, partially tax-exempt and fully tax-exempt government bonds outstanding in September 1942. The plot highlights that the price impact of

[5] Treasury Secretary McAdoo advocated for the creation of partially tax-exempt bonds as a means of stabilizing interest rates, which were increasing as surtaxes increased. He wanted to create a class of bonds to be held by households, rather than by banks who bought up tax-exempt debt to avoid their relatively higher tax burden.

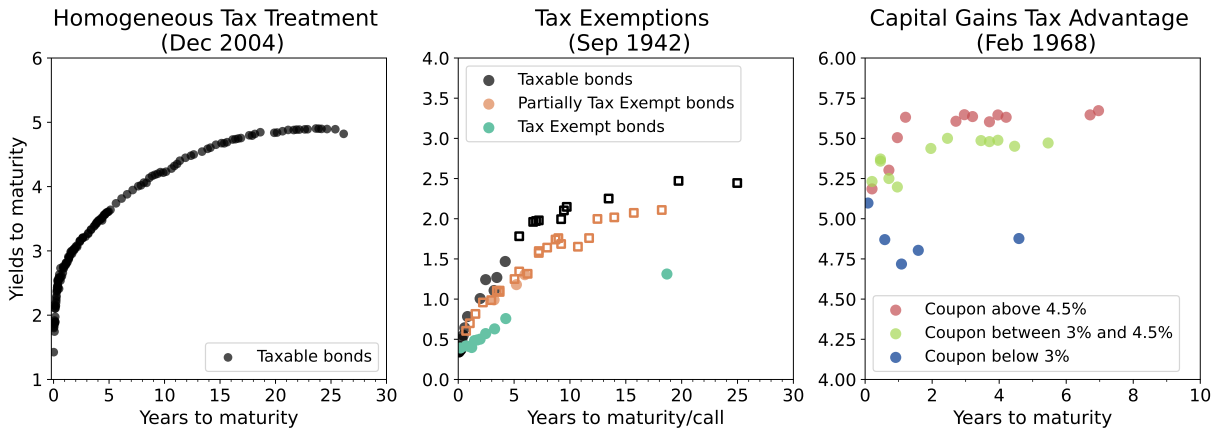

Figure 2: Price Implications of Tax Advantages.

Notes: Panels depict yields-to-maturity (y-axes) against years-to-maturity (x-axes) for government bonds on different dates (panel title). Each circle/square corresponds to a separate bond outstanding in the given month. Dots show non-callable bonds, squares represent callable bonds.

federal income tax exemptions was substantial. Notably, at the five-year horizon, tax-exempt bonds earned yields approximately 80 basis points lower than those of taxable bonds with comparable coupon rates and maturities. For longer maturities, the effect was even larger.

Capital Gains Tax Advantage on Low Coupon Bonds: The holding period return of a bond with coupon cp_i consists of two components: the coupon yield, $cp_i/p_{t,i}$, and capital gains or losses, $p_{t+1,i}/p_{t,i} - 1$. In equilibrium, (risk-adjusted) *after-tax* holding period returns are equalized across all outstanding bonds so—all else equal—bonds with lower coupon yields must trade at lower prices and earn higher capital gains.

As long as the taxation of coupon income and capital gains or losses remains symmetric, the equilibrium relationship between coupon rates and the proportion of income derived from capital gains has no direct impact on bond yields. In particular, capital losses are taxed at the same rate as coupon income and are amortized each period. Consequently, in periods dominated by capital losses, the tax treatment remains uniform across bonds (see Appendix E). A salient example is the 1985–2022 period, when most bonds were trading well above par and so the market understood there would be future price decreases back to par. The left panel of Figure 2 depicts the term structure of yields-to-maturity for a representative month within this interval. Evidently, despite the presence of taxation, the resulting price effects are strikingly homogeneous across the bond sample.

On the other hand, since 1921, the US tax code has consistently favored long-term capital gains over interest income by setting $\tau^{cg} < \tau^{inc}$ and by deferring capital gains taxation until realization (potentially until maturity). Consequently, low-coupon bonds—those with coupons below the prevailing market interest rate—were subject to a lower effective tax rate than high-coupon bonds. The price impact of this "capital gains tax advantage" became particularly evident in the period from 1955-1985, when rising interest rates caused low-coupon bonds issued in the 1950s to trade at deep discounts relative to par and so the market understood there would be future price increases as they reverted to par at maturity. The right panel of Figure 2 illustrates the corresponding coupon-rate effect on observed yields-to-maturity: in February 1968 bonds with the lowest coupons (blue dots) exhibited yields nearly a full percentage point lower than those with the highest coupons (red dots).

3.2.2 Embedded Options

Estate tax provisions ("flower bonds"): Between 1918 and 1971 the government issued a subclass of bonds, known as "flower bonds", which could be used to pay the bondholder's federal estate taxes upon their death *at par value* (instead of market value) plus accrued interest. Moreover, prior to 1976, flower bonds were valued as inherited property *at their par value* on the date of the decedent's death, effectively exempting them from long-term capital gains taxes when they were redeemed early for estate tax purposes. This capital gains tax exemption was terminated by the Tax Reform Act of 1976, which passed in October 1976.

Figure 1 shows that flower bonds were a significant subset of Treasury securities during the early decades of the post-WWII period. Importantly, from 1955-1971, almost all outstanding Treasurys with maturity greater than 10 years were flower bonds (see Appendix G.2.3). After March 1971 Congress stopped issuing bonds with flower bond privileges, ensuring a gradual reduction in their overall supply as outstanding issues matured or were used for estate tax purposes and progressively retired over time.

In practice, the flower bond provisions meant that they effectively acted as an inflation hedge. Rising inflation expectations would drive up interest rates, which, all else equal, would decrease bond market prices relative to their par value. This decline, in turn, would increase the value of both the flower bond privilege to offset estate taxes at par and the flower bond capital gains tax advantage. Indeed, the redemption of flower bonds increased during periods of high inflation. In this way, flower bonds contained an "inflation hedge" or "inflation put option" and so traded more akin to inflation protected bonds than nominal bonds.

To illustrate the importance of the flower bond price distortions, on the left panel of Figure 3, we show yields-to-maturity for flower bonds (in red) and non-flower bonds (in black) for the month of August 1976, a period with high inflation. Evidently the flower bond provisions had a significant price impact. For longer maturities, the flower bond yields-to-maturity are 1-3 percentage points below yields-to-maturity of comparable non-flower bonds (the black dots) and appear to follow a downward sloping yield curve.

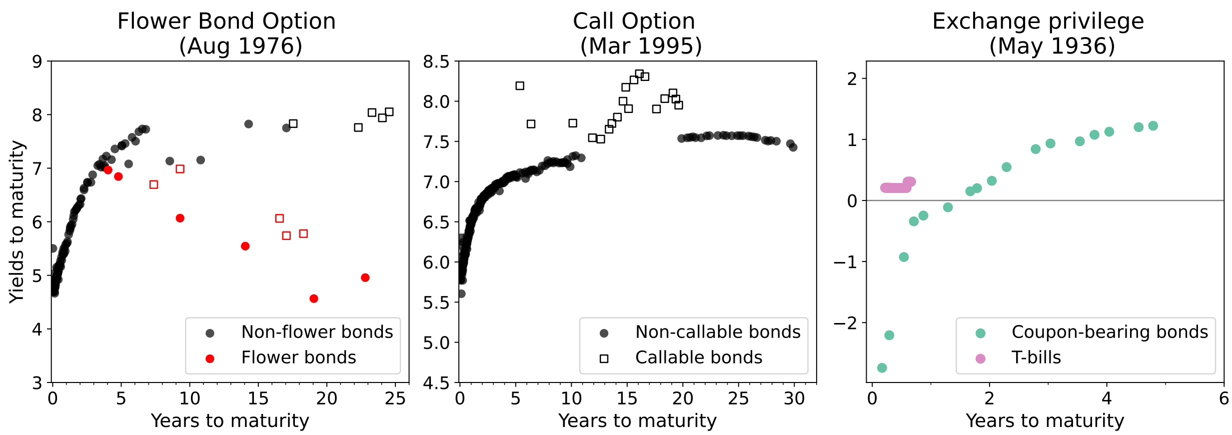

Figure 3: Price Implications of Embedded Options.

Notes: Panels depict yields-to-maturity (y-axes) against years-to-maturity (x-axes) for different dates (panel title). Each circle/square corresponds to a separate bond outstanding in the given month. Red color represents "flower bonds", black color is for regular taxable bonds. Dots show non-callable bonds, squares represent callable bonds.

Call provisions: Many government and corporate bonds contained call provisions, which grant the issuer the right to repurchase its bond before its maturity at a prespecified "call price". Call provisions give positive option value to the issuer but introduce cash flow uncertainty for bondholders and so typically trade at a discount compared to otherwise identical non-callable bonds. Because issuers are expected to call bonds when their market price sufficiently exceeds the call price, the call option discount tends to be high when bond prices are high. Call provisions are accompanied by a *call-deferment period*—a predetermined timeframe after issuance (but before maturity) during which the issuer cannot call the bond. Intuitively, the size of the discount investors demand for holding callable bonds is inversely related to the call price and the length of the call-deferment period.

Figure 18 in Appendix D.1 shows that a large proportion of government bonds were callable until the 1960s and a large proportion of corporate bonds were callable throughout our sample, except for the early 2000s. Prior to the 1960's, callable highest-grade corporate bonds typically had very brief call-deferment periods. Most were callable on any interest payment dates with notice periods typically ranging from 30 to 60 days. The other bonds generally only provided a little more protection, with call deferment periods typically around five years. In contrast, callable US government bonds typically featured 3-6-month notice periods along with long call-deferment periods often only a few years shorter than the bonds' maturity.

To illustrate the price implications of call options, the middle panel in Figure 3 shows yields-to-maturity for callable (squares) and non-callable government bonds (dots). Evidently, the value of call options was relatively large in March 1995 resulting in a visible divergence between the term structures of yields-to-maturity of callable and non-callable bonds. Appendix Section D.1 provides further details on differences in call features between corporate and government bonds.

Exchange Privilege: During the 1930s, interest-bearing US debt nearly doubled, placing substantial pressure on the US Treasury to allocate newly issued securities to the private sector. This challenge was further exacerbated by legal constraints that prohibited the issuance of new government debt securities below par value.[6] In response, as explained by Cecchetti (1988), the US Treasury began issuing new bonds with coupon rates implying market prices above par value, yet these bonds were sold at par. Holders of maturing government bonds and notes received preferential treatment in the allocation of these new issues, creating a valuable "exchange privilege": upon maturity, coupon-bearing Treasury securities could be exchanged for new bonds at par, which subsequently traded above par.

The value of this exchange option exerted significant downward pressure on the yields of coupon-bearing government bonds. In fact, throughout the 1930s, the yields of bonds nearing maturity often turned negative. The right panel in Figure 3, depicting yields-to-maturity for outstanding government bonds in May 1936, is a representative example. Except for the zero-coupon T-Bills (that did not have the exchange option), all bonds less than 18 months to maturity appear to have offered a negative yield-to-maturity! According to Cecchetti (1988), the value of the exchange privilege was non-trivial throughout the early 1940s. While the practice of exchange continued beyond 1944, the terms were no longer as favorable and the value of the exchange option disappeared.

3.3 Implications for US Treasury Funding Advantage Measures

The bond-specific features discussed in Subsection 3.2 potentially lead to distortions in the estimation of government funding advantage. To illustrate this, Figure 4 plots the yields-to-maturity for both government and corporate bonds in January 1976, a period of high

[6]The Second Liberty Bond Act required that new Treasury bonds and certificates of indebtedness be issued at par and new notes issued at not less than par.

inflation. It also depicts a collection of spreads that tell very different stories about government funding advantage. The spread between long-term non-flower bond yields and long-term corporate bond yields (20-30 years maturity), which we interpret as a reasonable approximation to the undistorted spread, is relatively small at approximately 55 basis points. By contrast, the spread between long-term corporate bonds and flower bonds, which we interpret as highly distorted by flower bond privileges, is very large at approximately 297 basis points.

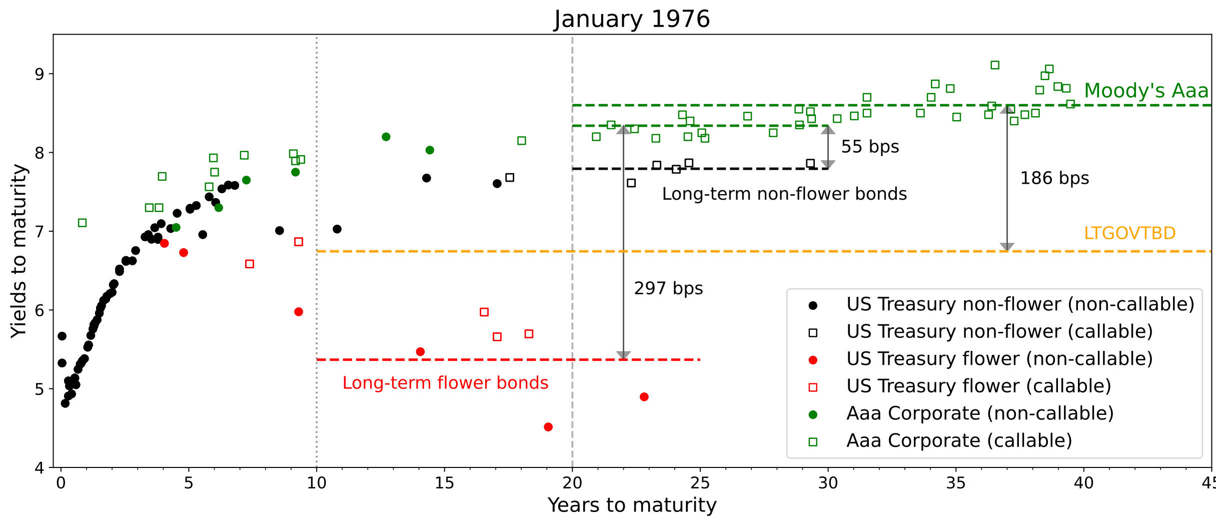

Figure 4: Calculation of Government Funding Advantage

Notes: Panel depicts yields-to-maturity (y-axes) against years-to-maturity (x-axes) for different dates (panel title). Each circle/square corresponds to a separate bond outstanding in the given month. Red color represents "flower bonds", black color is for regular taxable bonds. Dots show non-callable bonds, squares represent callable bonds.

Finally, we also depict the most widely used measure of historical government funding advantage on long-maturity bonds (initially proposed by Krishnamurthy and Vissing-Jorgensen (2012) and subsequently used in many papers), which is computed as the difference between two yield indices:

- Moody's Seasoned AAA-rated long-maturity corporate bond index (FRED code: AAA)—constructed from a sample of industrial and utility bonds (industrial only after 2002) with more than 20 years to maturity, and

- The Federal Reserve Bulletin's long-term US government bond yield index (FRED code: LTGOVTBD)—constructed as the average yield on *all* outstanding government bonds neither due nor callable in less than 10 years.[7]

For brevity, we will call this the *index-based* AAA Corporate-Treasury spread throughout the paper. The green and orange dashed lines on Figure 4 plot the Moody's index and the LTGOVTBD series values in January 1976 respectively. We also depict the index-based spread between these lines, which, like the flower bond spread, is very large at 186 basis points. This is because the LTGOVTBD series averages over flower and non-flower bonds, and there are sufficiently many flower bonds still outstanding in 1976 to distort the average. In this sense, the index-based spread includes the value of flower bond privilege and so significantly overstates the government's funding advantage.

4 Estimation Methodology

In this section, we describe how we estimate the term structure of the US government's funding advantage, while controlling for the tax and option-related distortions outlined in Section 3. Section 4.1 first describes how we correct for the distortions by specifying functional forms for the tax adjustment term $z_i(\theta_t, p_{t,i})$ and the option value $v_i(\theta_t, p_{t,i})$ that draw on tax legislation and option pricing theory. Section 4.2 then outlines a yield curve estimation strategy using Kernel Ridge regression (as in Filipović et al. (2022)) to estimate zero-coupon yield curves for both corporate and Treasury bonds.

As a sense check for our estimation, we establish a rough "benchmark" by constructing an index-based spread using a restricted sample of "standard" bonds that are not or only minimally affected by tax advantages or option features. This approach aligns closely with Salomon Brothers (1988) and Homer and Sylla (2004), as it averages yields-to-maturity within narrowly defined groups of bonds at specific maturities. This approach offers a natural sense-check because it addresses bond heterogeneity without needing to model distortions. However, it is insufficient to estimate a full term structure because there are many historical periods with insufficiently many "standard" bonds to construct an index-based spread using only these bonds and yields-to-maturity are not suitable for pricing bonds with different cash flow profiles. Instead, we integrate the selection-based index spread with the Kernel Ridge regressions by treating the former as an "anchor" that informs the shape and level of the estimated yield curves.

[7]More precisely, the Treasury bonds included are due or callable after 12 years for 1926–1941, 15 years for 1941–1951, 12 years for 1952, and 10 years for 1953–1999. The series was discontinued in 2000, after which point papers in the literature use the "market yield on US Treasury Securities at 20-year constant maturity" (FRED code: GS20).

4.1 Adjustments For Bond Heterogeneity

4.1.1 Tax Distortions

The modern yield curve literature has largely overlooked taxes and used the unadjusted law-of-one-price formula (Equation (2.1) in Section 2), to estimate discount functions from future cash flows. This approach implicitly assumes that price errors—defined as the difference between observed prices and those implied by Equation (2.1)—are invariant to taxes. This assumption would be true if bonds were restricted to a sample with homogeneous tax treatments so that the price effect of taxes is not maturity or bond specific (i.e., not indexed by i or j in our notation). In this case, taxes simply rescale the yield curve and so can be imposed after the discount functions have been estimated. We refer to this as the estimation being *scale-invariant* to taxes. In Appendix E.1, we show that this scale-invariance property holds when (i) the tax rate is common across all bonds, (ii) capital gains and capital losses are taxed each period, and (iii) coupon income, capital gains, and capital losses are all taxed at the same rate. When these conditions are not satisfied, standard yield curve estimation procedures will generate systematic patterns in price errors that reflect heterogeneity in tax treatment.

Section 3 demonstrated that these criteria are not generally met in our historical sample. Before World War II, condition (i) is violated because of heterogeneous tax exemptions on government bonds (as illustrated in the middle plot of Figure 2). After World War II, tax rates on new issues of government bonds become homogeneous but the second two conditions remain as issues because capital gains taxes are lower and can be deferred. From 1955-85, bonds primarily earned capital gains and so the distortions were large (as was illustrated in the right plot of Figure 2) while for 1985-2022, bond primarily earned coupon yields and so the distortions were small (as was illustrated in the left plot of Figure 2). This makes it essentially impossible to ignore taxes by restricting our historical sample to bonds without tax distortions. Instead, we need to find a way to correct for such tax distortions.

Consider a bond with maturity $M_{t,i}$, market price $p_{t,i}$, and yield-to-maturity $\widehat{y}_{t,i}$. Let the marginal income tax rates on fully taxable, partially tax-exempt, and fully tax-exempt government bonds be τ^{inc}, τ^{pte}, and τ^{fte}, respectively, and let τ^{cg} be the long-term capital gains tax rate. Our observations about the tax code suggest that the tax distortion $z_{t,i}^{(j)}$ on bond i at maturity j should depend upon the relative tax concession on the bond, the extent to which bond holders can defer capital gains, and the relative tax concession on capital gains. This motivates the following form for the tax adjustment factor:

$$z_{t,i}^{(j)} \approx \underbrace{\exp\left(\eta_{t,0}^{i}\widehat{y}_{t,i}j\right)}_{\text{tax exemption}} \underbrace{\underbrace{\exp\Big(-\eta_{t,1}\left(M_{t,i}-j\right)\widehat{y}_{t,i}\Big)}_{\text{tax deferral discount}} \underbrace{\left(1+\eta_{t,2}\sum_{s=1}^{j}\max\left\{\frac{\widehat{p}_{t+s,i}}{\widehat{p}_{t+s-1,i}}-1,0\right\}\right)}_{\text{adjustment for capital gains}}}_{\text{capital gains tax advantage}} \tag{4.1}$$

where $\eta_{t,0}^{i} := (\tau^{inc}-\tau^{i})/(1-\tau^{i})$ for $i \in \{inc, pte, fte\}$ is the relative tax concession on the bond, $(\eta_{t,1}, \eta_{t,2})$ parametrizes the capital gains advantage, and $\widehat{p}_{t+s,i}$ is the expected price for bond i at period $t+s$.[8] The first term in equation (4.1) rescales the cash flows to account for any differences between bond i's tax rate and the income tax rate. Since $\eta_{t,0}^{inc} = 0$, the first "tax exemption" term is only relevant for government bonds and only before the 1950s (see Figure 1). Moreover, for the 1917-1960 Treasury sample, we can infer $\eta_{t,0}^{pte}$ and $\eta_{t,0}^{fte}$ from directly comparing yields-to-maturity on outstanding fully taxable, partially tax-exempt, and fully tax-exempt bonds that are traded well above par.[9]

The other terms in equation (4.1) rescale the cash flows to account for the tax advantage on any capital gains earned while holding the bond. The third term computes the expected future capital gains while the second term discounts the future capital gains advantage back to time $t+j$. This means that the parameters $(\eta_{t,1}, \eta_{t,2})$ can be interpreted as characterizing how much to discount the future capital gains tax advantage given the investor's holding period and the magnitude of the tax advantage when those capital gains are realized. Since we cannot directly infer $(\eta_{t,1}, \eta_{t,2})$, they are the tax effect parameters we need to estimate.

By inspection, we get that $z_{t,i}^{(j)} = 1$ when bond i has no tax exemption, sells at or above par, and its premium is amortized every period. This means that our estimation approach reduces to the standard literature approach of estimating the unadjusted law-of-one-price formula (2.1) during periods where the conditions for scale-invariance are satisfied (e.g. 1985-2022) but activates additional complexity when the conditions are not satisfied (e.g. 1955-1985). In Section 5.3 we show that (4.1) leads to unbiased price errors and improves the fit during periods with tax exemptions and large capital gains. This suggests that formula (4.1) successfully captures bond-specific tax distortions relative to the common reference discount function q_t.

Our formula can be thought of as a generalization of the approach in the micro tax-

[8] We approximate expected bond price trajectories using those implied by the yields-to-maturity $\widehat{y}_{t,i}$. These can be derived from the recursion: $\widehat{p}_{t,i} = \exp(-\widehat{y}_{t,i})(cp_i + \widehat{p}_{t+1,i})$ with boundary conditions $\widehat{p}_{t+M_i} = 100$, and $\widehat{p}_{t,i} = p_{t,i}$.

[9] From 1917-1941, we don't observe fully-taxable Treasury bonds. Since partially tax exempt bonds were subject to federal income taxes less the normal income tax, we set $\tau_{inc} = \tau_{pte} + .03$ during this period, following our discussion in Section 3.2.1.

based asset pricing literature (e.g. Robichek and Niebuhr (1970), Colin and Bayer (1970), McCulloch (1975), Cook and Hendershott (1978)). This literature computes after-tax yields using variants of the following asset pricing formula:

$$p_{t,i} = \sum_{j=1}^{M_i} \overline{q}_t^{(j)} (1-\tau^i) cp_i + \\ + \overline{q}_t^{(M_i)} \left[100 - \tau^i \min\{100 - p_{t,i}, 0\} - \tau^{cg} \max\{100 - p_{t,i}, 0\} \right] \tag{4.2}$$

where $\{\overline{q}_t^{(j)}\}$ denotes the after-tax discount function. The literature has used this formula by substituting in observed bond prices, coupon rates, and various IRS tax rates based on the judgment of the different researchers. Formula (4.2) can be derived by assuming that the marginal investor holds the bond to maturity, capital losses at maturity are taxed at τ^i while capital gains at maturity are taxed at τ^{cg}, and tax rates are expected to stay fixed over the lifetime of the bond. Appendix E.2 shows that (4.2) approximately implies the following tax distortion relative to the reference discount function:

$$z_{t,i}^{(j)} = \exp\left(\eta_{t,0}^i \widehat{y}_{t,i} j - \tau^i (1 - \eta_{t,0}^i) \left(M_{t,i} - j \right) \widehat{y}_{t,i} \right) \underbrace{\left(1 + \left(\frac{\tau^i - \tau^{cg}}{1 - \tau^i} \right) \max\left\{ \frac{100}{p_{t,i}} - 1, 0 \right\} \right)}_{\text{capital gains tax advantage}}.$$

This equation resembles Equation (4.1), with two key distinctions. First, equation (4.1) does not impose cross-equation restrictions on the parameters $(\eta_{t,1}, \eta_{t,2})$ derived from features of the prevailing tax code and the model implied by equation (4.2). Second, it does not assume that investors hold all bonds to maturity but instead calculates capital gains from expected price changes.

The advantage of our estimation approach is that it is not tied to a narrow, potentially misspecified model of investor behavior. First, it enables us to remain agnostic about the identity of the marginal bond holder. Rather than selecting statutory tax rates from IRS schedules to compute *after-tax* yields, we estimate a flexibly parameterized distortion relative to the reference (before-tax) yield curve—an approach that obviates the need to identify the "true" marginal tax rates. Second, the literature assumption that all bonds are held to maturity is unrealistic, especially for samples with a large fraction of long-term bonds (20+ years), like our corporate bond sample. In particular, it tends to overstate the capital gains advantage because it exaggerates the discounting on the future capital gains tax. Decoupling the degree of tax deferment from the magnitude of the capital gains advantage—by relaxing the link between $\eta_{t,1}$ and $\eta_{t,2}$—and not imposing bonds are held to maturity enables us to mitigate this bias when warranted by the bond sample.

4.1.2 Embedded Options

Many bonds contain embedded options that affect their prices. Depending on the type of bond, the option value in (2.4) can be the (negative) value of the call option, the value of the inflation put option embedded in flower bonds, or the value of the exchange privilege, respectively.[10] We denote this by:

$$v_i(\theta_t, p_{t,i}) = \begin{cases} -v_i^c(\theta_t, p_{t,i}), & i = \text{callable bond} \\ v_i^f(\theta_t, p_{t,i}), & i = \text{flower bond} \\ v_i^e(\theta_t, p_{t,i}), & i = \text{exchange privileged bond} \end{cases}$$

Call Option (v_i^c): Consider a callable bond with maturity M_i, market price $p_{t,i}$, coupon rate cp_i, strike price $p_{t,i}^c$, and date from which the bond can be called, $T_{t,i}^c$. Option pricing theory (e.g. Black and Scholes (1973)) tells us that the current value of the bond's call option, $v_{t,i}^c$, should depend upon the return from exercising the option (the "moneyness" of the option), the time until the option becomes active, the window in which the option can be exercised, and the future path of macroeconomic variables (e.g. interest rates). This motivates the following functional form:[11]

$$v_i^c(\theta_t, p_{t,i}) := \beta^{(T_{t,i}^c - t)} \exp\Big(\underbrace{\phi_{t,0}}_{\substack{\text{common}\\ \text{component}}} + \phi_{t,1} \max\{\underbrace{\widehat{y}_{t,i}^c - \widehat{y}_{t,i}}_{\text{moneyness}}, 0\}\Big) \Big(\underbrace{M_i - T_{t,i}^c}_{\text{call window}}\Big)^{\phi_{t,2}} \tag{4.3}$$

where $(\widehat{y}_{t,i}, \widehat{y}_{t,i}^c)$ denotes the yields-to-maturity if the bond is purchased at the current market price and current strike price respectively and $(\beta, \phi_{t,0}, \phi_{t,1}, \phi_{t,2})$ denotes the set of parameters to be estimated subject to the restrictions that $\phi_{t,1} \geq 0$ and $\phi_{t,2} \geq 0$. We interpret $\widehat{y}_{t,i}^c - \widehat{y}_{t,i}$ as the "moneyness" of the option because it captures the excess return from buying the bond at strike price (exercising the call) over buying the bond at the market price. If the market price is greater than the call price, then the yield-to-maturity from exercising the call option is greater than the yield-to-maturity from purchasing the bond and so the moneyness becomes positive.[12] This implies that β can be interpreted as the time discount factor on the option, $\phi_{t,0}$ can be interpreted as the common component of the option value,

[10] Some bonds have multiple option features. For callable bonds with the exchange privilege, we take $v_i = v_i^e - v_i^c$ additively. We drop callable flower bonds from the estimation, as they have both an embedded call and a put.

[11] A similar functional form to capture the value of call option was proposed by Thies (1985).

[12] For stocks following a random walk process, the moneyness for a call option is often defined as $\max\{p_{t,i} - p_{t,i}^c, 0\}$. This doesn't make sense for finite maturity bonds because bond prices necessarily drift towards par value at maturity rather than following a random walk. For this reason, we instead include the excess yield from exercising the option.

$\phi_{t,1}$ can be interpreted as the responsiveness of the option value to the moneyness of the option, and $\phi_{t,2}$ can be interpreted as the responsiveness to the size of the call window. We allow $(\phi_{t,0}, \phi_{t,1}, \phi_{t,2})$ to be time varying to capture the sensitivity of the option value to the prevailing macroeconomic conditions.

Flower Bonds (v_i^f): Consider a flower bond with maturity M_i, market price $p_{t,i}$, and coupon rate cp_i. Flower bonds could be redeemed at par to offset estate taxes upon the holder's death, effectively providing a hedge against inflation risk. If flower bonds could be traded to investors near death, the flower bond provision was potentially priced like a put option. We allow for this possibility by modeling the flower bond privilege as a put option with the following functional form:

$$v_i^f(\theta_t, p_{t,i}) := \exp\Bigg(\underbrace{\gamma_{t,0}}_{\substack{\text{common}\\ \text{component}}} + \gamma_{t,1} \max\{\underbrace{\widehat{y}_{t,i} - \widehat{y}^p_{t,i}}_{\text{moneyness}}, 0\}\Bigg) M_i^{\gamma_{t,2}} \tag{4.4}$$

where $\widehat{y}^p_{t,i}$ is the par yield of bond i, and $(\gamma_{t,0}, \gamma_{t,1}, \gamma_{t,2})$ are the parameters to be estimated, subject to $\gamma_{t,1}, \gamma_{t,2} \geq 0$. For flower bonds, we refer to the "moneyness" of the flower bond privilege as $\widehat{y}_{t,i} - \widehat{y}^p_{t,i}$ because it represents the excess yield-to-maturity from using the flower bond privilege to redeem the bond at par value compared to selling it at market value. High moneyness (i.e., when the market price is far below par) implies a valuable put option. Correspondingly large estimated values for $\gamma_{t,0}, \gamma_{t,1}$ suggest that the option was actively priced by investors—possibly those most likely to redeem the bond, such as individuals close to death with imminent estate tax obligations[13]—while correspondingly low estimated values suggest the option was not priced. Large values of $\gamma_{t,2}$ suggest that longer maturity flower bonds held a more valuable option than shorter term flower bonds.

Exchange Privilege: Unlike the call or flower bond options, the exchange privilege could be exercised only at maturity so option value can be written more simply as

$$v^e_{t,i} := q_t^{(M_{t,i})} \zeta_i \tag{4.5}$$

where $\zeta^i \geq 0$ is a bond-specific parameter representing the expected payoff from exchanging the bond at maturity. Following Cecchetti (1988), we compute ζ_i directly from data for each

[13]This would be consistent with Mayers and Clifford (1987), which finds that the flower bonds with the deepest discount were redeemed at the fastest rate, suggesting that the most deeply discounted—and thus most in-the-money—flower bonds were concentrated in the hands of individuals with the highest death probabilities.

bond i when they are three months to maturity using the formula:

$$\zeta_i = \exp\left(y_t^{T\text{-}bill} M_{t,i}\right) p_{t,i} - \left(cp_{t+M_{t,i}} + pr_{t+M_{t,i}}\right)$$

where $y_t^{T\text{-}bill}$ is the yield on a T-Bill with the closest maturity to bond i. In general, the expected payoff at maturity fluctuates over time. However, since short-term T-Bills were the only assets without the exchange privilege, estimating how expectations evolved before the bond got near maturity is infeasible. Instead, (4.5) assumes that throughout the bond's lifetime, the representative investor has perfect foresight of the expected payoff three months prior to maturity, as captured by ζ_i.

4.2 Estimation

Our goal is to estimate the discount function, taking into account price distortions due to tax advantages and embedded options. This involves using bond-level data on trading prices, $p_{t,i}$, before-tax promised cash-flows, $\mathsf{c}_{t,i}$, call price schedules, $\{p^c_{t,i}\}_{t \geq T^c_i}$ and inferred values of tax exemptions $\{\eta^{pte}_{t,0}, \eta^{fe}_{t,0}\}$ and exchange privilege ζ_i, we estimate the reference discount function q_t that minimizes deviations from the law-of-one-price pricing formula, (2.4), subject to the tax and option distortions (4.1), (4.3), (4.4), and (4.5) with parameter vector:

$$\theta_t := (\eta_{t,1},\ \eta_{t,2},\ \phi_{t,0},\ \phi_{t,1},\ \phi_{t,2},\ \gamma_{t,0},\ \gamma_{t,1},\ \gamma_{t,2})$$

Conditional on our tax and option corrections, one could choose any popular yield-curve estimator, such as Diebold and Li (2006), Gürkaynak et al. (2007), Liu and Wu (2021), or Filipović et al. (2022) for the estimation of q_t, as the corrections (4.1)-(4.5) essentially homogenize our bond datasets, allowing estimation with like-for-like securities.

Regardless of the estimator used, we seek to ground our analysis in a homogeneous subset of bonds that are least affected by tax- and option-induced distortions. To this end, we will write the reference discount function as a sum of two components:

$$q_t^{(j)} = a_t^{(j)} + h_t^{(j)}, \qquad \text{s.t.} \qquad a_t^{(0)} = 1.$$

We refer to $a_t^{(j)}$ as an "anchor" and interpret $h_t^{(j)}$ as the deviation from this anchor. This formulation allows us to incorporate external information into the estimation of discount curves. We define the anchor, $\mathsf{a}_t := \{a_t^{(j)}\}_{j \geq 0}$, as a selection-based index spread. Specifically, we partition the bond sample into three maturity bins—less than 5 years, 5-15 years, and more than 15 years to maturity—and compute the average yields of non-callable, non-flower bonds traded at or above par within each bin. Although this restriction is well-suited to minimizing the distortions discussed in Section 3, it is sufficiently stringent that only the post-1990 period remains usable. Consequently, we expand our selection-based index to include option bonds that are "out-of-the-money." With this coarse term structure of yield indices serving as an anchor, estimation of q_t entails assessing the extent to which deviations from a_t are warranted by the data.[14]

To estimate q_t, we adapt the non-parametric Kernel Ridge estimator proposed by Filipović et al. (2022). The advantages of this estimator are threefold. First, the space of smooth discount functions to choose from is much larger than popular parametric forms, allowing for more flexibility, while the regularization component of the estimator preserves the smoothness of the fitted curve as desired in a parametric specification. Second, the degree of flexibility permitted in the estimator is chosen to obtain the strongest out-of-sample performance, which Filipović et al. (2022) show improves on the performance of other popular yield curve models in the literature. Finally, this estimator is tractable; its closed form solution along with additional details are discussed in Appendix F.

The goal of the Kernel Ridge estimator is to estimate a discount function $\mathsf{q}_t \in \mathcal{Q}(\alpha, \delta)$, given tuning parameters $\lambda > 0, \alpha > 0, \delta \in [0,1]$ and tax/option parameters θ_t. The space of discount functions $\mathcal{Q}(\alpha, \delta)$ is the set of twice weakly differentiable functions with finite smoothness, where the smoothness norm is defined by equation (4.7) below and characterized by the parameters (α, δ). Conditional on a_t, the discount function, $\mathsf{q}_t := \mathsf{a}_t + \mathsf{h}_t$, is chosen by minimizing the weighted mean squared pricing errors while rewarding smoothness:

$$\min_{\mathsf{q}_t \in \mathcal{Q}(\alpha,\delta),\ \theta_t} \quad \sum_{i \in \mathcal{N}_t} \rho_i \Big(\underbrace{p_{t,i} - v_i(\theta_t, p_{t,i}) - \sum_{j=1}^{M_i} q_t^{(j)} z_i^{(j)}(\theta_t, p_{t,i}) c_{t,i}^{(j)}}_{\text{price error}} \Big)^2 + \underbrace{\lambda ||\mathsf{h}_t||^2_{\alpha,\delta}}_{\text{regularization}} \tag{4.6}$$

where $\{\rho_i\}_{i \in \mathcal{N}_t}$ denotes a set of exogenous weights, and the smoothness norm is:

$$||\mathsf{h}||_{\alpha,\delta} = \left(\int_0^\infty \left(\delta h'(x)^2 + (1-\delta) h''(x)^2 \right) \exp(\alpha x) dx \right)^{\frac{1}{2}}. \tag{4.7}$$

Norm (4.7) represents a δ-weighted linear trade-off between the squared first and second derivatives of h, penalizing oscillations and kinks respectively, under an exponential weighting scheme governed by α. The tuning parameters $(\lambda, \alpha, \delta)$ are selected via K-fold stratified cross-validation across the maturity spectrum. Following Gürkaynak et al. (2007), Payne et al. (2025), and Filipović et al. (2022), the exogenous weights ρ_i are set equal to the squared

[14] In this sense, the anchor can be interpreted as a "prior yield curve."

duration times price of bond i, so that the weighted mean squared error in (4.6) approximates the mean squared yield fitting error.

5 Results

In this section, we show our estimates for the term structure of US funding advantage over 1860-2024. We infer a collection of stylized facts. First, there are low frequency movements in average US funding advantage that correspond to changes in financial regulation and the Fed's quantitative easing programs. Second, existing series have mismeasured long-term yield spreads in the post WWI period leading to a significant overstatment of US funding advantage in the 1920s, and 1970-80s. Third, the US lost its funding advantage during the high inflation in the 1970-80s.

5.1 Long-Term Funding Spreads

We start by inspecting spreads at long maturities. The black lines in figure 5 show time series for the 20-year (top) and 10-year (bottom) US funding advantage, as measured by our estimate for the highest-grade corporate zero-coupon yield minus our estimate for the Treasury zero-coupon yield. Evidently, US funding advantage emerged in the mid 1860s with the end of the Civil War and the introduction of the National Banking system which gave National Banks the privilege to create bank notes so long as they backed them by holding long-term government debt (referred to as "circulation privilege"). It stayed high at around 1.5% until 1920 when it sharply declined to around 0.5%. This corresponds to the elimination of National Bank circulation privilege and the introduction of the Fed monopoly on money creation. Funding advantage then followed a downward trend reaching zero in the late 1970s before reversing course and increasing back up to around 0.5-1.0% in the 2000s.

We compare our estimates to two other time series for long-maturity US funding advantage. First, we compare to the index-based AAA Corporate-Treasury spread defined in Subsection (3.3) and commonly used in the literature, which uses average yields-to-maturity over all bonds. The index-based spread is depicted by the red lines on both subplots in Figure 5. Our 20-year spread estimate follows the index-based spread fairly closely except during the 1920s, when varying degrees of tax exemption on government bonds suppressed long-term Treasury yields, and during the 1970s–1980s, when high inflation and elevated interest rates amplified both the capital gains advantage and the embedded option value of flower bonds. In particular, while the index-based measure (the red line) reaches its highest values during this period, our estimate shows the opposite: the highest-grade corporate to

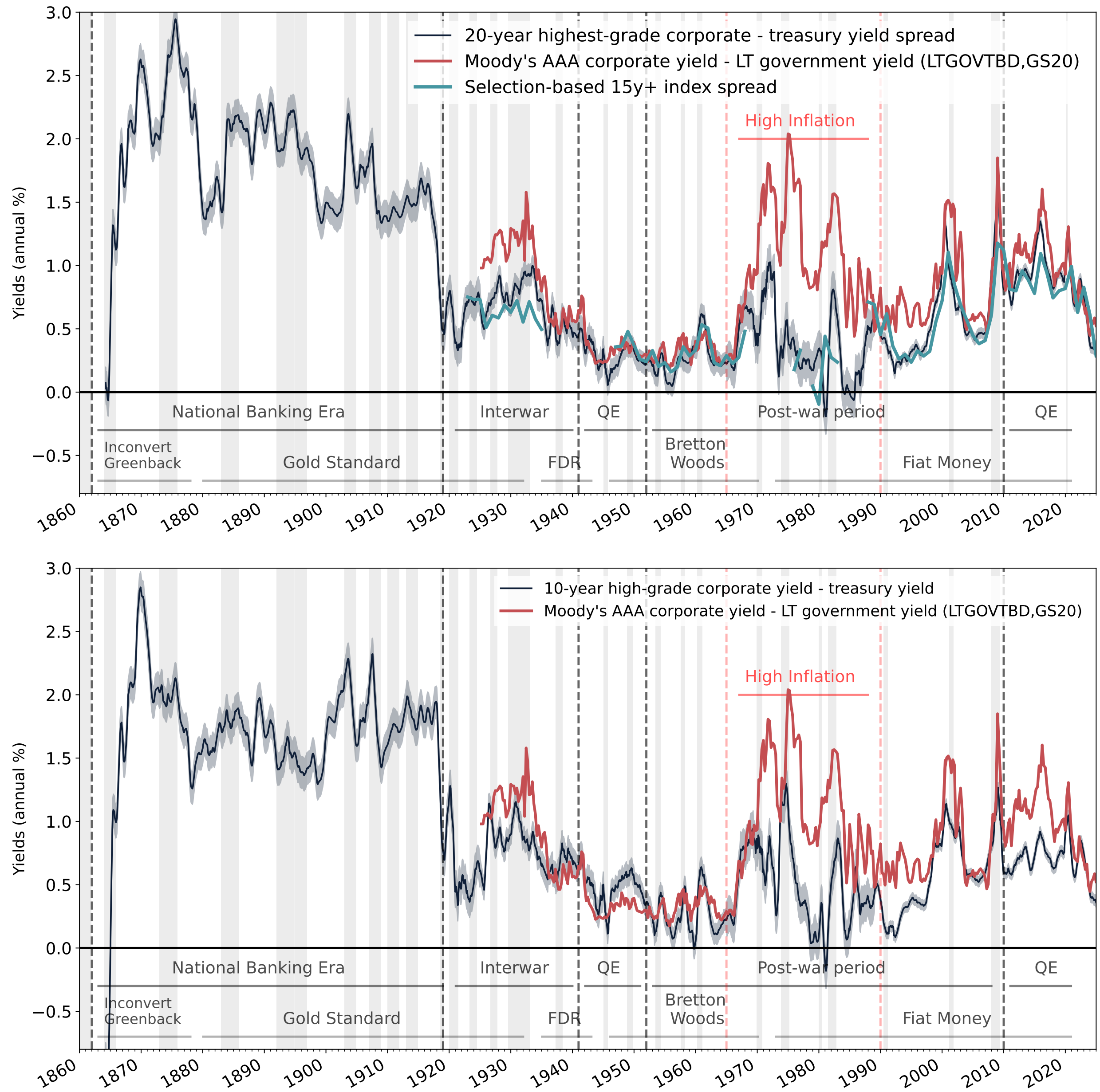

Figure 5: Highest-Grade Corporate to Treasury Spread Estimates: 1860-2024

Notes: Top panel depicts the 12-month centered moving average of the posterior median estimate of the 20-year highest-grade corporate-Treasury spread (black solid line) defined as the difference between 20-year zero-coupon yields on highest-grade corporate debt and US Treasurys. The gray bands depict 90% posterior interquantile ranges. The teal line depicts our selection-based yield index, constructed from a restricted subsample of bonds with maturities exceeding 15 years. The red solid line shows the 12-month centered moving average of the index-based AAA Corporate-Treasury spread proposed by Krishnamurthy and Vissing-Jorgensen (2012). Bottom panel depicts the 10-year highest-grade corporate-Treasury spread against the index-based measure. Dashed vertical lines denote financial regulatory eras. Bottom labeling shows monetary standards. The light gray intervals depict NBER recessions.

Treasury spread is close to zero. This suggests that a large portion of the variation in the index-based measure is attributable to an "inflation risk premium" instead of a "specialness premium" on US Treasurys.[15] We find additional discrepancies relative to the index-based measure at the 10-year maturity in the bottom subplot of Figure 5, which is arguably the more relevant maturity for US government borrowing costs because it is closer to median maturity. In particular, our 10-year spread is relatively high during the yield curve control period, and relatively low during the decade after the Global Financial Crisis (GFC).

Second, we compare to our selection-based index spread, which is depicted by the teal line in the top panel of Figure 5. This spread is constructed from a restricted subsample of bonds with maturities exceeding 15 years and homogeneous characteristics so our estimated 20-year yield spread should closely follow our selection based index spread. That is, the black line should line up with the teal line in Figure 5. Evidently, our estimated 20-year yield spread passes this "sense-check" for the periods at which the teal line can be calculated. The teal line also illustrates the difficulty with attempting to study yields by restricting to homogeneous bond samples: we can only compute the selection-based index spread for a limited range of dates and for an average of long-maturity bonds.

5.2 Term structure

Figure 6 depicts the spread differential between 20-year and 5-year AAA Corporate and Treasury yields. While the US funding advantage was, on average, relatively flat across maturities, certain subperiods reveal pronounced term structures with varying slopes. Specifically, our estimates show a negative slope—indicating a greater funding advantage at shorter maturities—during the yield curve control period, and a markedly positive slope—reflecting a larger advantage at the long end—throughout the decade following the GFC. These patterns in the term structure of AAA-Treasury spreads align with the Federal Reserve's Treasury purchase programs: in the 1940s, the Fed concentrated on short-term government debt, whereas the post-2008 quantitative easing programs prioritized acquisitions of long-term Treasurys.

5.3 Yield Curve Fit

We assess the fit of our yield curve estimation in a number of ways. First, Figure 7 shows properties of the fitted Treasury yield curve across different dimensions of coupons, maturities, and time. The errors appear to be noise, as desired. The estimates have the desirable

[15] This is consistent with Figure 1 in Cook and Hendershott (1978), which suggests that after adjusting for "tax effects" yield spreads between AA corporate and government bonds stayed below 1% before 1975.

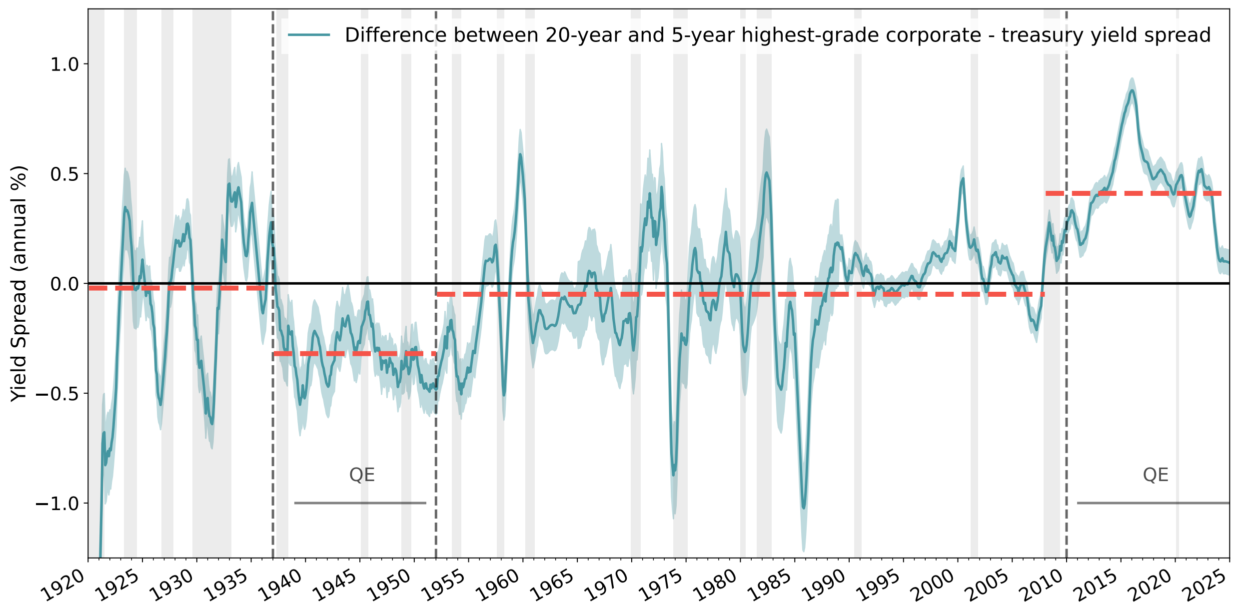

Figure 6: Term Structure of Highest-Grade Corporate to Treasury Spread: 1920-2024

Notes: The solid teal line shows the posterior median estimate of the 20-year minus 5-year US funding advantage estimates. The bands depict 90% posterior interquantile ranges. The orange dashed horizontal lines represent mean values across the corresponding subperiods. Bottom labeling shows two large quantitative easing (QE) episodes. The light gray intervals depict NBER recessions.

property that they fit long-term Treasurys, including those with option features, as well as bonds under 10 years-to-maturity as shown by the bottom left panel in Figure 7. We compare the errors from our estimates to that of Gürkaynak et al. (2007) in Appendix G.2.2. As expected, relative to Gürkaynak et al. (2007), our estimates yield the most substantial reduction in price errors in the 1960-80s when the capital gains advantage is most prominent.

Second, we return to the periods identified in Section 3.2, during which heterogeneous tax treatments and embedded option features gave rise to bond-specific distortions in yields-to-maturity. Figure 8 revisits the dates shown in Figures 2 and 3, substituting raw yields-to-maturity with our tax- and option-adjusted estimates. Evidently, our adjustments do a good job of homogenizing the data, aligning yields-to-maturity along a common par yield curve—mimicking the "ideal" configuration in the top left panel of Figure 8: bonds subject to heterogeneous tax treatments no longer trace distinct curves, and those with embedded flower (call) options no longer fall systematically below (or rise above) the curve.

Third, we investigate the time series properties of the estimated option prices. The top panel in Figure 9 depicts the estimated option prices of two flower bonds that were

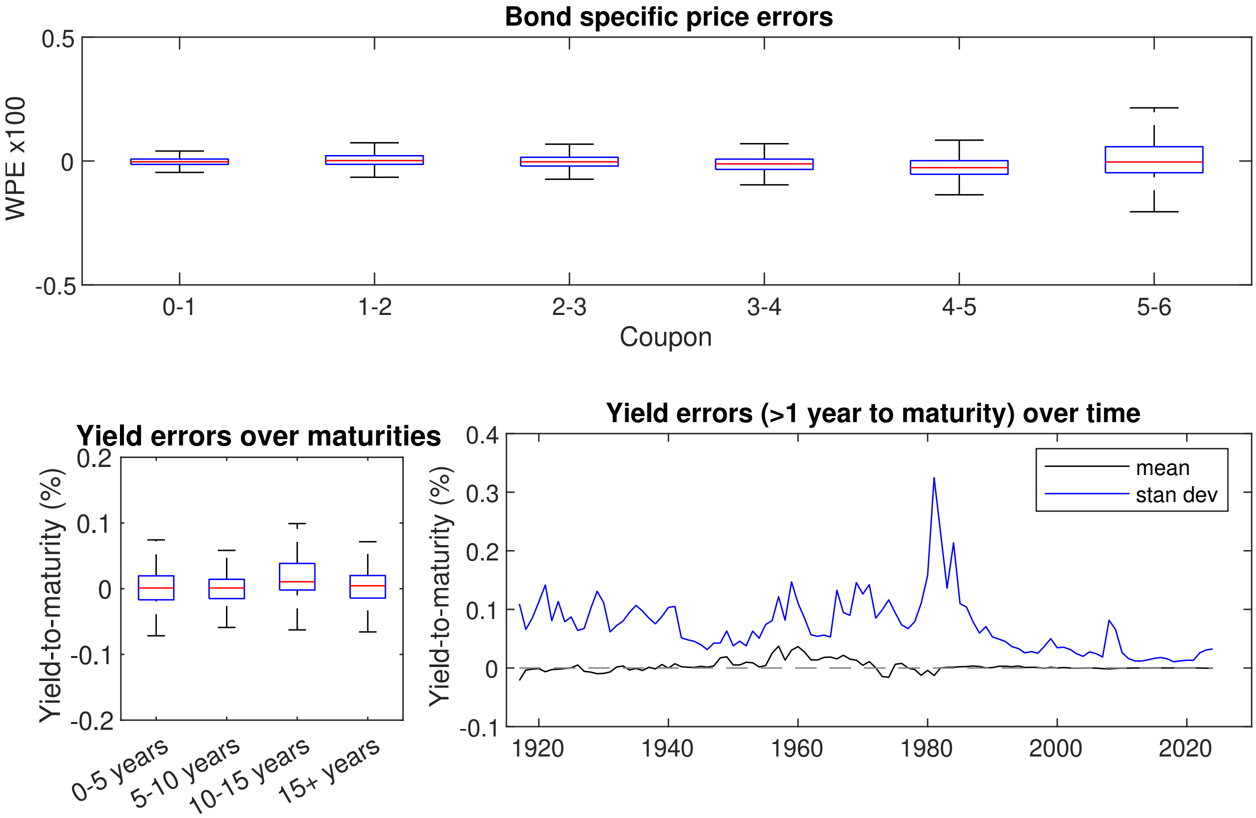

Figure 7: Statistical Fit

Notes: The top panel shows weighted price errors (WPE) by coupon for the entire Treasury sample. The bottom panels show the difference of observed and model implied yields-to-maturity. The bottom left panel shows quartiles of these yield errors across maturity bins for the entire sample. The bottom right plot shows the time series of the mean (black line) and standard deviation (blue line) yield errors for every year in the sample starting in 1917. Pre-1917, our estimates deviate minimally from the estimates of Payne et al. (2025), thus we do not show them here. We exclude option bonds under 15 years-to-maturity (under 10 years-to-call) in the calculations above.

likely purchased for estate-tax purposes.[16] These option values must be subtracted from the market prices of traded bonds to isolate the fundamental value of their underlying cash-flow stream. The estimated option values track the rate of inflation extremely closely, which is consistent with our interpretation that the flower bonds contained an "inflation put option," as described in Section 3.2.2. Additionally, we see the price impacts of two key events in the 1970s. First, following the Treasury's decision to stop issuing flower bonds in March 1971, and the subsequent rise in interest rates, we see that the flower bond options exhibit a large jump in value as investors price the combined effect of high interest rates and the impending decline in the supply of flower bonds. Second, option values fell dramatically in response

[16]Evidence of this can be seen in the amount outstanding, with the net decline from year to year measuring the amount redeemed for estate tax purposes. See Cook (1977).

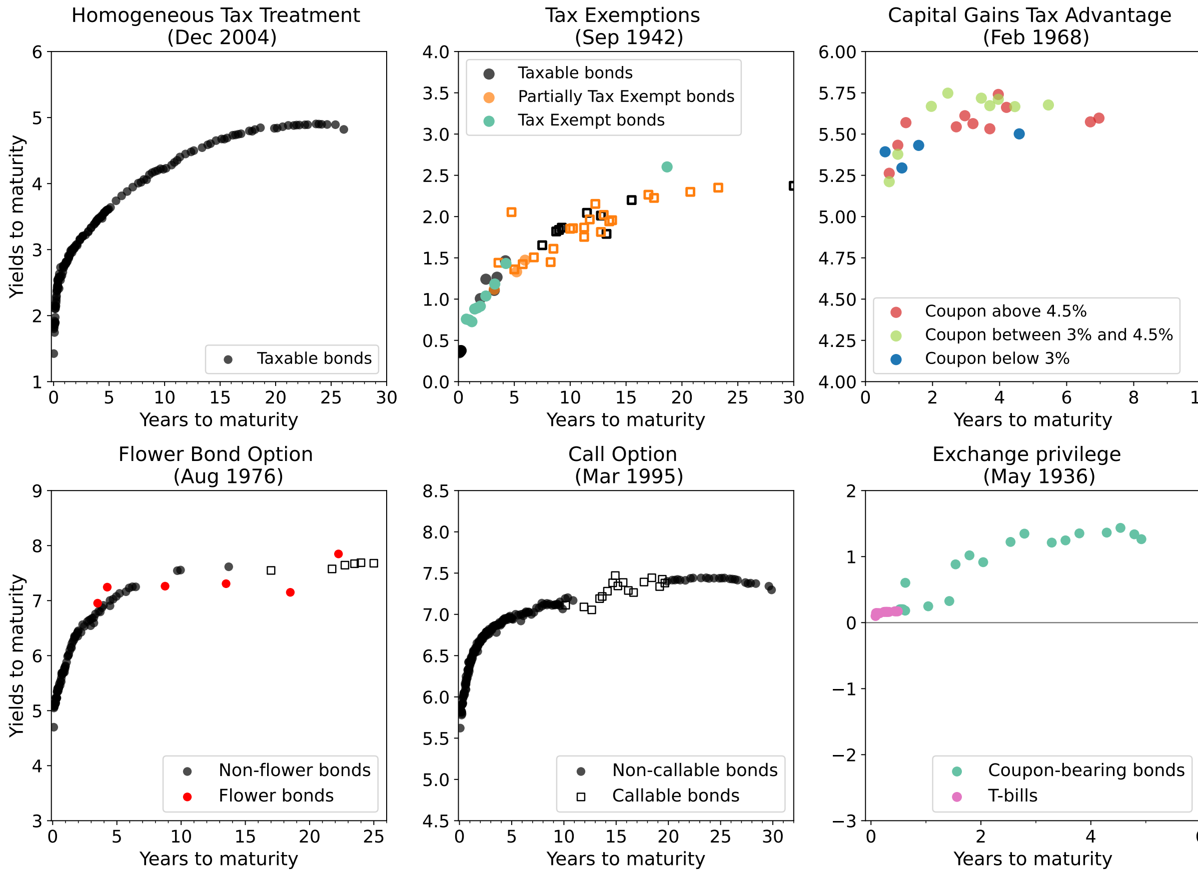

Figure 8: Tax- and Option-Adjusted Yields-to-Maturity

Notes: Tax- and option-adjusted yields-to-maturity are computed from formula (2.4), substituting the wedges z_i and v_i with their respective estimated values. Each circle/square corresponds to a separate bond outstanding in the given month. Dots show non-callable bonds, squares represent callable bonds.

to the Tax Reform Act of 1976. The Act eliminated the additional capital gains advantage flower bonds enjoyed when they were redeemed to pay estate taxes, depressing the effective payoff of the flower option when bond prices were low. Nevertheless, we estimate the value of the flower options as high as fifty cents on the dollar in 1981 as inflation peaked at around 15% and short-term interest rates reached nearly five times the coupons on flower bonds. We further investigate the flower bonds in Appendix G.2.3. We show that our estimator fits the flower bonds with minimal errors, the inclusion of the flower bonds reduces estimation uncertainty and is informative during periods when all long-term bonds are flower bonds, and our approach satisfies out-of-sample testing in periods with both long-term flower and non-flower bonds.[17]

[17]We are grateful to Greg Duffee for his insightful suggestions, which inspired this section.

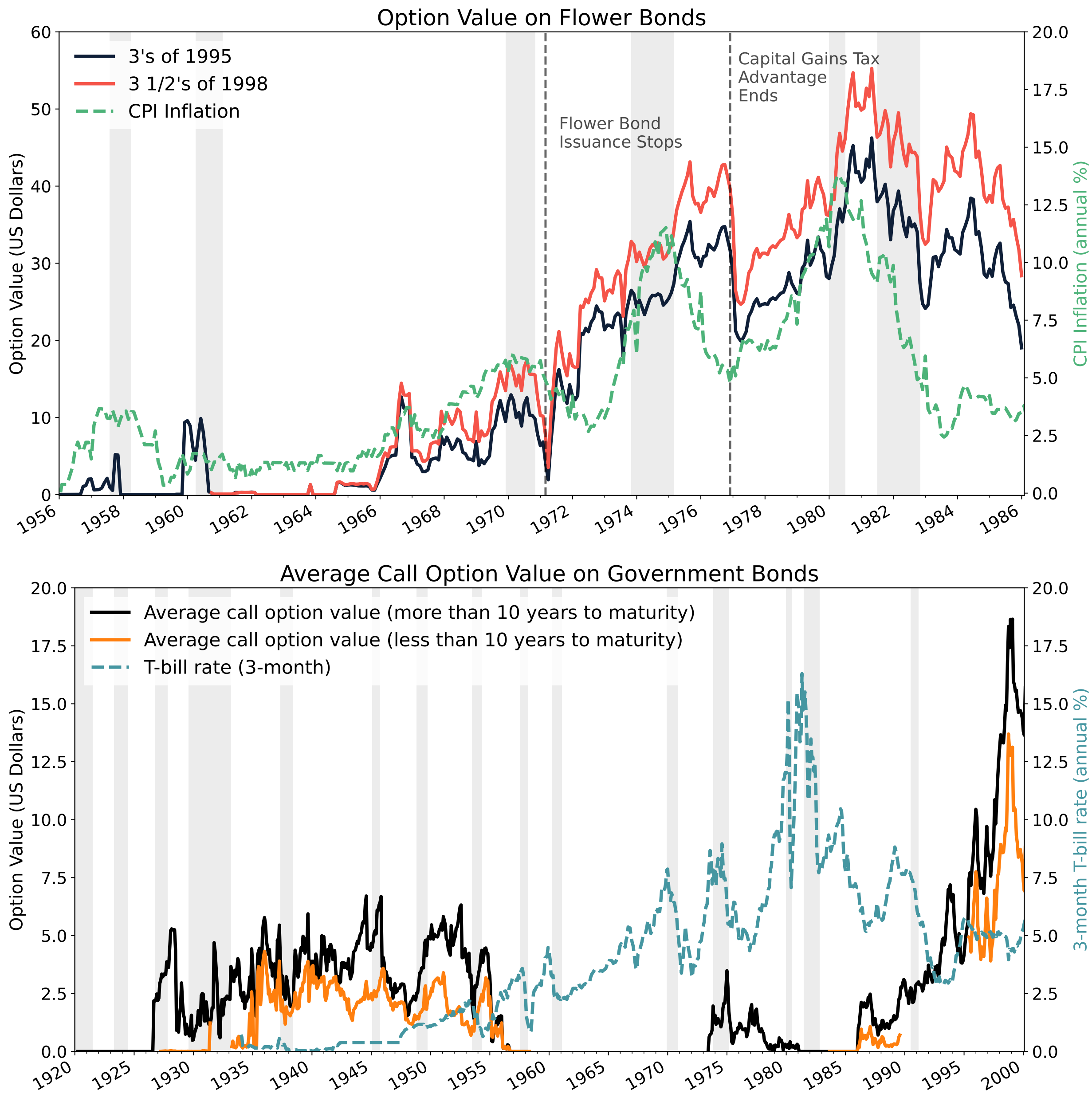

Figure 9: Estimated Option Values on Government Bonds

Notes: The top panel plots the fitted option values of the two longest-maturity flower bonds issued starting in 1955. CPI inflation is plotted in green. The bottom plot shows average call option values in the Treasury sample, with options over 10 years to maturity shown in black and under 10 years to maturity shown in orange. The T-Bill rate is shown in teal.

Finally, the bottom panel in Figure 9 shows maturity-specific averages of estimated call option prices for callable Treasury bonds. Call options on Treasurys were clearly valued from 1930-1955. Notably, call options issued on bonds to finance the New Deal in the

1930s became increasingly valuable as the government imposed yield curve control during World War II and effectively lowered its refinancing costs. The other wave of call options—with exceptionally high coupons—were issued from 1975-1984. As interest rates declined throughout the 1980s and 1990s and call dates approached, the embedded options on these bonds appreciated markedly. In both cases, the Treasury exercised the call option at the earliest permissible date, capitalizing on the opportunity to refinance at substantially lower rates.

5.4 Additional Considerations

We close this section by discussing two additional considerations that have been studied in the yield curve literature: default risk and state taxes.

5.4.1 Default Risk

Throughout our paper, we assume that AAA-rated bonds are close to default free and that any remaining default risk is not an influential component of the AAA-Treasury Spread. In this section, we investigate the plausibility of this assumption by calculating expected losses on AAA corporate bonds.

Default risk in AAA corporate bonds can arise from: (i) defaults while classified as a AAA bonds, and (ii) ratings downgrades that are subsequently followed by defaults. For AAA corporate bonds, Moody's Investors Service estimates the probability of default over a one-year horizon is essentially zero and the cumulative default rate on AAA-rated bonds over a 20-year horizon is only around 1.3 percent based on data from 1920–2024. As a result, nearly all of the relevant default risk stems from the second channel—i.e., changes in expected future defaults following ratings downgrades. To account for this, we estimate an expected loss measure that incorporates downgrade risk using historical corporate default rates, transition matrices and recovery rates provided by Moody's Investors Service dating back to 1920. This approach aligns closely with the methodology of Elton et al. (2001). Figure 10 shows that even when incorporating downgrade risk, the expected loss on AAA-rated bonds is close to zero and noticeably smaller than on AA- or A-rated bonds. This supports the findings in Elton et al. (2001) that the expected loss is clearly not large enough to be able to explain the AAA-Treasury spread alone.

5.4.2 State Taxes

A notable feature of corporate bonds is that they are subject to both federal and state income taxes while taxable Treasurys are only taxed at the federal level. As shown in Elton

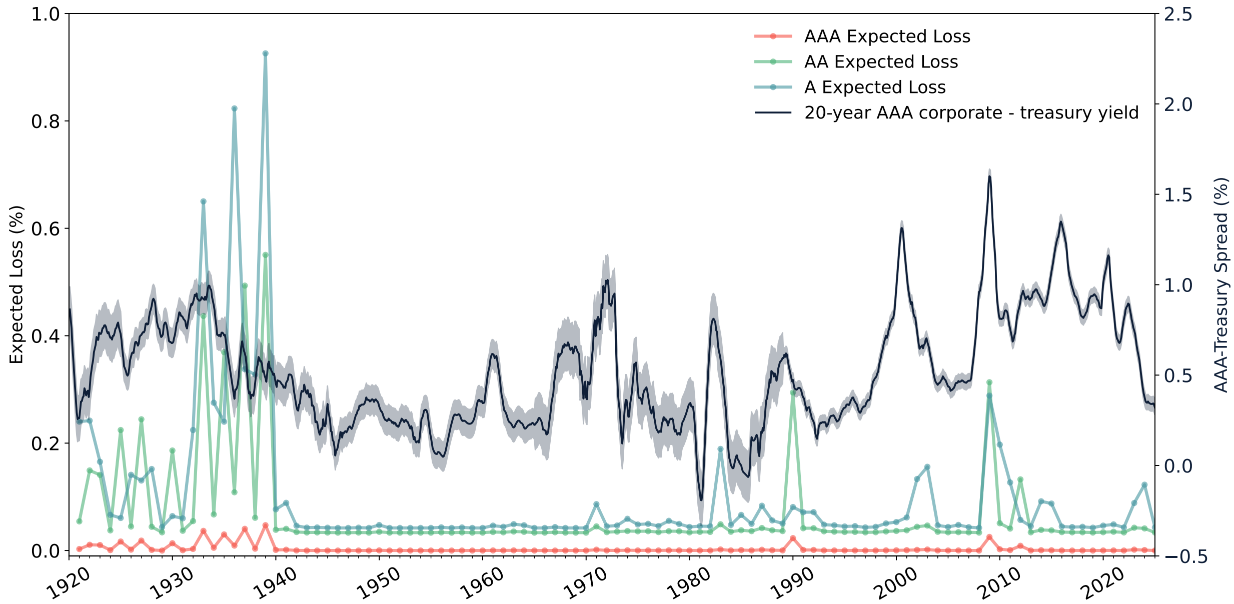

Figure 10: Expected Loss and AAA-Corporate to Treasury Spread: 1920-2024

Notes: The black solid line shows the posterior median estimate of the 20 year AAA-Treasury spread. The shaded region denotes 90% posterior interquantile ranges. The red, green and blue lines denote the expected loss on AAA, AA, A corporate bonds, respectively, as computed in Elton et al. (2001).

et al. (2001), any plausible effective state tax rate—estimated between 4-5%—accounts for approximately 20 basis points of the AA–Treasury yield spread during the 1985–1995 period, which we assume is comparable to that of the AAA-Treasury spread. Although this tax differential contributes more to the spread than default risk alone, it nonetheless explains only a modest fraction of the observed yield differential following the implementation of federal and state income taxes. Furthermore, assuming movements in the effective state taxes take place over low frequencies, little of the higher frequency variation in the spread can be explained by adjusting for state taxes. So, for the purposes of estimating an asset pricing model of the spread, discussed in Section 6, we gain little from any level shift we impose on the spread from state taxes. From the perspective of the government budget constraint examined in Section 2.2—specifically equation (2.3), and revisited in Section 7—one may interpret terms (ii) and (iii) as inclusive of the flows to the federal government from foregone state taxes on Treasurys. We stress that any contribution of foregone state tax revenue left in these terms is far too small to explain these terms in their entirety.

6 US Funding Advantage, Debt Supply, and Risk

We now look for an asset pricing model that explains movements in the US government's funding advantage. Formally, our goal is to identify a model for the wedge $\Omega_{t,t+1}$ that characterizes the non-pecuniary benefit of holding j-maturity government debt in the Euler equations for the government and corporate bond discount functions (the equations in (2.2) from Section 2):

$$q_t^{(j)} = \mathbb{E}_t\Big[\xi_{t,t+1}\Omega_{t,t+1}q_{t+1}^{(j-1)}\Big], \qquad \widetilde{q}_t^{(j)} = \mathbb{E}_t\Big[\xi_{t,t+1}\widetilde{q}_{t+1}^{(j-1)}\Big],\ \forall j \geq 1,\ \text{with}\ q_t^{(0)} = \widetilde{q}_t^{(0)} = 1.$$

Recent papers have argued that $\log(\Omega_{t,t+1})$ is well approximated by an affine function of the aggregate government debt-to-GDP ratio, potentially combined with the market value of other assets that have non-pecuniary benefits, and i.i.d. demand shocks (e.g. Krishnamurthy and Vissing-Jorgensen (2012), Krishnamurthy and Li (2023), Choi et al. (2022), Cieslak et al. (2024)). This work builds on a long literature debating whether changes in debt "quantities" can forecast variation in the government funding spread (e.g. Fair and Malkiel (1971), Cook and Hendershott (1978)). Our new funding advantage estimates allow us to re-evaluate this literature and develop a richer factor model for $\Omega_{t,t+1}$.

We start in Subsection 6.1 by examining the unconditional relationship between quantities and spreads for different maturity bins. We find that there is a clear negative relationship between funding advantage and debt-to-GDP for maturities less than 1 year, a small negative relationship for maturities between 1-10 years, and a slightly positive relationship for maturities greater than 10 years. These heterogeneous relationships suggest a complicated, maturity specific connection between quantities and spreads that is not well approximated by the single-factor models used in the literature.

To better understand these connections, in Subsection 6.2, we estimate an asset pricing model for $\Omega_{t,t+1}$ that uses the principal components of the yield curves and government debt obligations to forecast changes in the discount functions $\{\tilde{\mathsf{q}}_t, \mathsf{q}_t\}$ for highest-grade corporate and government bonds while respecting no-arbitrage across time. Being able to fit this model highlights the value of having estimated the term structure of government funding advantage in Section 5: we can now use standard asset pricing tools to understand corporate-to-government bond spreads. Despite allowing for a highly flexible connection between quantities and spreads, our model finds that variation in government funding advantage is primarily driven by the standard risk factors that are known to forecast excess returns well. That is, in contrast to the recent literature, we find that changes in government debt obligations explain very little of the variation in government funding advantage.

In Section 6.3, we explore why our results differ from those in the literature by rerunning the regressions from Krishnamurthy and Vissing-Jorgensen (2012). We show that the historical evidence used to support their argument is influenced by the distortions in the index-based spread discussed in Section 3. Using our series for government funding advantage, neither the scatter plots nor the regressions from Krishnamurthy and Vissing-Jorgensen (2012) provide strong support for a clear, unconditional relationship between funding advantage and the aggregate debt-to-GDP ratio.

6.1 Quantities and Spreads

We start by inspecting the unconditional relationship between quantities and spreads at different maturities. We define the quantity-weighted average funding advantage for the zero-coupon portfolio of government bonds with maturities between T_1 and T_2 by:

$$\chi_t^{(T_1,T_2)} = \frac{\sum_{j=T_1}^{T_2} \chi_t^{(j)} q_t^{(j)} b_t^{(j)}}{\sum_{j=T_1}^{T_2} q_t^{(j)} b_t^{(j)}}$$

Figure 11 plots the quantity-weighted average of the funding advantage within different maturity bins against the market value of debt to GDP within those same bins[18]. The first, second, and third subplots in Figure 11 show the relationship for bonds with maturities less than 1 year, between 1-10 years, and more than 10 years respectively (i.e. $\chi_t^{0,1}$, $\chi_t^{1,10}$, $\chi_t^{10,\infty}$). The final plot shows the relationship for the weighted average funding advantage across all maturities (i.e. $\chi_t^{(0,\infty)}$). Evidently, for short maturities there is a clear negative relationship, for medium maturities there is a weak negative relationship, and for long maturities there is a slightly positive relationship. We show these correlations more formally in Appendix H.1, where we run the Krishnamurthy and Vissing-Jorgensen (2012) regressions using maturity-specific quantities and controls for the VIX and the yield curve slope.

6.2 An Asset Pricing Model of Funding Advantage

The maturity specific scatter plots and regressions in Section 6.1 suggest that most of the variation in government funding advantage is unrelated to quantity changes and any connection between quantities and spreads is complicated and maturity dependent. To explore these features, we use our yield curve estimates to fit an affine Gaussian model for the Treasury wedge, $\Omega_{t,t+1}$, that potentially depends upon the full maturity structure of government

[18] In all analysis throughout this Section, we use the collection of marketable government securities to compute the the market value of government debt. This excludes non-marketable debt issued to other branches of the government.

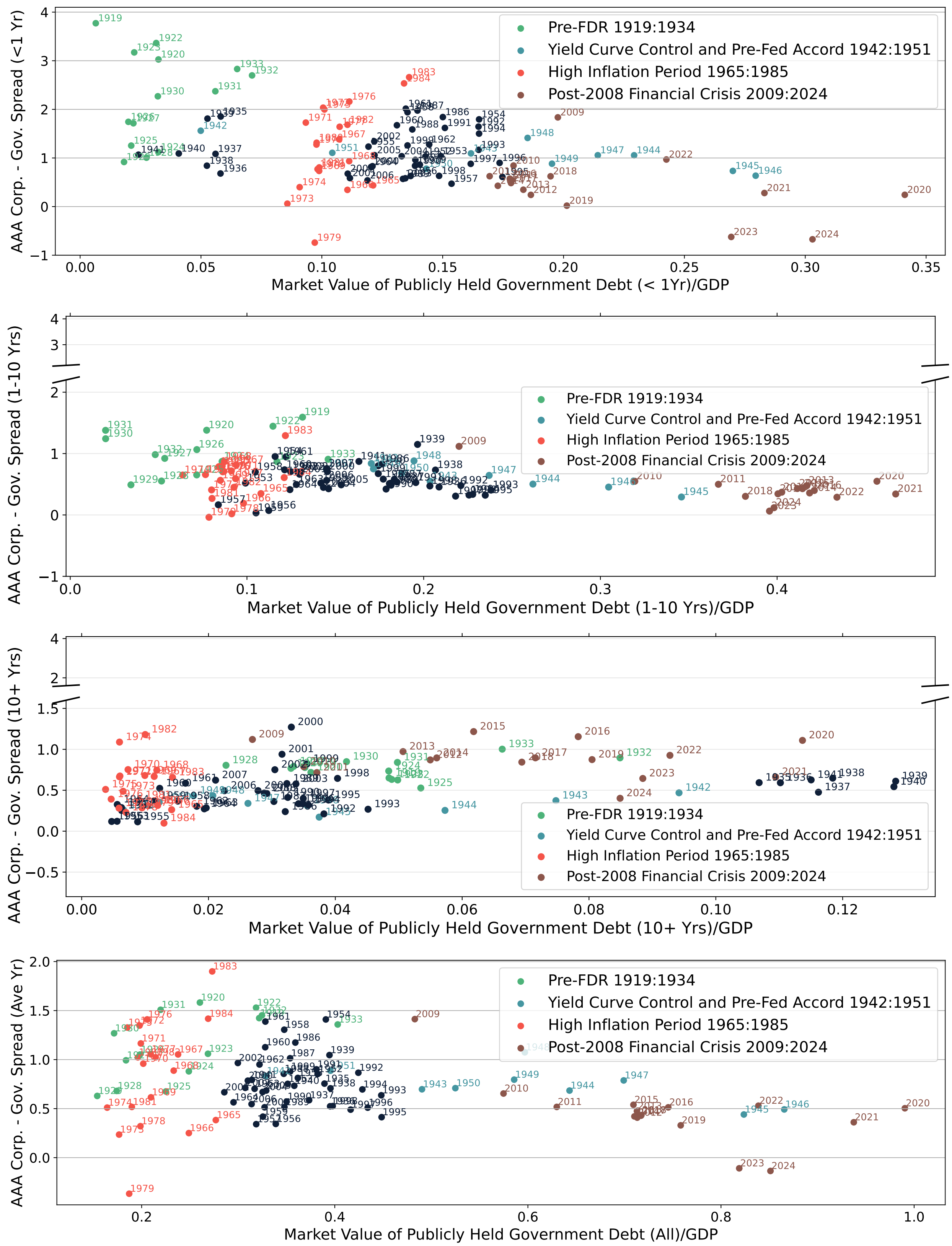

Figure 11: Spreads versus Debt-to-GDP for 1919 to 2024. (a) The top panel has maturities < 1 year. (b) The second panel has maturities from 1-10 years (c) The third panel has maturities for 10+ years. (d) The final panel has weighted average spread across all maturities.

debt obligations and the residual principal components of the yield curves.

6.2.1 Model

We set up a state space motivated by the affine asset pricing literature. Let $\tilde{x}_t$ denote a vector with the first K_C principal components of the highest-grade corporate yield curve and let x_t denote the first K_G principal components of the government yield curve. These are the factors that have traditionally been used to fit affine asset pricing models. In addition, let b_t denote a vector with the first K_D principal components of the term structure of the government's promised debt repayment normalized by GDP (i.e. the principal components of the vector of the government's promised debt repayments at all maturities divided GDP). Incorporating b_t allows us to flexibly investigate how much of the variation can be explained by quantity changes at all maturities. Let v_t denote the residuals in the projection of x_t onto $[\tilde{x}_t^T, b_t^T]$. Let $X_t := [\tilde{x}_t^T, v_t^T, b_t^T]$ denote the state vector for the model. We impose the law of motion on the state space:

$$X_t = \mu_X + \Phi_X X_{t-1} + \ \Sigma\epsilon_t, \quad \epsilon_t \sim N(0, I_{n_\epsilon})$$

We assume a standard affine asset pricing model for the corporate pricing kernel $\xi_{t,t+1}$. Formally, we impose that the corporate pricing kernel takes an exponential affine form:

$$\begin{aligned}
\xi_{t,t+1} &= \exp\left(-r_t - 0.5\lambda_t^T \Sigma\Sigma^T \lambda_t - \lambda_t^T \Sigma\epsilon_{t+1}\right) \\
r_t &= \delta_0 + \delta_1^T X_t \\
\lambda_t &= \lambda_0 + \lambda_1^T X_t
\end{aligned}$$

where r_t is the short rate, λ_t is vector of factor exposures, and $\xi_{t,t+1}$ satisfies the corporate bond Euler equation:

$$\widetilde{q}_t^{(j)} = \mathbb{E}_t\left[\xi_{t,t+1}\widetilde{q}_{t+1}^{(j-1)}\right], \ \forall j \geq 1, \text{ with } \widetilde{q}_t^{(0)} = 1.$$

Finally, for Treasurys, we impose that the wedge also takes an exponential affine form:

$$\begin{aligned}
\Omega_{t,t+1} &= \exp\left(-\mu_0 - 0.5\omega_t^T \Sigma\Sigma^T \omega_t - \omega_t^T \Sigma\epsilon_{t+1}\right) \\
\omega_t &:= \omega_0 + \omega_1^T X_t
\end{aligned}$$

where μ_0 is a level effect, ω_t is the vector of factor exposures for the wedge, and $\Omega_{t,t+1}$ satisfies the Treasury Euler equation:

$$q_t^{(j)} = \mathbb{E}_t\Big[\xi_{t,t+1}\Omega_{t,t+1}q_{t+1}^{(j-1)}\Big].$$

Here, we interpret ω_t for the different components of shocks to b_t as implicitly capturing the elasticity of the Treasury wedge to principal components of the debt supply shocks. In this sense, our formulation generalizes the existing models in the literature by allowing for much greater flexibility in how quantities can impact yield spreads.

6.2.2 Estimation Results

We set the number of principal components to $K_C = K_G = K_D = 3$. We estimate the state space, corporate pricing kernel, and Treasury pricing kernel model parameters $(\mu_X, \Phi_X, \Sigma, \delta_0, \delta_1, \lambda_0, \lambda_1, \mu_0, \omega_0, \omega_1)$ by adapting standard indirect inference techniques from the asset pricing literature (e.g. Adrian et al. (2013)). We explain the details of estimation approach in Appendix H.2 and show that our model generates a tight fit in Appendix H.3.

Figure 12 shows the variance decomposition of how much different shocks contribute to explaining the variation in the difference between the excess holding returns on highest-grade corporate and Treasury bonds with maturities of 0 to 20 years. The different colors denote the contribution from all the debt-to-GDP factors (red), the corporate principal components (green), and the residuals when the Treasury principal components are projected onto the other states (blue). Evidently, the residualized principal components of the Treasury yield curve explain the majority of the variation while the debt-to-GDP factors explain very little. In this sense, the factors that explain changes in government funding advantage are essentially the same Treasury risk factors that explain changes in the Treasury yield curve. That is, regular asset pricing can explain spread changes. We explore the properties of the risk factors further in Appendix H.3.

6.3 Revisiting Krishnamurthy and Vissing-Jorgensen (2012)

Krishnamurthy and Vissing-Jorgensen (2012) consider a similar environment in which the price of government Treasurys satisfies:

$$q_t^{(j)} = \mathbb{E}_t[\breve{\xi}_{t,t+1}\breve{\Omega}_{t,t+1}q_{t+1}^{(j-1)}]$$

where $\breve{\xi}_{t,t+1}$ is interpreted as the household pricing kernel and $\breve{\Omega}_{t,t+1}$ is the corresponding

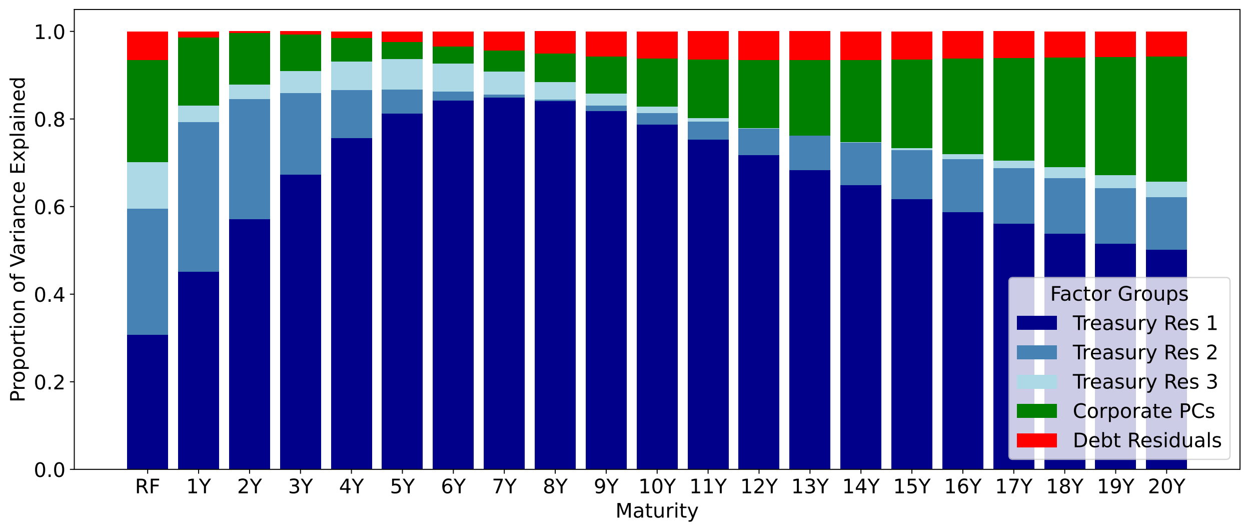

Figure 12: Variance Decomposition of The Excess Return Spread Between Holding Corporate and Treasury Bonds

Notes: The first column shows the variance decomposition of the spread between the risk-free rate on corporate bonds $\tilde{r}f_t$ and on Treasurys rf_t. The other columns show the variance decomposition of the spread between the excess holding return on j-maturity corporate bonds $\tilde{rx}_{t+1}^{(j-1)} := \log(\tilde{q}_{t+1}^{(j-1)}) - \log(\tilde{q}_t^{(j)}) - \tilde{r}f_t$ and the excess holding return on j-maturity Treasurys $rx_{t+1}^{(j-1)} := \log(q_{t+1}^{(j-1)}) - \log(q_t^{(j)}) - rf_t$ for j between 1 and 20 years. In all columns, the variance decomposition is broken down into the contributions from shocks to the different residualized principal components of the Treasury yield curve, the principal components of the corporate yield curve (grouped together), and the principal components of the government promised cash flows (grouped together).

non-pecuniary wedge. They argue that the wedge $\breve{\Omega}_{t,t+1}$ satisfies the parametric specification:

$$\breve{\Omega}_{t,t+1} = \exp\left(\beta_0 + \beta_1 \log\left(d_t/y_t\right) + \log(\zeta_t)\right) \tag{6.1}$$

where d_t is the market value of all "convenience assets" that earn a non-pecuniary benefit, y_t is GDP, and $\log(\zeta_t)$ is a time-t adapted random variable often interpreted as a demand shifter.[19] Like our asset pricing model, specification (6.1) rejects the frictionless markets model, which assumes that $\breve{\Omega}_{t,t+1} = 1$. However, unlike our asset pricing model, (6.1) restricts deviations from frictionless markets by imposing that d_t and ζ_t are the only factors that can predict the non-pecuniary component of the pricing kernel for government debt.

The authors define the convenience yield to be $\breve{\chi}^{(j)} := \log(q_t^{(j)})/j - \log(\breve{q}_t^{(j)})/j$, where $\breve{q}_t^{(j)}$ is the price of a j-maturity bond without non-pecuniary benefit (i.e. "without convenience") that satisfies the asset pricing equation $\breve{q}_t^{(j)} = \mathbb{E}_t[\breve{\xi}_{t,t+1}\breve{q}_{t+1}^{(j-1)}]$. Equation (6.1) implies that

[19]This form can be derived by imposing that agents receive utility from holding particular assets and β_0 has time varying, predictable components.

the convenience yield on 1-period Treasurys is given by:

$$\breve{\chi}_t^{(1)} = \beta_0 + \beta_1 \log(d_t/y_t) + \log(\zeta_t)$$

while for $j-$maturity Treasurys, the convenience yield has a similar formula that also includes additional covariance terms.[20]

Krishnamurthy and Vissing-Jorgensen (2012) tests specification (6.1) by looking for comovement between the index-based AAA Corporate to Treasury spread and the ratio of the market value of publicly held government debt to GDP (as well as looking for comovement with other spreads). We repeat their analysis using our new series. Figure 13 reconstructs the scatter plot analysis from Figure 1 in Krishnamurthy and Vissing-Jorgensen (2012). The top panel replicates the scatter plot using their data (the index-based spread) and their time period (1920-2007). The middle panel plots the same time period as Krishnamurthy and Vissing-Jorgensen (2012) but uses our estimates for the 20-year funding advantage and our estimates for the market value of marketable government debt. The bottom panel plots our estimates for our entire sample (1865-2024). The key periods where our estimates differ from the existing studies are highlighted with colors and lines linking consecutive years to show the direction of time. The relatively stable unconditional negative relationship that Krishnamurthy and Vissing-Jorgensen (2012) observed using the index-based spread is significantly weakened by using our new estimates. This is because the periods that identify the shape in the Krishnamurthy and Vissing-Jorgensen (2012) plot (the 1920s, the 1940s, and the 1970-80s) are also the periods where the distortions discussed in Section 3 are most pronounced.

The high inflation period in the 1970-80s (the red dots and lines on the scatter plot) offers a particularly interesting example of how our new series changes our understanding of government funding advantage. Looking at the top panel, one can get the impression that the highest-grade corporate-Treasury spread started to increase when inflation shocks started to devalue long-term government debt after 1965. So it looks like the economy could be moving along a stable demand function for US Treasurys. Indeed, in the top panel, the spread reaches its maximum value in the midst of the high inflation in the mid 1970s. The

[20] If ζ_t is i.i.d., then, to a first order approximation, this becomes (see Appendix H.4):

$$\begin{aligned}\breve{\chi}_t^{(j)} \approx\ & \frac{1}{j}\left(\beta_0 + \beta_1 \log\left(d_t/y_t\right) + \log(\zeta_t)\right) + \frac{1}{j}\left(\log\left(\mathbb{E}_t\left[\tilde{q}_{t+1}^{(j-1)}\right]\right) - \log\left(\mathbb{E}_t\left[q_{t+1}^{(j-1)}\right]\right)\right) \\ & + \frac{1}{j}\left(\frac{\mathrm{Cov}\left[\xi_{t,t+1}, \tilde{q}_{t+1}^{(j-1)}\right]}{\mathbb{E}_t\left[\xi_{t,t+1}\right]\mathbb{E}_t\left[\tilde{q}_{t+1}^{(j-1)}\right]} - \frac{\mathrm{Cov}\left[\xi_{t,t+1}, q_{t+1}^{(j-1)}\right]}{\mathbb{E}_t\left[\xi_{t,t+1}\right]\mathbb{E}_t\left[q_{t+1}^{(j-1)}\right]}\right)\end{aligned}$$

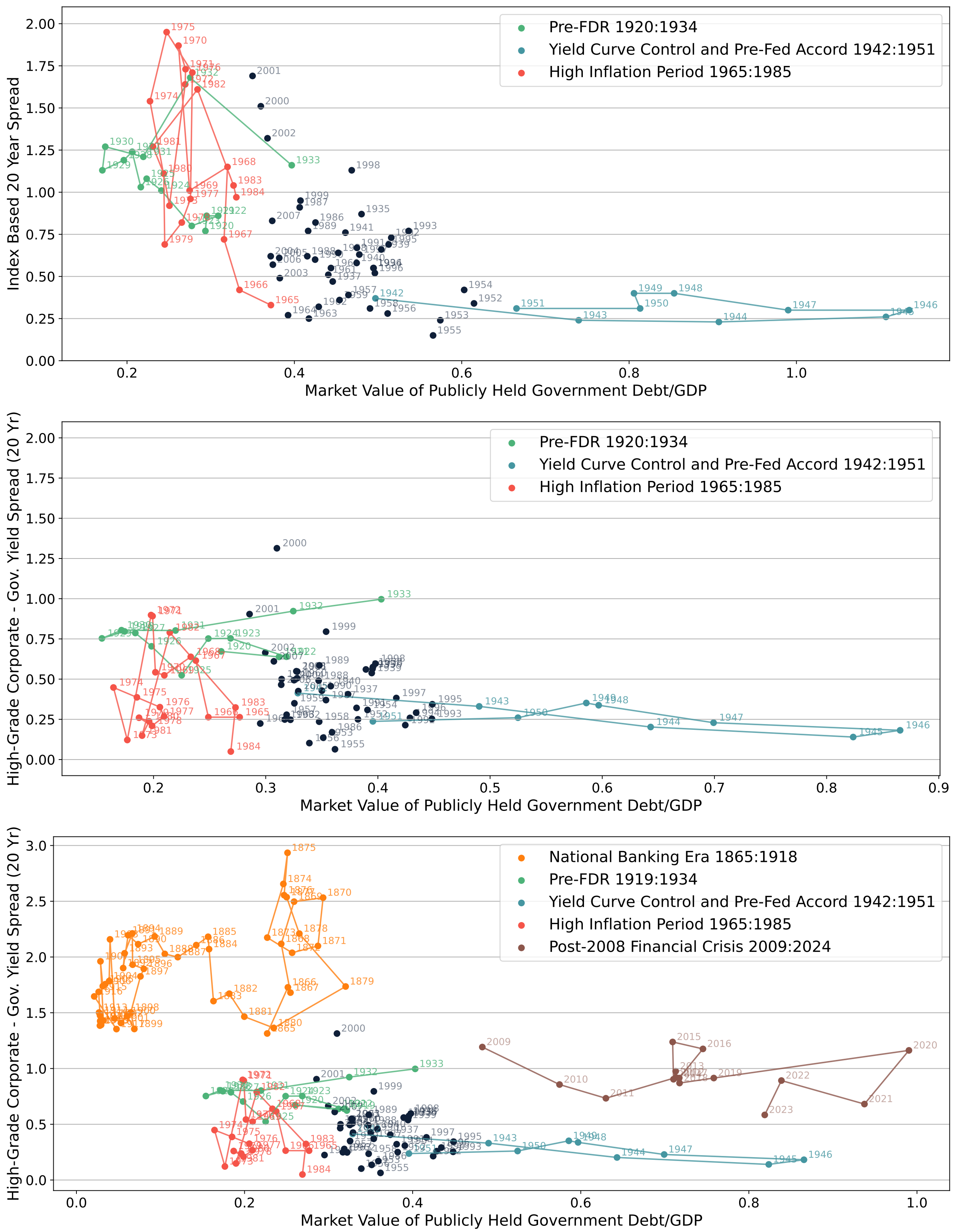

Figure 13: (a) The top panel replicates Krishnamurthy and Vissing-Jorgensen (2012) using their data and time period from 1920-2007. (b) The middle panel uses our estimate of the spread to replicate the top panel. (c) The bottom panel uses our estimate for our full sample from 1865-2024.

middle panel, with our data, tells a very different story: as government debt got devalued in the 1970-80s, the highest-grade corporate-Treasury spread fell to around zero, its lowest value in the sample. So it looks like high inflation coincided with a breakdown (or leftward shift) of the relationship between spreads and quantities. This analysis also casts doubt on other papers in the literature that rely on the behavior of the index-based measure during the high-inflation period of 1965–1985 in their identification schemes. For example, in Appendix I, we show that the identification of government market power in Choi et al. (2022) no longer holds with our new spread estimates.

The bottom panel with our full sample from 1860-2024 sheds light on how sharply government funding advantage has varied across financial regulatory eras. For a given level of debt-to-GDP, the spread was approximately 0.5-1.0 percentage points higher during the National Banking Era (approximately 1865-1920) compared to later periods. This is similar in size to the drop in the spread around 1920 in Figure 5 when National Banks stopped using government debt to create bank notes (that is, when the National Bank circulation privilege was eliminated). This is suggestive evidence that the circulation privilege contributed approximately 1 percentage point to the government's funding advantage in the 19th century.

We formalize these observations in Appendix H.1, where we replicate the Krishnamurthy and Vissing-Jorgensen (2012) regressions and show that $\log(Debt/GDP)$ is no longer significant across our long sample once we control for financial regulatory regimes and volatility.

Discussion on funding advantage, convenience yields, and quantities: Our analysis suggests that quantity changes explain very little of the variation in the AAA Corporate to Treasury spread. However, this doesn't necessarily confirm that quantity changes cannot explain the convenience yield from Krishnamurthy and Vissing-Jorgensen (2012), because AAA Corporate bonds may also earn some non-pecuniary benefits and so the AAA Corporate to Treasury spread need not be equal to the convenience yield. To make progress on estimating convenience yields, we would need to bring in historical equity pricing data and estimate a pricing kernel undistorted by any kind of convenience benefit.

7 Non-Pecuniary Revenue in Government Budgets

We close the paper by returning to the government budget constraint from Section 2 and quantifying the non-pecuniary revenue the US government has received from its funding advantage. We begin by studying the extent to which period-t government liabilities were backed by the present discounted value of future non-pecuniary revenues. Figure 14 uses our estimated time series for government funding advantage to compute terms (ii) and (iii) in the lifetime government budget constraint (2.3) under the assumption that investors have perfect foresight over future debt issuance. Because these terms are essentially stocks that capitalize the present discounted value of future spreads, we divide the series by GDP. Evidently, the US government's funding advantage in the bond market had a meaningful impact on the backing of government debt. In particular, during the largest debt expansions (WWII and the Global Financial Crisis), non-pecuniary revenue backing was in the range of 6-8% of GDP.

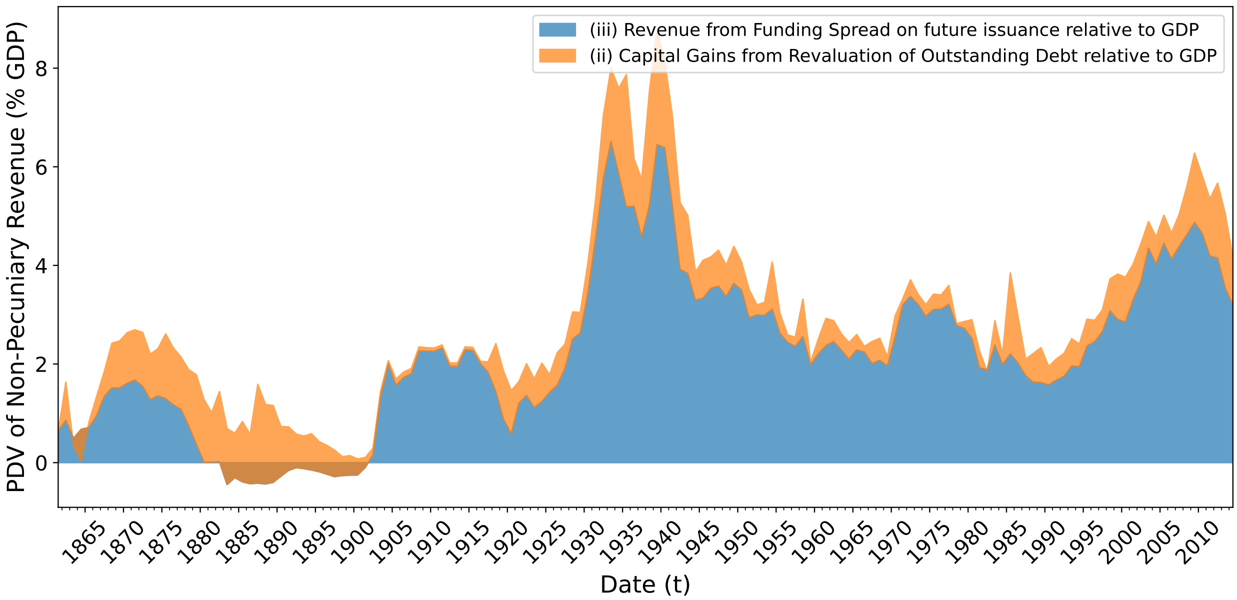

Figure 14: Capitalized Non-Pecuniary Revenue as percentage of GDP

Notes: The blue area shows the present discounted value of the future non-pecuniary revenue from the funding spread on future issuance under perfect foresight and relative to GDP (term (iii) in Equation (2.3)). The orange area shows the premium on outstanding debt relative to GDP (term (ii) in Equation (2.3)). Perfect foresight calculations are done using formula (A.1) in Appendix A with foresight horizon of 10 years.

We also compute the ex-post contribution of non-pecuniary revenue to government financing across years in Figure 15. The black line shows the total annualized non-pecuniary revenue of the government normalized by total federal receipts for each year. The teal and orange bars decompose the period-t non-pecuniary revenue into the contribution from premium changes (the teal bar) and the spread on new issuance (the orange bar). We describe the exact calculations in Appendix A.2. The plots show that it was costly for the government to establish its funding advantage at the end of the Civil War: the government had to absorb capital losses when Treasurys started to trade at a premium in the late 1860s. However, this was a short-term cost that reaped significant long-term gains. During periods of crisis in the

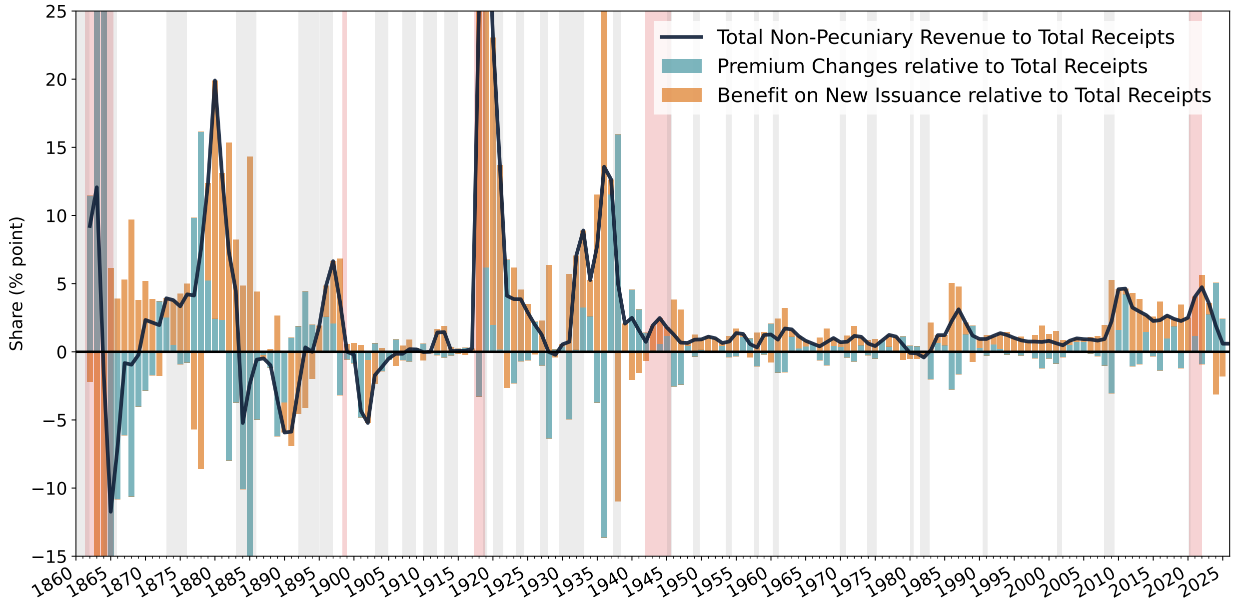

Figure 15: Non-Pecuniary Revenue as percentage of Total Federal Revenue

Notes: Components of the non-pecuniary revenue is expressed relative to total annual federal revenue. "Premium changes" are defined as $-\sum_{j=1}^{\infty}((q_t^{(j)} - \tilde{q}_t^{(j)}) - (q_{t-1}^{(j)} - \tilde{q}_{t-1}^{(j)}))b_{t-1}^{(j+1)}$. "Benefit on new issuance" is defined as $\sum_{j=1}^{\infty}((q_t^{(j)} - \tilde{q}_t^{(j)})b_t^{(j)} - (q_{t-1}^{(j)} - \tilde{q}_{t-1}^{(j)})b_{t-1}^{(j+1)})$. The two terms add up to the period-t non-pecuniary revenue, i.e., $\sum_{j=1}^{\infty}(q_t^{(j)} - \tilde{q}_t^{(j)})(b_t^{(j)} - b_{t-1}^{(j+1)})$ from term (iii) in Equation (2.3). The value of the non-pecuniary revenue relative to total receipts (black line) in 1918 is 37.6%. The light gray intervals depict NBER recessions. The light red bands, from left to right, depict the Civil War, the Spanish-American War, WW1, WW2, and COVID.

twentieth century (World Wars, New Deal, GFC, COVID), the government used its funding advantage as a significant form of revenue. In particular, non-pecuniary revenue was over 25% of total revenue during WWI, approximately 15% of total revenue during the Depression, and approximately 5% of total revenue during the GFC. This suggests that in these periods, the government preferred financing expansionary measures by having the private sector hold its debt as opposed to raising taxes.

8 Conclusion

In this paper, we construct new estimates for historical highest-grade corporate and US Treasury yield curves and use them to compute the first full term structure of AAA Corporate-Treasury spreads since 1860. This necessitates adapting yield curve estimation techniques to handle a long time series with heterogeneous tax advantages and option features. We use our estimates to show how the US funding advantage has evolved over time, and the role it has played in financing the government during critical periods of US history. We show that it is the standard risk factors, not quantities, that explain variation in US funding advantage.

References

Adrian, T., Crump, R. K., and Moench, E. (2013). Pricing the term structure with linear regressions. *Journal of Financial Economics*, 110(1):110–138.

Bernstein, A., Frydman, C., and Hilt, E. (2025). The value of ratings: Evidence from their introduction in securities markets. *Journal of Political Economy*.

Black, F. and Scholes, M. (1973). The pricing of options and corporate liabilities. *Journal of Political Economy*, 81(3):637–654.

Carlson, M., Correia, S., and Luck, S. (2022). The effects of banking competition on growth and financial stability: Evidence from the national banking era. *Journal of Political Economy*, 130(2):462–520.

Cecchetti, S. G. (1988). The case of the negative nominal interest rates: New estimates of the term structure of interest rates during the great depression. *Journal of Political Economy*, 96(6):1111–1141.

Chen, Z., Jiang, Z., Lustig, H., Van Nieuwerburgh, S., and Xiaolan, M. Z. (2022). Exorbitant privilege gained and lost: Fiscal implications. Technical report, National Bureau of Economic Research.

Choi, J., Kirpalani, R., and Perez, D. J. (2022). The macroeconomic implications of us market power in safe assets. Working Paper 30720, National Bureau of Economic Research.

Cieslak, A., Li, W., and Pflueger, C. (2024). Inflation and treasury convenience. Working Paper 32881, National Bureau of Economic Research.

Colin, J. W. and Bayer, R. J. (1970). Calculation of tax effective yields for discount instruments. *Journal of Financial and Quantitative Analysis*, 5(2):265–273.

Cook, T. (1977). Changing yield spreads in the u.s. government bond market: Flower bonds bloom, then wilt. *FRB Richmond Economic Review, Vol. 63, No. 2, March/April 1977, pp. 3-8,*.

Cook, T. Q. and Hendershott, P. H. (1978). The impact of taxes, risk and relative security supplies on interest rate differentials. *The Journal of Finance*, 33(4):1173–1186.

Department of the Treasury (1976). The congress should consider repealing the 4-l/4-percent interest rate limitation on long-term public debt. *Report to the Congress by the Comptroller General of the United States*, OPA-76-26.

Diebold, F. X. and Li, C. (2006). Forecasting the term structure of government bond yields. *Journal of Econometrics*, 130(2):337–364.

Duffee, G. R. (1996). Idiosyncratic variation of treasury bill yields. *The Journal of Finance*, 51(2):527–551.

Duffee, G. R. (1998). The relation between treasury yields and corporate bond yield spreads. *The Journal of Finance*, 53(6):2225–2241.

Elton, E. J., Gruber, M. J., Agrawal, D., and Mann, C. (2001). Explaining the rate spread on corporate bonds. *the journal of finance*, 56(1):247–277.

Fair, R. C. and Malkiel, B. G. (1971). The determination of yield differentials between debt instruments of the same maturity. *Journal of Money, Credit and Banking*, 3(4):733–749.

Fama, E. F. and Bliss, R. R. (1987). The information in long-maturity forward rates. *The American Economic Review*, 77(4):680–692.

Filipović, D., Pelger, M., and Ye, Y. (2022). Stripping the discount curve-a robust machine learning approach. *Swiss Finance Institute Research Paper*, (22-24).

Garbade, K. (2020). Managing the treasury yield curve in the 1940s. *FRB of New York Staff Report*, (913).

Ghaderi, M., Plante, S., Roussanov, N. L., and Seo, S. B. (2025). Pricing of corporate bonds: Evidence from a century-long cross-section. *Available at SSRN 5218755*.

Goetzmann, W. N., Ibbotson, R. G., and Peng, L. (2001). A new historical database for the nyse 1815 to 1925: Performance and predictability. *Journal of financial markets*, 4(1):1–32.

Gürkaynak, R. S., Sack, B., and Wright, J. H. (2007). The U.S. treasury yield curve: 1961 to present. *Journal of Monetary Economics*, 54(8):2291–2304.

Hall, G. J., Payne, J., Sargent, T. J., and Szőke, B. (2018). US federal debt 1776-1940: Prices and quantities. https://github.com/jepayne/US-Federal-Debt-Public.

Hickman, W. B. (1958). *Corporate Bond Quality and Investor Experience*. National Bureau of Economic Research, New York.

Homer, S. (1968). *The bond buyer's primer*. Salomon Bros. & Hutzler.

Homer, S. and Sylla, R. E. (2004). *A History of Interest Rates*. Rutgers University Press.

Hong, G. and Warga, A. (2000). An empirical study of bond market transactions. *Financial Analysts Journal*, 56(2):32–46.

Jiang, Z., Lustig, H., Stanford, G., Van Nieuwerburgh, N. S., and Xiaolan, M. Z. (2022). Fiscal capacity: An asset pricing perspective.

Jordà, Ò., Knoll, K., Kuvshinov, D., Schularick, M., and Taylor, A. M. (2019). The rate of return on everything, 1870–2015. *The Quarterly Journal of Economics*, 134(3):1225–1298.

Koijen, R. S. and Yogo, M. (2020). Exchange rates and asset prices in a global demand system. Technical report, National Bureau of Economic Research.

Krishnamurthy, A. and Li, W. (2023). The demand for money, near-money, and treasury bonds. *The Review of Financial Studies*, 36(5):2091–2130.

Krishnamurthy, A. and Vissing-Jorgensen, A. (2012). The aggregate demand for treasury debt. *Journal of Political Economy*, 120(2):233–267.

Liu, Y. and Wu, J. C. (2021). Reconstructing the yield curve. *Journal of Financial Economics*, 142(3):1395–1425.

Macaulay, F. R. (1938). Some theoretical problems suggested by the movements of interest rates, bond yields and stock prices in the united states since 1856. *NBER Books*.

Mayers, D. and Clifford, S. J. W. (1987). Death and taxes: The market for flower bonds. *The Journal of Finance*, 42(3):685–698.

McCulloch, J. H. (1975). The tax-adjusted yield curve. *The Journal of Finance*, 30(3):811–830.

Nagel, S. (2016). The Liquidity Premium of Near-Money Assets*. *The Quarterly Journal of Economics*, 131(4):1927–1971.

Nelson, C. R. and Siegel, A. F. (1987). Parsimonious modeling of yield curves. *The Journal of Business*, 60(4):473–489.

Officer, L. H. and Williamson, S. H. (2021). Explaining the measures of worth. *Measuring Worth*.

Payne, J., Szőke, B., Hall, G., and Sargent, T. J. (2025). Costs of financing U.S. federal debt under a gold standard: 1791-1933. *The Quarterly Journal of Economics*, 140(1):793–833.

Reinhart, C. M. and Rogoff, K. S. (2009). This time is different. In *This Time Is Different*. princeton university press.

Robichek, A. A. and Niebuhr, W. D. (1970). Tax-induced bias in rerported treasury yields. *The Journal of Finance*, 25(5):1081–1090.

Rose, J. (2021). Yield curve control in the united states, 1942 to 1951. *Economic Perspectives*, (2).

Salomon Brothers (1988). *An Analytical Record of Yields and Yield Spreads from 1945*. New York.

Schmelzing, P. (2020). Eight centuries of global real interest rates, rg, and the 'suprasecular'decline, 1311–2018. *Bank of England: Working Paper 845*.

Svensson, L. E. O. (1995). Estimating forward interest rates with the extended Nelson and Siegel method. *Sveriges Riksbank Quarterly Review*, 3.

Sylla, R. E., Wilson, J., and Wright, R. E. (2006). Early U.S. security prices. *http://eh.net/databases/early-us-securities-prices*.

Thies, C. F. (1985). New estimates of the term structure of interest rates: 1920–1939. *Journal of Financial Research*, 8(4):297–306.

van Binsbergen, J. H., Diamond, W. F., and Grotteria, M. (2022). Risk-free interest rates. *Journal of Financial Economics*, 143(1):1–29.

A Government Budget Constraint Arithmetic

From Section (2.2), the inter-period government budget constraint is:

$$b_{t-1}^{(1)} + g_t - \tau_t = \sum_{j=1}^{\infty} q_t^{(j)} \left(b_t^{(j)} - b_{t-1}^{(j+1)} \right)$$

which states that interest payments today plus the primary deficit is equal to the market value of newly issued debt. We rearrange the terms to get:

$$\sum_{j=1}^{\infty} q_t^{(j-1)} b_{t-1}^{(j)} = \tau_t - g_t + \sum_{j=1}^{\infty} (q_t^{(j)} - \tilde{q}_t^{(j)}) b_t^{(j)} + \sum_{j=1}^{\infty} \tilde{q}_t^{(j)} b_t^{(j)}$$

To get the lifetime budget constraint, we need to iterate this forward. This requires forecasting future prices, which we do by imposing the asset pricing equation for corporate bonds:

$$\tilde{q}_t^{(j)} = \mathbb{E}_t \left[\xi_{t,t+1} \tilde{q}_{t+1}^{(j-1)} \right], \quad \forall j$$

in the government budget constraint. This gives:

$$\begin{aligned}
\sum_{j=1}^{\infty} q_t^{(j-1)} b_{t-1}^{(j)} &= \tau_t - g_t + \sum_{j=1}^{\infty} (q_t^{(j)} - \tilde{q}_t^{(j)}) b_t^{(j)} + \sum_{j=1}^{\infty} \mathbb{E}_t \left[\xi_{t,t+1} \tilde{q}_{t+1}^{(j-1)} \right] b_t^{(j)} \\
&= \tau_t - g_t + \sum_{j=1}^{\infty} (q_t^{(j)} - \tilde{q}_t^{(j)}) b_t^{(j)} + \mathbb{E}_t \left[\xi_{t,t+1} \sum_{j=1}^{\infty} (\tilde{q}_{t+1}^{(j-1)} - q_{t+1}^{(j-1)}) b_t^{(j)} \right] \\
&\quad + \mathbb{E}_t \left[\xi_{t,t+1} \sum_{j=1}^{\infty} q_{t+1}^{(j-1)} b_t^{(j)} \right].
\end{aligned}$$

By adding and subtracting corporate bond prices, this can be written as

$$\begin{aligned}
\sum_{j=1}^{\infty} q_t^{(j-1)} b_{t-1}^{(j)} = \tau_t - g_t + \sum_{j=1}^{\infty} (q_t^{(j)} - \tilde{q}_t^{(j)}) b_t^{(j)} + \mathbb{E}_t \left[\xi_{t,t+1} \sum_{j=1}^{\infty} (\tilde{q}_{t+1}^{(j)} - q_{t+1}^{(j)}) b_t^{(j+1)} \right] \\
+ \mathbb{E}_t \left[\xi_{t,t+1} \sum_{j=1}^{\infty} q_{t+1}^{(j-1)} b_t^{(j)} \right].
\end{aligned}$$

Iterating the final term forward and imposing the transversality condition gives:

$$\sum_{j=1}^{\infty} q_t^{(j-1)} b_{t-1}^{(j)} = \mathbb{E}_t \left[\sum_{s=0}^{\infty} \xi_{t,t+s} (\tau_{t+s} - g_{t+s}) \right] + \sum_{j=1}^{\infty} (q_t^{(j)} - \tilde{q}_t^{(j)}) b_t^{(j)}$$
$$+ \mathbb{E}_t \left[\sum_{s=1}^{\infty} \xi_{t,t+s} \sum_{j=1}^{\infty} \left(q_{t+s}^{(j)} - \tilde{q}_{t+s}^{(j)} \right) \left(b_{t+s}^{(j)} - b_{t-1+s}^{(j+1)} \right) \right]$$

which after rearranging terms gives:

$$\sum_{j=1}^{\infty} q_t^{(j-1)} b_{t-1}^{(j)} = \mathbb{E}_t \left[\sum_{s=0}^{\infty} \xi_{t,t+s} (\tau_{t+s} - g_{t+s}) \right] + \sum_{j=1}^{\infty} (q_t^{(j)} - \tilde{q}_t^{(j)}) b_{t-1}^{(j+1)}$$
$$+ \mathbb{E}_t \left[\sum_{s=0}^{\infty} \xi_{t,t+s} \sum_{j=1}^{\infty} \left(q_{t+s}^{(j)} - \tilde{q}_{t+s}^{(j)} \right) \left(b_{t+s}^{(j)} - b_{t-1+s}^{(j+1)} \right) \right]$$

as stated in (2.3).

A.1 Special Case: Perfect Foresight

We consider a special case, which is used in Section 7. If we impose perfect foresight, then the asset pricing equation becomes:

$$\tilde{q}_t^{(s)} = \xi_{t,t+s}$$

and so the budget constraint becomes:

$$\begin{aligned} \sum_{j=1}^{\infty} q_t^{(j-1)} b_{t-1}^{(j)} = &\sum_{j=1}^{\infty} (q_t^{(j)} - \tilde{q}_t^{(j)}) b_{t-1}^{(j+1)} + \sum_{s=0}^{\infty} \tilde{q}_t^{(s)} (\tau_{t+s} - g_{t+s}) \\ &+ \sum_{s=0}^{\infty} \tilde{q}_t^{(s)} \sum_{j=1}^{\infty} \left(q_{t+s}^{(j)} - \tilde{q}_{t+s}^{(j)} \right) \left(b_{t+s}^{(j)} - b_{t-1+s}^{(j+1)} \right) \end{aligned} \tag{A.1}$$

A.2 Flow Revenue

In Section 7, we also decompose the flow revenue from government funding advantage. To do this, we rearrange the intertemporal government budget constraint to identify the capital gains on existing debt and the premia on new issuance. The intertemporal budget constraint at time t can be written as:

$$\begin{aligned}\sum_{j=1}^{\infty} q_t^{(j-1)} b_{t-1}^{(j)} &= \tau_t - g_t + \sum_{j=1}^{\infty} q_t^{(j)} b_t^{(j)} \\ \Rightarrow g_t - \tau_t &= -\sum_{j=1}^{\infty} q_t^{(j-1)} b_{t-1}^{(j)} + \sum_{j=1}^{\infty} q_t^{(j)} b_t^{(j)} \\ &= -\sum_{j=1}^{\infty} (q_t^{(j-1)} - q_{t-1}^{(j-1)}) b_{t-1}^{(j)} + \sum_{j=1}^{\infty} (q_t^{(j)} b_t^{(j)} - q_{t-1}^{(j-1)} b_{t-1}^{(j)})\end{aligned}$$

where the first term is the capital gains/loss from the revaluation of debt between $t-1$ and t and the second term is the market value of new issuance. We can write this in spreads to get:

$$\begin{aligned}g_t - \tau_t = & -\sum_{j=1}^{\infty} (\tilde{q}_t^{(j-1)} - \tilde{q}_{t-1}^{(j-1)}) b_{t-1}^{(j)} - \sum_{j=1}^{\infty} ((q_t^{(j-1)} - \tilde{q}_t^{(j-1)}) - (q_{t-1}^{(j-1)} - \tilde{q}_{t-1}^{(j-1)})) b_{t-1}^{(j)} \\ & + \sum_{j=1}^{\infty} (\tilde{q}_t^{(j)} b_t^{(j)} - \tilde{q}_{t-1}^{(j-1)} b_{t-1}^{(j)}) + \sum_{j=1}^{\infty} ((q_t^{(j)} - \tilde{q}_t^{(j)}) b_t^{(j)} - (q_{t-1}^{(j-1)} - \tilde{q}_{t-1}^{(j-1)}) b_{t-1}^{(j)})\end{aligned}$$

where the second and fourth terms are the contributions from premium changes and non-pecuniary benefit on new issuance (which are depicted by the by the blue and orange bars on Figure 15 respectively).

B Historical Context

This appendix provides historical and institutional context for interpreting the long-run data on US corporate and government bond markets, highlighting key developments in issuance practices, regulation, and market structure over time.

Brief History of the US Bond Market: The US corporate bond market traces its origins to the early 19th century, driven by the need to finance large infrastructure projects. The first corporate bonds were issued by banks and canal companies, but the market truly expanded with the rise of the railroad industry. By the 1850s, railroad companies were expanding into the west at a scale and level of uncertainty that they could no longer raise sufficient capital from the local and fragmented banking sector. The solution was to issue bonded debt to a broader pool of investors, which created what is considered the world's first corporate bond market (Sylla et al., 2006). In the following decades, the corporate bond market expanded rapidly and by the early 2000s was several times larger than the entire UK or US sovereign debt markets.[21] Throughout the early 20th centuries, the market matured, with securities becoming more standardized, and industrial corporations and utilities also began issuing bonds.

Concurrently, throughout the nineteenth century, the federal government issued bonds infrequently, as Congress was responsible for debt management, leading to long-maturity issuances with significant variations in maturities, coupon rates, denominations, and units of account (Payne et al., 2025). The expansion and standardization of federal debt issuance occurred gradually over time, with Congress delegating more autonomy in designing and issuing securities to the Treasury Department between 1917 and 1939. Both markets continued to expand throughout the 20th century and by the mid-20th century, US Treasury securities had become the world's largest and most liquid debt market, with a standardized set of securities at various maturities.

Both corporate and Treasury bonds traded actively on major exchanges like the New York Stock Exchange (NYSE) and were held by similar investors, including banks, insurers, and wealthy individuals. Both corporate and government bonds shared similar features, such as fixed coupon payments and typically long maturities and were traded more frequently than other asset classes.

Denomination: The denomination of both Treasury and corporate bonds has evolved similarly throughout American financial history. From 1800 to 1933, the US adhered to a gold standard except from 1861 to 1878 when it temporarily suspended gold convertibility and issued a paper currency known as "greenbacks". During this period, both federal and corporate bonds were typically denominated in gold (or greenbacks during the suspension). Following the Gold Reserve Act of 1933, which prohibited private US citizens from holding gold coins, both markets transitioned to nominal dollar denomination. The Bretton Woods Agreement (1944-1971) reintroduced a type of gold standard by establishing an international system of fixed exchange rates with the US dollar convertible to gold until its collapse in 1971 when the dollar was floated. Since then, both Treasury and corporate bonds have been issued exclusively in nominal terms until the introduction of Treasury Inflation-Protected Securities (TIPS) in 1997, which provide explicit inflation indexing.

Credit ratings: The rise of corporate bonds was accompanied by the development of credit ratings. Beginning in 1832, the "American Railroad Journal" published detailed assessments of railroad companies, covering physical descriptions of the railroads, their assets, liabilities, and earnings. In 1868, its former editor Henry V. Poor published the first volume of "Poor's

[21] The US actually paid off its entire national debt in 1836.

Manual of the Railroads of the United States", a comprehensive resource detailing financial statements, operational statistics, and the capital structure of their securities. In 1909, John Moody in his "Moody's Manual of Railroads and Corporation Securities" first introduced a structured rating system for these securities that established the foundation for modern credit ratings.

Default Risk: In the early 1900s, Moody's Investors Service began assigning credit ratings to bonds and other financial assets, with "AAA" denoting the highest level of creditworthiness. This rating was based on factors such as physical capital, debt levels relative to assets and revenue, profitability, and liquidity. To qualify for an "AAA" rating, bonds needed a long-term track record of exceptionally strong interest coverage and substantial physical assets backing the issue, ensuring minimal investment risk. Most bonds were either first mortgages or well protected underlying mortgages. Moody's argued that even in changing economic conditions, the fundamental strength of these securities would remain intact. As Hickman (1958) found, credit ratings offered investors valuable insights into bond quality and default probabilities.

Policy Interventions: Corporate and government bond markets have historically been subject to different regulatory frameworks, evolving in response to financial and economic pressures. In the decades before the Civil War, only state-chartered banks existed, which were not incentivized to hold Treasurys.[22] This changed with the National Banking Acts of 1863–1866, which established a system of nationally chartered single-branch banks. These banks were permitted to issue banknotes up to 90% of the lower of the par or market value of qualifying US federal bonds, effectively tying their balance sheets to government debt. However, national banks were prohibited from using railroad bonds as backing for their notes and faced strict limitations on the types of loans they could issue.

World War II brought further regulatory intervention, as concerns over war financing led to the government "fixing" the yield curve from 1942 to 1951, with the T-Bill rate set to 3/8% and the long-term bond yield capped at 2.5% (see Garbade (2020) and Rose (2021)). This policy was implemented through coordination between the Treasury and the Federal Reserve, with the Fed agreeing to absorb excess bond supply at the fixed price, and implicit coordination with the banking system, which ended up predominantly holding government debt and reserves. The arrangement ended with the 1951 Treasury-Fed Accord, establishing

[22] These banks, chartered by state legislatures, could issue their own banknotes and were subject to diverse balance sheet regulations, often requiring them to hold gold and state bonds. However, no state banks could operate nationally.

official Fed independence from the Treasury.

The 2007–2009 financial crisis triggered extensive regulatory reforms, including the Dodd-Frank Wall Street Reform and Consumer Protection Act, which introduced new oversight for financial institutions. Additionally, the Basel III regulations imposed stricter capital requirements and portfolio constraints on banks, penalizing excessive leverage and encouraging the holding of government debt over assets like corporate bonds. In response to the crisis, the Federal Reserve also launched a quantitative easing (QE) program, purchasing long-term government bonds to lower interest rates and stabilize financial markets.

C The Corporate and Government Bond Datasets

We construct a new historical dataset of high-grade US corporate bonds, providing monthly data on trading prices and cash-flows as well as bond characteristics and credit ratings from 1840-2024. Monthly prices and cash-flows date back to 1840, along with detailed bond characteristics such as maturity, denomination and callability. Annual Moody's credit ratings date back to their earliest availability: 1909 for railroads and 1914 for public utilities and industrials. Our dataset integrates existing databases with hand-collected prices and bond characteristics from historical newspapers, business magazines, and financial releases by companies. We complement the corporate bond data with a comprehensive panel of prices and quantities for all US Treasury securities from 1776 to 2024.

C.1 Corporate Bond Data

C.1.1 Bond Prices

To compile end-of-month trading prices from 1840-2024 we rely on six main data sources: *Global Financial Data (GFD)*, the *New York Times (NYT)*, the *Commercial & Financial Chronicle (CFC)*, *Barron's Magazine*, the *Lehman Brothers Fixed Income Database*, and the *Merrill Lynch Bond Index Database*. From 1840-1884 we take bond price data from *Global Financial Data (GFD)*. The GFD dataset covers nearly 800 corporate bonds from 1791 to 1884, almost all of which are railroad bonds, reflecting their dominance in the bond market during that period. The price data is particularly rich between 1870-1884, featuring both daily time series of trading prices and bond characteristics such as the bond's name, coupon, and company information. The data does not include further bond characteristics such as maturity date or denomination. From 1886 to 1963, we collect end-of-month trading prices from the *Commercial & Financial Chronicle*. The *Commercial & Financial Chronicle* was a weekly business newspaper published from 1865 to 1987.[23] We use bond quotations from the New York Stock Exchange, focusing on actual sale prices, as reported in the "Stock Exchange Quotation / Bond Record" section. From 1884 to 1918, we collect only railroad bond prices. Beginning in January 1918, we expand the collection to include all corporate bonds, reflecting the growing importance of utility and industrial securities in the corporate bond market during the early 20th century. From 1964 to 1973, we collect bond closing prices from *Barron's Magazine*. *Barron's* is a weekly financial newspaper founded in 1921, providing coverage of closing prices for actively traded corporate bonds in their "Listed Bond Quotations" section. From 1973 to 1997 we rely on the *Lehman Brothers Fixed Income Database* distributed by Hong and Warga (2000) which provides comprehensive monthly bond-specific information from January 1973 to December 1997, including bond price, ratings and coupons. After 1997 we use the *Merrill Lynch Bond Index Database* which provides a similar level of detail. We use daily closing prices from the New York Stock Exchange as reported in *The New York Times (NYT)* to fill in any gaps in our sample between 1840 and 1973.

C.1.2 Bond Characteristics

A major challenge in estimating yield curves is that we need accurate information about bond maturity, coupon payments, and embedded options (e.g., call features). For the pre-1900 period, we draw maturity, coupon and callability information from a variety of sources. These include the *Investors' Supplement of the Commercial and Financial Chronicle*, the *American Railroad Journal*, *Poor's Manual of Railroads*, the *Catalogue of Railroad Mortgages*, various publications by Joseph G. Martins on the Boston stock market, and annual reports to stockholders of various railroad companies. For bonds maturing between 1900 to 1972, we extract the maturity, coupon and call features (i.e., call window, call date and call price) from various *Moody's Manuals* which were first published in 1900. Initially titled *Moody's Manual of Industrial and Miscellaneous Securities*, it was later replaced by *Moody's Manual of Railroads and Corporation Securities*, and subsequently by *Moody's Analyses of Investments*. These manuals provide comprehensive information on outstanding bonds, including the issue and maturity dates, coupon rates and schedules. For the period after 1972, we are able to rely on detailed bond information from the *Lehman Brothers Fixed Income Database* and the *Merrill Lynch Bond Index Database*.

[23] Scanned digital copies of the Chronicle are available from the Federal Reserve Archival System for Economic Research (FRASER) from July 1865 to December 1963.

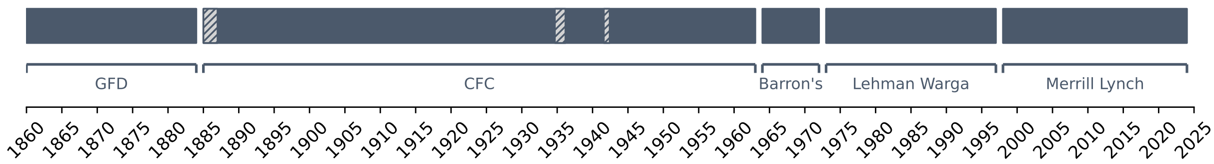

Figure 16: Corporate Bond Price Data Sources

Data sources for bond prices from 1860-2024. GFD, Lehman Warga, and Merrill Lynch are existing datasets, while bond price data from the CFC and Barron's was manually collected using scans from digital archives. Light gray areas indicate gaps in the current sample.

C.1.3 Credit Ratings

To classify high-grade bonds, we mainly rely on Moody's credit ratings which are readily available from the *Lehman Brothers Fixed Income Database* and the *Merrill Lynch Bond Index Database*. Prior to the availability of these datasets, we collect annual bond ratings from the *Moody's Manuals*. Moody's first issued credit ratings in 1909 for railroads, expanding to public utilities and industrial companies in 1914.[24] For bonds maturing before 1909, we follow Macaulay (1938) in identifying high-quality issuers, relying on the selection of railroad companies included in his high-grade railroad bond yield index. Specifically, we include companies from which Macaulay selected at least one bond for his index. Macaulay carefully selected companies based on their financial strength and excluded them before they encountered financial trouble, to ensure that his index reflected only the most creditworthy issuers. However, as pointed out in Homer and Sylla (2004), constructing an index equivalent to a modern AAA-bond-index prior to 1900 presents challenges due to the limited number of true high-grade issuers and even Macaulay's "high-grade" sample exhibits some variation in credit quality. Hence, these classifications should be treated with some caution. In addition, the introduction of credit ratings may have changed market risk assessment, as detailed in Bernstein et al. (2025).

C.2 Treasury Data

We use a comprehensive panel of prices and quantities of all US Treasury securities from 1776 to 1925, compiled by Hall et al. (2018) and used in Payne et al. (2025). We complement this historical panel with the CRSP US Treasury database after 1925. Quantities outstanding are quarterly from 1776 to 1871 and monthly thereafter. Prices are monthly, using end-

[24]We focus on Moody's ratings since they are the earliest available, whereas Poor's ratings began in 1922 and Fitch's in 1924.

of-month closing price when available. If no closing price is available, either the average of high and low prices or the average of bid and ask quotes are used. We restrict our historical sample to bonds with more than one year to maturity, excluding short-term debt due to liquidity premia and omitting bonds with ambiguous currency denomination. We also exclude Treasury Inflation-Protected Securities (TIPS), but keep bonds with varying tax exemptions and bonds with embedded call and put options. Details on data sources and construction of the historical Treasury panel can be found in Appendix A of Payne et al. (2025).

D Bond Characteristics and Institutional Treatment

This section provides further details on differences in bond characteristics and institutional treatment between US government and corporate debt that present challenges for measuring the funding advantage of the US government.

D.1 Additional Composition Plots

Figure 17 shows the share of government and corporate debt trading at a discount (as measured by whether the price is less than 98 dollars). Figure 18 shows the composition of callable and non-callable bonds among outstanding US government and corporate debt. Figure 19 shows the number of flower and non flower bonds for maturity bins less than 5 years, between 5 and 10 years, and more than 10 years. Evidently, flower bonds made up most of the long-term debt during the period from 1960-1974.

D.2 Interest Rate Ceiling on Government Bonds

A key legislation that unexpectedly gained prominence in the late 1960s and early 1970s was the Congressional mandate, established in 1917, which imposed a 4-1/4 percent interest rate ceiling on new long-term Treasury bonds.[25] Consequently, when interest rates surpassed the 4-1/4 percent ceiling in the 1960s, the US Treasury was unable to issue new bonds with maturities exceeding 5 years (extended to 7 years in 1967) and so the average maturity of outstanding US debt declined significantly, and the government bond portfolio became heavily concentrated in seasoned discount bonds. The ceiling on long-term US Treasury

[25] As explained in Department of the Treasury (1976), the primary rationale for setting a ceiling rate of 4-1/4 percent on long-term government bonds was to minimize borrowing costs tied to the United States' involvement in WWI. This ceiling was intentionally set 25 basis points below prevailing market yields, reflecting the belief that the American public would buy Liberty Bonds for reasons beyond comparative yield considerations.

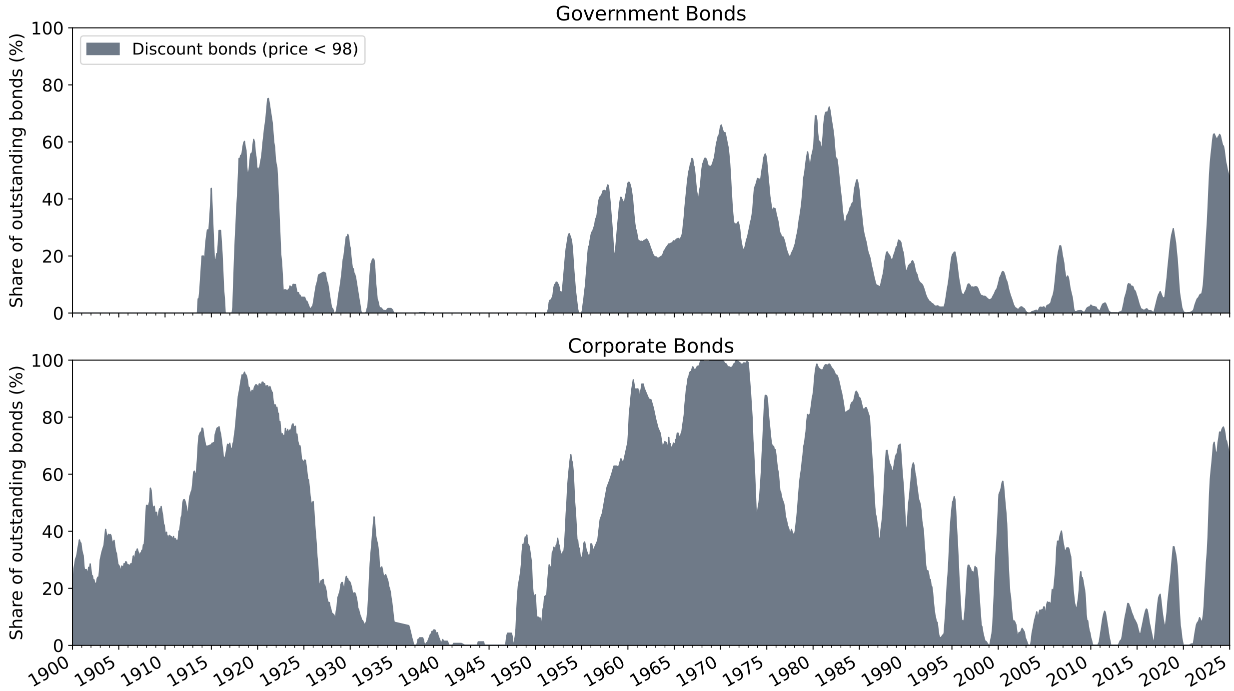

Figure 17: Composition of Government & Corporate Debt by Discount: This figure shows the share of bonds trading below par among outstanding US government and corporate debt from 1900 to 2025.

bonds was effectively lifted in 1971, when $10 billion worth of bonds were authorized without regard to the ceiling. Since then, the bond authorization limit has been raised multiple times, and the issuance of long-term bonds has become a regular component of the Treasury's refunding operations.

D.3 Circulation Privilege

During the National Banking Era (1863–1913), US federal bonds held a special regulatory status known as *circulation privilege*, which allowed federally chartered banks to issue national bank notes backed by eligible US Treasury bonds. This privilege created a strong institutional demand for long-term government securities, as banks could profitably convert them into currency liabilities. Crucially, corporate bonds were not eligible for this privilege, so the resulting yield suppression applied exclusively to US government debt. As a result, the circulation privilege helped support bond prices and depress long-term yields of government bonds, contributing to a widening of the AAA–Treasury spread during this period.

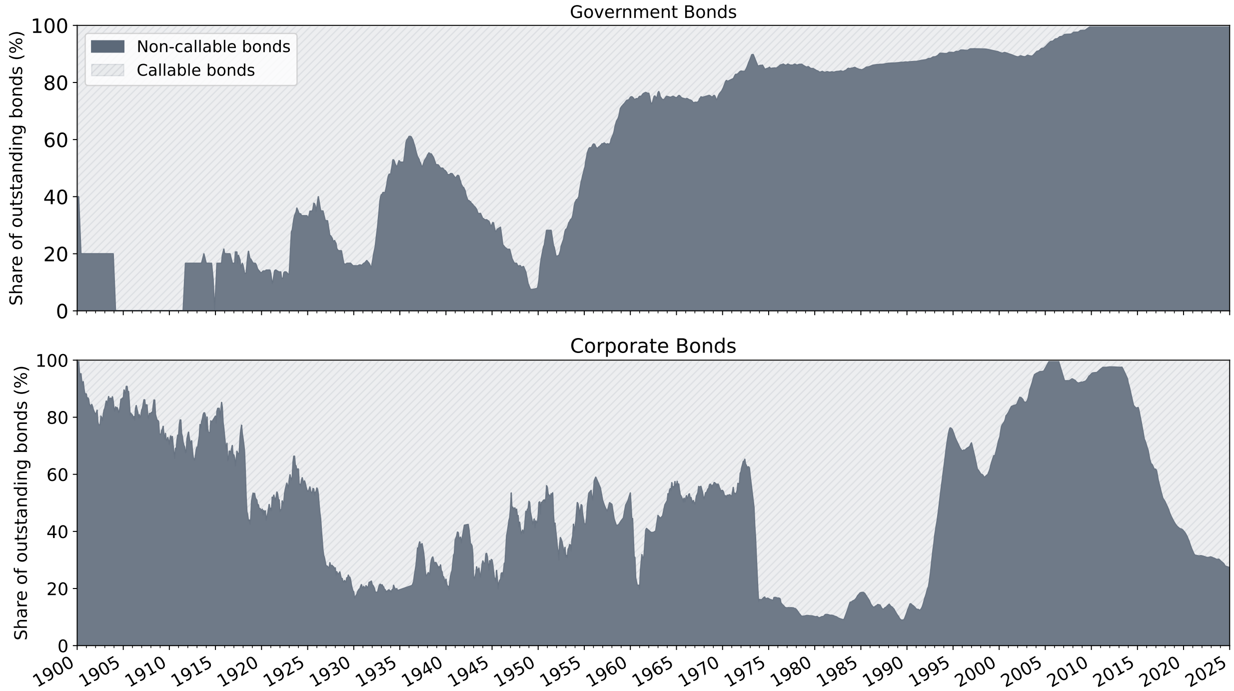

Figure 18: Composition of Government & Corporate Debt by Callability: This figure shows the share of callable and non-callable bonds among outstanding US government and corporate debt from 1900 to 2025.

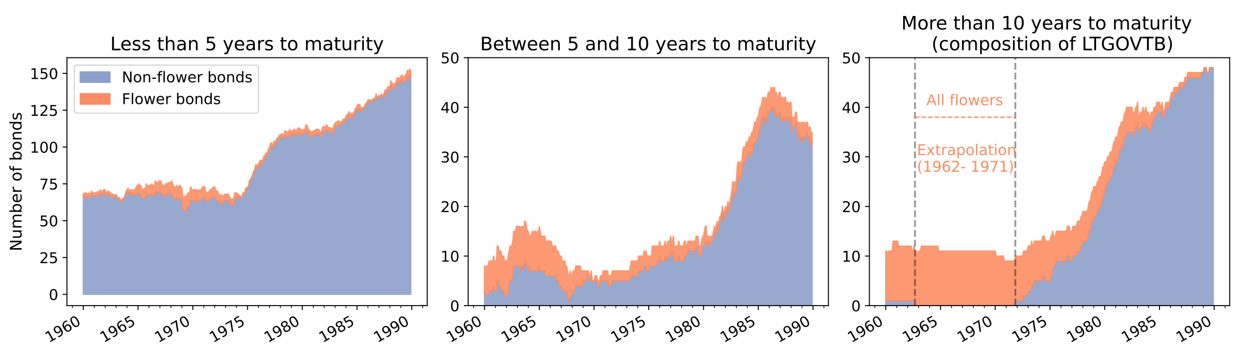

Figure 19: Composition of Treasurys: 1960-1990. The left subplot shows the number of bonds with less than 5 years to maturity. The middle subplot shows the number of bonds with 5-10 years to maturity. The right subplot shows the number of bonds with more than 10 years to maturity.

D.4 Default Risk

To account for time-varying changes in default risk we calculate an expected default probability and expected loss on corporate bonds by rating including downgrade risk over a one-year horizon. Let: $P_{r\to j}$ be the probability that a bond rated r migrates to rating j over one year (from the transition matrix); $d_j(t)$ the empirical one-year default probability for rating j in year t (from annual default rates); and R_j the average recovery rate for rating j over the sample period.

Then the expected loss for a bond rated r in year t is:

$$\text{Expected Loss}_r(t) = \sum_{j\in\mathcal{R}} P_{r\to j} \cdot d_j(t) \cdot (1 - R_j) + P_{r\to\text{Def}} \cdot (1 - R_r)$$

where $\mathcal{R}$ is the set of non-default ratings (e.g., AAA, AA, A, BAA, etc.). The first term captures indirect default risk via downgrade (i.e., migrate to a worse rating j, and then default). The second term captures direct default risk from rating r. The default probability is calculated analogously assuming that recovery rates R_j are zero for all ratings. Figure 20 shows the expected default probability over a one year-horizon.

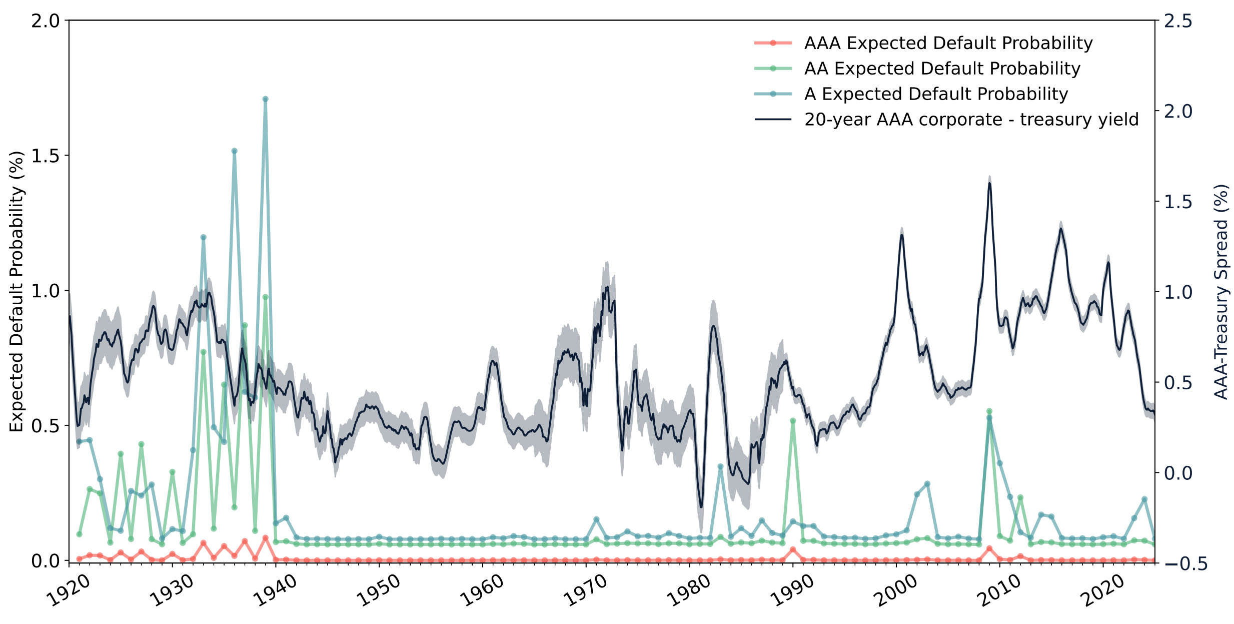

Figure 20: Expected Default Probability and AAA-Corporate to Treasury Spread

E Additional Details on Tax Distortions

The modern yield curve estimation literature (e.g. Diebold and Li (2006), Gürkaynak et al. (2007), Liu and Wu (2021), Filipović et al. (2022)) has attempted to handle bond heterogeneity by restricting the sample to bonds that do not bias the yield curve fit. It is well understood that the call, flower, and exchange options create biases and many of these papers have restricted their samples by excluding bonds with these characteristics. However, these papers ignore taxes. In this section of the appendix we outline when and how to adapt yield curve estimation techniques to handle distortions from tax treatments.

E.1 Scale-Invariant Bond Samples

The presence of taxation does not necessarily alter the estimation of yield curves. In this subsection, we formalize a notion of scale-invariance to taxes and discuss when scale-invariance fails to hold both theoretically and empirically.

Let $\mathcal{N}_t$ denote a (potentially restricted) sample of bonds that we consider for yield curve estimation. As before, let $\mathsf{q}_t := \{q_t^{(j)}\}_{j\geq 0}$ denote the discount function, with $q_t^{(0)} = 1$, that can be inferred from the tax-unadjusted cash-flows of these bonds while imposing the following asset pricing formula

$$p_{t,i} = \sum_{j=1}^{M_i} q_t^{(j)} c_i \qquad \forall i \in \mathcal{N}_t \tag{E.1}$$

and let $\mathsf{y}_t := \{y_t^{(1)}, y_t^{(2)}, \ldots\}$ denote the embedded zero-coupon yield curve defined as

$$y_t^{(j)} := \left(\frac{1}{q_t^{(j)}}\right)^{\frac{1}{j}} - 1 \qquad \forall j \geq 1.$$

Evidently, adjusting the cash flows for taxes would yield a different discount function $\{\overline{q}_t^{(j)}\}_{j\geq 0}$, with $\overline{q}_t^{(0)} = 1$, and consequently a different yield curve $\overline{\mathsf{y}}_t := \{\overline{y}_t^{(1)}, \overline{y}_t^{(2)}, \ldots\}$, where $\overline{y}_t^{(j)} := [1/\overline{q}_t^{(j)}]^{1/j} - 1$, even when using the same bond sample $\mathcal{N}_t$. The corresponding asset pricing formula is:

$$p_{t,i} = \sum_{j=1}^{M_i} \overline{q}_t^{(j)} (c_i - tax_{t,i}^{(j)}) \qquad \forall i \in \mathcal{N}_t. \tag{E.2}$$

where $tax_{t,i}^{(j)}$ denotes all taxes incurred from holding bond i in period $t + j$.

While the two yield curves are different, their relationship is not necessarily complicated. A particularly convenient case arises when the two yield curves y_t and $\bar{\mathsf{y}}_t$ are scalar multiples of one another, which we refer to as scale invariance.

Definition 1 (Scale-invariance to taxes)**.** For a given tax structure $\{tax_{t,i}^{(j)}\}$, a bond sample $\mathcal{N}_t$ is scale-invariant to taxes, if the zero-coupon yield curve, y_t, inferred from tax-unadjusted cash-flows using (E.1) is proportional to the zero-coupon yield curve, $\bar{\mathsf{y}}_t$, inferred from tax-adjusted cash-flows using (E.2) with

$$\overline{y}_t^{(j)} = (1-\tau)y_t^{(j)}, \qquad \forall j \geq 1$$

for some positive scalar $\tau \in [0,1)$.

For a sample that is scale invariant to taxes, the presence of taxation "does not matter for yield curve estimation" because the implied tax distortions are neither bond-specific nor maturity-specific: they simply scale the zero-coupon yield curve. This means that estimating equation (E.1) and (E.2) will lead to the same quality of fit despite the presence of taxation. So, when we have a scale-invariant bond sample, there is a *separation* between yield curve estimation and tax adjustment. We can estimate a so-called *reference yield curve*, y_t, from tax-unadjusted cash-flows without taking a stand on who is the marginal holder of the bonds and what is her relevant tax rates. Then once the reference curve y_t is estimated, an individual's after-tax yield curve can be derived by applying their specific marginal tax rates.

E.1.1 Sufficient Conditions for Scale Invariance

A scale-invariant bond sample is an ideal case which might not always hold in reality. Section 3 provided evidence that the available samples contained bonds with heterogeneous tax treatments, at least before the 1980s. To get a theoretical sense of when scale-invariance is a good approximation (and so modern yield curve estimates are reliable) and when it is not (and so modeling bond-specific tax distortions is necessary), the following proposition provides a set of sufficient conditions for scale-invariance to hold.

Proposition 1. *Suppose that investors are risk neutral. A bond sample $\mathcal{N}_t$ is scale-invariant to taxes, if the tax system satisfies the following conditions:*

1. *Coupon income, capital gains, and capital losses are taxed at the same rate τ.*

2. *Capital gains and capital losses are taxed each period (they can be amortized/accreted)*

3. The tax rate τ is common across all bonds $i \in \mathcal{N}_t$: no bonds have tax exemptions.

Proof. Suppose bond i has price $p_{t,i}$ with coupon cp_i, and there is one prevailing tax rate τ. Under (1)-(3), the bond pricing formula that defines $\bar{\mathsf{q}}_t$ can be written as

$$p_t = \sum_{j=1}^{M_i} \bar{q}_t^{(j)} \left\{(1-\tau)cp_i - \tau(\widehat{p}_{t+j,i} - \widehat{p}_{t+j-1,i})\right\} + \bar{q}_t^{(M_i)}100$$

where $\widehat{p}_{t+j,i}$ is the implied price of the bond at time $t+j$ that solves the following recursion for each $j \in \{0, M-1\}$

$$\widehat{p}_{t+j} = \frac{\bar{q}_t^{(j+1)}}{\bar{q}_t^{(j)}} \left[(1-\tau)cp_i + \widehat{p}_{t+j+1} - \tau(\widehat{p}_{t+j+1} - \widehat{p}_{t+j})\right]$$

with $\widehat{p}_{t+M} = 100$ and $\widehat{p}_t = p_t$. This recursion can be rearranged as

$$1 + \frac{\bar{q}_t^{(j)}/\bar{q}_t^{(j+1)} - 1}{1-\tau} = \frac{cp_i + \widehat{p}_{t+j+1}}{\widehat{p}_{t+j}}$$

Let $\bar{f}_t^{(j-1,j)} := \bar{q}_t^{(j-1)}/\bar{q}_t^{(j)} - 1$ be the one-period forward rate between period $t+j-1$ and $t+j$ and note that $\bar{y}_t^{(j)} \approx \frac{1}{j}\sum_{s=1}^{j} \bar{f}_t^{(s-1,s)}$ which becomes exact with continuous compounding. Using this approximation, the above recursion becomes:

$$\begin{aligned} p_{t,i} &= \sum_{j=1}^{M_i} \prod_{s=1}^{j} \left(\frac{1}{1+\frac{\bar{f}_t^{(s-1,s)}}{1-\tau}}\right) cp_i + \prod_{s=1}^{M_i} \left(\frac{1}{1+\frac{\bar{f}_t^{(s-1,s)}}{1-\tau}}\right) 100 \\ &\approx \sum_{j=1}^{M_i} \left(\frac{1}{1+\frac{\bar{y}_t^{(j)}}{1-\tau}}\right)^j cp_i + \left(\frac{1}{1+\frac{\bar{y}_t^{(M_i)}}{1-\tau}}\right)^{M_i} 100 \end{aligned}$$

Applying the definition of y_t, this implies that

$$(1-\tau)y_t^{(j)} = \bar{y}_t^{(j)} \qquad \forall j \geq 1.$$

$\square$

E.1.2 Institutional and Empirical Relevance

US Federal Income Taxation: Let τ^{inc} be the marginal income tax rate on ordinary income and let τ^{cg} be the marginal tax rate on long-term capital gains income. For a bond, the coupon payments are taxed at the rate τ^{inc} as they fall due. The tax implications of capital gains/losses from price appreciation/depreciation are more complicated.

- Capital losses can be deducted from ordinary income (so they are taxed at rate τ^{inc}) and typically they can be amortized, i.e. capital losses are effectively realized at the end of each period. This means that capital losses are zero at maturity/the time of selling.

- In contrast, capital gains are taxed at the rate τ^{cg} and cannot be amortized, i.e., all capital gains are realized at the end of the holding period. The implication of this is that tax effects become functions of the expected holding period. The longer the average holding period, the lower the present discount value of capital gains taxes over the lifetime of the bond.

Important Subperiods: As we saw above, ignoring income taxes would not be a problem if bond samples included bonds with homogeneous tax treatments. Proposition 1 shows this is satisfied when (i) coupon income, capital gains, and capital losses are all taxed at the same rate, (ii) capital gains and capital losses are taxed each period, and (iii) the tax rate is common across all bonds. Here we discuss when and how these conditions are violated in our historical sample:

- Before World War II, the main issue is that condition (iii) is violated because there were heterogeneous tax exemptions on government bonds.

- After World War II, tax rates become homogeneous and so the first two conditions become the main issues. The major violations to conditions (i) and (ii) come when bonds predominately earn capital gains because capital gains are taxed at a lower rate and deferred. As we can see in Figure 17 in Section D, a key example of this is the period from 1955-1985 when bonds were trading well below par and so the market understood there would future price increases back to par.

- Conditions (i) and (ii) are approximately satisfied when bonds predominately incur capital losses. This is because coupon income and capital losses are taxed at the same rate and capital losses are amortized each period. As we can see in Figure 17 in Section D, a key example of this is the 1985-2022 period when most bonds were trading above par and so the market understood there would be future price decreases back to par.

Consequently, outside of the 1985-2022 period, it is largely impossible to find a restricted bond sample with homogeneous tax treatments. Instead, we need to find a way to correct for bond- and maturity-specific tax distortions.

E.2 Reference Yield Curve and Tax Distortions

What breaks a bond sample's scale-invariance to taxes is heterogeneous tax treatments: when tax effects introduce bond-specific distortions relative to the *common* reference yield curve y_t. Historically, there are three kinds of tax effects that we need to consider:

1. *Tax exemptions*: when bonds are subject to differing tax rates, independent of their holders.

2. *Deferred tax payment*: unpaid taxes can be reinvested until the end of the holding period at the after-tax rate of return, then discounted back at the reference discount rate which is higher than the after-tax rate. This implies that bonds that are held for longer tend to have a lower tax burden (a lower "effective tax rate").

3. *Capital gains tax advantage*: the level of projected taxes declines as the level of projected capital gains on a bond increases. This implies that bonds that have larger projected capital gains have a lower tax burden (a lower "effective tax rate").

As we discussed in Section 2.3, these tax effects induce bond-specific distortions *relative to* the common reference yield curve that we represent by a multiplicative wedge z_i:

$$p_{t,i} = \sum_{j=1}^{M_i} \overline{q}_t^{(j)} c_{t,i} - \sum_{j=1}^{M_i} \overline{q}_t^{(j)} tax_{t,i}^{(j)} = \sum_{j=1}^{M_i} q_t^{(j)} z_i^{(j)}(\theta, p_{t,i}) c_{t,i} \qquad \forall i \in \mathcal{N}_t. \tag{E.3}$$

which is a function of parameters to be estimated, θ and potentially some observable bond characteristics such as the bond price $p_{t,i}$. When the bond sample is scale-invariant to taxes, bond-specific distortions are zero and so $z_i^{(j)} = 1$, $\forall j$ and $\forall i \in \mathcal{N}_t$.

This formulation allows us to shift focus from the $tax_{t,i}^{(j)}$-dependent after-tax discount function $\{\overline{q}_t^{(j)}\}_{j\geq 1}$ to a reference discount function $\{q_t^{(j)}\}_{j\geq 1}$ which can be inferred from tax-unadjusted cash-flows. Implicitly, this reference discount function does embed a reference tax rate, however, we do not need to estimate this rate, we only need to estimate the extent to which the "effective tax rate" of each bond i differs from this reference tax rate. The effective tax rate of bond i can differ from the reference rate because of tax exemptions, deferred tax payment, or lower relative tax rate on capital gains.

To make progress, we propose a parametric functional form for z_i that captures the three distinct tax effects: tax exemptions, deferral of tax payments, and the preferential treatment of capital gains. Our formulation is designed to generalize the approach in the tax-based bond pricing literature.

E.2.1 Functional forms of z_i

There is an older finance literature that has studied tax distortions in the bond market (e.g. Robichek and Niebuhr (1970), Colin and Bayer (1970), McCulloch (1975), Cook and Hendershott (1978)).[26] This literature uses variants of the following tax-adjusted asset pricing formula which is meant to represent key features of the tax code:

$$p_{t,i} = \sum_{j=1}^{M} \overline{q}_t^{(j)}(1-\tau^i)c_i + \overline{q}_t^{(M)}\left[100 - \tau^i \min\{100 - p_{t,i}, 0\} - \tau^{cg}\max\{100 - p_{t,i}, 0\}\right] \tag{E.4}$$

where $\tau^i \in \{\tau^{inc}, \tau^{pte}, \tau^{fte}\}$ is the marginal investor's income tax on fully taxable, partially tax exempt, and fully tax exempt bonds, respectively, and τ^{cg} is the long-term capital gains tax rates on the marginal investor. This formula can be derived by assuming that the bond is held to maturity, capital losses at maturity are taxed at τ^i while capital gains at maturity are taxed at τ^{cg}, and tax rates are expected to stay fixed over the lifetime of the bond. The literature has typically used this formula to compute after-tax yields by substituting in observed bond prices, coupon rates, and various IRS tax rates based on the judgment of the different researchers. As a result, the resulting after-tax discount function $\{\overline{q}_t^{(j)}\}_{j\geq 1}$ becomes a function of the specific (τ^i, τ^{cg}) values and is not directly comparable to estimates in the modern literature that ignores taxes.

In addition, there are two key reasons why this approach is inappropriate for our sample. First, the marginal buyer is unknown so the tax rates need to be estimated. However, formula (E.4) cannot jointly identify the income and capital gains tax rates. Second, the assumption that all bonds are held to maturity is unrealistic, particularly for samples with a large fraction of long-term (20+ years) bonds, like our corporate bond sample. This is because the held-to-maturity assumption tends to overestimate the capital gains advantage because it exaggerates the discounting of the future capital gains tax.

To address the first issue, we recast formula (E.4) in terms of our general asset pricing framework (E.3), which allows us to shift focus from the (τ^i, τ^{cg})-dependent after-tax discount function to a reference discount function $\{q_t^{(j)}\}_{j\geq 1}$ that can be inferred from tax-unadjusted cash-flows. In Section E.2.2, we show that (E.4) implies the following tax distortion to the

[26] Unsurprisingly, this literature was most active during the period from 1955-1985 when the tax distortions were largest.

reference curve:

$$z_{t,i}^{(j)} \approx \exp\Bigg(\underbrace{\left(1-\frac{1-\tau^{inc}}{1-\tau^{i}}\right)\widehat{y}_{t,i}j}_{\text{conversion from }\tau^i\text{ to }\tau^{inc}}\Bigg)\underbrace{\exp\left(-\tau^{i}\left(\frac{1-\tau^{inc}}{1-\tau^{i}}\right)(M_i-j)\widehat{y}_{t,i}\right)}_{\text{discounting from period }M\text{ to period }j} \underbrace{\left(1+\left(\frac{\tau^{i}-\tau^{cg}}{1-\tau^{i}}\right)\max\left\{\frac{100-p_{t,i}}{p_{t,i}},0\right\}\right)}_{\text{tax correction at period-}M\text{ (capital gains advantage)}} \tag{E.5}$$

where $\widehat{y}_{t,i}$ is bond i's yield-to-maturity.[27] The first term captures the distortion from tax exemptions, i.e., the relative distortions due to $\tau^i < \tau^{inc}$. The second term in (E.5) captures the distortion from deferred (until maturity) tax payment. The third term captures the distortion from the fact that capital gains are taxed at a lower rate than ordinary income.

To address the second issue, we relax the held-to-maturity assumption by introducing parameter H (common across bonds) which represents the market's average holding period. In Section E.2.3, we show how this assumption generalizes (E.5) to the following formula:

$$z_{t,i}^{(j)} \approx \exp\Bigg(\underbrace{\left(1-\frac{1-\tau^{inc}}{1-\tau^{i}}\right)\widehat{y}_{t,i}j}_{\text{conversion from }\tau^i\text{ to }\tau^{inc}}\Bigg)\underbrace{\exp\left(-\tau^{i}\left(\frac{1-\tau^{inc}}{1-\tau^{i}}\right)\left(\left\lceil\frac{j}{H}\right\rceil-\frac{j}{H}\right)H\widehat{y}_{t,i}\right)}_{\text{discounting from period }M\text{ to period }j} \underbrace{\left(1+\left(\frac{\tau^{i}-\tau^{cg}}{1-\tau^{i}}\right)\sum_{s=1}^{j}\max\left\{\frac{\widehat{p}_{t+s}}{\widehat{p}_{t+s-1}}-1,0\right\}\right)}_{\text{tax correction at period-}M\text{ (capital gains advantage)}} \tag{E.6}$$

where H is the average holding period (not bond-specific), while $\widehat{p}_{H_{t,k},i}$ is the period-t "expectation" of the market price of bond i for the trading date $H_{t,k} := \min\{kH, M_{t,i}\}$. The terms in (E.6) generalize those in (E.5) to account for cases where the average holding period is shorter than the bond's maturity.

Because we are interested in estimating tax pricing distortions rather than tax rates and holding periods, we combine the relevant terms into coefficients $(\eta^i_{t,0}, \eta_{t,1}, \eta_{t,2})$ defined by the following approximation to Equation (E.6):

$$z_{t,i}^{(j)} \approx \exp\Bigg(\underbrace{\eta^i_{t,0}\cdot\widehat{y}_{t,i}\cdot j}_{\text{tax exemption}}-\underbrace{\eta_{t,1}\left(M_{t,i}-j\right)\widehat{y}_{t,i}}_{\text{deferred taxes}}\Bigg)\underbrace{\left(1+\eta_{t,2}\sum_{s=1}^{j}\max\left\{\frac{\widehat{p}_{t+s,i}}{\widehat{p}_{t+s-1,i}}-1,0\right\}\right)}_{\text{capital gains tax advantage}} \tag{E.7}$$

[27] This formula is derived under the assumption that the one-period forward rates can be approximated by the bond's yield-to-maturity $\widehat{y}_{t,i}$.

where we have that $\eta_{t,0}^{inc} = 0$ for fully taxable bonds and $\eta_{t,0}^{pte} > 0$ and $\eta_{t,0}^{pte} > 0$ for partially tax exempt or fully tax exempt bonds respectively. To derive the approximation in Equation (E.7), we also assumed that (1) capital gains are taxed every period, (2) the "saw tooth"-like function of j in the deferred taxes term can be approximated with a decreasing linear function which reaches 0 at $j = M_{t,i}$. In addition, we approximate the expected bond price trajectories with those implied by $\widehat{y}_{t,i}$. These can be derived from the recursion: $\widehat{p}_{t,i} = \exp(-\widehat{y}_{t,i})(cp_i + \widehat{p}_{t+1,i})$ with boundary conditions $\widehat{p}_{t+M_i} = 100$, and $\widehat{p}_{t,i} = p_{t,i}$.

E.2.2 Derivation of Equation (E.5)

To derive Equation (E.5), we go in steps. First, following the literature, we present a formula which ignores tax exemptions, i.e. all bonds face the same ordinary income tax rate τ^{inc}. We then generalize this formula to accommodate differences in the tax rate on ordinary income.

Without tax exemptions. Robichek and Niebuhr (1970), Colin and Bayer (1970), McCulloch (1975), Cook (1977), and Cook and Hendershott (1978) study the price implications of income taxes under the assumption that all bonds are held to maturity. In particular, they impose the following asset pricing formula

$$p_{t,i} = \sum_{j=1}^{M} \overline{q}_t^{(j)}(1-\tau^{inc})c_i + \overline{q}_t^{(M)}\left[100 - \tau^{inc}\min\{100-p_{t,i},0\} - \tau^{cg}\max\{100-p_{t,i},0\}\right]$$

where $\{\overline{q}_t^{(j)}\}$ denotes the after-tax discount function. This formula can be rewritten as

$$\begin{aligned}
p_{t,i} &= \sum_{j=1}^{M_i} \overline{q}_t^{(j)}(1-\tau^{inc})c_i + \overline{q}_t^{(M_i)}\left[100 - \tau^{inc}(100-p_{t,i}) + (\tau^{inc}-\tau^{cg})\max\{100-p_{t,i},0\}\right] \\
&= \sum_{j=1}^{M_i} \overline{q}_t^{(j)}(1-\tau^{inc})c_i + \\
&\qquad + \overline{q}_t^{(M_i)} p_{t,i}\left[(1-\tau^{inc})\left(\frac{100}{p_{t,i}}-1\right) + (\tau^{inc}-\tau^{cg})\max\left\{\frac{100}{p_{t,i}}-1,0\right\}+1\right]
\end{aligned}$$

This leads to

$$1 + \frac{1/\overline{q}_t^{(M_i)}-1}{1-\tau^{inc}} - \frac{\tau^{inc}-\tau^{cg}}{1-\tau^{inc}}\max\left\{\frac{100-p_{t,i}}{p_{t,i}},0\right\} = \sum_{j=1}^{M_i}\frac{\overline{q}_t^{(j)}}{\overline{q}_t^{(M)}}\frac{c_i}{p_{t,i}} + \frac{100}{p_{t,i}}$$

or

$$p_{t,i} = \underbrace{\left(\frac{1/\overline{q}_t^{(M_i)}}{1 + \frac{1/\overline{q}_t^{(M_i)}-1}{1-\tau^{inc}} - \frac{\tau^{inc}-\tau^{cg}}{1-\tau^{inc}} \max\left\{\frac{100-p_{t,i}}{p_{t,i}}, 0\right\}} \right)}_{=:w_{t,i}} \left(\sum_{j=1}^{M_i} \overline{q}_t^{(j)} c + \overline{q}_t^{(M_i)} 100 \right).$$

where the tax distortion $w_{t,i}$ can be approximated as

$$\begin{aligned} w_{t,i} &= \frac{1/\overline{q}_t^{(M_i)}}{1 + \frac{1/\overline{q}_t^{(M_i)}-1}{1-\tau^{inc}} - \frac{\tau^{inc}-\tau^{cg}}{1-\tau^{inc}} \max\left\{\frac{100-p_{t,i}}{p_{t,i}}, 0\right\}} \\ &\approx \frac{q_t^{(M_i)}}{\overline{q}_t^{(M_i)}} \left(\frac{1}{1 - \frac{\tau^{inc}-\tau^{cg}}{1-\tau^{inc}} \max\left\{\frac{100-p_{t,i}}{p_{t,i}}, 0\right\}} \right). \end{aligned}$$

The tax-adjusted discount function used to discount tax-unadjusted cash-flows can be written as:[28]

$$\widehat{q}_{t,i}^{(j)} := \overline{q}_t^{(j)} w_{t,i} \approx \underbrace{q_t^{(M_i)}}_{\text{discounting}} \quad \underbrace{\frac{\overline{q}_t^{(j)}}{\overline{q}_t^{(M_i)}}}_{\substack{\text{move period-}j\\ \text{payoff to period-}M}} \underbrace{\left(\frac{1}{1 - \frac{\tau^{inc}-\tau^{cg}}{1-\tau^{inc}} \max\left\{\frac{100-p_{t,i}}{p_{t,i}}, 0\right\}} \right)}_{\text{capital gains advantage in period-}M\text{ dollar}}$$

The first term captures discounting from the end-of-holding-period to today using the reference discount rate. The second term transforms period-j dollars to period-M dollars (end of holding period) using after-tax discount rate. This captures the value of deferment: unpaid taxes in period j can be reinvested until the end of the holding period. The third term is an adjustment due to the fact that the "effective tax rate" on bond i is lower than the reference tax rate because of the reduced tax rate on capital gains paid at the end of the holding period.

We can get a formula for the multiplicative distortion z_i by breaking up $q_t^{(M_i)}$:

$$\widehat{q}_{t,i}^{(j)} := \underbrace{q_t^{(j)}}_{\text{reference}} \underbrace{\frac{q_t^{(M_i)}}{q_t^{(j)}} \frac{\overline{q}_t^{(j)}}{\overline{q}_t^{(M_i)}}}_{\text{deferment}} \underbrace{\left(\frac{1}{1 - \frac{\tau^{inc}-\tau^{cg}}{1-\tau^{inc}} \max\left\{\frac{100-p_{t,i}}{p_{t,i}}, 0\right\}} \right)}_{\text{capital gains at end-of-holding-period}}$$

The component labeled as "deferment" captures the fact that between period j and the end

[28] Relative to the after-tax yield curve, $\overline{\mathsf{q}}_t$, tax effects are captured by the $w_{t,i}$ term. The $w_{t,i}$ term is independent of horizon j and depends solely on the bond's maturity M_i. The horizon independent tax effect $w_{t,i}$ tends to underweight longer-horizon payoffs, thereby making $\widehat{q}_t^{(j)}$ more downward-sloping than the after-tax yield curve $\overline{q}_t^{(j)}$.

of the holding period M, unpaid taxes can be reinvested, then discounted back to period j at the reference rate. This term can be rewritten as

$$\frac{q_t^{(M_i)}}{q_t^{(j)}}\frac{\overline{q}_t^{(j)}}{\overline{q}_t^{(M_i)}} = \prod_{s=j+1}^{M_i}\left(\frac{1+\overline{f}_t^{(s-1,s)}}{1+\frac{\overline{f}_t^{(s-1,s)}}{1-\tau^{inc}}}\right) = \prod_{s=j+1}^{M_i}\left(\frac{\left(1+\frac{\overline{f}_t^{(s-1,s)}}{1-\tau^{inc}}\right)(1-\tau^{inc})+\tau^{inc}}{1+\frac{\overline{f}_t^{(s-1,s)}}{1-\tau^{inc}}}\right)$$
$$= \prod_{s=j+1}^{M_i}\left(1-\tau^{inc}\left(1-q_t^{(s-1,s)}\right)\right) \approx \prod_{s=j+1}^{M_i}\left(1-\tau^{inc}\left(\frac{\overline{f}_t^{(s-1,s)}}{1-\tau^{inc}}\right)\right)$$

Consequently, relative to the (scale-invariant) reference yield curve, tax distortions can be summarized by the $z_{t,i}^{(j)}$ variable, which is approximately:

$$z_{t,i}^{(j)} \approx \underbrace{\left(\frac{1}{1+\frac{\tau^{inc}}{1-\tau^{inc}}\sum_{s=j+1}^{M_i}\overline{f}_t^{(s-1,s)}}\right)}_{\text{discounting capital gains/losses to period-}j}\underbrace{\left(1+\left(\frac{\tau^{inc}-\tau^{cg}}{1-\tau^{inc}}\right)\max\left\{\frac{100-p_{t,i}}{p_{t,i}},0\right\}\right)}_{\text{capital gains advantage at the end of holding period}}$$

The second term is coming from capital gains tax advantage and it depends on the magnitude of the projected capital gains. This term introduces a downward pressure on the reference yield curve. When capital gains taxes are paid only at maturity (end of holding period), it needs to be discounted back to period $j < M_i$. The first term captures the appropriate discount factor. The term z_i constitutes a bond-specific (negative) level shift relative to the reference yield curve.

We approximate the discount rate with the bond's yield-to-maturity:

$$\tau^{inc}\sum_{s=j+1}^{M_i}\frac{\overline{f}_t^{(s-1,s)}}{1-\tau^{inc}} \approx \tau^{inc}(M_i-j)\widehat{y}_{t,i}$$

As a result, we get the following approximation of z_i:

$$z_{t,i}^{(j)} \approx \underbrace{\exp\left(-\tau^{inc}(M_i-j)\widehat{y}_{t,i}\right)}_{\text{discounting from end-of-holding-period to }j}\underbrace{\left(1+\left(\frac{\tau^{inc}-\tau^{cg}}{1-\tau^{inc}}\right)\max\left\{\frac{100-p_{t,i}}{p_{t,i}},0\right\}\right)}_{\text{tax advantage correction at end-of-holding-period}}$$

The reduced form version becomes

$$z_{t,i}^{(j)} \approx \exp\left(-\eta_{t,1}(M_i-j)\widehat{y}_{t,i}\right)\left(1+\eta_{t,2}\max\left\{\frac{100-p_{t,i}}{p_{t,i}},0\right\}\right)$$

with $\eta_{t,1}, \eta_{t,2} \geq 0$.

With tax exemptions: The formula can be easily generalized to accommodate different income taxes present in our pre-WW2 government bond sample. Let $\tau^i \in \{\tau^{pte}, \tau^{fe}, \tau^{inc}\}$ be the income tax on partially tax exempt, fully tax exempt and fully taxable bonds, respectively. The above formula of $z^j_{t,i}$ is still relevant, but the discount function relative to which it represents deviations is now

$$\underline{q}_t^{(j)} := \prod_{s=1}^{j} \left(\frac{1}{1 + \frac{\overline{f}_t^{(s-1,s)}}{1-\tau^i}} \right)$$

In other words, the discount function inferred from tax-unadjusted cash-flows become

$$\widehat{q}_{t,i}^{(j)} = \underline{q}_{t,i}^{(j)} \underbrace{\left(\frac{1}{1 + \frac{\tau^i}{1-\tau^i} \sum_{s=j+1}^{M_i} \overline{f}_t^{(s-1,s)}} \right)}_{\text{discounting capital gains/losses to period-}j} \underbrace{\left(1 + \left(\frac{\tau^i - \tau^{cg}}{1-\tau^i} \right) \max \left\{ \frac{100 - p_{t,i}}{p_{t,i}}, 0 \right\} \right)}_{\text{capital gains advantage at the end of holding period}}$$

To change this to deviations relative from the reference discount function we can introduce an extra term that captures the "exchange rate" between $\underline{q}_t^{(j)}$ and $q_t^{(j)}$:

$$\widehat{q}_{t,i}^{(j)} = q_t^{(j)} \underbrace{\left(\frac{\underline{q}_t^{(j)}}{q_t^{(j)}} \right) \frac{\left(1 + \left(\frac{\tau^i - \tau^{cg}}{1-\tau^i} \right) \max \left\{ \frac{100 - p_{t,i}}{p_{t,i}}, 0 \right\} \right)}{\left(1 + \frac{\tau^i}{1-\tau^i} \sum_{s=j+1}^{M_i} \overline{f}_t^{(s-1,s)} \right)}}_{=: z_{t,i}}$$

The conversion term can be rewritten as

$$\frac{\underline{q}_t^{(j)}}{q_t^{(j)}} = \prod_{s=1}^{j} \left(\frac{1 + \frac{1/\overline{q}_t^{(s-1,s)} - 1}{1-\tau^{inc}}}{1 + \frac{1/\overline{q}_t^{(s-1,s)} - 1}{1-\tau^i}} \right) = \prod_{s=1}^{j} \left(\frac{1 + \frac{\overline{f}_t^{(s-1,s)}}{1-\tau^{inc}}}{\left(1 + \frac{\overline{f}_t^{(s-1,s)}}{1-\tau^{inc}} \right) \frac{1-\tau^{inc}}{1-\tau^i} + \frac{\tau^{inc} - \tau^i}{1-\tau^i}} \right)$$

$$= \frac{1}{\prod_{s=1}^{j} \left(1 - \left(\frac{\tau^{inc} - \tau^i}{1-\tau^i} \right) \left(1 - q_t^{(s-1,s)} \right) \right)} \approx \frac{1}{1 - \left(\frac{\tau^{inc} - \tau^i}{1-\tau^i} \right) \sum_{s=1}^{j} \frac{\overline{f}_t^{(s-1,s)}}{1-\tau^{inc}}}$$

So the distortion relative to the reference discount function becomes approximately:

$$z_{t,i}^{(j)} \approx \underbrace{\left(\frac{1}{1-\left(\frac{\tau^{inc}-\tau^{i}}{1-\tau^{i}}\right)\sum_{s=1}^{j}\frac{\overline{f}_t^{(s-1,s)}}{1-\tau^{inc}}}\right)}_{\text{conversion to reference tax rate}} \underbrace{\left(\frac{1}{1+\frac{\tau^{i}}{1-\tau^{i}}\sum_{s=j+1}^{M_i}\overline{f}_t^{(s-1,s)}}\right)}_{\text{discounting capital gains/losses to period-}j}$$
$$\underbrace{\left(1+\left(\frac{\tau^{i}-\tau^{cg}}{1-\tau^{i}}\right)\max\left\{\frac{100-p_{t,i}}{p_{t,i}},0\right\}\right)}_{\text{capital gains advantage at the end of holding period}}$$

As a result, we get the following approximation of z_i:

$$z_{t,i}^{(j)} \approx \underbrace{\exp\left(\widehat{y}_{t,i}j\right)\exp\left(-\left(\frac{1-\tau^{inc}}{1-\tau^{i}}\right)\widehat{y}_{t,i}j\right)}_{\text{conversion between }\tau^{i}\text{ and }\tau^{inc}} \underbrace{\exp\left(-\tau^{i}\left(\frac{1-\tau^{inc}}{1-\tau^{i}}\right)(M_i-j)\widehat{y}_{t,i}\right)}_{\text{discounting from period }M\text{ to period }j}$$
$$\underbrace{\left(1+\left(\frac{\tau^{i}-\tau^{cg}}{1-\tau^{i}}\right)\max\left\{\frac{100-p_{t,i}}{p_{t,i}},0\right\}\right)}_{\text{tax correction at period-}M} \tag{E.8}$$

Note also that $q_t^{(j)} \approx \exp(-\widehat{y}_t j)$.

E.2.3 Derivation of Equation (E.6)

Let $M_{t,i}$ denote bond i's remaining lifetime in period t. Partition $M_{t,i}$ into holding periods of length H, by defining a series of trading dates as follows:

$$H_{t,k} = \min\{kH,\ M_{t,i}\} \qquad k \in \{0,1,\ldots,K_{t,i}\}, \quad \text{s.t.} \quad K_{t,i} := \left\lceil \frac{M_{t,i}}{H} \right\rceil$$

where $\lceil\cdot\rceil$ denotes the ceiling function and $K_{t,i}$ is the number of holding periods between t and $t+M_i$.[29] Note that as $H\to\infty$, we have only two trading dates, $H_{t,0}=0$ and $H_{t,1}=M_{t,i}$, and only one holding period, $K_{t,i}=1$. This case corresponds to the held-to-maturity assumption. For given horizon j, the start and end dates of the relevant holding period are

$$\left\lfloor \frac{j}{H} \right\rfloor H \le j \le \left\lceil \frac{j}{H} \right\rceil H$$

where $\lfloor\cdot\rfloor$ is the floor function.

[29] Except for the last holding period (the length of which can be a fraction of H), each holding period has length H.

Let $\widehat{p}_{t+H_{t,k}}$ denote the $H_{t,k}$-period-ahead "expected" bond price in period-t, such that $\widehat{p}_{t+H_{t,K_{t,i}}} = 100$ and for each $k \in \{0, 1, \dots, K_{t,i} - 1\}$, $\widehat{p}_{t+H_{t,k}}$ solves the following recursion:

$$\widehat{p}_{t+H_{t,k}} = \frac{\overline{q}_t^{(H_{t,k+1})}}{\overline{q}_t^{(H_{t,k})}} \Big[(1-\tau^i)(c + \widehat{p}_{t+H_{t,k+1}} - \widehat{p}_{t+H_{t,k}}) + (\tau^i - \tau^{cg}) \max\{\widehat{p}_{t+H_{t,k+1}} - \widehat{p}_{t+H_{t,k}}, 0\} + \widehat{p}_{t+H_{t,k}}\Big]$$

Following the same steps as in section E.2.2, the tax-adjusted discount function that can be used to discount tax-unadjusted cash-flows can be written as:

$$\widehat{q}_{t,i}^{(j)} := q_t^{(j)} \underbrace{\frac{\underline{q}_t^{(j)}}{q_t^{(j)}}}_{\text{conversion}} \underbrace{\frac{\underline{q}_t^{(\lceil \frac{j}{H} \rceil H)}}{\underline{q}_t^{(j)}} \frac{\overline{q}_t^{(j)}}{\overline{q}_t^{(\lceil \frac{j}{H} \rceil H)}}}_{\text{deferment}} \underbrace{\prod_{k=1}^{\lceil \frac{j}{H} \rceil} \left(1 + \left(\frac{\tau^i - \tau^{cg}}{1-\tau^i}\right) \max\left\{\frac{\widehat{p}_{t+H_{t,k}}}{\widehat{p}_{t+H_{t,k-1}}} - 1, 0\right\}\right)}_{\text{capital gains at end-of-holding-period}}$$

So the distortion relative to the reference discount function becomes approximately:

$$z_{t,i}^{(j)} \approx \underbrace{\left(\frac{1}{1 - \left(\frac{\tau^{inc} - \tau^i}{1-\tau^i}\right) \sum_{s=1}^{j} \frac{\overline{f}_t^{(s-1,s)}}{1-\tau^{inc}}}\right)}_{\text{conversion to reference tax rate}} \underbrace{\left(\frac{1}{1 + \frac{\tau^i}{1-\tau^i} \sum_{s=j+1}^{\lceil \frac{j}{H} \rceil H} \overline{f}_t^{(s-1,s)}}\right)}_{\text{discounting capital gains/losses to period-}j}$$
$$\underbrace{\prod_{k=1}^{\lceil \frac{j}{H} \rceil} \left(1 + \left(\frac{\tau^i - \tau^{cg}}{1-\tau^i}\right) \max\left\{\frac{\widehat{p}_{t+H_{t,k}}}{\widehat{p}_{t+H_{t,k-1}}} - 1, 0\right\}\right)}_{\text{capital gains advantage at the end of holding period}}$$

As a result, we get the following approximation of z_i:

$$z_{t,i}^{(j)} \approx \underbrace{\exp\left(\widehat{y}_{t,i} j\right) \exp\left(-\left(\frac{1-\tau^{inc}}{1-\tau^i}\right) \widehat{y}_{t,i} j\right)}_{\text{conversion between } \tau^i \text{ and } \tau^{inc}} \underbrace{\exp\left(-\tau^i \left(\frac{1-\tau^{inc}}{1-\tau^i}\right) \left(\left\lceil \frac{j}{H} \right\rceil H - j\right) \widehat{y}_{t,i}\right)}_{\text{discounting from period } M \text{ to period } j}$$
$$\underbrace{\left(1 + \left(\frac{\tau^i - \tau^{cg}}{1-\tau^i}\right) \sum_{k=1}^{\lceil \frac{j}{H} \rceil} \max\left\{\frac{\widehat{p}_{t+H_{t,k}}}{\widehat{p}_{t+H_{t,k-1}}} - 1, 0\right\}\right)}_{\text{tax correction at end-of-holding-period}}$$

Two special cases:

- As $H \to 1$ and so the length of the holding period equals the length of the coupon period, the distortion from deferment goes away (investor pays taxes every period)
- As $H \to \infty$, we get the held-to-maturity case. The formula boils down to (E.8).

F Additional Details on Yield Curve Estimation

F.1 High Level Strategy

We seek to find yield curves that price one dollar of ordinarily taxed cash flow from a straight bond at a given time in the future. Accordingly, we need machinery that makes the appropriate "corrections" from the tax-distorted, option-contaminated space to the option and tax-adjusted cash flow space. An itemized list of the steps we take to achieve this on a given date is as follows:

- Obtain the matrix $C_t^{promised}$ of promised cash flows for bonds with observed prices P_t. $C_{ij}^{promised}$ corresponds to the promised cash flow of bond i at time j in the future.
- For every bond i, apply $z_{t,i}^j$ to each cash flow $C_{ij}^{promised}$, as necessary. Cash flows are now homogeneous with respect to taxes across bonds in the sample.
- For bonds with embedded options, we insert the option wedge, $v_{t,i}$, at this stage. This is done as prescribed in Section 4.1.
- Fit the discount function q. This process is detailed in section F.2 If there are embedded options in the sample for a given date, a nested minimization is performed to find the optimal option wedges that minimize the Filipović et al. (2022) objective function given their closed form q.

F.2 Yield Curve Fitting

We observe prices $P_1, \ldots, P_N$ of N coupon bonds with cash flows summarized in the $N \times M$ matrix C, where M spans the observed maturity spectrum. Entries $C_{i,j}$ correspond to the cash flow of bond $1 \leq i \leq N$ occurring at time $1 \leq j \leq M$ in the future. We seek to estimate the vectorized discount function $q(\mathbf{x})$, where $\mathbf{x}$ is the vector spanning the maturity spectrum M periods in the future. The law of one price dictates that the fitted price of the bond be:

$$P_i(q) = \sum_{j=1}^{M} C_{i,j} q(x_j)$$

In order to impose structure on the estimates and penalize overfitting, we follow Filipović et al. (2022) (henceforth FPY-22) and define a measure of smoothness as a weighted average of the first and second derivatives of the discount function:

$$||q||_{\alpha,\delta} = \left(\int_0^\infty \left(\delta q'(x)^2 + (1-\delta) q''(x)^2 \right) e^{\alpha x} dx \right)^{\frac{1}{2}} \tag{F.1}$$

for maturity weight parameter $\alpha \geq 0$ and shape parameter $\delta \in [0, 1]$. δ closer to 0 forces the curve to be tense, avoiding oscillations, while δ closer to 1 forces the curve to be straight, avoiding kinks. The weighting term $e^{\alpha x}$ allows the smoothness term to be maturity dependent. Increasing α gives way to more flexibility at the shorter end while enforcing the longer end of the curve to be smooth.

Define $\mathcal{Q}_{\alpha,\delta}$ to be the set of twice weakly differentiable discount curves q with finite smoothness (i.e. the integral in (F.1) is convergent). Then the convex optimization problem to solve for q is:

$$\min_{q \in \mathcal{Q}_{\alpha,\delta}} \sum_{i=1}^{M} \omega_i (P_i - \hat{P}_i(q))^2 + \lambda ||q||^2_{\alpha,\delta} \tag{F.2}$$

for exogenous weights ω_i and smoothness parameter λ. FPY-22 show that (F.2) has a unique close-form solution for any tuple of $(\lambda, \alpha, \delta)$, except in the ill-defined case $\alpha = \delta = 0$. Toward a discussion on the distributional aspect of the estimator, we may define q to be made up of an exogenous prior curve p with $p(0) = 1$ plus a deviation from prior h, $q(\mathbf{x}) = p(\mathbf{x}) + h(\mathbf{x})$. The objective function decomposes into the following:

$$\min_{h \in \mathcal{H}_{\alpha,\delta}} \sum_{i=1}^{M} \omega_i \Big(P_i - C_i(p(\mathbf{x}) + h(\mathbf{x})) \Big)^2 + \lambda ||h||^2_{\alpha,\delta} \tag{F.3}$$

where C_i is a row vector of cash flows over the maturity spectrum for bond i, or equivalently, the i-th row of C. $\mathcal{H}$ is a *reproducing kernel Hilbert space* of functions h with initial condition $h(0) = 0$. See FPY-22 for further discussion.

Problem (F.3) can be decomposed in terms of β given an $M \times M$ kernel matrix $\mathbf{K}$. The entries of $\mathbf{K}$ are determined by the parameters α and δ in five cases. (See FPY-22 for details). With this formulation, the optimization problem simplifies further to:

$$\min_{\beta} \sum_{i=1}^{M} \omega_i \left(P_i - C_i p(\mathbf{x}) - C_i \mathbf{K} \beta \right)^2 + \lambda \beta^T \mathbf{K} \beta$$

which emits a unique solution:

$$\hat{\beta} = C^T \left(C \mathbf{K} C^T + \Lambda \right)^{-1} (P - C p(\mathbf{x}))$$

where P is the vector of observed prices and Λ is defined by:

$$\Lambda = \mathrm{diag}\Big(\frac{\lambda}{\omega_1}, \ldots, \frac{\lambda}{\omega_M} \Big)$$

The fitted discount function $\hat{q}(\mathbf{x})$ is therefore

$$\hat{q}(\mathbf{x}) = p(\mathbf{x}) + \mathbf{K}\hat{\beta}$$

We obtain a fitted zero-coupon yield curve, which we denote $\hat{y}(\mathbf{x})$, by taking;

$$\hat{y}(\mathbf{x}) = -\log\left(\hat{q}(\mathbf{x})\right)/\mathbf{x}$$

To summarize the estimation process, we obtain a flexible closed-form estimator assuming that the estimated discount function is twice weakly differentiable and obeys some level of smoothness for a given tuple $(\lambda, \alpha, \delta)$. To choose an optimal tuple, we adopt the same cross-validation strategy as FPY-22, discussed in Section 3.2 of their paper. This ensures that the parameters we choose best minimize the out-of-sample error.

F.3 Distributional Aspects

A feature of the Kernel Ridge estimator is that assuming a normally distributed prior curve, we obtain a normally distributed posterior distribution for the estimated curve $\hat{q}$. Specifically, assume a Gaussian distribution for q:

$$q(\mathbf{x}) \sim \mathcal{N}(p(\mathbf{x}), s\mathbf{K})$$

emits a normal posterior distribution with mean function m and covariance function v for scalars y, z:

$$\begin{aligned} m^{post}(z) &= p(z) + k(z, \mathbf{x}^{\mathbf{T}})\hat{\beta} \\ v^{post}(y, z) &= s\Big(k(y, z) - k(y, \mathbf{x}^{\mathbf{T}})C^T(C\mathbf{K}C^T + \Lambda)^{-1}Ck(\mathbf{x}, z)\Big) \end{aligned}$$

where $k(y, z) = \mathbf{K}_{yz}$ and we assume that the price errors have variance $\Sigma_\epsilon = \Lambda$. We follow FPY-22 and set s to be:

$$s = \frac{1}{M}(P - Cp(\mathbf{x}))^T(C\mathbf{K}C^T + \Lambda)^{-1}(P - Cp(\mathbf{x}))$$

which maximizes the prior log-likelihood function of s given observed prices P. We can therefore easily obtain confidence bounds on the fitted discount function $\hat{q}$. The posterior distribution provides additional information on extrapolated discount functions during periods with only short-term bonds outstanding. As expected, the confidence intervals tend to expand dramatically as we extrapolate past the maximum observed maturity in a given period.

G Additional Results on Yield Curve Estimates

In this section, we describe the key outputs from our estimation: the highest-grade corporate bond yield curve and the Treasury yield curve for the period 1860-2024.

G.1 Highest-Grade Corporate Bond Yield Curves

The top panel of Figure 21 depicts selected long-term nominal yields on high-grade US corporate bonds. The solid black line represents the median of our 20-year zero-coupon yield estimates. Bands around the posterior median depict the 90% interquantile range. Between 1860-1900, long-term high-grade corporate yields trended downward from around 8% to around 4% (the "great bond bull market"), then climbed slowly back to 5% by World War I. During the war and the subsequent 1920 recession long-term corporate yields reached more than 7% before they began their renewed downward decline (interrupted briefly by the Great Depression). During World War II and the 1950s, the 20-year high-grade corporate yield exhibited surprising stability up until the late 1960s when, in tandem with increasing inflation, it reached its peak of 18% during the 1981-1982 recession.

The blue dashed line in the top panel of Figure 21 depicts the high-grade railroad bond index from Macaulay (1938) computed as the average yield-to-maturity on selected long-term bonds issued by reputable railroad companies between 1857-1937. The red solid line is Moody's Seasoned AAA Corporate Bond Yield index computed as the average yield-to-maturity on bonds with maturity 20 years and above. This index is available from 1919 onward. While yields-to-maturity are different from the notion of a zero-coupon yield, we find it reassuring that our estimates broadly align with Macaulay's high-grade railroad and Moody's AAA indexes.[30]

One of the main advantages of estimating the whole yield curve is to observe shorter maturity private borrowing costs. The middle panel of Figure 21 depicts our posterior median estimates of the 10-year and 2-year zero-coupon yields on high-grade corporate bonds. The bottom panel shows the corresponding spread. Evidently, short- and medium-term yields follow the same trend as the 20-year yield, but they are more volatile, especially in the post WWII period. Before the 1980s, the spread between the 10-year and 2-year zero-coupon

[30] Yield-to-maturity is computed under the assumption of a flat yield curve. In this sense, yield-to-maturity of a particular bond can be considered as the weighted average of zero-coupon yields with the bond's cash-flows acting as weights.

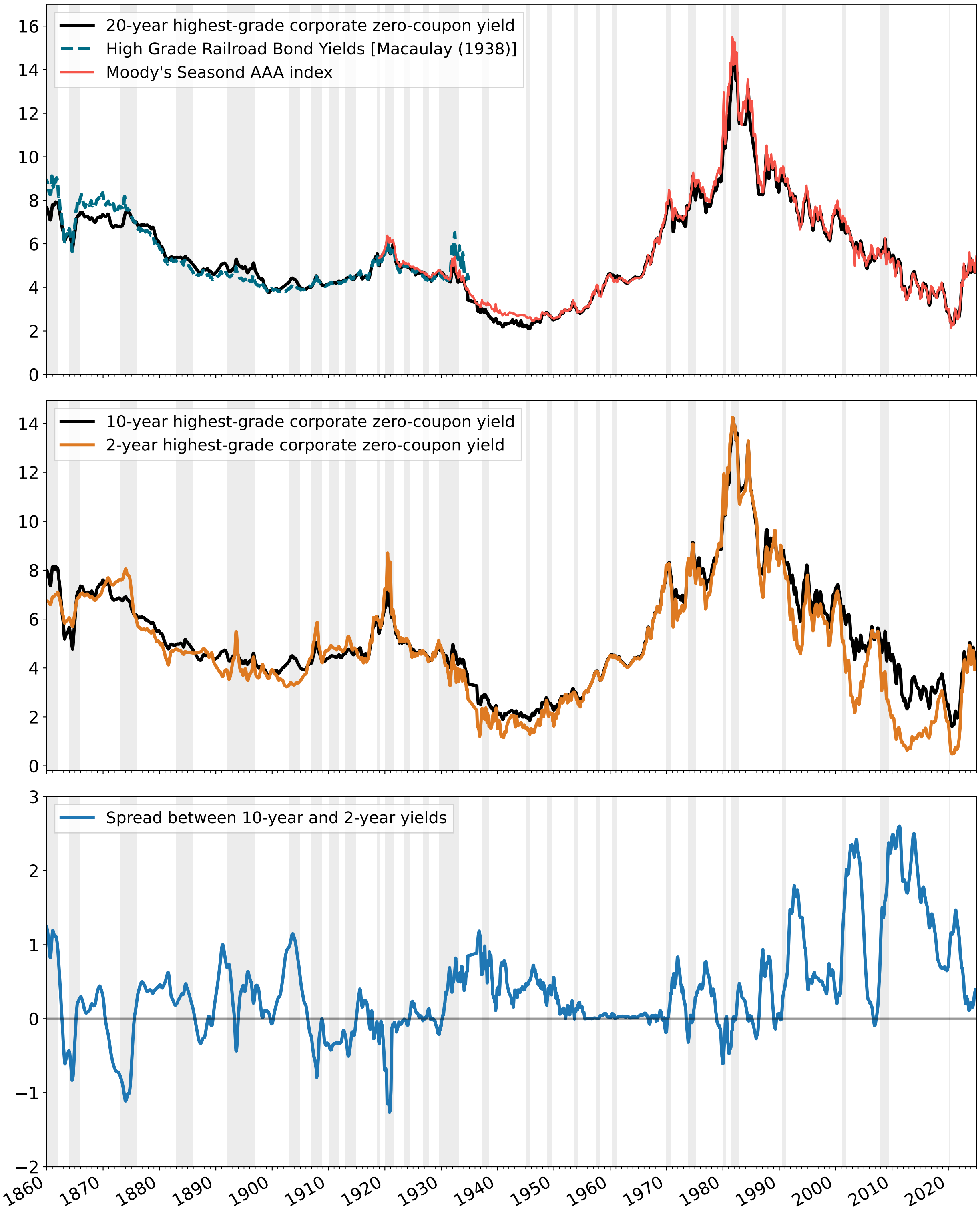

Figure 21: Highest-grade Nominal Corporate Zero-Coupon Yields 1860-2024

Top panel depicts our posterior median estimate of the 20-year high-grade corporate zero-coupon yield (black). The blue dashed line depicts the High Grade Railroad Bond Index from Macaulay (1938). The red solid line is Moody's Seasoned AAA bond index. Middle panel depicts posterior median estimates of the 10- (black) and 2-year (orange) high-grade corporate yields. Bottom panel depicts the spread between the 10-year and 2-year yields. The light gray intervals depict NBER recessions.

yields is close to zero, suggesting that for about 100 years, the average yield curve on high-grade corporate bonds was flat on average.

G.2 Treasury Yield Curves

In previous work, we estimated historical zero-coupon yield curves on US Treasurys from 1790-1933 (see Payne et al. (2025)). For this paper, we extend our estimation to 1934-2024 and make the adjustments for taxes and embedded options described in Section 4 to provide a consistent comparison to the corporate yield curve. Here we explore these estimates. In subsection G.2, we highlight importance of adjusting for the flower bonds. In subsection G.2.1 we then discuss the overall time series for the Treasury yield curve.

G.2.1 Treasury Yields

It is instructive to see the extent to which the Treasury and corporate yield curves co-move with each other. The top panel of Figure 22 depicts the 10-year highest-grade corporate yield against the 10-year zero-coupon Treasury yields. Evidently, the two yields follow similar trend dynamics, but long-term Treasury yields are persistently lower than highest-grade corporate yields throughout our sample. In addition, despite the similar trend, short- and medium-term fluctuations of the two yield curves around their respective trends are very different in the early part of the sample. We can see this reflected in the middle and bottom panels of Figure 22. The middle panel depicts yield curve slopes defined as the spreads between the 10 year and 2 year zero-coupon yields on highest-grade corporate bonds (black) and on US Treasurys (red). The bottom panel shows the 10 year centered rolling correlation between the long end of the yield curves (green) and the 2-year yields (dashed orange). The corporate and Treasury yield curves are only weakly correlated between 1860-1920 and then became highly synchronized after the 1950s. Despite this convergence, the two yield curves seemed to decouple during the yield curve control period (1942-1951) and to some extent during the Great Inflation period.

G.2.2 Modern Treasury Sample

In addition to estimating a longer historical sample of zero-coupon Treasury yield curves, we estimate yield curves in the modern period which build upon popular estimators. In particular, within a restricted sample of coupon-bearing bonds without option features since June 1961, the flexibility of the Kernel Ridge estimator accompanied by adjustments for capital gains tax advantage improves the fit compared to the parametric estimates of Gürkaynak et al. (2007). We show this in Figure 23 where we plot one-year rolling means and standard

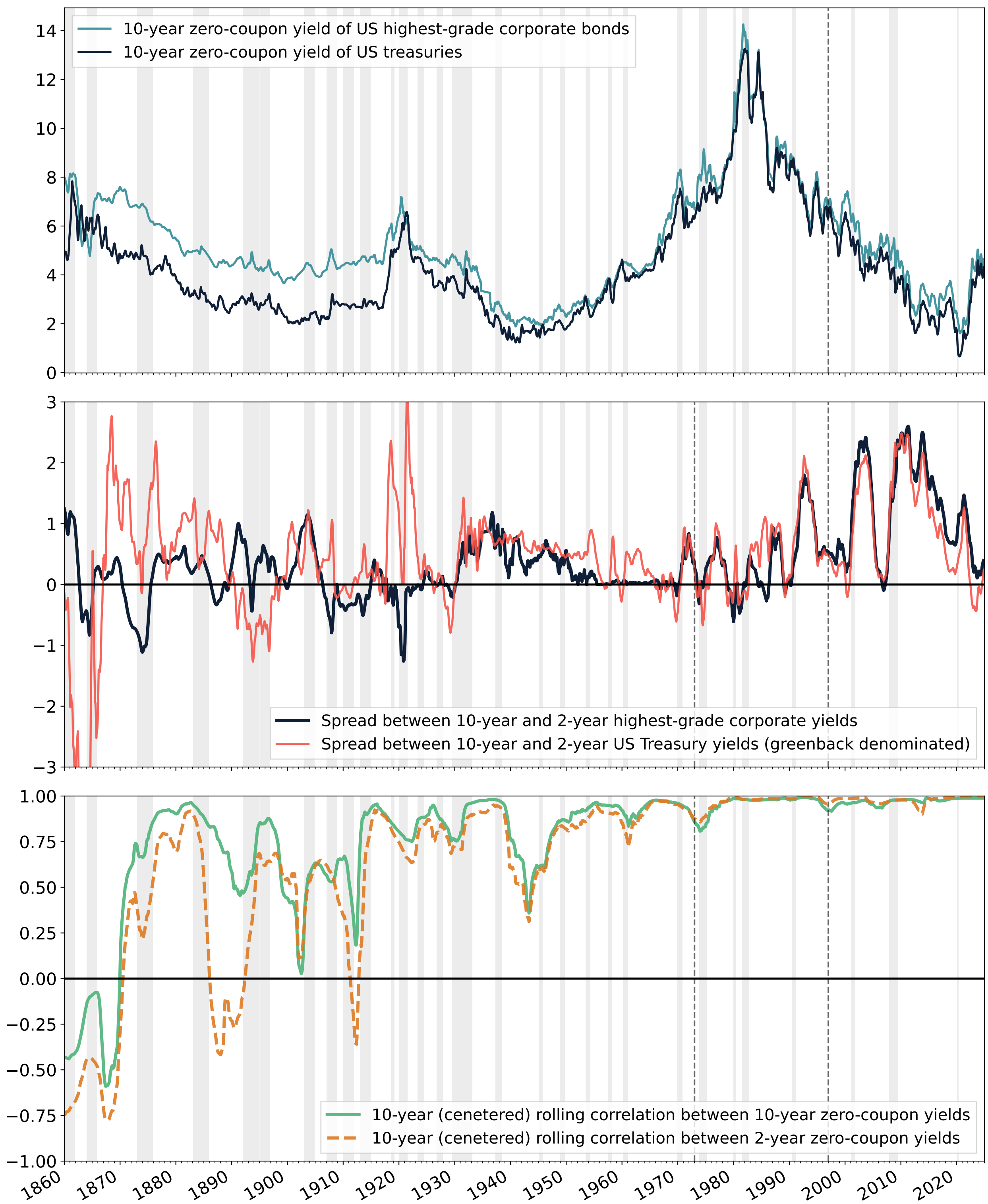

Figure 22: Difference Between Private and Public Borrowing Costs

Top panel depicts posterior median estimates of the 10-year zero-coupon yields on high-grade corporate debt (teal) and US Treasurys (black). Middle panel depicts spreads between 10-year and 2-year yields for highest-grade corporate debt (black) and US Treasurys (red). Bottom panel depicts 10-year (centered) rolling correlations computed from the monthly series of posterior median estimates of 10-year (green solid) and 2-year (orange dashed) zero-coupon yields.

deviations of weighted price errors for the non-option, coupon-bearing bonds used in our yield curve estimation. Despite our estimator also fitting option bonds and T-Bills, the errors on the coupon-bearing bonds alone are reduced significantly. While our rolling standard deviation of weighted price errors is generally a few basis points lower than Gürkaynak et al. (2007), we see the greatest improvement in the 1960s as interest rates rose and investors priced the capital gains tax advantage of low coupon bonds. At the peak of the capital gains tax advantage in the late 1960s, the standard deviation of our weighted pricing errors are a third of Gürkaynak et al. (2007).

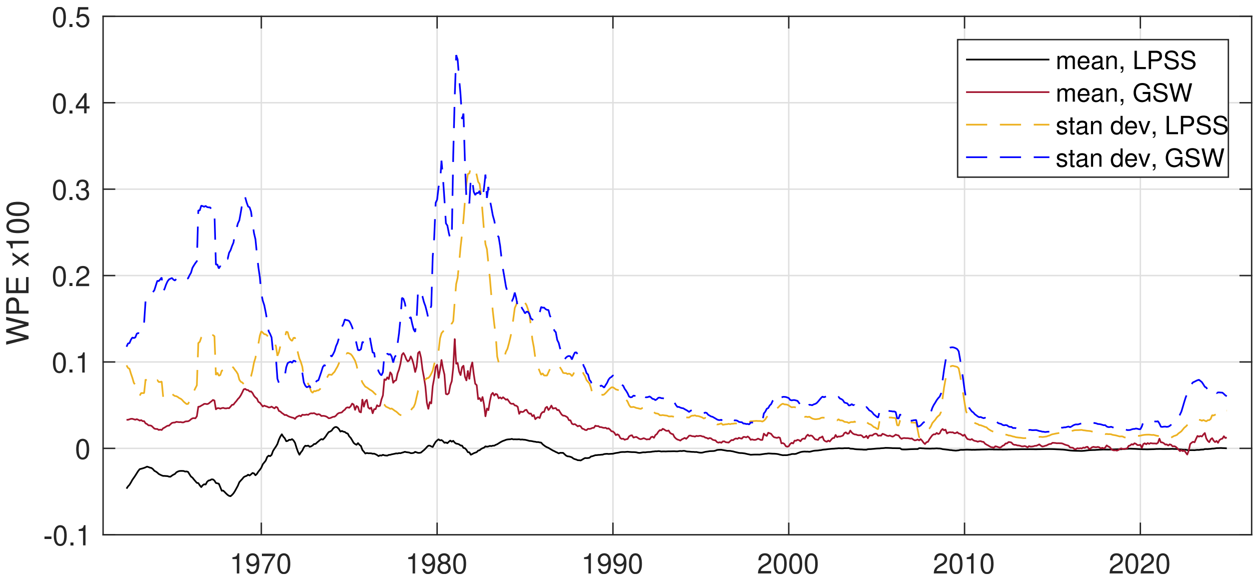

Figure 23: Treasury Yield Fit, Coupon Bonds

Notes: The figure shows one-year rolling means and standard deviations of our estimator's (LPSS) weighted price errors (WPE) of non-option, coupon-bearing bonds compared with the same weighted price errors implied by the parameters from Gürkaynak et al. (2007).

G.2.3 Flower Bonds

In this section we study how the inclusion of flower bonds may affect our baseline yield curve estimate.[31] Ideally, our procedure enables us to extract information about non-callable long-term "plain vanilla" bonds embedded within flower bonds, thereby allowing to construct a comprehensive estimate of the term structure of Treasury yields during the 1960s and early 1970s—a period in which only flower bonds are observable at the long end. The left panel of Figure 24 shows our baseline yield curve estimates in May 1967 when we observe only flower

[31]We are grateful to Greg Duffee for his insightful suggestions, which inspired this section.

bonds after 7 years-to-maturity. We compare our baseline fit, which utilizes flower bonds, to a fully extrapolated fit, where we drop all option bonds (callables and flower bonds). As shown in the left panel, incorporating flower bonds serves two key purposes. First, it provides insight into the shape of the yield curve at longer maturities, while the extrapolated estimate approximates a flat extrapolation anchored to the yield-to-maturity of the longest-maturity non-callable, non-flower bond. This shows that there is nothing mechanical driving our long-term bond estimates during this period: the estimator is extracting information about the embedded straight bond within the flower bond. Second, including the flower bonds in the estimation halves the standard errors at the long end, which reduces our estimation uncertainty. This is in part because the flower bonds themselves tend to exhibit a "well behaved" term structure, despite being distorted by an option.

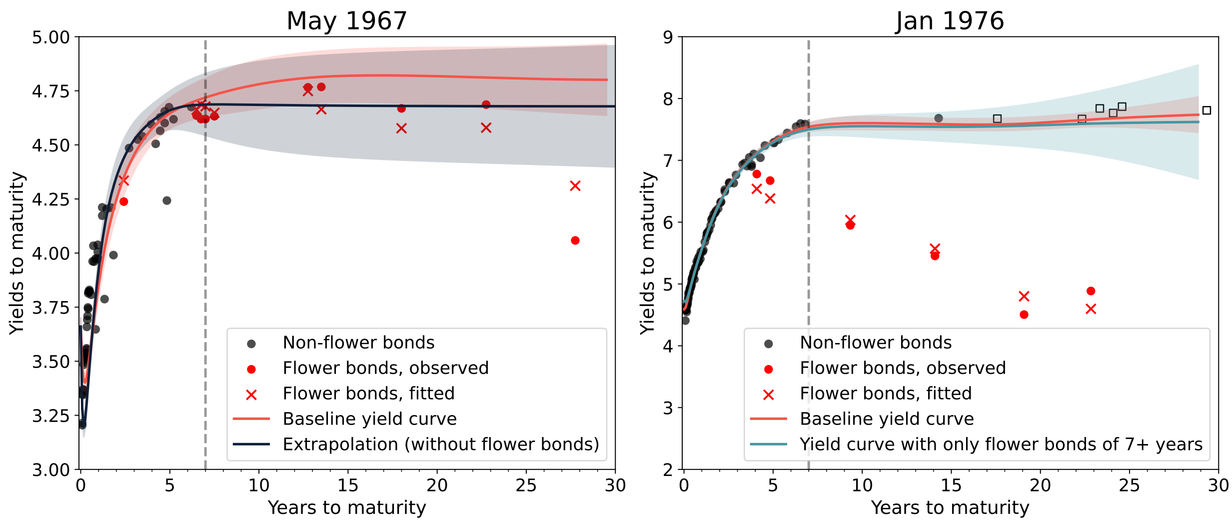

Figure 24: Fitting Flower Bonds

The figure compares our baseline estimate of the January 1976 yield curve, in black, compared with a "sense-check" estimate in light blue, where we exclude non-callable bonds after 7 years-to-maturity, and all callable bonds. Dots are yields-to-maturity, and the yield curves shown are par yields. We drop bonds which previously incurred large capital gains.

To further ensure that our estimator captures genuine yield curve information—rather than the mere influence of embedded options at the long end—we conduct a targeted "sense check" using periods in which both flower and non-flower bonds are observable at long maturities. Specifically, we re-estimate the Treasury yield curve for January 1976 using only non-callable non-flower bonds with maturities under 7 years (even though longer term non-callable, non-flower bonds exist), supplemented by longer-term flower bonds. We then compare these estimates to our baseline specification for the same date, which does incorporate long-term non-flower bonds, and assess the estimator's ability to fit these longer-term non-flower bond yields that were excluded from the restricted sample. The right panel of Figure 24 presents the baseline yield curve alongside the sense check estimate for January 1976. Three findings stand out:

- The yield curve estimates differ minimally, on the order of approximately 5 basis points difference between 10 to 20 years to maturity.
- The estimator can fit the flower bonds well. Fitted yields-to-maturity are only a few basis points off observed yields-to-maturity for all flower bonds.
- The sense check estimator does not take a stand on curvature at the long end. However, as seen in the right panel of Figure 24, the curvature of the long end of the yield curve, picked up in our baseline estimate, is well within one standard deviation of our sense check estimate.

Consequently, even when we do not observe "plain vanilla" long-term bonds, we can still get a good estimate of the long end of the yield curve just from fitting the flower bonds. This exercise serves as an out-of-sample confirmation that we can effectively extract information about the "plain vanilla" yield curve from the flower bonds.

In Figure 25, we show the time-series implications of estimating the yield curve including flower bonds. In the top panel, we show 10-year par yields estimated on "plain-vanilla" bonds and 10-year par yields estimated on flower bonds only, not adjusting for the option component. Before the end of 1965, the two yields are indistinguishable. This implies that the average long-term government yield index, represented by the red line in Figure 25, is a good approximation of long-term Treasury yields. However, from 1966 onward, a gap opens up between the black and green lines as inflation picked up and the flower bond premium slowly increased.[32]

Clearly, not adjusting for this gap would introduce downward bias to the fitted yield curve. The standard approach in the literature (e.g. Gürkaynak et al. (2007)) is to drop all flower bonds in the sample and extrapolate to longer maturities when appropriate. We show in the bottom panel of Figure 25 that our baseline estimates which incorporate adjustments for the flower bond option almost exactly match the estimates of a fully extrapolated estimate, dropping all option bonds. However, during the extrapolation period of 1962-1971,

[32]Among the outstanding flower bonds, the ones actually purchased because of the estate-tax feature tended to be the lowest coupon bonds, such as the 3's of 1995 and the 3-1/2 of 1998, which were selling at the largest discounts. Evidence of this can be seen in the amount outstanding, with the net decline from year to year measuring the amount redeemed for estate tax purposes. See Cook (1977).

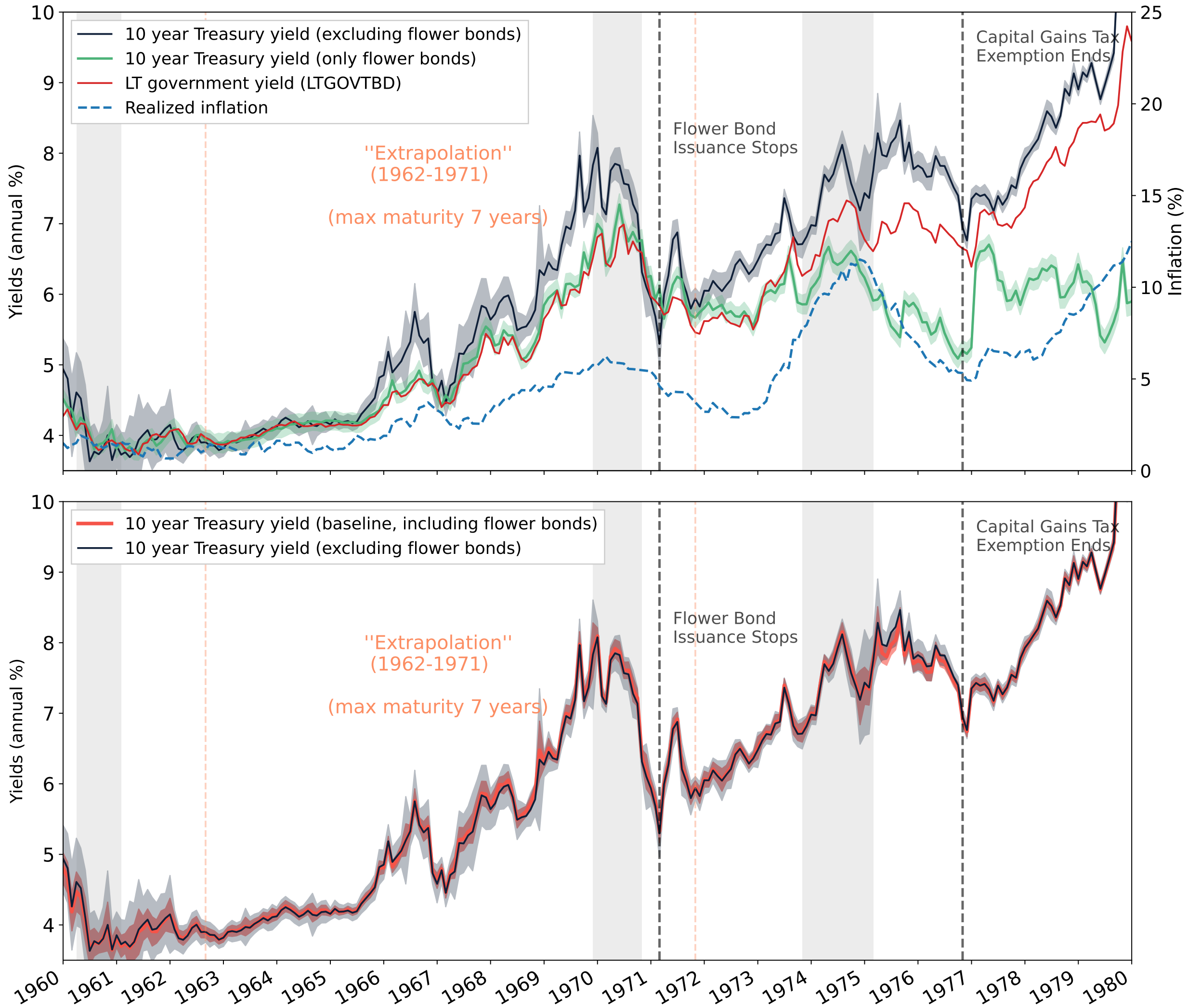

Figure 25: Long-term Government Yields of Non-Flower and Flower Bonds

Top panel: The black solid line is posterior median of the 10-year par yield on US Treasurys excluding all flower bonds from the sample. The green solid line is the posterior median estimate of the 10-year par yield fitted to flower bonds only. Bands denote 90% posterior interquantile ranges. The red solid line is the average long-term government yield index (LTGOVTBD).
Bottom panel: The red solid line is the posterior median of the 10-year par yield on US Treasurys from our baseline estimates. The black line is the posterior median of the 10-year par yield on US Treasurys excluding callable and flower bonds. Bands denote 90% posterior interquantile ranges.

it is evident that our baseline standard errors are halved by including adjustments to the flower bonds as opposed to performing a full extrapolation. This confirms that we can use information embedded within the flower bonds to estimate long-term yields.

H Additional Details on Asset Pricing in Section 6

H.1 Additional Regressions

To study the co-movement between government debt supply and funding advantage more systematically, in Table 2 we run KVJ-12 style regressions on the four maturity weighted funding advantages from Figure 11, and in Table 3 we rerun the regressions from KVJ-12 using our extended dataset. The first column in 3 uses the data from KVJ-12 for their time period 1925-2007, the second column replicates the KVJ-12 regression using our data, the third column adds in holding return volatility, and columns four to six study our entire sample from 1865-2024.

The regressions confirm what can be seen visually in the scatter plots. The maturity specific regression in Table 3 confirms that the negative elasticity is largest for short-maturity Treasurys and non-existent for long-maturity Treasurys. For the non-maturity weighted regressions in Table 3, for the original KVJ-12 sample, once we correct for tax and option distortions, there is a less pronounced statistical relationship between spreads and quantities. For our extended sample, column three of Table 3 shows a negative relationship. However, this relationship weakens once we control for the National Banking Era in columns four and five, which also have a significantly higher R^2. This indicates that the low frequency negative relationship between quantities spreads in the long sample is almost entirely accounted for by the change in financial regime. Indeed, if we subtract our estimate for the circulation privilege that government debt enjoyed from 1865-1918 (approximately 1 percentage point), then the orange dots would drop down further the relationship.

Period:	1920-2024	1920-2024	1920-2024	1920-2024
	Maturity 0-1	Maturity 1-10	Maturity 10+	Weighted Ave.
	(1)	(2)	(3)	(4)
log(Debt/GDP)[0-1 Yrs]	-0.526***			
	(0.093)			
log(Debt/GDP)[1-10 Yrs]		-0.234***		
		(0.040)		
log(Debt/GDP)[10+ Yrs]			0.080***	
			(0.030)	
log(Debt/GDP)[All]				-0.417***
				(0.072)
Volatility	0.549	0.698***	0.960***	0.648**
	(0.616)	(0.248)	(0.276)	(0.323)
Slope	0.384***	0.125***	-0.020	0.206***
	(0.059)	(0.025)	(0.026)	(0.032)
Constant	-0.447*	-0.079	0.718***	0.045
	(0.238)	(0.099)	(0.147)	(0.115)
Significance:	* $p<0.1$	** $p<0.05$	*** $p<0.01$	
Observations	104	104	104	104
Adjusted R^2	0.406	0.346	0.215	0.364

Table 2: Regression Results: Funding Advantage Analysis

Period:	1925-2007	1925-2007	1865-2024	1865-2024	1865-2024
	KVJ	LPSS	LPSS	LPSS	LPSS
	(1)	(2)	(3)	(4)	(5)
log(Debt/GDP)[KVJ]	-0.649***				
	(0.089)				
log(Debt/GDP)[LPSS]		-0.182***	-0.438***		0.091
		(0.069)	(0.052)		(0.076)
Volatility	0.779	1.694***	2.354***	1.020***	0.872***
	(0.508)	(0.319)	(0.389)	(0.260)	(0.261)
Slope	0.011				
	(0.037)				
Slope		-0.020	0.116***	0.035	0.002
		(0.029)	(0.040)	(0.024)	(0.026)
Pre-1920 Dummy				1.231***	1.526***
				(0.061)	(0.167)
Pre-1920 Dummy × log(Debt/GDP)					0.069
					(0.091)
Constant	0.164	-0.013	-0.267**	0.320***	0.474***
	(0.100)	(0.098)	(0.125)	(0.060)	(0.109)
Significance:	* p<0.1	** p<0.05	*** p<0.01		
Observations	83	82	157	157	157
Adjusted R^2	0.462	0.313	0.433	0.771	0.779

Table 3: Regression Results: Each column regresses the 10-year funding advantage on the listed variables. (1) Replicates the regression from KVJ-12 using their data for the period 1925–2007. (2) Replicates (1) using our estimated spread and market value series. (3) Replicates (2) with our full sample. (4) Excludes log(Debt/GDP) and includes a dummy for the end of the National Banking Era. (5) Includes all controls for the full sample.

H.2 Estimation Approach

We fit all pricing kernel parameters using indirect inference in the style of Adrian et al. (2013). We outline the key steps for estimating the corporate pricing kernel below. Throughout, we let J denote the maximum maturity bond used in the estimation and use hats to refer to fitted values.

1. *Estimate the state space evolution.* Fit a VAR-N model (or other time series model) to estimate the evolution of the state variables:

$$X_{t+1} = \mu_X + \Phi_X X_t + \Sigma \epsilon_{t+1}$$

   Let $\hat{v}_t := \hat{\Sigma}\hat{\epsilon}_{t+1}$ denote the fitted innovations.

2. *Fit excess holding period returns.* Regress the short corporate rate and excess corporate bond holding period returns on states and estimated innovations:

$$\begin{aligned} rf_t &= \delta_0 + \delta_1^T X_t \\ rx_{t+1}^{(j-1)} &= \alpha_{j-1} + \beta_{j-1}^T \hat{v}_t + \gamma_{j-1} X_t + e_{t+1}^{(j-1)} \end{aligned}$$

   where $rx_{t+1}^{(j-1)}$ is the holding period return on a j-maturity corporate bond defined by:

$$rx_{t+1}^{(j-1)} := \log\left(q_{t+1}^{(j-1)}\right) - \log\left(q_t^{(j)}\right) - rf_t$$

   and $e_{t+1}^{(j-1)}$ denotes bond maturity specific measurement error, which is assumed to be i.i.d. with variance σ^2. We can stack the excess holding period return regression across the j and t dimensions to get:

$$rx = \hat{\alpha}\iota_T^T + \hat{\beta}^T \hat{\Sigma}\hat{\epsilon} + \hat{\gamma} X_- + \hat{E}$$

   where $\hat{\alpha}$, $\hat{\beta}$, $\hat{\gamma}$, $\hat{\epsilon}$, X_-, and $\hat{E}$ are the fitted values of $\{\alpha_j\}_{j\leq J}$, $\{\beta_j\}_{j\leq J}$, $\{\gamma_j\}_{j\leq J}$, $\{\epsilon_t\}_{t\in[t_0,T-1]}$, $\{X_t\}_{t\in[t_0,T-1]}$, and $\{e_t^{j-1}\}_{j\leq J, t\in[t_0,T-1]}$ stacked across the appropriate j and/or t dimensions.

3. *Recover kernel parameters.* Find the pricing kernel parameters (λ_0, λ_1) that best equate the values of (α, β, γ) implied by asset pricing theory with the values from the regression in the previous step $(\hat{\alpha}, \hat{\beta}, \hat{\gamma})$. Using standard asset pricing results (e.g. see Adrian et al.

(2013)), this involves solving the set of equations:

$$\begin{aligned}
\hat{\alpha}\iota_T^T &= \beta^T\hat{\Sigma}\hat{\Sigma}^T\lambda_0\iota_T^T - 0.5(B^* vec(\hat{\Sigma}\hat{\Sigma}^T) + \hat{\sigma}^2\iota_J)\iota_T^T \\
\hat{\beta} &= \beta \\
\hat{\gamma} &= \beta^T\hat{\Sigma}\hat{\Sigma}^T\lambda_1
\end{aligned}$$

where $B^* = [(\beta^{(1)}(\beta^{(1)})', \ldots, \beta^{(J)}(\beta^{(J)})')$. This implies that:

$$\begin{aligned}
\lambda_1 &= (\hat{\beta}\hat{\beta}^T\hat{\Sigma}\hat{\Sigma}^T)^{-1}\hat{\beta}\hat{\gamma} \\
\lambda_0 &= (\hat{\beta}\hat{\beta}^T\hat{\Sigma}\hat{\Sigma}^T)^{-1}\hat{\beta}(\hat{\alpha} + 0.5(\hat{B}^* vec(\hat{\Sigma}\hat{\Sigma}^T) + \hat{\sigma}^2\iota_J))
\end{aligned}$$

4. *Recover bond pricing parameters.* Finally, set up a recursion for the bond pricing parameters. Using standard asset pricing results (e.g. see Adrian et al. (2013)), the bond price takes the form $log(q_t^{(j)}) = A_j + B_j^T X_t + u_t^{(j)}$, where (A_j, B_j) satisfy the recursions:

$$\begin{aligned}
A_{j-1} + B_{j-1}^T\hat{\mu}_X - A_j + A_1 &= \hat{\beta}_{j-1}^T\hat{\Sigma}\hat{\Sigma}^T\hat{\lambda}_0 - 0.5\hat{\beta}_{j-1}^T\hat{\Sigma}\hat{\Sigma}^T\hat{\beta}_{j-1} - 0.5\hat{\sigma}^2 \\
B_{j-1}^T\hat{\Phi}_X - B_j^T + B_1^T &= \hat{\beta}_{j-1}^T\hat{\Sigma}\hat{\Sigma}^T\hat{\lambda}_1
\end{aligned}$$

Rearranging we get:

$$\begin{aligned}
A_n &= A_{j-1} + B_{j-1}^T\hat{\mu}_X + A_1 - \hat{\beta}_{j-1}^T\hat{\Sigma}\hat{\Sigma}^T\hat{\lambda}_0 + 0.5\hat{\beta}_{j-1}^T\hat{\Sigma}\hat{\Sigma}^T\hat{\beta}_{n-1} + 0.5\hat{\sigma}^2 \\
B_n^T &= B_{j-1}^T\hat{\Phi}_X + B_1^T - \hat{\beta}_{j-1}^T\hat{\Sigma}\hat{\Sigma}^T\hat{\lambda}_1 \\
A_1 &= -\hat{\delta}_0, \quad B_1 = -\hat{\delta}_1 \\
A_0 &= 0, \quad B_0 = 0
\end{aligned}$$

We estimate the wedge Ω parameters an analogous way.

H.3 Yield Curve Fit

In this Subsection we show selected results for the fit of the corporate and Treasury yield curve asset pricing models. Figure 26 shows the observed and fitted excess returns and yields for the corporate yield curve. Figure 27 shows the analogous plots for the Treasury yield curve. Finally, Figure 28 shows the risk factors for Ω.

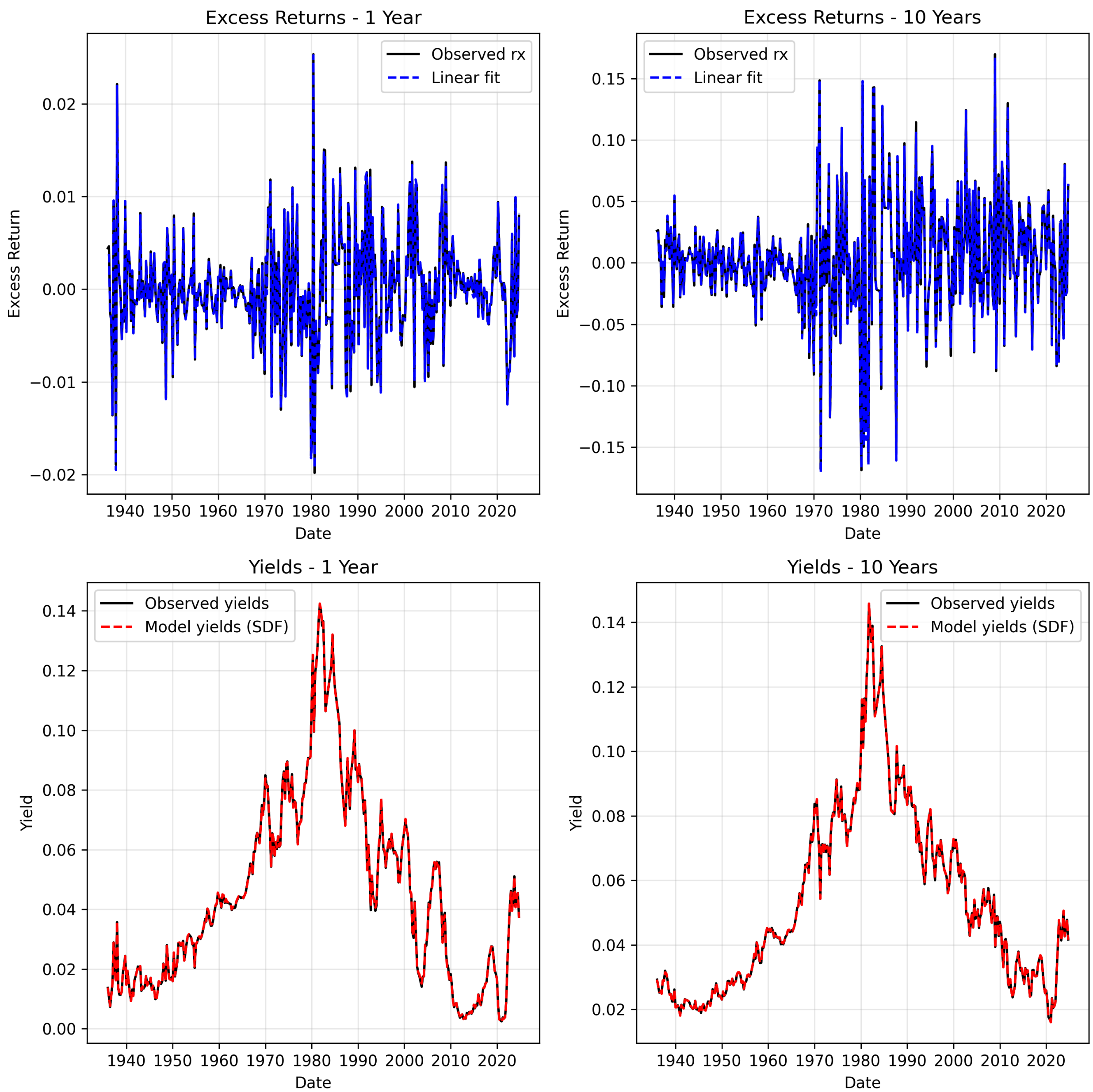

Figure 26: Observed and fitted corporate yields at maturities 1 and 10.

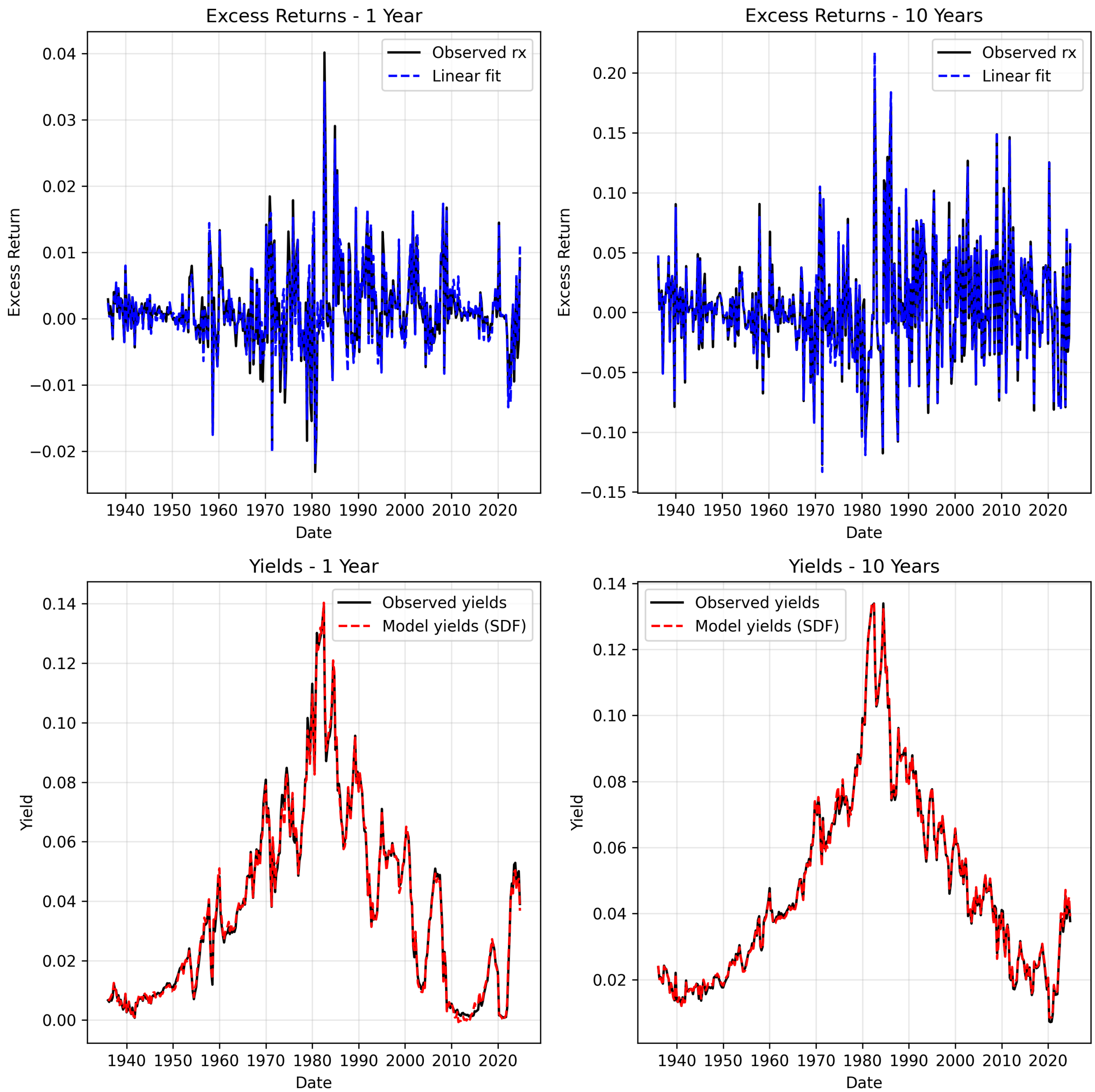

Figure 27: Observed and fitted corporate yields at maturities 1 and 10.

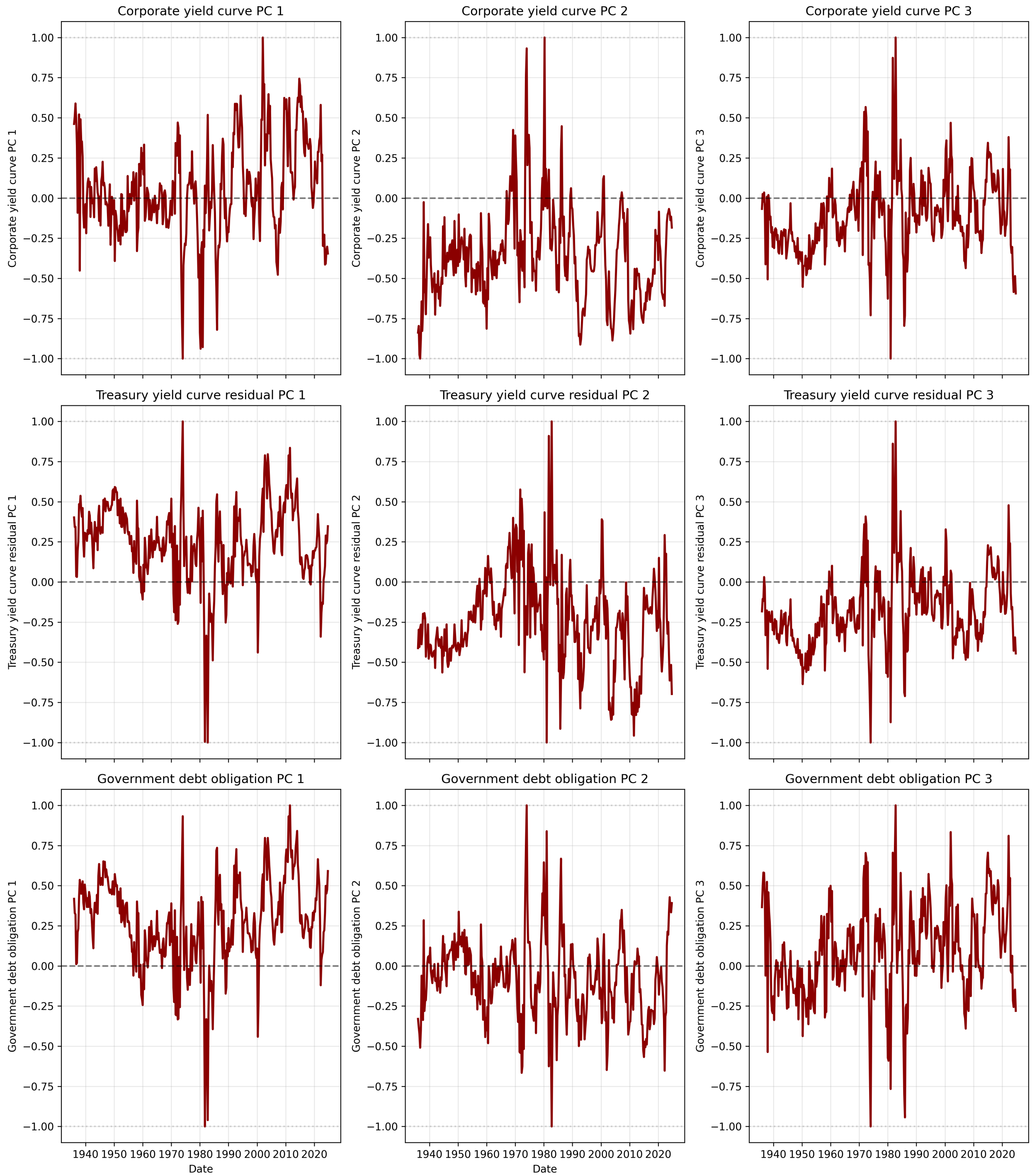

Figure 28: Normalized risk factors for Ω over time.

H.4 Additional Proofs

In this section of the Appendix, we derive additional results for the asset pricing model.

Theorem 1. *To a first order approximation, the spread takes the form:*

$$\begin{aligned}\chi_t^{(j)} \approx & \frac{1}{j}\left(\beta_0+\beta_1\log\left(\frac{\theta_t}{y_t}\right)+\log(\zeta_t)\right)+\frac{1}{j}\left(\log\left(\mathbb{E}_t\left[\tilde{q}_{t+1}^{(j-1)}\right]\right)-\log\left(\mathbb{E}_t\left[q_{t+1}^{(j-1)}\right]\right)\right)\\ & +\frac{1}{j}\left(\frac{Cov\left[\xi_{t,t+1},\tilde{q}_{t+1}^{(j-1)}\right]}{\mathbb{E}_t\left[\xi_{t,t+1}\right]\mathbb{E}_t\left[\tilde{q}_{t+1}^{(j-1)}\right]}-\frac{Cov\left[\xi_{t,t+1},q_{t+1}^{(j-1)}\right]}{\mathbb{E}_t\left[\xi_{t,t+1}\right]\mathbb{E}_t\left[q_{t+1}^{(j-1)}\right]}\right)\end{aligned}$$

Proof. Because $\Omega_{t,t+1}$ is time t adapted it can be taken out of the expectation in the asset pricing equations. Thus, we have:

$$\begin{aligned}q_t^{(j)} =& \exp\left(\beta_0+\beta_1\log\left(\frac{\theta_t}{y_t}\right)+\log(\zeta_t)\right)\mathbb{E}_t\left[\xi_{t,t+1}q_{t+1}^{(j-1)}\right]\\ =& \exp\left(\beta_0+\beta_1\log\left(\frac{\theta_t}{y_t}\right)+\log(\zeta_t)\right)\mathbb{E}_t\left[\xi_{t,t+1}\right]\mathbb{E}_t\left[q_{t+1}^{(j-1)}\right]\left(1+\frac{\mathrm{Cov}\left[\xi_{t,t+1},q_{t+1}^{(j-1)}\right]}{\mathbb{E}_t\left[\xi_{t,t+1}\right]\mathbb{E}_t\left[q_{t+1}^{(j-1)}\right]}\right)\\ \tilde{q}_t^{(j)} =& \mathbb{E}_t\left[\xi_{t,t+1}\tilde{q}_{t+1}^{(j-1)}\right]\\ =& \mathbb{E}_t\left[\xi_{t,t+1}\right]\mathbb{E}_t\left[\tilde{q}_{t+1}^{(j-1)}\right]\left(1+\frac{\mathrm{Cov}\left[\xi_{t,t+1},\tilde{q}_{t+1}^{(j-1)}\right]}{\mathbb{E}_t\left[\xi_{t,t+1}\right]\mathbb{E}_t\left[\tilde{q}_{t+1}^{(j-1)}\right]}\right)\end{aligned}$$

So, the funding advantage is:

$$\begin{aligned}\chi_t^{(j)} =& \frac{1}{j}\log\left(q_t^{(j)}\right)-\frac{1}{j}\log\left(\tilde{q}_t^{(j)}\right)\\ =& \frac{1}{j}\left(\beta_0+\beta_1\log\left(\frac{\theta_t}{y_t}\right)+\log(\zeta_t)\right)\\ &+\frac{1}{j}\log\left(\mathbb{E}_t\left[\tilde{q}_{t+1}^{(j-1)}\right]\right)+\frac{1}{j}\log\left(1+\frac{\mathrm{Cov}\left[\xi_{t,t+1},\tilde{q}_{t+1}^{(j-1)}\right]}{\mathbb{E}_t\left[\xi_{t,t+1}\right]\mathbb{E}_t\left[\tilde{q}_{t+1}^{(j-1)}\right]}\right)\\ &-\frac{1}{j}\log\left(\mathbb{E}_t\left[q_{t+1}^{(j-1)}\right]\right)-\frac{1}{j}\log\left(1+\frac{\mathrm{Cov}\left[\xi_{t,t+1},q_{t+1}^{(j-1)}\right]}{\mathbb{E}_t\left[\xi_{t,t+1}\right]\mathbb{E}_t\left[q_{t+1}^{(j-1)}\right]}\right)\end{aligned}$$

To a first order approximation, this becomes:

$$\chi_t^{(j)} \approx \frac{1}{j}\left(\beta_0 + \beta_1 \log\left(\frac{\theta_t}{y_t}\right) + \log(\zeta_t)\right) + \frac{1}{j}\left(\log\left(\mathbb{E}_t\left[\tilde{q}_{t+1}^{(j-1)}\right]\right) - \log\left(\mathbb{E}_t\left[q_{t+1}^{(j-1)}\right]\right)\right)$$
$$+ \frac{1}{j}\left(\frac{\text{Cov}\left[\xi_{t,t+1}, \tilde{q}_{t+1}^{(j-1)}\right]}{\mathbb{E}_t\left[\xi_{t,t+1}\right]\mathbb{E}_t\left[\tilde{q}_{t+1}^{(j-1)}\right]} - \frac{\text{Cov}\left[\xi_{t,t+1}, q_{t+1}^{(j-1)}\right]}{\mathbb{E}_t\left[\xi_{t,t+1}\right]\mathbb{E}_t\left[q_{t+1}^{(j-1)}\right]}\right)$$

□

I Treasury Demand and US Government Market Power

There has been recent interest in finding instruments for US Treasury demand and estimating the US government's market power. In this section, we investigate one such instrument that has been used in the literature: foreign volatility shocks as rotators for US debt demand.

Figure 29 depicts the relationship between the AAA Corporate-Treasury spread and debt issuance for maturities less than one year (the left panel) and for maturities greater than one year (the right panel). The red dots depict periods with high foreign volatility while the blue dots depict periods with low volatility in returns on UK equities. Changes to the shape of the equilibrium relationship in periods of high volatility have been interpreted as evidence of rotation in US debt demand (e.g. by Choi et al. (2022)). Contrary to the literature, we find little evidence that the foreign volatility acts as a rotator, except for very short-term maturities.

Our findings have implications for estimation of US Treasury market power. Following Choi et al. (2022), we impose a log linearized government issuance policy rule:

$$\lambda \log(q_t^b B_t / Y_t) = \log(\chi_t) + \log(1 - \xi \epsilon_t^{-1}(\sigma_t)) - \omega_t$$

where $q_t^b B_t / Y_t$ is the market value of debt-to-GDP ratio, χ_t is the AAA Corporate-Treasury spread, ξ is an indicator function whether debt issuance reacts systematically to elasticity, $\epsilon_t^{-1}(\sigma_t)$ is the inverse elasticity, $\sigma_t \in \{\sigma_L, \sigma_H\}$ is foreign volatility, and ω_t is an iid policy shock. We then estimate the price elasticity ϵ_t in high and low foreign volatility periods $\sigma \in \{\sigma_L, \sigma_H\}$. Finally, we test if $\xi = 1$ (debt issuance reacts systematically to elasticity) or $\xi = 0$ (debt issuance does not react systematically to elasticity) is a better fit. The results are shown in Table 4. Contrary to Choi et al. (2022), we find little evidence that US government issuance reacts systematically to elasticity shocks at maturities greater than 1 year. In other words, using the framework of Choi et al. (2022), our results suggest that the US hasn't been exploiting its market power in the bond market for maturities above 1

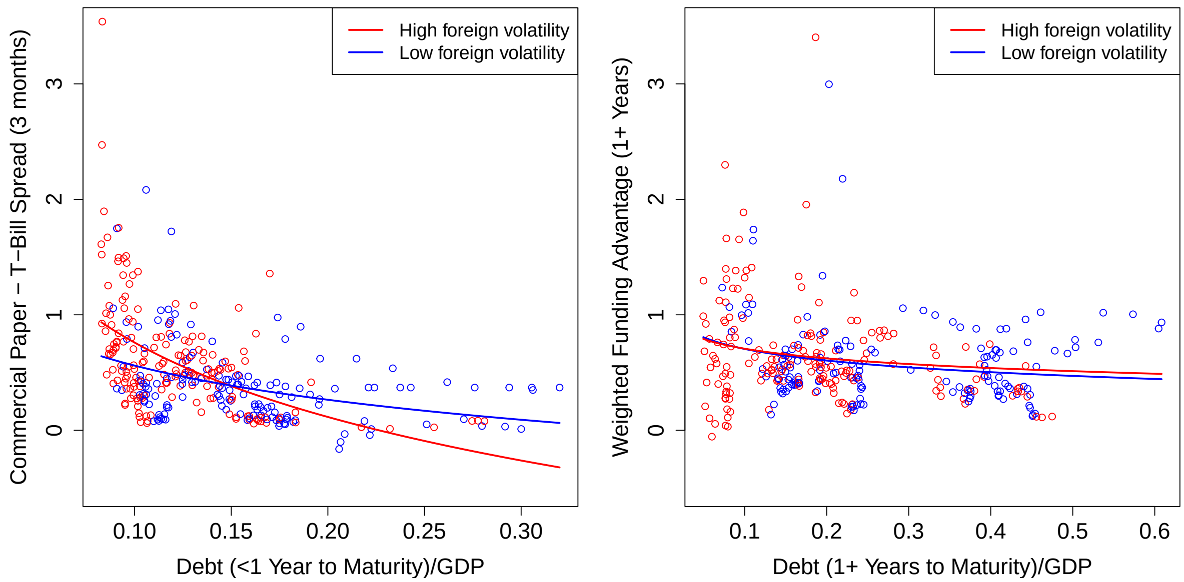

Figure 29: Convenience Spread vs Debt/GDP: 1919-2008, Annual, High and Low Foreign Volatility

year. However, we do find evidence for systematic reaction at maturities < 1 year. Since inflation and volatility are correlated, this may reflect monetary policy adjustments rather than exploitation of safe-asset monopoly power.

Cost elasticity	$\lambda = 0$	$\lambda = 1$	$\lambda = 2$
<1 Year to Maturity	-2.630^{***}	-2.712^{***}	-2.281^{**}
1+ Year to Maturity	0.575	-1.439	-1.585

Table 4: Null hypothesis: US debt issuance does not react to elasticity ($\xi = 0$)