

# Costs of Financing US Federal Debt Under a Gold Standard: 1791-1933\*

Jonathan Payne<sup>†</sup> Bálint Szőke<sup>‡</sup> George Hall<sup>§</sup> Thomas J. Sargent<sup>¶</sup>

July 30, 2022

## Abstract

This paper uses a statistical model with drifting parameters to infer term structures of real and nominal yields on US federal bonds during the gold standard era from 1791-1933. Gold denominated yields trended downwards throughout the 19th century, falling below UK levels by the 1880s. Bonds near maturity carried a “liquidity premium” except during the height of the National Banking Era from 1880-1913. Long term price expectations were anchored until the late 19th century, even in 1862-1879 when the greenback was inconvertible. We note how rearrangements in monetary, financial, and fiscal institutions coincided with changes in US borrowing costs.

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

KEY WORDS: Big data, default premia, yield curve, units of account, convenience yield, gold standard, government debt, Hamilton Monte Carlo, pricing errors, specification analysis.

---

\*We thank Clemens Lehner for outstanding research assistance and Anmol Bhandari, Francesco Bianchi, Michael Bordo, Markus Brunnermeier, Mark Carlson, John Cochrane, Refet Gürkaynak, Sebastian Di Tella, Lars Peter Hansen, Arvind Krishnamurthy, Moritz Lenel, Pascal Maenhout, Emi Nakamura, Monika Piazzesi, Martin Schneider, Lars Svensson, Christopher Tonetti, Min Wei, Eugene White, Moto Yogo, and seminar and conference participants at Brandeis University, University of Chicago, the Chicago FED, Claremont University, University of Illinois Urbana-Champaign, the Minnesota Workshop in Macroeconomic Theory, the NBER Summer Institute 2022 (Monetary Economics, Macro Public Finance), Princeton University, Stanford University, and University of Sydney for suggestions. The views expressed here are those of the authors and do not necessarily represent the views of the Federal Reserve Board or its staff.

<sup>†</sup>Princeton University, Department of Economics. Email: jepayne@princeton.edu

<sup>‡</sup>Federal Reserve Board, Division of Monetary Affairs. Email: balint.szoke@frb.gov

<sup>§</sup>Brandeis University, Department of Economics. Email: ghall@brandeis.edu

<sup>¶</sup>New York University, Department of Economics and Hoover Institution, Stanford University. Email: thomas.sargent@nyu.edu

# 1 Introduction

In 1790, Alexander Hamilton argued that the US federal government could reduce its borrowing costs to UK levels by sustaining a reputation for timely debt service, minting gold and silver coins, and chartering a monopoly federal bank. Throughout the next century, Congresses adjusted monetary, fiscal, and financial arrangements in efforts either to implement or to unwind Hamilton’s program. This makes the 19th century a particularly interesting laboratory for studying how monetary-financial-fiscal interactions influenced US borrowing costs. Studying these issues requires data on prices and quantities of US government bonds and finding a way to work with a long but thin panel that spans large institutional changes. This paper takes up these challenges.

For a data set collected by [Hall et al. \(2018\)](#) that includes the gold standard period from 1791-1933<sup>1</sup>, this paper uses a non-linear state space model with drifting parameters and stochastic volatility and a novel application of state-of-the-art sampling techniques to infer term structures of *yields* on US federal bonds and evolving dynamics of *inflation*. At different times, various currencies circulated, including gold and silver coins, greenback paper dollars, and notes issued by state and federally chartered banks. We start by focusing on (nominal) yield curves for gold coin denominated US federal debt contracts because gold coins circulated throughout the entire period and were dominant for most of it. To approximate ex-ante *real* yield curves from 1791-2020, we combine our nominal yield curve estimates with estimates of inflation expectations from a related statistical model. Exploiting new computational techniques to handle drifting parameter models offers a novel way of working with very long time series that span different institutional arrangements. We thereby build bridges between macroeconomic and history literatures.

We infer the following collection of stylized facts about bond yields during the “gold standard era.” First, real yields trended downwards throughout the 19th century, with the 10-year gold yield dropping from around 8% in 1800 to around 0% in 1900, and stabilizing around zero afterwards.<sup>2</sup> Second, until the 1880s, US debt typically carried a risk premium relative to UK debt, the “safe-asset” of the era, but this gap reversed after 1905 when US yields became persistently lower than UK yields. Third, there were large spikes in real yields during 19th century wars, but not during 20th century wars. Fourth, yield curves typically sloped downward before the Civil War but then turned positive after the 1880s. Fifth, we find a “short rate disconnect” for most of the 19th century, in the sense that government

---

<sup>1</sup>George Washington and Alexander Hamilton introduced a gold standard in 1791 that was theoretically maintained until 1933, at which point Franklin Roosevelt accepted Irving Fisher’s advice to abandon the gold standard.

<sup>2</sup>This is consistent with the global super-secular decline hypothesis put forward by [Schmelzing \(2020\)](#) but suggests that, from the turn of the 20th century, US debt started to play a different role to other debt securities.

debts close to maturity traded at a 0.5 percentage point premium over the short yields implied by prices of long maturity government securities.

Understanding what drives these changes to real costs of financing the government requires knowing how evolving monetary and banking regulations affected currency creation and inflation throughout the gold standard era. Although we find that long run inflation expectations were anchored around zero before the 1890s,<sup>3</sup> this did not necessarily foster a “stable currency.” Before the Civil War the federal government issued only gold and silver coins and left the heterogeneously regulated state chartered banks to issue bank notes that were incompletely backed by gold and state government bonds.<sup>4</sup> Through this period, our inflation model points to persistent deflation and high, counter-cyclical inflation volatility with peaks during major bank crises and wars. These findings suggest that money was scarce and that the market value of broad money was volatile. The Civil War brought major changes to monetary and banking systems. Early in the war, Congress introduced a paper currency called “greenbacks” that was initially not convertible into gold and that traded at a volatile discount to gold during the war. In addition, during 1862-66, Congress passed four National Bank Acts that constructed a system of federally chartered banks that could issue *standardized* bank notes backed by long-term U.S. government debt. Coinciding with these changes, inflation volatility dropped by two-thirds and stabilized at a lower level after the 1870s. We find no evidence of trend deflation in the gold to goods price after the Civil War, in the sense that an estimated permanent component of inflation stays near zero.

An objective of the National Banking Acts was to increase banks’ demand for long term US Federal debt and thereby lower long term yields. Our estimates of a “short-rate-disconnect” provides a novel contribution to historical debates about the effectiveness of those reforms. We find that until the 1880s, bonds close to maturity traded with a premium in a range of 0.5 to 1.0 percentage points, which is consistent with our evidence that money-like assets were scarce and so earned a “liquidity” premium. However, following the introduction of the National Banking Act and the start of gold-greenback parity in January 1879, the premium on short term debt had vanished from 1885 until 1917. This timing pattern offers suggestive evidence that parity between greenbacks and gold helped the National Banking Act to work as had been hoped, which in turn suggests that early in the National Bank Era, bank note issuance had been restrained by currency devaluation risks. It also suggests that making long term US federal bonds be the backing behind U.S. National Bank notes contributed to the gradual decline in long term US federal yields toward UK

---

<sup>3</sup>So that gold denominated yields closely approximated real yields over this period.

<sup>4</sup>In the early 19th century, the First (1791-1811) and Second (1816-36) Banks of the US operated nationally and had some indirect control over state bank money and credit creation. After the non-renewal of the Second Bank of the US, state governments progressively deregulated entry in the banking sector creating the, so called “free banking era” from 1837-63.

levels. A short rate disconnect appears again during the 1920s when the Federal Reserve System created separate markets for short term certificates of indebtedness, once again making short-term government debt relatively more liquid than longer term government debt. Large variations in short-rate disconnects across different regulation regimes indicate that a short rate disconnect is something that a government can promote.

During the Civil War, another complicated monetary-fiscal interaction took the form of a Legal Tender Act that authorized the Treasury to issue inconvertible greenback dollars. During and after the War, the federal government issued bonds denominated in both gold and greenbacks dollars, a situation that enables us to estimate a greenback denominated yield curve and also investors' expectations about the volatile gold-greenback exchange rate. Despite a 60% depreciation in the greenback to gold exchange rate during the Civil War, we infer a strong nominal anchor: investors seemed to have anticipated that greenbacks would trade one-for-one with gold dollars soon after the war. That anticipated appreciation of the greenback meant that greenback yields were persistently lower than the gold yields. Having that firm nominal anchor helped the Union government earn seigniorage revenues by printing greenbacks.

Our estimates shine light on macroeconomic relationships that prevailed throughout the gold standard era. We find a strong positive correlation between per capita output growth and inflation during 1790-1933<sup>5</sup> and a strong negative correlation from the late 1930s until 2000. This striking change coincided with FDR's decision to abandon the gold standard and reorganize the financial sector during the 1930s. Before FDR, business cycle downturns had often been accompanied by bank crises during which households demanded more gold by seeking to convert state or national bank notes into gold, which in turn forced banks to demand more gold. As a result, gold appreciated and the price level declined during recessions. FDR's New Deal reforms eradicated that feedback loop by preventing households from holding gold and having the Federal Deposit Insurance Corporation insure the dollar value of bank deposits. Thus, a post FDR "Phillip's curve" appears at least partly to have been the outcome of attempts to alleviate difficulties that pre FDR governments experienced in stabilizing the banking sector under a gold standard in which it could not control the supply of banks' "reserve" asset, namely, gold.

A positive pre-FDR correlation between output growth and inflation suggests that investors valued gold paying government bonds as an inflation hedge. We present evidence that the change from a negative yield curve slope to a positive yield curve slope during the 1870s reflects changes in inflation risks that investors wanted to hedge. The inflation process changed from a near i.i.d. stochastic process before 1880 to a more persistent, less volatile process with a higher long-run mean afterwards. This meant that in the early years

---

<sup>5</sup>Except for the Civil War when the two series become uncorrelated.

in our 1790-1933 sample the major inflation risks were at long horizons, so that long-term bonds acted as a relatively better inflation hedge, while in later years short-term inflation risks became more important, making short-term bonds the better hedge. This suggests that the shape of the yield curve has always been closely tied to inflation dynamics and that the positive slope of the yield curve has extended across different monetary policy arrangements that predated a Fed practice of using a short term interest rate as its policy instrument.

Our long term perspective suggests that relationships that macroeconomists sometimes treat as invariant structural features look more like outcomes of ways that different government administrations have balanced trade-offs among lowering federal borrowing costs, price stability, and financial stability. During the gold standard era, the government prioritized decreasing costs of financing the government and keeping trend inflation low. As a result, the government was willing to give up control of the reserve asset as a way of “externalizing” a commitment to price level stability and to let the banking sector control money creation in exchange for holding long-term US federal debt, with limited regard to financial stability. Starting with FDR, the government put more weight on its concerns about ensuring financial and business cycle stability and less weight on its concerns about ensuring price stability, so the government became willing to use inflation taxes to lower its debt obligations. This led the government to abandon the gold standard, to replace it with a system in which the government controlled the supply of the reserve asset, and to concentrate on setting up short term debt markets that allowed liquidity premia to move over the business cycle.

In parameterizing and estimating a stochastic process for yield curves on US federal bonds, we confront several challenges. A first is that 19th century macroeconomic data are unreliable. This prevents us from directly estimating a stochastic discount factor process that prices macroeconomic risks, especially at high frequency. For this reason, we follow a flexible approach that specifies a general discount function process with a law-of-one price restriction across maturities for each date, but does not explicitly impose the absence of arbitrage. This approach potentially a variety of models ranging from affine asset pricing models to preferred habitat models; but using it restricts us to estimating yield curves that bundle haircut risk and convenience premia into a “time-varying pricing kernel.”

A second challenge is that our data set is sparse along the cross-section dimension. We tackle this problem by adopting a time-varying version of a statistical model proposed by [Nelson and Siegel \(1987\)](#). Economists at policy institutions use a similar parameterization, but in inferring a yield curve from observed prices and quantities they face a different challenge than we do. Because they have a superabundance of *cross-section* data on prices and quantities at each date, they solve an *overdetermined* inference problem. Our data are

too sparse along the cross-section dimension to allow us to use even a *just-identified* version of the commonly used procedure. To confront this data deficiency, we enlist a “prejudice” or “induction bias” in the form of a parameterized statistical model of a panel having scattered missing observations. The data and statistical model tell us how much *smoothing* across time to do.

A third challenge is that 19th century US federal bonds often gave lenders and the Treasury discretion over maturity dates, conversions, and other features. Our inference procedure assumes that agents priced bonds under perfect foresight about those discretionary contract features. To prevent such assumptions from influencing our inferences too much, we introduce bond-specific idiosyncratic pricing errors. This decreases the influence of peculiar bonds on our yield estimates while alerting us to situations when our assumptions prevent our pricing formulas from consistently pricing our *cross-section* of bonds.

Another challenge is to infer posterior distributions associated with a complicated non-linear statistical model without relying on the particle filter or Gibbs sampling. We approximate posterior probabilities by deploying Hamiltonian Monte Carlo and No U-Turn sampling (HMC-NUTS). Our data set presents many technical difficulties — such as changing numbers of observed assets, bonds that have payoff streams of varying lengths, periods without price observations, relevant sets of bond-specific pricing errors changing over time in complicated ways — that prevent us from applying a “standard” `Stan` toolkit and force us to code our log posterior functions from scratch. Our application of the `DynamicHMC.jl` package by Papp et al. (2021) can be used for other economic models with tractable likelihood functions that do not easily fit into the `Stan` framework.

**Related Work** In the spirit of Friedman and Schwartz (1963), we present a narrative history supported by data and statistics.<sup>6</sup> There has been recent work compiling international historical interest rate series and examining long-term trends (e.g., Shiller (2015), Hamilton et al. (2016), Jordà et al. (2019), Schmelzing (2020), Officer and Williamson (2021), Chen et al. (2022)). An important data constraint is that these studies have limited coverage of US Federal yields. Instead, they use a commercial paper rate as a “short interest rate” and a “long market rate” from Homer and Sylla (2004) that combines yields-to-maturity on US Federal bonds pre-Civil War with yields-to-maturity on New England Municipal bonds and corporate bonds post-Civil War.<sup>7</sup> By estimating the full yield curve on US Federal bonds, this paper opens up new and exciting questions about historical trends in

---

<sup>6</sup>Our interpretations are shaped by a statistical model that we regard as an auxiliary model in the sense of Gallant and Tauchen (1996) in terms of how it would connect to an explicit structural model cast in terms of parameters that describe preferences, constraints, and information flows of purposeful agents inside the model.

<sup>7</sup>We offer a detailed comparison to other historical series in appendix G.

government financing costs.

Technically, our work is related to [Svensson \(1995\)](#), [Dahlquist and Svensson \(1996\)](#), [Cecchetti \(1988\)](#), [Annaert et al. \(2013\)](#), [Andreasen et al. \(2019\)](#), [Diebold and Li \(2006\)](#) and [Diebold et al. \(2008\)](#) who, like [Gürkaynak et al. \(2007\)](#) and ourselves, implement versions of the parametric yield curve model of [Nelson and Siegel \(1987\)](#). Our non-linear state space model with drifting parameters and stochastic volatility builds on [Cogley and Sargent \(2005, 2015\)](#). Our analysis of events during the greenback period from 1862 to 1879 revisits issues presented in landmark studies of [Mitchell \(1903, 1908\)](#) and [Roll \(1972\)](#). Computing posterior distributions implied by our data and our statistical model is a formidable task that we accomplish by using the HMC-NUTS algorithm of [Hoffman and Gelman \(2014\)](#) and [Betancourt \(2018\)](#). While this estimator has been used extensively in statistics, economic applications are scarce. Prominent exceptions are [Bouscasse et al. \(2021\)](#) who use it to study the evolution of productivity in England from 1250 to 1870 and [Farkas and Tatár \(2021\)](#) who estimate DSGE models with ill-behaved posterior densities.

**Outline** Section 2 describes data and provides historical context. Section 3 outlines how we parameterise the gold dollar yield curve, and delineates our econometric strategy. Section 4 discusses some stylized facts about the “gold standard era” from 1791 to 1933. Section 5 discusses statistical inferences about greenback dollar yield curves and gold-greenback price expectations during and after the Civil War. Section 6 is an epilogue that connects our results with recent data and discusses implications of studying long time series across different monetary and fiscal regimes.

## 2 Data Set and Historical Context

We have assembled prices, quantities, and descriptions of all securities issued by the US Treasury between 1776 and 1960.<sup>8</sup> In Appendix A.1, we spotlight decisions about our data that we made to prepare for the statistical inferences presented in this paper. In this section, we provide historical context to help understand the data. We first discuss the characteristics of 19th century monetary policy, financial sector regulation, and treasury debt management. For reference, the major events are summarized in Table 2 in Appendix B. We then outline the challenges that these characteristics pose for yield curve estimation. These challenges shape specification and estimation strategies deployed in Section 3.

---

<sup>8</sup>The data set (excluding any data taken from non-publicly accessible data sets) is available at the Github repository <https://github.com/jepayne/US-Federal-Debt-Public> and construction methods are explained in [Hall et al. \(2018\)](#).

## 2.1 Monetary Policy and Financial Sector Regulation

*1791-1862: Bimetallism, Banks of The US, and State Banks.* Between April 1792 and February 1862, the US dollar was defined in terms of gold and silver (a “bimetallic” system).<sup>9</sup> The federal government minted gold and silver coins but not paper notes. Instead, paper notes were created by the banking sector. Throughout the period, state legislatures chartered state banks, which could issue their own bank notes. Initially, the First (1791-1811) and Second (1816-1836) Banks of the United States operated at the national level. These banks were privately owned and undertook similar commercial operations to the state banks. However, they also had the special privileges of acting as the banker for the federal government (depositing tax revenue and making loans) and operating across state boundaries. Because tax revenues could be paid in state bank notes and were deposited in the First and Second Banks of the US, these banks effectively acted as a lender to the state banking system. This meant that the First and Second Bank of the US could influence state bank note and credit creation by setting the rate at which they redeemed their state bank notes into gold.<sup>10</sup>

The rechartering of the Second Bank of the US turned into a political struggle during the Presidency of Andrew Jackson (1829-1837). Andrew Jackson vetoed a bill to recharter the bank (1832), removed federal deposits from the bank (1833), and, ultimately, allowed the bank’s charter to expire (1836). In the subsequent decades (1837-1862), states expanded their banking sectors by allowing the automatic chartering of banks without requiring explicit approval from the state legislature. This period is often referred to as the “free banking era” and was perceived to be characterized by high bank risk taking and discounted state bank notes.

*1862-1913: Greenbacks, Gold Standard, and the National Banking System.* The outbreak of the Civil War in 1861 put significant strain on the monetary and financial systems, leading to major policy changes. In January 1862, state banks stopped honoring their legal obligation to convert their notes into specie (they “suspended” convertibility). On February 25, 1862, Congress passed a Legal Tender Act that authorized the Treasury to issue 150 million dollars of a paper currency known as greenbacks that the government did not promise immediately to exchange for gold dollars. Subsequent acts authorized the Treasury to issue more notes, eventually totalling 450 million dollars. Investors could use greenbacks to purchase bonds from the federal government at their par values. Gold dollars continued to be used to settle international transactions and to pay US tariffs. From 1862 to December 31, 1878 paper notes (“greenbacks” or “lawful money”) traded at discounts relative to gold dollars (“gold”

---

<sup>9</sup>Prior to 1792, a dollar referred to a Spanish silver coin.

<sup>10</sup>See [Hammond \(1947\)](#) for a discussion of the operations of the First and Second Bank of the US.



or “coin”). The greenback depreciated substantially during the Civil War and did not attain parity with gold until January 1, 1879, when the US Treasury started converting greenbacks into gold dollars one-for-one.

In addition, between 1863-6, Congress passed a collection of National Banking Acts, which established a system of nationally chartered banks and the Office of the Comptroller of the Currency. National banks faced restrictions on what loans they could make<sup>11</sup> and were allowed to issue bank notes up to 90% of the minimum of par and market value of qualifying US federal bonds.<sup>12</sup> These national bank notes were intended to replace the state bank notes as a standardised currency that could be used across the country. In order to achieve this, Congress imposed a 10% annual tax on state bank notes, which was significantly greater than the 1% annual tax on national bank notes.<sup>13</sup>

*1913-1933: Establishment of Federal Reserve Bank.* Bank runs and stock market crashes were a common feature of all different monetary and banking policy arrangements during the 19th century. There were country wide bank panics in 1819, 1827, 1857, 1873, 1893, and 1907 as well as many other local bank panics in New York and other financial hubs. In response, The Federal Reserve System was passed in 1913 to create a Federal Reserve Bank to act as a reserve money creator of last resort to prevent bank runs. Convertibility between gold and US notes at par prevailed through World War I and the 1929 stock market crash until 1933 when Franklin D. Roosevelt increased the paper price of gold and prohibited private US citizens from holding gold coins. For the purposes of this paper, we consider this the end of the gold standard in the US.

## 2.2 19th Century US Federal Bonds

Before World War I, the federal government issued bonds infrequently. New bond issues were often small. The US Congress, rather than the Treasury, designed each government security with the consequence that securities varied over time in terms of their coupon rates, denominations, lengths, units of account, tax exemptions, and call features. Before the 1920s, the federal government occasionally issued customized long term debt, mostly to

---

<sup>11</sup>National banks could only operate one branch. They were restricted from making mortgages unless they were operating in rural areas, where they could make a limited range of loans collateralized by agricultural land.

<sup>12</sup>Technically, national banks could issue bank notes for circulation according to the following rules. Banks had to deposit certain classes of US Treasury bonds as collateral for note issuance. Permissible bonds were US federal registered bonds bearing coupons of 5% or more. Deposited bonds had to be at least one-third of the bank's capital (not less than \$30,000). Banks could issue bank notes up to an amount of 90% of the maximum of the market value of the bonds and the par value of the bonds. The 90% value was changed to 100% in 1900.

<sup>13</sup>Before 1900, the banks had to pay 1.0% tax on the notes they had issued. After 1900, they had to pay a 0.5% tax.

finance wars, debt reschedulings, and specific infrastructure projects. As a result, between 1776 and World War I, the US Congress only authorized the Treasury to issue a total of approximately 200 distinct securities, with at most 8 distinct ones being authorized in any one year.

Between 1917 and 1939, Congress gradually delegated more and more decisions about designing US debt instruments to the Treasury and the Treasury gradually standardized security design. As a result, from 1920 to 1960 alone, the Treasury issued about 2500 securities with a wide range of maturities. Ultimately, this transformed the market for US Treasury securities into the world’s most liquid debt market with a collection of standardized securities at many maturities that allowed a large national debt to be issued and rolled over.

When gold and greenback dollars coexisted (1862-1878), different US Treasury bonds promised payments in different currencies. Some bonds promised all payments in gold (we refer to these as “gold dollar” bonds); other bonds promised all payments in greenbacks (we refer to these as “greenback dollar” bonds); and yet other bonds offered coupons in gold but left ambiguous whether the principal would be paid in gold or greenbacks (we refer to these as “ambiguously” denominated bonds). While bonds denominated in different currencies present an opportunity because they allow us to estimate both gold and greenback dollar nominal yield curves, the difficulty is that we observe only 9 greenback dollar bonds and only 6 ambiguously denominated bonds. Consequently, we will focus on the gold dollar bonds to obtain our baseline yield curve estimate. When we turn to estimating the greenback dollar yield curve in Section 5, we will build on this baseline gold dollar yield curve.

### 2.3 Inference Challenges

*Q1. How should we handle periods that provide sparse or inaccurate macroeconomic data?* In principle, we could attempt to use historical macroeconomic data to estimate a model of the stochastic discount factor that prices macroeconomic risks. However, we are skeptical about the quality of 19th century macroeconomic data, especially at high frequency. For this reason, we estimate a model that sidesteps directly specifying a pricing kernel process.

*Q2. How should we handle periods with sparse bond data?* Figure 1 depicts the monthly time series for the number of securities with observed prices and times to maturity of *all* outstanding bonds. There were frequently fewer than 5 price observations in a given period and no price observations in the late 1830s when the Federal government had no outstanding debt. This means that while we have “big data,” our unbalanced sample prevents us from applying commonly used techniques from the yield curve estimation literature. Instead, we must posit a statistical model that lets us learn about yields at all dates simultaneously by pooling information across time periods.

*Q3. How should we handle peculiar bonds?* Throughout our sample, many US Treasury

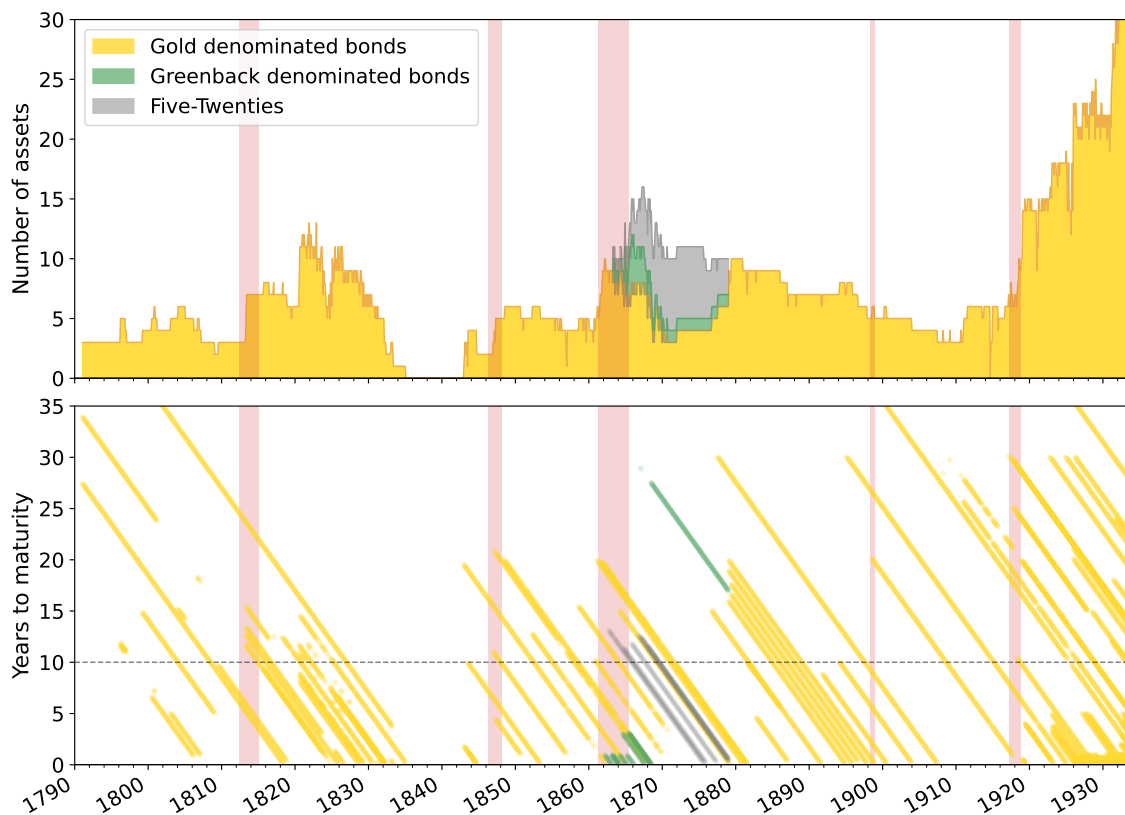


Figure 1: Our Dataset

The top panel depicts the number of securities with observed prices each month. The bottom panel depicts maturities (in years) of observed securities. Darker lines indicate overlapping securities. Red bars correspond to wars.

securities had custom features such as indefinite maturities associated with call or conversion options. We start by *ex post* imputing perfect foresight about call dates and other discretionary components of the contracts (see Appendix A.3 for the details). We then inspect and refine these assumptions by studying bond-specific pricing errors.

*Q4. How should we handle haircut risk and convenience yields?* There are many reasons to think that different maturities of US federal debt carried different haircut risk and “convenience” (or “liquidity”) yields at different periods of the 19th century. We address this by packaging haircut risk and convenience benefits into a time varying pricing kernel that imposes that haircut risk and convenience benefits can vary across maturities but not across bonds. This allows us to estimate the prices of risky government promises.

### 3 Statistical Models

In this section, we describe the non-linear state space model that we estimate to obtain gold denominated yield curves. A key feature of our approach is to impose a tight parametric structure *across maturities*, while letting the yield curve parameters vary *across time* in a flexible way that nonetheless allows to pool information across time periods.

#### 3.1 Tight parameterization across maturities

Suppose that at time  $t$  we observe prices on an integer number  $M_t$  of *coupon-bearing* government bonds. A given bond,  $i$ , promises a sequence of gold dollar coupon and principal payments  $\bar{m}_t^{(i)} := \{\bar{m}_{t+j}^{(i)}\}_{j=1}^{\infty}$ . Let  $p_t^{(i)}$  denote the price of a coupon-bearing gold dollar bond in terms of gold.

**Assumption 1.** The law of one price holds for government bonds and for each  $t \geq 0$  there exists a discount function  $\mathbf{q}_t := \{q_t^{(j)}\}_{j=0}^{\infty}$  such that

$$p_t^{(i)} = \sum_{j=1}^{\infty} q_t^{(j)} \bar{m}_{t+j}^{(i)}.$$

Assumption 1 expresses our key identifying restriction: within each time period, there is a common discount function that prices all bonds that we include in our sample, i.e., there is no cross-sectional variation in how government promises of bond repayment are priced. Note that in principle  $\mathbf{q}_t$  implicitly includes compensations for haircut risk, convenience benefit or inflation risk so it should be thought of as the price of a *risky* government promise. Our specification allows these components to vary with the maturity  $j$  and time  $t$ , just not by individual bond.

We do not impose a particular pricing kernel structure because we have insufficient macro data during the 19th century. Instead, we specify a discount function process,  $\{\mathbf{q}_t\}_{t \geq 0}$ , directly that we view as the conditional expectation of some time-dependent pricing kernel. While this approach imposes the law-of-one-price across maturities for each date, it does not explicitly restricts the discount function process to ensure the absence of arbitrage across time. This flexible specification of  $\{\mathbf{q}_t\}_{t \geq 0}$  nests a wide range of models, from affine asset pricing models to preferred habitat models.

We parameterize the discount function  $\mathbf{q}_t$  by parameterizing the corresponding  $j$ -period zero-coupon yields defined as  $y_t^{(j)} := -\log q_t^{(j)}/j$ .

**Assumption 2.** The  $j$ -period gold dollar zero-coupon yield takes the form

$$y_t^{(j)} = \exp(\lambda_{0,t}) \left[ \left( \frac{1 - \exp(-j\tau)}{j\tau} \right) (j\tau - 2) \right] + (\exp(\lambda_{1,t}) + \exp(\lambda_{2,t})) \left[ \frac{1 - \exp(-j\tau)}{j\tau} \right] - \exp(\lambda_{2,t} - j\tau) \quad (3.1)$$

with parameters  $\lambda_t := [\lambda_{0,t}, \lambda_{1,t}, \lambda_{2,t}]'$  and  $\tau$ .<sup>14</sup>

This Nelson and Siegel (1987) parameterization<sup>15</sup> has a number of desirable features. First, it is flexible enough to generate “typical yield curve shapes” (e.g., monotonic, humped, and S-shaped curves). Second, as showed by Diebold and Li (2006), the elements of  $\lambda_t$  are associated with the “level, slope, and curvature” of the yield curve. Finally, it is compatible with estimates of recent yield curves.<sup>16</sup>

### 3.2 Flexible parameterization across time

Because prior to the First World War, price data are sparse and coverage varies over time, we use a multilevel (a.k.a. an hierarchical) statistical model to efficiently pool information over time. This is in contrast with Gürkaynak et al. (2007) who—for the period after 1960—estimate yield curves period-by-period, assuming no intertemporal dependence among the elements of  $\lambda_t$ .

Three key features characterize the way our model pools information across time: (i) we allow  $\lambda_t$  to have a mean-reverting, stationary component and a slowly moving long-run mean  $\bar{\lambda}_t$ , (ii) we allow the degree of information pooling to vary over time by introducing stochastic volatility, and (iii) we ensure bonds that violate Assumptions 1-2 have relatively little influence on the yield estimates by introducing bond specific pricing errors.

**Assumption 3.** Parameter  $\tau$  is time-invariant. Parameter vector  $\lambda_t$  follows:

$$\lambda_{t+1} = \bar{\lambda}_t + \varrho(\lambda_t - \bar{\lambda}_t) + \Sigma_t^{\frac{1}{2}} \varepsilon_{\lambda,t+1}$$

<sup>14</sup>The exponentials in (3.1) facilitate the efficient operation of our sampler, but imply  $y_t^{(j)} \geq 0$ . To avoid that we introduce a fixed lower bound  $y_t^j \geq \underline{y}$  and add it to  $\exp(\lambda_t)$ . We set  $\underline{y}$  low enough ( $\underline{y} = -100$ ) so that the sampled  $\{y_t^{(j)}\}$  paths never get close to  $\underline{y}$ .

<sup>15</sup>Nelson and Siegel (1987) advocate the form  $y_t^{(j)} = b_0 + (b_1 + b_2) \frac{1 - \exp(-\tau j)}{\tau j} - b_2 \exp(-\tau j)$ . It is straightforward to show that by setting  $\exp(\lambda_0) = b_0$ ,  $\exp(\lambda_1) = b_0 + b_1$ , and  $\exp(\lambda_2) = b_0 + b_2$  our parametrization matches theirs. We prefer our parameterisation because the HMC-NUTS sampler appears to handle it more easily than the Nelson-Siegel form.

<sup>16</sup>For example, Gürkaynak et al. (2007) use this form for the period 1961-1980. After 1980, they use an extension proposed by Svensson (1994) to allow for a second hump in the yield curve. Recent work by Liu and Wu (2021) suggests to use a non-parametric approach to capture more “local variation”. We are unable to use a similar approach due to data limitations. However, as we discuss in Appendix F, we find consistently small pricing errors along bond, time, and maturity dimensions.

where  $\varrho$  is a  $3 \times 3$  matrix,  $\Sigma_t$  is a covariance matrix with  $\Sigma_t = \Xi_t \Omega \Xi_t$ . Here,  $\Omega$  is the time-invariant correlation matrix and  $\Xi_t$  is a diagonal matrix containing the marginal standard deviations  $\sigma_t := [\sigma_{1,t}, \sigma_{2,t}, \sigma_{3,t}]'$  that follow:

$$\log \sigma_{t+1} = \log \sigma_t + \Xi_\sigma \varepsilon_{\sigma,t+1}$$

where  $\Xi_\sigma$  is a positive definite diagonal matrix. In addition

$$\bar{\lambda}_{t+1} = \begin{cases} \bar{\lambda}_t + \bar{\Xi} \varepsilon_{\bar{\lambda},t+1} & \text{if } t = k\Delta \text{ for } k \in \mathbb{N} \\ \bar{\lambda}_t & \text{otherwise} \end{cases}$$

where  $\bar{\Xi}$  is a positive definite diagonal matrix and  $\Delta \geq 1$  is the frequency at which  $\bar{\lambda}_t$  updates. Shocks  $\varepsilon_{\lambda,t}$ ,  $\varepsilon_{\sigma,t}$ , and  $\varepsilon_{\bar{\lambda},t}$  are Standard Normal for  $t \geq 1$ .

Parameter matrix  $\Sigma_t$  governs the degree of information pooling over time. The closer are two dates to each other, the more correlated are the associated yield curves, with  $\Sigma_t$  capturing what “close” means.<sup>17</sup> The limit  $\Sigma \rightarrow 0$  corresponds to *complete pooling*: here the yield curve is assumed to be fixed over time. Contrary situations in which  $\Sigma \rightarrow \infty$  call for *no pooling*: there is no relationship between adjacent parameter estimates as in [Gürkaynak et al. \(2007\)](#). In this context, “stochastic volatility” means that the amount of pooling can be time varying throughout the sample.<sup>18</sup> Long-run mean  $\bar{\lambda}_t$  of the yield curve parameters follows a random walk with updates at frequency  $\Delta$ .<sup>19</sup> We set  $\Delta = 24$  months as a compromise between identifying the long-run mean with high accuracy and letting it move over time.

Idiosyncratic bond characteristics, such as flexible maturities and conversion options, require custom pricing formulas for each bond. However, it is a priori unclear that all bond characteristics are equally important. To decide which ones warrant special treatments, we use *bond specific* pricing errors.

**Assumption 4.** Each bond  $i$  has a pricing error which is independent from errors on other bonds and has a time-invariant Gaussian distribution with mean 0 and standard deviation

<sup>17</sup>One might be tempted to call this procedure “stochastic smoothing” because consecutive  $\lambda_t$  vectors are linked by a sequence of random variables  $\{\varepsilon_{\lambda,t}\}$ . Alternatively, one could define a deterministic smoothing function that specifies the sequence  $\{\lambda_t\}$  in terms of parameters  $\lambda_0$  and  $\Sigma$ , mimicking a simple moving-average. Modeling the sequence  $\{\lambda_t\}$  as a stochastic process allows our algorithm to choose from a much richer set of smoothing functions.

<sup>18</sup>We gain additional pooling by letting shocks to different components of  $\lambda_t$  be correlated. Assuming that different parts of the yield curve follow correlated but time-invariant dynamics allows us to transmit what we learn about co-movements between short- and long-term yields from years when many maturities are outstanding to years when data are scarce.

<sup>19</sup>As  $\Delta \rightarrow \infty$ , the frequency of parameter updates goes to zero, providing a state-space model with time-invariant long-run mean  $\bar{\lambda}$ .

$\sigma_m^{(i)}$ .

Introducing these errors enables our model to decrease the influence of peculiar bonds on our yield estimates while still informing us about situations when our collective assumptions prevent us from consistently pricing the *cross-section* of bonds. Starting with presuming that all bonds can be priced with a common discount function, we look for patterns in the estimated pricing errors, the idea being that misjudgments in our bond classification would show up as large, cluster-specific relative pricing errors.<sup>20</sup>

The observation equation of our nonlinear state space model becomes:

$$\tilde{p}_t^{(i)} = \langle \mathbf{q}(\lambda_t, \tau), \bar{\mathbf{m}}_t^{(i)} \rangle + \sigma_m^{(i)} \varepsilon_t^{(i)}$$

with  $(\lambda_t, \tau)$  following the process as in Assumption 3 and  $\tilde{p}_t^{(i)}$  denoting the *observed* period- $t$  price of bond  $i$  in terms of gold. To estimate this model’s (more than 7,500) parameters, we apply Bayesian Markov Chain Monte Carlo methods. We specify weakly informative prior distributions for the model’s hyper-parameters (see Appendix E.1) with the specific purpose of *regularizing* our estimator and facilitating smooth operation of the sampling algorithm. Non-trivial features of our data set make the estimation procedure non-standard. We discuss the methodological contributions in Appendix E.2. We conduct a “laboratory experiment” in Appendix E.3 to illustrate when our procedure can recover the true yield curves from an artificially generated data set.

### 3.3 Real Yield Curves

Ultimately, we are interested in estimating real yields which requires us to estimate inflation expectations at various horizons. Denote (net) gold inflation between period  $t$  and  $t + j$  as  $\pi_t^{(j)}$ . We use the following “risk-neutral” approximation of the *ex-ante* real yield:

$$r_t^{(j)} := y_t^{(j)} + \frac{1}{j} \log \mathbb{E}_t \left[ \exp \left( - \pi_t^{(j)} \right) \right] \quad (3.2)$$

To obtain a proxy for inflation expectations, we estimate a flexible statistical model of inflation with random walk stochastic volatility and drifting mean and persistence. Appendix D describes details of our procedure—a step separate from our strategy for estimating the gold yield curve.

---

<sup>20</sup>We identified two types of bonds that require special treatment: (i) greenback-denominated bonds, for which we devise custom pricing formulas in Subsection 5.1 and (ii) bonds that are close to maturity, in which case, we suspect the large relative pricing errors are due to a liquidity premium that emerges from the relative ease in which such bonds could be used for transactions. We drop prices of bonds that are less than one year to maturity from the sample and in Subsection 4.2 use the residual pricing errors on these bonds as a proxy for the liquidity premium on money-like federal liabilities.

## 4 The Gold Standard Era: 1791-1933

In this section, we use our estimate of the gold denominated US federal yield curve to establish a collection of stylized facts: (i) US debt traded at higher yields than UK debt until the late 19th century, (ii) a “short rate disconnect” existed until the late 19th century, in the sense that debts close to maturity carried a “liquidity” premium, (iii) long term inflation expectations were close to zero until the 1880s so that long term gold denominated yields can be interpreted as real yields, and (iv) the slope of the yield curve was typically negative before the Civil War and positive afterwards. We discuss how these facts reflect changes in the US federal government’s reputation, monetary policy, and financial regulation.

### 4.1 Long term US yields fell to UK rates

Figure 2 depicts selected long term yield estimates. The solid black and grey lines depict the median of our posterior estimate for the 10-year, gold denominated, zero coupon yield. We use black for periods with price observations for bonds with maturity within 1 to 10 years so the estimate can be considered an interpolation. Otherwise, we use grey. We show the 25 year gold dollar zero-coupon yield for dates before 1800 because we only have price observations for very long term bonds during that period. The grey bands around the posterior median depict the 90% interquantile range.

Long yields trended downward throughout the 19th century interrupted by sharp (but temporary) increases during times of war and financial turmoil. Our approximating yields are quite volatile during the 1790s when secondary markets in Treasury securities were thin. Yields fell steadily from January 1791 to March 1792 when a financial panic caused sharp drops in bond prices and corresponding increases in yields. Long-term yields remained high for the remainder of the decade and spiked at 9% in August 1798, one month after the Congress authorized a 15-year loan paying an 8% coupon to cover increased military spending at the outbreak of the Quasi-War with France. Yields trended downward thereafter, and by 1803 the US government was able to issue at par a \$11.25 million 15-year loan with a 6% percent coupon to finance the Louisiana Purchase. The sharpest increases come during the War of 1812 and the Civil War. During the War of 1812, the 10-year zero-coupon yield spiked to over 9%. A big source of funds for this war was the Treasury’s issuing of five long-term loans with face values totaling \$66 million. Resistance to the war mainly from Federalists in the Northeast and a failure to replace lost customs revenue with internal taxes forced the Treasury to sell these bonds at deep discounts. [Bayley \(1882\)](#) reports that two of these loans were sold at 12% discounts, and a third was sold at a 20% discount. Those officially-stated discounts understate the true discounts, since for payment the Treasury accepted at face value bank notes whose market values had sunk substantially below par.



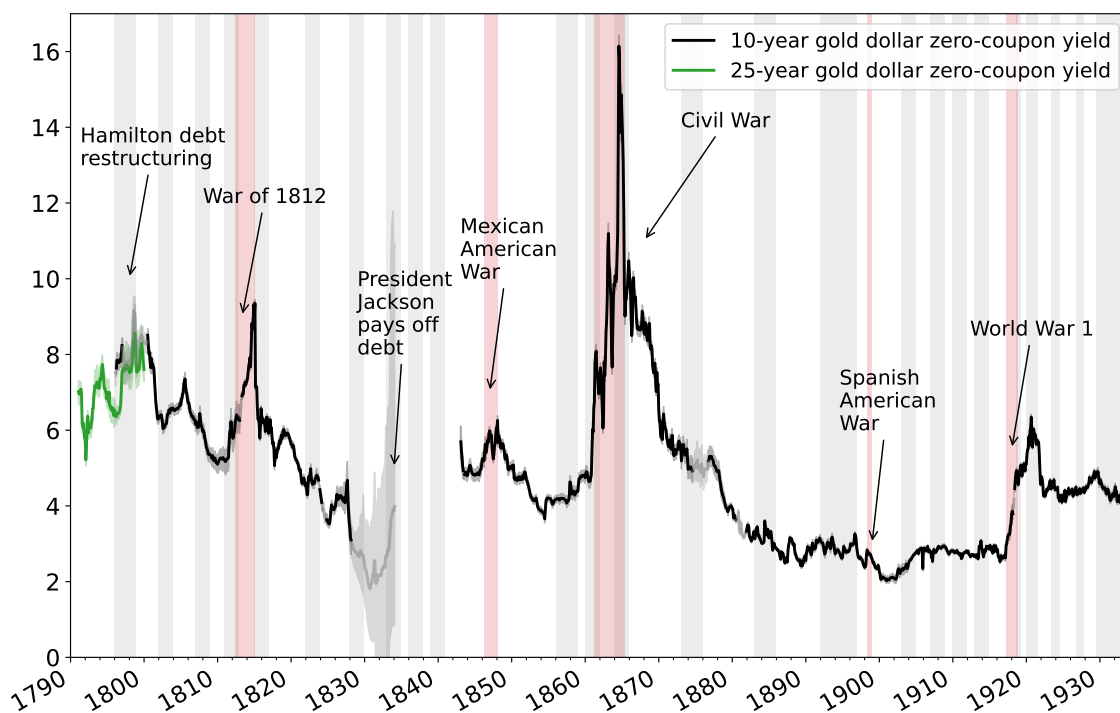


Figure 2: Long-Term Yield Estimates.

The solid black line depicts the mean of our posterior estimate for the 10-year, gold denominated, zero coupon yield. The grey bands around the posterior mean depict the 95% interquantile range. The light gray intervals depict recessions as dated by [Davis \(2006\)](#) for the 1796-1914 period and NBER recessions thereafter. The light red intervals depict wars (from left to right: the War of 1812, the Mexican-American War, the Civil War, the Spanish-American War, and World War I).

The Treasury again had trouble selling new bonds at par during the Civil War, leading to much higher yields. Our ten-year gold yield estimate reaches a peak of 16% near the end of the Civil War.

One explanation for the sustained decrease in long yields is a fall in the risk premium on US federal debt securities. After the American War for Independence, the Continental Congress owed approximately \$52 million in foreign loans to France, Spain, and Holland, loan office and debt certificates to the American public, and unpaid interest. The Congress confronted substantially higher long term yields than the UK even though the UK then had a high debt-to-GDP ratio. This situation spawned a lively debate in the US about whether and how to service wartime debts. Treasury Secretary Alexander Hamilton argued in his *1790 Report on Public Credit*

For when the credit of a country is in any degree questionable, it never fails to give an extravagant premium, in one shape or another, upon all the loans it has

occasion to make. Nor does the evil end here; the same disadvantage must be sustained upon whatever is to be bought on terms of future payment.

Ultimately, Hamilton and others persuaded Congress to repay the foreign debt at face value and issue new bonds to refinance the domestic certificates and interest in arrears. Hamilton claimed that by following through on this policy the US could eventually acquire a reputation for servicing its debts that would reduce US interest rates to the lower levels than paid by the UK government.

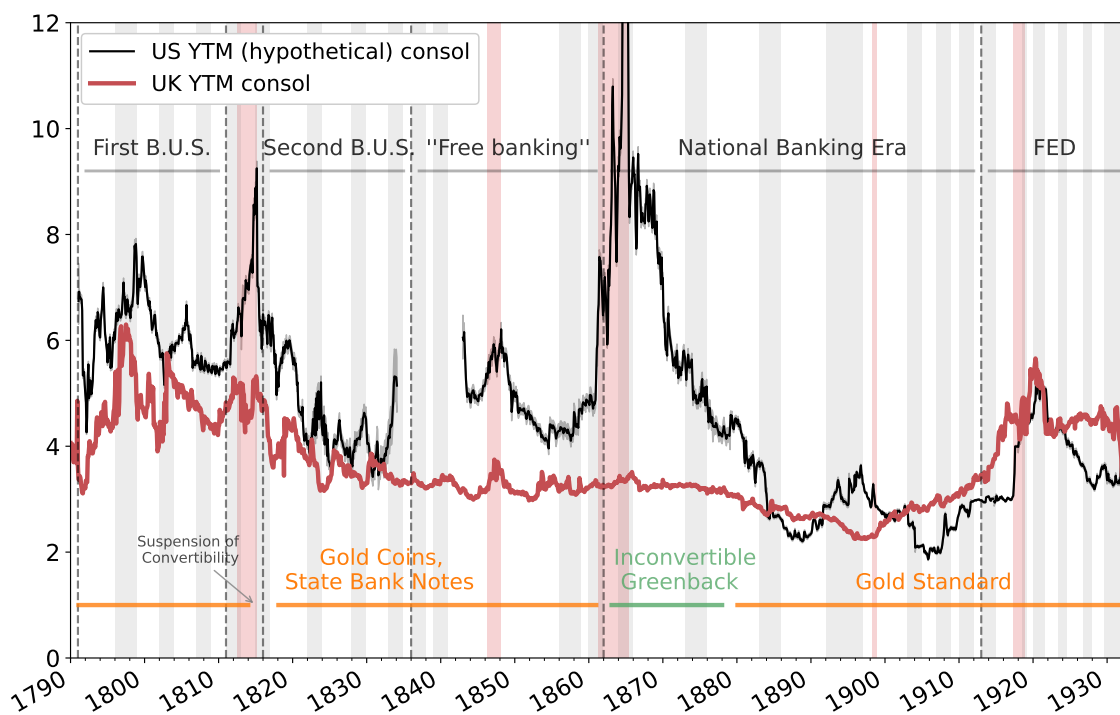


Figure 3: US and UK Long Term Yields.

The solid black line depicts the mean of our posterior estimate for the yield-to-maturity on hypothetical gold denominated US consols that promise the same coupon flows as the UK consols. The grey bands around the posterior mean depict the 90% interquantile range. The solid green line depicts the mean of our posterior estimate for the 10-year, gold denominated, zero coupon yield. The pale green bands around the posterior mean depict the 90% interquantile range. The green line depicts the UK long-term yield (implied by the 3% consol price) from [Thomas and Dimsdale \(2017\)](#). The light gray intervals depict recessions, and the light red intervals depict wars.

We use Figure 3 to quantify whether and when Hamilton's hopes were fulfilled. The figure compares yields-to-maturity on gold denominated UK consols to yields-to-maturity on *hypothetical* gold denominated US consols that promise the same coupon flows as the

UK consols.<sup>21</sup> We plot a yield-to-maturity on gold denominated UK consols because almost all UK government bonds were consols, so that is the only UK yield that can be reliably estimated. First, notice that the hypothetical US consol yield exhibits a downward trend, falling from close to 8% at the beginning of the 19th century to around 2% at the end of the century. Second, notice that the US yield was typically higher than the UK yield until the 1880s with a temporary convergence during the 1820s. Third, notice that the US yield was persistently lower than the UK yield after 1900. This suggests that the combination of the federal government’s having serviced War of Independence IOUs, admittedly with substantial haircuts to domestic creditors, and having completely retired all debt by the mid 1830s, along with activities of the First and Second Bank of the United States made significant progress toward realizing Hamilton’s hopes. However, the reemergence of the spread between US and UK debt during the period from 1840-1880 suggests that it wasn’t until the introduction of the National Banking Act and the reestablishment of gold-greenback parity that Hamilton’s vision was fully realized.

The difference between the yield-to-maturity on the UK consol and the hypothetical US consols most likely reflects different haircut risks. UK debt was considered a “safe-asset” during the 19th century, whereas many military and political incidents probably induced investors to regard 19th century US debt to be risky. In Appendix C.1, we state conditions under which one can interpret the difference between US and UK consol yields as reflecting the risk premium on US federal debt. Under this interpretation, Figure 3 suggests that US federal debt traded with a risk premium until the late 19th century when it became an alternative “safe-asset”. Evaporation of those risk-premia signals a realignment of global finance that ultimately led US government debt to replace UK debt as a global “safe-asset” during and after the years of the Bretton Woods arrangement.<sup>22</sup>

We can better understand the trend decline in the yields by studying the “low-frequency” component of the yield curve. We do this in Figure 25 in Appendix J. We interpret the long run mean as reflecting the impact of long term structural changes in the economy and interpret the difference between the yield and its long run mean as reflecting the impact of temporary events such as wars and economic crises. Figure 25 shows that the low frequency component of the yield curve declines steadily until the 1880s when it stabilizes around 2%. This suggests a possible structural break during the National Bank Act. We explore this possibility further in the subsequent sections.

---

<sup>21</sup>The UK consol yield is the series “Spliced consol yield 1753-2015, corrected for Goschen’s conversion issues” from [Thomas and Dimsdale \(2017\)](#). The hypothetical, gold denominated US consols promise the same annuity coupon payments as those used in the UK consol yield series

<sup>22</sup>[Chen et al. \(2022\)](#) describe this realignment in detail focusing on its fiscal implications for both the UK and US.

## 4.2 Premium on short term bonds

Analysts have argued that the modern US federal debt yield curve exhibits a “short-term disconnect,” in the sense that short term bonds are over-priced relative to a hypothetical price implied by pricing kernels that successfully price bonds at longer maturities.<sup>23</sup> In Figure 4, we use our statistical model to examine whether a similar short-rate disconnect existed during the 19th century. The pale blue dots depict the difference between model-implied and observed yield-to-maturities for bonds with *less than one year* to maturity. Because our model was estimated using bonds with maturity greater than 1 year, these dots represent an “out-of-sample” fit at the short end of the yield curve. The solid blue line depicts the 15-year centered moving average of these blue dots. The orange solid line depicts the 15-year centered moving average of the difference between model-implied and observed yield-to-maturities for bonds with *more than one year* to maturity. Evidently, pricing errors average out for bonds with long maturities but are systematically positive for extended periods for bonds close to maturity.<sup>24</sup> In particular, until the 1880s, bonds close to maturity traded with a premium in a range of 0.5 to 1.0 percentage points. The premium effectively disappeared from the 1880s until the First World War before reappearing in the 1920s. We interpret this as strong evidence that there has been a short rate disconnect through most US history, with a period towards the end of the 19th century when the short rate disconnect disappeared.

The evolution of the short rate disconnect probably indicates how successfully different money and banking eras were able to create a stable currency throughout the 19th century. Before the Civil War, the money supply was limited to gold dollars and state bank notes, the latter typically trading at volatile discounts that reflected inconsistent and opaque backing. This is consistent with the persistent premium we observe in the first half of the 19th century. In particular, the short rate disconnect is large early in the tenure of the Second Bank of the US, which coincides with the Second Bank of the US’s attempt to restrict bank money creation and credit.

During the Civil War, the government started issuing paper greenbacks (in 1861) and passed three National Banking Acts (in 1862, 1865, and 1866) that established a system of federally regulated national banks. National banks could issue standardized bank notes backed by their holdings of US federal bonds. From 1862-1878, greenback dollars traded at a significant discount to gold dollars. On January 1, 1879, the government began converting greenbacks into gold dollars at par. Key goals of the National Banking Acts were to increase

---

<sup>23</sup>For instance, see [Duffee \(1996\)](#), [Greenwood et al. \(2018\)](#), and [Lenel et al. \(2019\)](#).

<sup>24</sup>In appendix J, we present and discuss evidence that the pricing errors also average out within a finer set of maturity bins. We take this as evidence that the short rate disconnect is not driven by the inability of the [Nelson and Siegel \(1987\)](#) parameterization to fit the maturities that we include in our estimation.

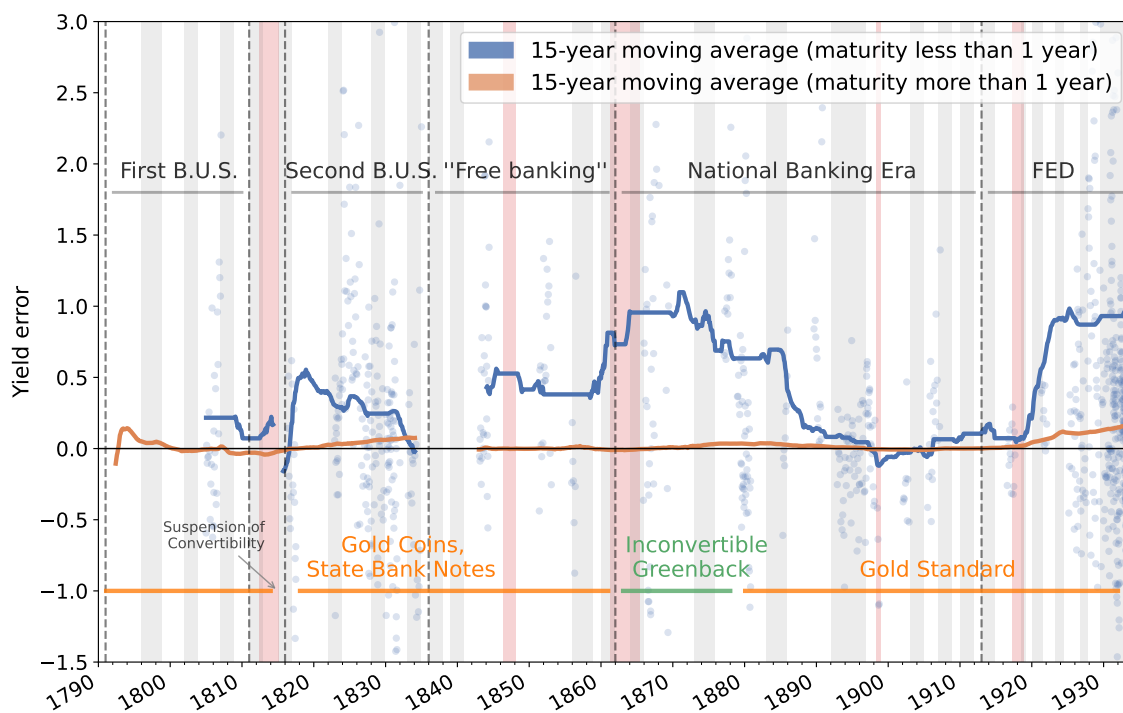


Figure 4: Short Rate Disconnect

Pale blue dots depict the difference between model-implied and observed yield-to-maturities for bonds with *less than one year* to maturity. The solid blue line depicts the 15-year centered moving average of these dots excluding yield errors with magnitude greater than 4 (to handle potential outliers from data issues). The orange solid line depicts the 15-year centered moving average of the difference between model-implied and observed yield-to-maturities for bonds with *more than one year* to maturity. The light gray intervals depict recessions, and the light red intervals depict wars.

supplies of liquid assets and to increase financial sector demand for long term US federal debt so that the government could borrow at a lower cost. Our estimates enable a novel evaluation of how successfully those Acts achieved their goals. Translated into our calculations, the National Banking Acts sought to eliminate the short rate disconnect and decrease long term yields. Figures 3 and 25 indicate that neither goal was immediately achieved in the 1860s but that both goals were largely achieved by the 1880s. This timing pattern offers suggestive evidence that parity between greenbacks and gold helped get the National Banking Act to work as desired, which in turn suggests that bank note issuance had initially been restrained by risks associated with currency devaluation. This allows us to shed light on a long standing puzzle about the issuance of bank notes. Researchers have argued that there was persistent under-issuance of national bank notes during the National Banking Era because the yield on eligible treasuries did not consistently fall to the tax rate on notes

outstanding (see [Champ et al. \(1994\)](#), [Champ and Wallace \(2003\)](#), [Champ \(2007\)](#)). We show in Figure 26 in Appendix J that our estimates confirm this observation; short term and long term yields were typically above the tax rates. However, as acknowledged by many researchers, comparing yields to the tax rate on note issuance is a misleading way to test the National Banking Act because many other forces could have shifted levels of yield curves. Our analysis shows that, if we focus on the short rate disconnect rather than a the spread relative to the tax rate, then it appears that the National Bank Act achieved considerable success once parity between greenbacks and gold was restored.

After the introduction of the Federal Reserve System (FED) and World War I, the short-rate disconnect reemerge. This likely reflects the Treasury’s decision to introduce Certificates of Indebtedness—interest-bearing securities with less than 1 year maturity—to smooth the mismatch between quarterly tax receipts and the Liberty Bonds’ irregular coupon and principal payments. Most blue dots that we see in Figure 4 during the FED era correspond to these certificates. [Garbade \(2012\)](#) describes how three innovations by the New York FED in 1920 increased the liquidity of these certificates relative to other government bonds: (i) they started to raise discount rates that forced the Treasury to let certificates be traded below par, (ii) they extended credit to all banks and dealers via repurchase agreements (“repos”) secured by certificates, and (iii) they offered a service for “wire transfer” of certificates.<sup>25</sup> This increase in the relative liquidity of the Certificates of Indebtedness is consistent with a short rate disconnect reappearing. The large variation in the short rate disconnect across the different regulation eras suggests that it can be thought of as reflecting a government design choice.

### 4.3 Inflation anchor until 1880s

The previous subsections discussed nominal gold denominated yield curves. To understand the real cost of financing, we need to estimate inflation expectations and a real yield curve. As mentioned in Subsection 3.3 and explained in detail in Appendix D, we estimate a flexible statistical model of inflation with stochastic volatility, drifting mean and persistence to obtain inflation expectations.<sup>26</sup> The posterior distributions of conditional moments implied by this model are depicted in Figure 5. The top panel shows conditional inflation expectations: color grey refers to long term expectations (permanent component of inflation), color blue represents inflation expectations one year ahead. The grey line in the bottom plot depicts the posterior median estimate for the model implied 5 year ahead conditional

---

<sup>25</sup>The US Treasury started to issue *zero-coupon* Treasury Bills in 1929.

<sup>26</sup>Our model is similar in spirit to the one used by [Cogley and Sargent \(2015\)](#), except that the mean-reverting part of inflation is more flexibly parameterized. In addition, we use an inflation series that combines wholesale prices with CPI whereas [Cogley and Sargent \(2015\)](#) use wholesale price inflation from 1850 to 2012. [Cogley and Sargent \(2015\)](#) also include measurement errors.

inflation volatility.<sup>27</sup>

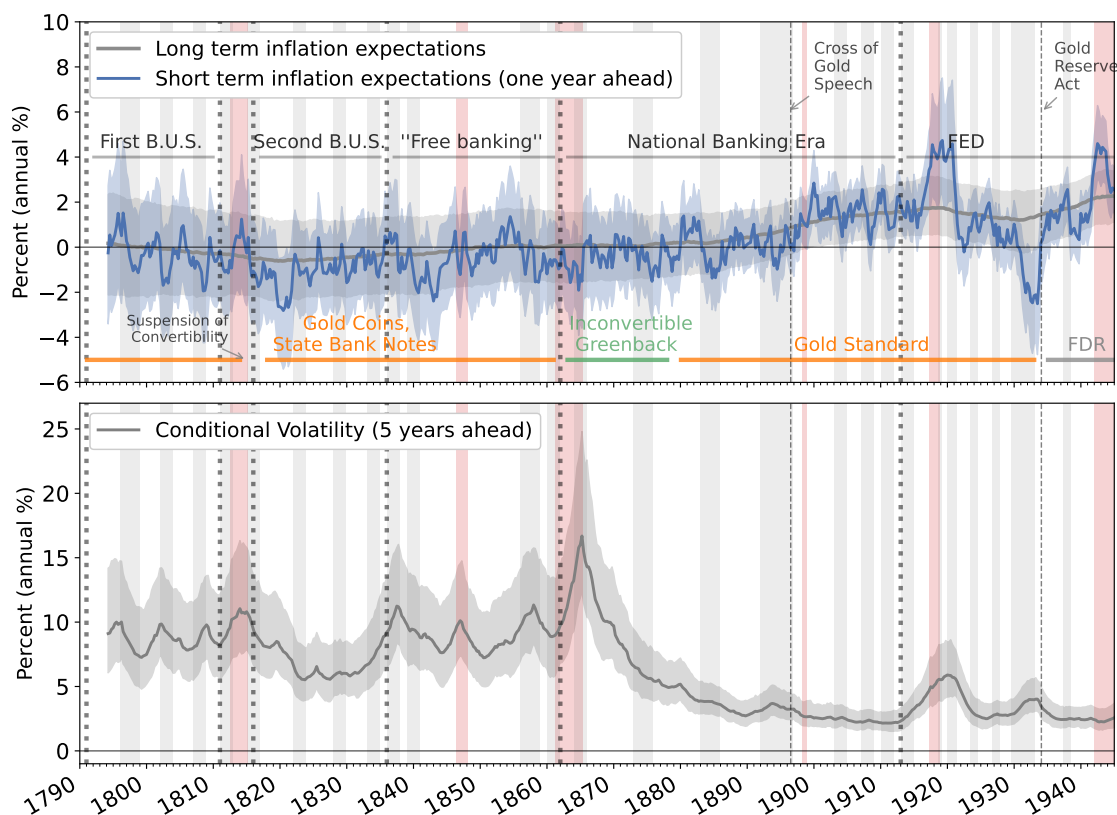


Figure 5: Smoothed Conditional Moments of Inflation

*Top plot:* The solid grey line depicts the posterior median estimate for the permanent component of inflation. The solid blue line depicts the posterior median estimate for one year ahead inflation expectations implied by our statistical model. *Bottom plot:* The solid grey line depicts the posterior median estimate for the smoothed, annualized conditional inflation volatility 5 years ahead.

We infer slow moving changes within the gold standard era. Throughout most of the 19th century, gold inflation expectations were anchored around zero or negative (especially between 1810-1850). However, this did not mean *stable* inflation: wars, recessions, and panics were associated with sharp increases in inflation volatility. The story starts to change in the 1880s when long-run gold inflation expectations started to become positive and inflation volatility dropped. In this sense, we transition from a period with large but temporary inflation shocks to a period where shocks primarily hit the permanent component, implying an increase in inflation persistence.<sup>28</sup>

<sup>27</sup>We plot the *annualized* conditional volatility  $\sigma_{\pi,t}^{(j)} := \sqrt{\frac{1}{j} (\mathbb{E}_t [\exp(2\pi_t^{(j)})] - \mathbb{E}_t [\exp(\pi_t^{(j)})]^2)}$ .

<sup>28</sup>These findings are broadly consistent with Barro (1979, 1982) and the empirical results of Benati (2008)

A possible source of the elimination of deflation and the decrease in inflation volatility is the introduction of the National Banking Act in 1863-5, which created a supply of national bank notes, backed by federal government debt, that could act as a stable currency. This is in sharp contrast to the pre-Civil War period, which was characterized by restrictions on the quantity and high volatility in the quality of bank money supply. In addition, there was a large gold rush in California from 1848-1855 that significantly increased the supply of gold in the US. A possible source of the increase in long run inflation expectations in the late 19th century was the strong support from elements of both major political parties for returning to a bimetallic gold-silver standard at a mint price ratio of 16-1 when the market price ratio had become much higher. Prospects of a return to bimetallism at an exchange rate that overvalued silver naturally made investors fear inflation (See [Friedman \(1990a\)](#), [Friedman \(1990b\)](#), [Velde and Weber \(2000\)](#), [Weiss \(2020\)](#), and [Fulford and Schwartzman \(2020\)](#)).<sup>29</sup> In addition, the Witwatersrand (1886) and Klondike (1896) gold rushes increased the supply of gold (See [Friedman and Schwartz \(1963\)](#) and [Bordo et al. \(2004\)](#)).

Short-run inflation expectations spiked to over 4% per annum during World War I but stabilized at around 1% per annum soon afterwards. At the same time, long term inflation expectations moved little and stayed around 1-1.5%. That pattern may reflect that the US was one of the few Western countries to not formally abandon the gold standard during the war. The next major change came in 1933 when Roosevelt signed the Gold Reserve Act that, at least for US citizens, effectively took the US off the gold standard. Short term inflation expectations immediately increased by approximately 3 percentage points and remained positive throughout the rest of the 20th century.

#### 4.4 Slope of yield curve switched signs

While the previous sections studied the level of the yield curve, in this section, we turn to the slope. The top plot in Figure 6 depicts the 10-year gold dollar yield minus the 2-year yield, which we refer to as the term spread. A positive term spread indicates an upward sloping yield curve (i.e., longer maturity bonds have higher rates), while a negative term spread indicates an inverted yield curve (i.e., shorter maturity bonds have higher rates). As can be seen, the term spread was typically negative before the Civil War and positive afterwards, with major decreases during the War of 1812, the Mexican-American War, and the Civil War.

---

who shows that whenever a monetary regime has a clearly defined nominal anchor inflation is only weakly persistent.

<sup>29</sup>The “free silver” movement advocated for the introduction of silver dollars. The 1896 Democratic presidential nominee William Jennings Bryan made the case for silver coinage in his *Cross of Gold speech*. The Democratic Party made free silver central to its 1896 presidential campaign but ultimately lost the election. The Gold Standard Act was passed in 1900, essentially ending the “free silver” movement.



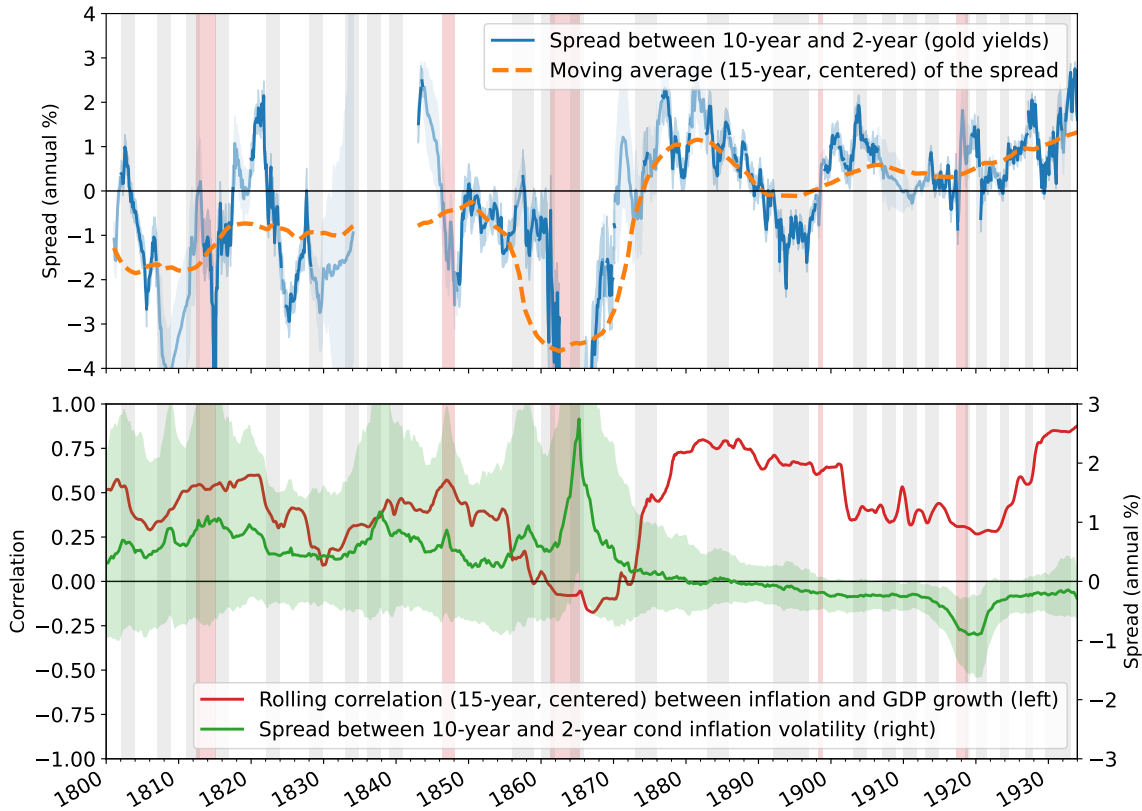


Figure 6: Term Spread and Inflation Risk

*Top plot:* The solid blue line depicts the posterior median for the yield on 10-year, gold denominated, zero coupon US government bonds minus the yield on 2-year bonds. The orange dashed line depicts the 15-year centered moving average spread. *Bottom plot:* The green solid line (right axis) depicts the posterior median for the difference between the 10-year ahead (smoothed) annualized conditional inflation volatility and the 2-year ahead inflation volatility. The red solid line (left axis) depicts 15-year centered rolling correlation between inflation and GDP per capita.

A possible explanation for why the slope of the yield curve switched signs is related to a striking change in the inflation dynamics. The green solid line in the bottom plot in Figure 6 shows the change in the relative forecastability of inflation at long and short horizons, as measured by the difference between the 10- and 2-year ahead conditional inflation volatility.<sup>30</sup> Positive values indicate that inflation was harder to predict at the 10-year horizon than at the 2-year horizon. Negative values indicate the opposite. We see that long term inflation became relatively easier to predict following the Civil War<sup>31</sup> and that this change

<sup>30</sup>More precisely, we plot the posterior distribution of the statistic  $\sigma_{\pi,t}^{(10)} - \sigma_{\pi,t}^{(2)}$ . Apart from the difficulty of predicting inflation, the wide posterior band reflects the significant parameter uncertainty underlying our estimates.

<sup>31</sup>Mechanically, this comes from the stunning fact that the persistence and long run mean of inflation

coincides with the sign switch of the slope of the yield curve from negative to positive. This suggests that the term spread becoming positive might be connected to the decrease in the long run “inflation risk.” This relationship would be consistent with asset pricing theory if the inflation risk premium was negative. That is, if federal gold bonds provided a good hedge against inflation. The red line in the bottom plot, depicting the rolling correlation between inflation and real GDP growth per capita, provides suggestive evidence that this was indeed the case. The correlation between GDP growth and inflation appears to be positive in the gold era which is consistent with inflation risk premium being negative.

An extensive literature has studied the slope of the yield curve in the modern period and argued that a negative slope is a strong predictor of recessions. In Appendix I, we connect our estimate of the historical nominal yield curve with existing estimates for the post-WW2 period and plot the slope of yield curve from 1800 to 2020. We find that the persistence in the slope of the yield curve is substantially lower following the end of the Bretton-Woods system. In Appendix I, we replicate studies of the forecasting power of the slope of the yield curve for the 19th century period and find some evidence that changes in the slope have some predictive power, especially after the Civil War.

## 5 The Greenback Era: 1862-1878

The period from 1862-1878, during which greenback dollars circulated at a volatile discount to gold, offers a particularly interesting case study on how government credibility can survive major monetary policy changes and impact government borrowing costs. Figure 7 shows the greenback to gold exchange rate as well as the price of bonds that promised payment in gold. As can be seen, bond prices only start to track the greenback to gold exchange rate close to maturity. This suggests that investors did not expect a persistent deviation from greenback to gold parity, despite the dramatic devaluation of the greenbacks during the Civil War. In this sense, we find there was a strong nominal anchor. We formalize this intuition by using price data for greenback paying bonds and data on the gold to greenback exchange to estimate expectations about future exchange rates and a greenback denominated yield curve.

### 5.1 Estimation Strategy

In principle, we could impose a parameterized greenback dollar yield curve similar to that captured by Assumptions 1-4. However, the fact we only observe 9 greenback dollar bonds

---

increased while inflation volatility fell *simultaneously* after Resumption. Because gross inflation  $\exp(\pi_t^j)$  is modeled as a *log-normal* random variable, finding the exact source of the change is difficult, but inflation becoming more persistent is certainly a key factor.

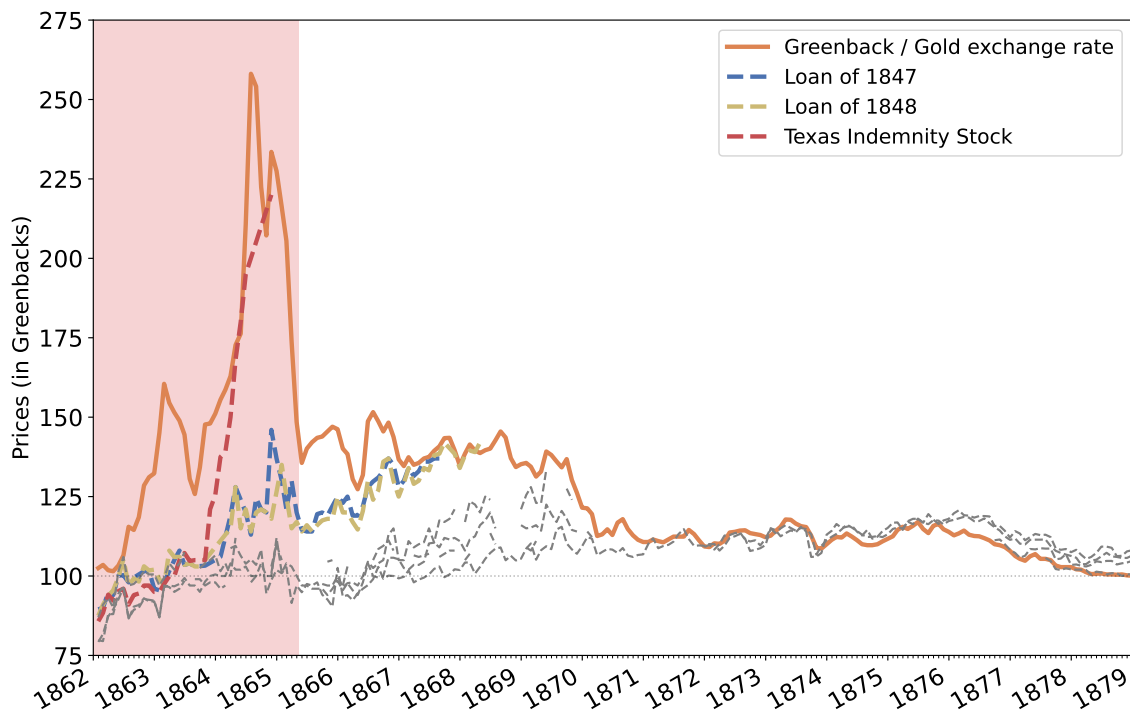


Figure 7: Prices of Gold and Bonds: 1860-1880.

The solid orange line depicts the greenback to gold exchange rate (expressed as the number of greenback dollars required to purchase 100 gold dollars). The dashed lines depict observed prices (denominated in greenbacks) for the outstanding bonds. The grey lines depict prices of bonds that matured after 1868. The light red interval depicts the Civil War.

means that our sparse cross-section problem is worse for estimating the greenback yield curve and so this approach is infeasible. We instead proceed by positing additional, admittedly strong assumptions that let us use information about *both* gold and greenback dollar bonds to estimate greenback yield curves.

Let  $e_t^{(g)}$  denote the quantity of consumption goods that can be exchanged for one gold dollar at time  $t$  (i.e., the consumption goods price of gold dollars) and let  $P_t$  denote the quantity of gold dollars that can be exchanged for one greenback dollar at time  $t$  (i.e., the gold-to-greenback exchange rate at time  $t$ ). We impose the following form of interest rate parity between gold and greenback zero-coupon bond prices.

**Assumption 5.** Let  $v_t = \{P_t, e_t^{(g)}\}$  denote observable macroeconomic price variables at time  $t$ . Then, the gold price of a government promise to one *greenback dollar* at time  $t + j$

is:

$$q_t^{(j,d)} = q_t^{(j)} \frac{\mathbb{E}[P_{t+j}|v_t]}{P_t} \quad (5.1)$$

where, as before,  $q_t^{(j)}$  is in units of  $t$ -period gold dollar per time  $(t+j)$ -period *gold* dollar.

Literally, Assumption 5 says that  $P_{t+j}$  was conditionally independent of the pricing kernel implicitly contained in  $q_t^{(j)}$  and all the relevant information for forecasting  $P_{t+j}$  was contained in observable prices. Since the major driver of the greenback-to-gold exchange rate was most likely “default” due to wartime losses, this assumption can be interpreted as saying that all information relevant for forecasting financial effects of the war is contained in the greenback-to-gold exchange rate and the price level. Although this is a strong assumption, greenback money issuance during the Civil War was closely tied to Union fortunes on the battlefield, particularly over a medium term horizon. We also find it encouraging that the greenback-to-goods exchange rate tracks the gold yield curve during big Civil War changes.

Equation (5.1) tells us that, in order to use information from both gold and greenback dollar bonds, we need to infer a sequence of conditional expectations about future exchange rates. We model this conditional expectation by a bivariate state-space model with time varying long-run mean and persistence parameter specified in appendix H.1. Let the parameters of this exchange rate model be denoted as  $\theta_t$ .

Consider a given bond  $i$  promising a sequence of greenback dollar coupon and principal payments  $\{\bar{m}_{t+j}^{(i,d)}\}_{j=1}^{\infty}$ , where we allow  $\bar{m}_{t+j}^{(i,d)}$  to be zero. Define  $\mathbf{z}_t := \{z_t^{(j)}\}_{j=1}^{\infty}$ , where  $z_t^{(j)} := \mathbb{E}[P_{t+j}|v_t]/P_t$  is the “conversion multiplier” that converts  $(t+j)$ -period greenback dollars to  $(t+j)$ -period gold dollars. Implicitly,  $\mathbf{z}_t$  is a function of  $\theta_t$ . Then, the gold dollar price of any greenback dollar bond is the inner product:

$$p_t^{(i)} = \langle \mathbf{q}(\lambda_t, \tau) \odot \mathbf{z}(\theta_t), \bar{\mathbf{m}}_t^{(i,d)} \rangle + \sigma_m^{(i)} \varepsilon_t^{(i)}$$

where  $\odot$  denotes a Hadamard (element-wise) product. We introduce this additional pricing equation into the non-linear state space model from Subsection 3.2 using a two step approach described in appendix H.2.

## 5.2 The Nominal Anchor

Our approach allows us to infer how investors’ expectations about the greenback-dollar exchange rate evolved during and after the Civil War. Figure 8 shows our estimate for the expected Gold/Greenback exchange rate 10 years into the future at each date and our estimate of the greenback denominated yield curve. As can be seen, 10 year exchange rate expectations moved very little during the Civil War despite the large depreciation of the

greenback. In this sense, there was a very strong “nominal anchor” throughout the Civil War. We elaborate on this in appendix H.3 where we plot expected exchange rate paths at different dates.

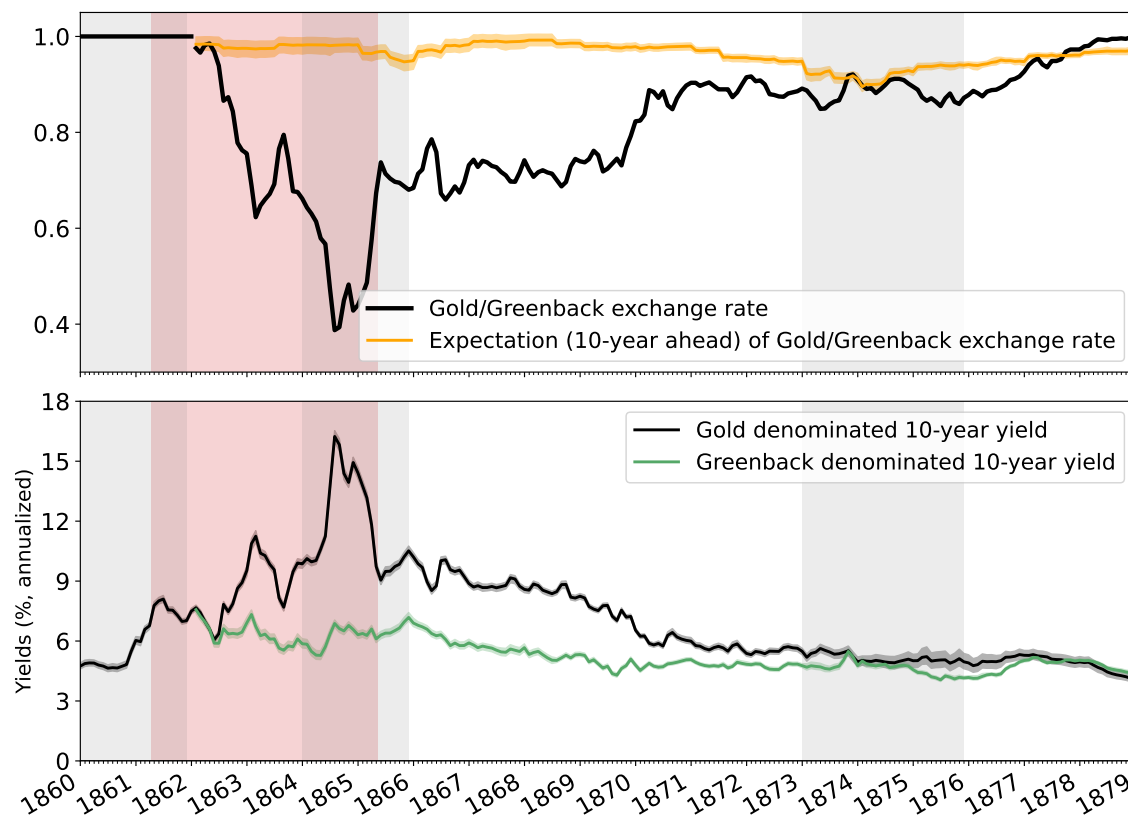


Figure 8: Nominal Anchor

*Top Plot:* The black line shows the path of the gold/greenback exchange rate,  $P_t$ . The orange line shows the median of our posterior estimate for the expected Gold/Greenback exchange rate 10 years into the future at each date. The orange shaded area is the 90% interquartile range for our estimate. *Bottom Plot:* The black line is the ten-year gold denominated zero-coupon yield curve. The green line is the 10-year greenback denominated zero-coupon yield curve.

We can also see in Figure 8 that the greenback denominated yield is systematically below the gold denominated yield. The top panel of Figure 8 suggests that this is because investors expected a return to the gold standard post Civil War and so expected greenbacks to appreciate in value. This meant that they were willing to accept a low greenback yield.<sup>32</sup> Unlike for the gold yield curve, the slope of the greenback yield curve became positive during the Civil War monetary expansion and negative shortly before the recession

<sup>32</sup>Roll (1972) makes a similar point when he discusses the greenback yield through this period.

of 1873. Interestingly, this behaviour is consistent with the behavior of the post World War II nominal yield curves.

The low greenback yields during the Civil War indicate the powerful influence of beliefs about government commitment on asset pricing. After the Civil War, President Andrew Johnson and much of the Democratic party proposed to reduce debt servicing costs by redefining the unit of account from gold to greenbacks that were then trading at a substantial discount relative to gold. That units-of-account sleight of hand was contested in the 1868 election. During the 1868 Presidential election campaign, the Republican party and its candidate General Ulysses S. Grant promised to sustain the practice of servicing federal debts in gold dollars that Alexander Hamilton had proposed in 1790. Grant won.

## 6 Concluding Remarks and Epilogue

We have established stylized facts about US federal debt financing costs from 1791 to 1933. These facts shed light on a long process of adopting and adapting a “Hamiltonian program” for organizing monetary, financial, and fiscal institutions. We conclude by offering a narrative assessment of outcomes. We focused on the years before 1933 since we believe that FDR’s Gold Reserve Act embraced an alternative vision for organizing monetary, financial, and fiscal institutions. Nonetheless, we believe that studying our time series statistics dating to the founding of the US offers lessons about challenges that confront contemporary macroeconomists and policy makers. Taking a long-term perspective and using a flexible auxiliary statistical model as our guide allows us to study which “stylized facts” reflect enduring economic forces and which reflect peculiar outcomes from various monetary, financial, and fiscal policy eras. That provides us with a framework for evaluating macroeconomic theories that aspire to represent consequences of forces that are invariant to changes in institutional arrangements. We present tentative thoughts about some things that have endured and others that have not between 1791 and 2020.

### 6.1 The Hamiltonian Program

In three reports, 34 year old Alexander Hamilton advocated a project to improve the fiscal capacity of the federal government. His project sought to buffer medium-frequency government expenditure surges by sustaining a reputation for timely debt service (*1790 Report on the Public Credit*); to foster a bimetallic stable national currency (*1791 Report on the Establishment on a Mint*); and to help finance high-frequency government expenditure fluctuations by chartering a monopoly federal bank (*1790 Report on the National Bank*).

From 1790-1829 a sequence of actions unfolded that were designed to implement Hamilton’s vision. The federal government restructured Revolutionary War IOUs, established a

gold dollar, restricted states' ability to issue paper currency, and introduced the First and Second Banks of the United States to serve as fiscal agent of the federal government and to regulate state banks' creation of money and credit. We have described evidence that these reforms reduced the spread between US and UK yields by the 1820s, suggesting that federal policy makers did foster an improved reputation for servicing federal debts. The reforms also had at least some success in currency management. We find little persistence in inflation during the early 19th century, and inflation volatility declined significantly during the tenure of the Second Bank of US (1816-36). However, we also see persistent deflation and high liquidity premia on short-duration federal bonds, suggesting that growth rates of stocks of currency fell short of growth rates of real GDP. That may have been caused by low rates of growth of state bank notes that were restrained by state-bank-note-buying programs of the Second Bank of the US, and that neither the First nor the Second Bank of the US issued enough of a national currency.

But these accomplishments did not endure. Following political struggles about the role of the Second Bank of the US and Andrew Jackson's veto of the bank's charter, during the 1840s we watch spreads between US and UK yields widen back to 1790s levels and eventually well above 1790s levels during the Civil War. Ultimately, difficulties of financing the Civil War persuaded the Union to restart a Hamiltonian program by establishing the National Banking System (1862-5) and sustaining gold-greenback parity after January 1, 1879. Our estimates of a "short rate disconnect" offer novel indirect evidence about how those policies affected the money supply. We find that the money-like premium on short term government debt declined significantly in the 1880s and stayed relatively low until after World War I. During the 1880s, the US yield again converged to the UK yield. Although US yields again temporarily rose above UK yields in the 1890s, by the turn of the twentieth century, US yields were well below UK yields, portending the emergence of US debt as a global safe asset in the twentieth century. We interpret this package of evidence as indicating that by the late 19th century significant progress had been made towards implementing Hamilton's vision.

## 6.2 Epilogue: 1933-2020

*Cost of Financing Wars:* An outcome of 19th century reforms was that, by the early twentieth century, the US federal government could finance large deficits at low or negative real yields. See Figure 9, which plots our estimates of 5-year *ex ante* real yields on US Treasuries, our estimates of 5-year nominal zero-coupon yields on US Treasuries, and US surpluses as percentages of GDP.<sup>33</sup> Evidently, large deficits during the War of 1812 and

---

<sup>33</sup>We combine our nominal yield curve estimates for 1790-1947 with the zero-coupon yield estimates of McCulloch and Kwon (1993) covering the period 1947 - 1961 and the estimates of Gürkaynak et al. (2007),

the Civil War coincided with high real yields. That pattern stands in stark contrast to the US experience during the twentieth century when it financed large deficits during WW1, WW2, the Depression, and the Great Recession at low real yields.

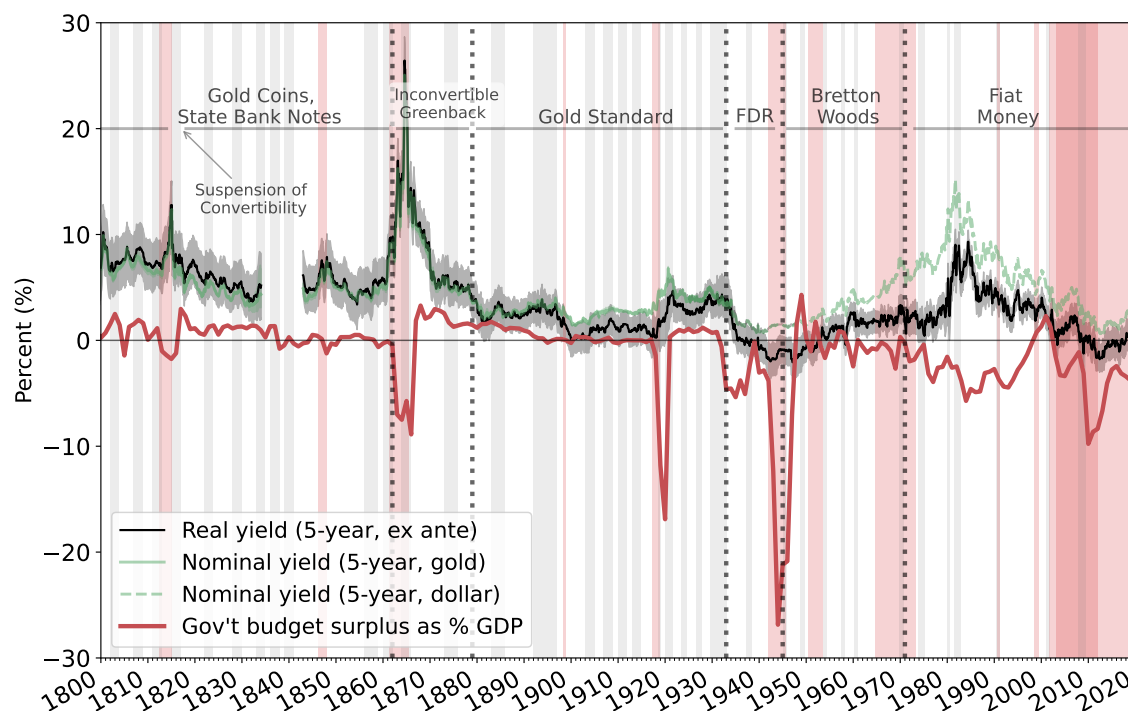


Figure 9: US Budget Surpluses and *Ex Ante* Real Bond Yields

The solid black line depicts the posterior median estimate for the 5-year, gold denominated, zero coupon yield. The grey bands around the posterior median depict the 90% interquartile range. The solid green line depicts the posterior median for the 5-year gold denominated yield. The dashed green line depicts the combination of our posterior median estimate for the 5-year dollar (post 1933) yield with the zero-coupon yield estimates of [McCulloch and Kwon \(1993\)](#) and [Gürkaynak et al. \(2007\)](#). The solid red line shows US surplus as a percentage of GDP. The light gray intervals depict recessions. The light red intervals depict wars.

This figure sheds light on a historical contest between two founding fathers: Alexander Hamilton and Thomas Jefferson. During the late 18th and early 19th centuries, the UK serviced high debt-GDP ratios at low interest rates. US statesmen disagreed about whether the US could and should foster a similar outcome. One of Hamilton’s motivations for his reform “program” was to ensure the US could on occasions run large deficits to finance wars and build infrastructures. By contrast, Jefferson advocated low federal taxes and spending and a limited federal borrowing capacity, partly to prevent the US from supporting a standing army and becoming entangled in foreign adventures. Figure 9 assesses

---

which is available since 1961.



the success of both Hamilton and Jefferson as advocates and prophets. Hamilton’s hopes of low interest rate deficit financing were eventually realized in the early twentieth century. However, as Jefferson feared, the achievement of a low financing cost regime coincided with the nation’s introducing a big standing army and more frequently waging foreign wars.

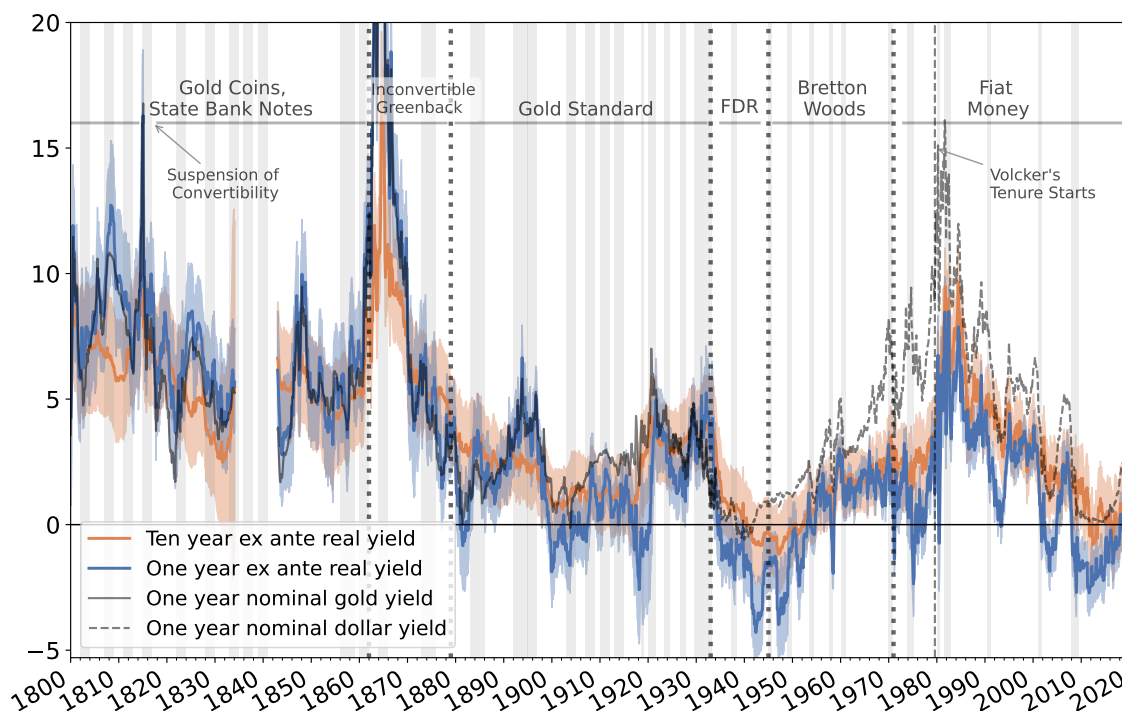


Figure 10: *Ex ante* Real Yields and “The” Nominal Interest Rate

The solid orange line depicts the posterior median estimate for the 10-year *ex ante* real zero coupon yield. The solid blue line depicts the posterior median estimate for the 1-year *ex ante* real zero coupon yield. The bands around the posterior medians depict 90% interquartile ranges. The solid black line depicts the posterior median for the 1-year gold denominated yield. The black dashed line depicts the combination of our posterior median estimate for the 1-year dollar (post 1933) yield with the zero-coupon yield estimates of McCulloch and Kwon (1993) and Gürkaynak et al. (2007). The light gray intervals depict recessions.

*Interest Rates For Policy and Macroeconomic Modeling:* Recently, there has been a lively discussion about a “trend decline” in “real rates” over the past 40 years. Figure 10 puts recent declines in historical context. The blue line corresponds to the 1-year real yield, a key variable in contemporary macroeconomic models, the orange line corresponds to the 10-year real yield, and the black line corresponds to the combination of our 1-year nominal yield estimates with recent zero-coupon yield curve estimates. After the slow decline in the 19th century, short term real yields on government debt were typically close to zero

throughout the twentieth century and frequently negative.<sup>34</sup> The 1980-1990 period that witnessed prolonged high inflation and high ex ante real rates stands out as an exception. Evidently, during the 1970s inflation started to exhibit random walk-like behavior,<sup>35</sup> indicating that an “inflation anchor” started to drift. By not recognizing drifting long run inflation expectations, the FED’s putative “tightening” during the early 1970s resulted in flat or slightly decreasing ex-ante real yields. That made it harder to bring down inflation expectations in the 1980s and 1990s during Volcker’s and Greenspan’s tenures as FED Chairmen. Nevertheless, a lesson from this episode is that, in principle, a *well-managed* fiat regime can re-stabilize long run inflation expectations without necessarily promising some form of gold backing.

Our long time series is consistent with a view in the asset pricing literature that yields on government debt are strongly influenced by inflation risk premia (e.g. Piazzesi and Schneider (2007), Rudebusch and Swanson (2012), Campbell et al. (2020)). We conjecture that if we were to estimate a statistical model with sufficient structure to allow us to construct an inflation risk-premium-free measure of a real rate on government debt, we would infer that it was close to zero (and often negative) throughout the twentieth century. This would suggest that a sizable portion of the recent “trend decline” in real rates was attributable to the Fed’s effort to re-stabilize long run inflation expectations during the 1980s and 1990s. This poses pressing questions as to what is a “correct” proxy for a “shadow rate” for macroeconomic modeling.

*Evolving Purposes of Monetary Policy Makers:* A much discussed feature of the 2007-9 financial crisis was the combination of output decline and deflationary pressures. To many contemporary researchers, the positive correlation between output growth and inflation seemed to be a historical anomaly. Figure 11 provides a long term perspective that challenges this view by showing that a positive correlation was actually the historical norm until World War II. The top plot of figure 11 shows that the rolling correlation between per capita output growth and inflation was positive from 1790 to 1933, except for the Civil War period when the two series became uncorrelated.<sup>36</sup> This relationship changes dramatically following World War II, when the correlation becomes significantly negative due to a series of low inflation booms and the “stagflation” of the 1970s and 1980s.<sup>37</sup>

---

<sup>34</sup>Recent papers, such as Schmelzing (2020), have documented a long term average decline in interest rates around the world. Our estimates suggests that the US contributed to this trend decline during the 19th century. However, during the 20th century, yields on US debt followed a different trend, likely because of the privileged role that US debt has come to play.

<sup>35</sup>See e.g. Cogley and Sargent (2005), Stock and Watson (2007), and Benati (2008).

<sup>36</sup>Figure 11 plots the 15 year rolling correlation, but our finding is robust to other horizons. In fact, one can easily spot the changing co-movement between inflation and output growth per capita by inspecting the raw series, which also appear in figure 11.

<sup>37</sup>The figure shows the irony that a “Phillips curve” prevailed for approximately 150 years but then

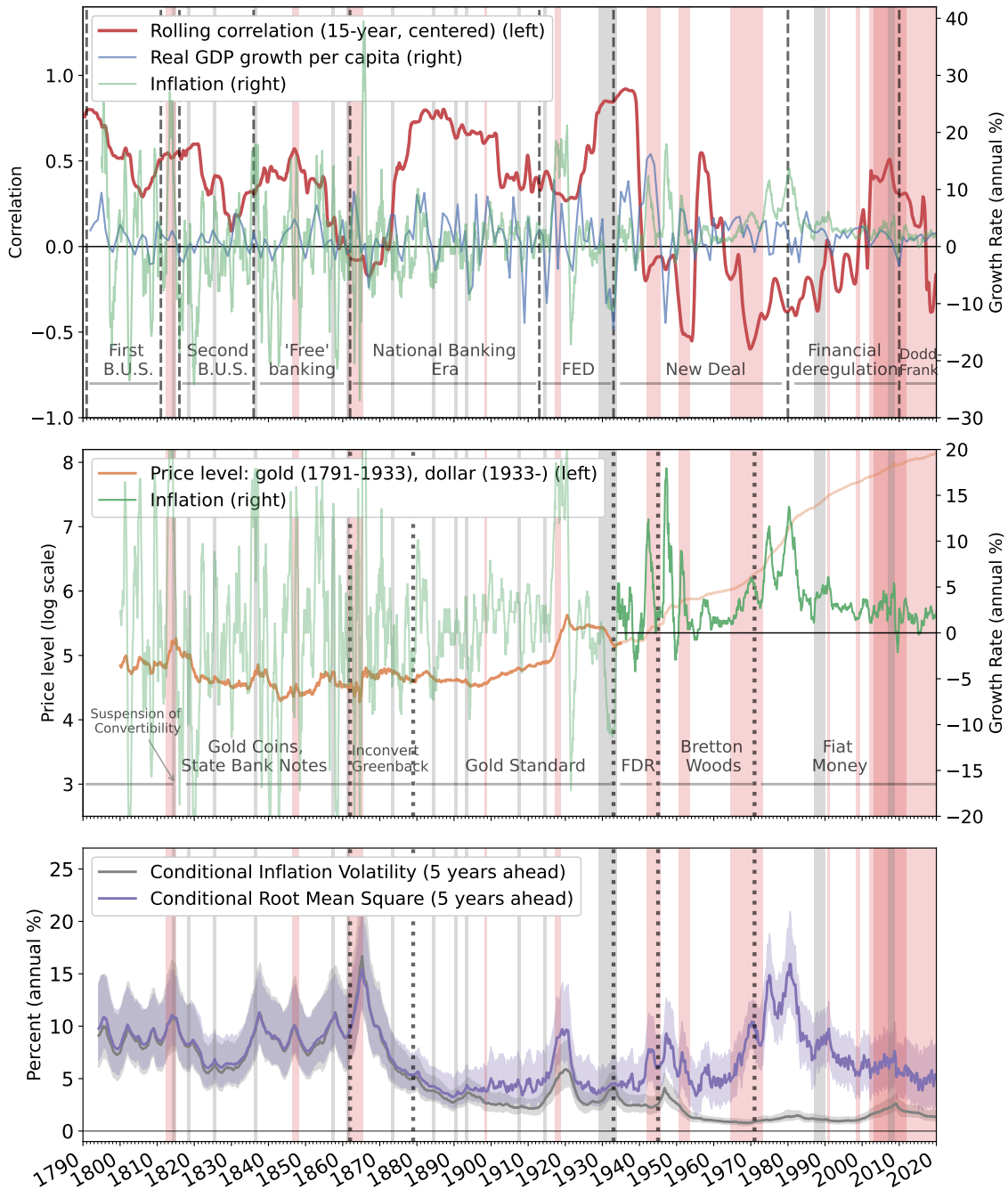


Figure 11: Output and Inflation.

*Top plot:* The pale blue line depicts annual real GDP growth per capita, the pale green line depicts our annual inflation series, both measured on the right axis. The red thick line shows the 15-year (centered) rolling correlation between the blue and green series, measured on the left axis. *Middle plot:* The orange line depicts our combined log price index (left axis). It measures the gold price of goods before 1933 and the price of goods in dollar after 1933. The green line shows the annual growth rates (inflation) of the orange line (right axis). *Bottom plot:* The solid grey line depicts the posterior median estimate for the 5-year-ahead smoothed, annualized conditional inflation volatility. The solid purple line depicts the posterior median estimate for the 5-year-ahead smoothed conditional root mean square statistic. The light gray intervals depict banking crises from [Reinhart and Rogoff \(2009\)](#).

We suggest that these changes reflect how different administrations have balanced trade-offs between lowering federal borrowing costs, price stability, and financial stability. Before the Civil War, the government prioritized decreasing the cost of government financing and keeping trend inflation low. It implemented this by adhering to the gold standard and, part of the time, via monopoly powers given to the First and Second Banks of the US. The middle and bottom plots of Figure 11 show that these policies came at the costs of volatile inflation, long run deflation, and relatively frequent financial crises. This suggests an economy characterized by downturns with bank crises, in which households demand more gold by seeking to convert state bank notes into gold, which in turn forces state banks to demand more gold. As a result, we see gold appreciation (deflation) in the midst of recessions. In this sense, under the gold standard, frequent financial crises generated strong positive co-movement between output growth and inflation.

After the Civil War, the government had similar priorities but, now armed with more powerful tools under its new institutions, focused more on lowering inflation volatility. The key new institution was the National Banking System, which allowed the government to earn a higher convenience yield on long term government debt and stabilize the market value of broad money. That the government accomplished those purposes is indicated by the evaporation of the spread between US and UK debt yields, the elimination of the “short rate disconnect,” the substantial decrease in inflation volatility, and the stabilization of the trend price level. Although the National Banking Acts restricted bank lending, they did not create a government-run lender-of-last-resort backstop for the financial system. The system still experienced large financial crisis shocks and the positive relationship between output growth and inflation continued.

During the first half of the 20th century the government’s priorities changed. Concerns about ensuring financial and business cycle stability increased while concerns about ensuring price stability decreased as the government used inflation taxes to lower its borrowing costs especially during wars. Institutional changes accompanied these shifting priorities. Created by the Federal Reserve Act of 1913 and beginning to operate in late 1914, the Federal Reserve Bank was empowered to act as a lender-of-last-resort to member banks. During the 1930s, Franklin D. Roosevelt’s New Deal devalued the dollar relative to gold, introduced national deposit insurance, passed the Glass-Steagall Banking Act of 1933, and established the Federal National Mortgage Association (“Fannie Mae”) to insure a large fraction of bank issued mortgage loans. After World War II, the Fed focused more and more on taming business cycles. We see these changes reflected in the increase in long run inflation expectations and the relative stability of the financial sector from 1933 through

---

abruptly broke down just when economists discovered it in the late 1950s.

to 2007.<sup>38</sup> A plausible explanation for the changed correlation between output growth and inflation during 1940-2000 was the government's decision to refocus from price stability to financial stability during the middle of the twentieth century. The government's priorities change again towards the end of the century when it embarks on a program of financial deregulation. During this period the correlation between inflation and output increased and eventually became positive again in the early decades of the twenty-first century.

Our data and auxiliary statistical model have helped us detect how coincident arrangements for regulating financial institutions and administering monetary and fiscal policies have impinged on costs of government finance. To understand more about connections between arrangements and outcomes, we plan to construct structural macroeconomic models that make contact with statistics from our auxiliary model.<sup>39</sup>

---

<sup>38</sup>It is enlightening to compare frequencies of gray bands in Figure 11 before and after the New Deal.

<sup>39</sup>As in footnote 6, the distinction between auxiliary and structural comes from [Gallant and Tauchen \(1996\)](#).

## References

- Andreasen, M. M., Christensen, J. H., and Rudebusch, G. D. (2019). Term structure analysis with big data: One-step estimation using bond prices. *Journal of Econometrics*, 212:26–46.
- Annaert, J., Claes, A. G., Ceuster, M. J. D., and Zhang, H. (2013). Estimating the spot rate curve using the nelson–siegel model: A ridge regression approach. *International Review of Economics and Finance*, 27:482–496.
- Barro, R. J. (1979). Money and the price level under the gold standard. *The Economic Journal*, 89(353):13–33.
- Barro, R. J. (1982). United states inflation and the choice of monetary standard. In *Inflation: Causes and effects*, pages 99–110. University of Chicago Press.
- Bayley, R. A. (1882). *The National Loans of the United States, from July 4, 1776, to June 30, 1880*. Number 246. US Government Printing Office.
- Benati, L. (2008). Investigating inflation persistence across monetary regimes. *The Quarterly Journal of Economics*, 123(3):1005–1060.
- Betancourt, M. (2018). A conceptual intro to Hamiltonian Monte Carlo.
- Bordo, M. D., Lane, J. L., and Redish, A. (2004). Good versus bad deflation: Lessons from the gold standard era. Working Paper 10329, National Bureau of Economic Research.
- Bouscasse, P., Nakamura, E., and Steinsson, J. (2021). When did growth begin? new estimates of productivity growth in England from 1250 to 1870. Technical report, National Bureau of Economic Research.
- Campbell, J., Pflueger, C., and Viceira, L. (2020). Macroeconomic drivers of bond and equity risks. *Journal of Political Economy*, 128(8):3148–3185.
- 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.
- Champ, B., Wallace, N., and Weber, W. (1994). Interest rates under the U.S. national banking system. *Journal of Monetary Economics*, 34(3):343–358.
- Champ, B. A. (2007). The National Banking System: The national bank note puzzle.
- Champ, B. A. and Wallace, N. (2003). Resolving the National Banking System note-issue puzzle.
- Chen, Z., Jiang, Z., Lustig, H., Van Nieuwerburgh, S., and Xiaolan, M. Z. (2022). Exorbitant privilege gained and lost: Fiscal implications. Working Paper 30059, National Bureau of Economic Research.

- Cogley, T. and Sargent, T. J. (2005). Drifts and volatilities: monetary policies and outcomes in the post WWII US. *Review of Economic Dynamics*, 8(2):262–302.
- Cogley, T. and Sargent, T. J. (2015). Measuring price-level uncertainty and instability in the United States, 1850-2012. *The Review of Economics and Statistics*, 97(4):827–838.
- Dahlquist, M. and Svensson, L. E. O. (1996). *Scandinavian Journal of Economics*, pages 163–183.
- Davis, J. H. (2006). An improved annual chronology of u.s. business cycles since the 1790s. *The Journal of Economic History*, 66(1):103–121.
- Diebold, F. X. and Li, C. (2006). Forecasting the term structure of government bond yields. *Journal of Econometrics*, 130(2):337–364.
- Diebold, F. X., Li, C., and Yue, V. Z. (2008). Global yield curve dynamics and interactions: A dynamic Nelson-Siegel approach. *Journal of Econometrics*, 146(2):351–363.
- Duffee, G. R. (1996). Idiosyncratic variation of treasury bill yields. *The Journal of Finance*, 51(2):527–551.
- Farkas, M. and Tatár, B. (2021). Bayesian estimation of DSGE models with Hamiltonian Monte Carlo. Technical report, IMFS Working Paper Series.
- Friedman, M. (1990a). Bimetallism Revisited. *Journal of Economic Perspectives*, 4(4):85–104.
- Friedman, M. (1990b). The Crime of 1873. *Journal of Political Economy*, 98(6):1159–1194.
- Friedman, M. and Schwartz, A. (1963). *A Monetary History of the United States, 1867-1960*. Princeton University Press.
- Fulford, S. L. and Schwartzman, F. (2020). The Benefits of Commitment to a Currency Peg: Aggregate Lessons from the Regional Effects of the 1896 US Presidential Election. *Review of Economics and Statistics*, 102(3):600–616.
- Gallant, A. R. and Tauchen, G. (1996). Which moments to match? *Econometric theory*, 12(4):657–681.
- Garbade, K. D. (2012). *Birth of a Market: The US Treasury Securities Market from the Great War to the Great Depression*. MIT Press.
- Greenwood, R., Hanson, S. G., Stein, J. C., et al. (2018). The Federal Reserve’s balance sheet as a financial-stability tool. In Evanoff, D. D., Kaufman, G. G., and Malliaris, A. G., editors, *Innovative Federal Reserve Policies During the Great Financial Crisis*, volume 15, chapter 3. World Scientific.
- 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 Szöke, B. (2018). US federal debt 1776-1940: Prices and quantities. <https://github.com/jepayne/US-Federal-Debt-Public>.
- Hamilton, J. D., Harris, E. S., Hatzius, J., and West, K. D. (2016). The Equilibrium Real Funds Rate: Past, Present, and Future. *IMF Economic Review*, 64(4):660–707.
- Hammond, B. (1947). Jackson, biddle, and the bank of the united states. *The Journal of Economic History*, 7(1):1–23.
- Hoffman, M. D. and Gelman, A. (2014). The No-U-Turn sampler: Adaptively setting path lengths in hamiltonian monte carlo. *Journal of Machine Learning Research*, 15(47):1593–1623.
- Homer, S. and Sylla, R. E. (2004). *A History of Interest Rates*. Rutgers University Press.
- 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.
- Lenel, M., Piazzesi, M., and Schneider, M. (2019). The short rate disconnect in a monetary economy. *Journal of Monetary Economics*, 106:59–77.
- Liu, Y. and Wu, J. C. (2021). Reconstructing the yield curve. *Journal of Financial Economics*, 142(3):1395–1425.
- McCulloch, J. and Kwon, H.-C. (1993). U.S. term structure data, 1947-1991. Technical Report Working Paper 93-6., Ohio State University.
- Mitchell, W. C. (1903). *A History of the Greenbacks with Special Reference to the Economic Consequences of Their Issue: 1862-1865*. University of Chicago Press, Chicago, Illinois.
- Mitchell, W. C. (1908). *Gold, Prices, and Wages under the Greenback Standard*. University of California, Berkeley, California.
- 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*.
- Papp, T. K., Aluthge, D., JackRab, Widmann, D., TagBot, J., and Piibelegt, M. (2021). `tpapp/dynamichmc.jl`: v3.1.0. Julia package version 3.1.0.
- Piazzesi, M. and Schneider, M. (2007). Equilibrium yield curves. *NBER Macroeconomics Annual*, 21:389–472.
- Reinhart, C. M. and Rogoff, K. S. (2009). This time is different. In *This Time Is Different*. princeton university press.
- Roll, R. (1972). Interest rates and price expectations during the civil war. *Journal of Economic History*, 32:476–498.



- Rudebusch, G. D. and Swanson, E. T. (2012). The bond premium in a dsge model with long-run real and nominal risks. *American Economic Journal: Macroeconomics*, 4(1):105–43.
- Schmelzing, P. (2020). Eight centuries of global real interest rates, rg, and the ‘suprasecular’ decline, 1311–2018. *Bank of England: Working Paper 845*.
- Shiller, R. J. (2015). *Irrational Exuberance, 3rd edition*. Princeton University Press, revised and expanded third edition edition.
- Stock, J. H. and Watson, M. W. (2007). Why has u.s. inflation become harder to forecast? *Journal of Money, Credit and Banking*, 39(s1):3–33.
- Svensson, L. E. (1994). Estimating and interpreting forward interest rates: Sweden 1992 - 1994. Working Paper 4871, National Bureau of Economic Research.
- Svensson, L. E. O. (1995). Estimating forward interest rates with the extended Nelson and Siegel method. *Sveriges Riksbank Quarterly Review*, 3.
- Thomas, R. and Dimsdale, N. (2017). A millennium of uk data. *Bank of England OBRA dataset*.
- Velde, F. R. and Weber, W. E. (2000). A Model of Bimetallism. *Journal of Political Economy*, 108(6):1210–1234.
- Weiss, C. (2020). Contractionary Devaluation Risk: Evidence from the Free Silver Movement, 1878–1900. *The Review of Economics and Statistics*, 102(4):705–720.

## A Data Appendix

Here we provide details about how the data sets were constructed. We first outline which bonds are included and excluded in the different estimation exercises. We then describe the assumptions made in constructing of the cash flow series. Finally, we discuss the recession bands that we use. Some of these points have already been referenced in the main text but we collect the assumptions here for completeness.

### A.1 Summary of Data Sources

We combined existing historical databases with transcription from the digital archives of newspapers and government reports. Table 1 summarizes the different data sources that we have used throughout the paper. The data set for bond prices and quantities is available at the Github repository <https://github.com/jepayne/US-Federal-Debt-Public> and construction methods are explained in [Hall et al. \(2018\)](#).<sup>40</sup> In this subsection of the appendix, we spotlight decisions about our data that we made to prepare for the statistical inferences presented in this paper.

Our bond price data are monthly. When available, we use the closing price at the end of each month. However, if a closing price is not available, then we use an average of high and low prices or an average of bid and ask prices. The sources for the price data from 1776 to 1839 are *Global Financial Data*, [Razaghian \(2002\)](#), and [Sylla et al. \(2006\)](#). Prices from 1840 to 1859 are from [Razaghian \(2002\)](#), *The New York Times*, and *Global Financial Data*. Prices from 1860 to 1925 are from the *Commercial and Financial Chronicle*, *Global Financial Data*, [Martin \(1886\)](#), *Merchants' Magazine and Commercial Review*, the *New York Times*, and *US Treasury Circulars*. When overlaps occurred, data were taken from the US Treasury Circulars. Prices from 1919 to 1925 are from “United States Govt. Bonds” tables in the *New York Times*. Prices after 1925 are taken from the *CRSP US Treasury Database*.<sup>41</sup> Data on contractually promised dollar payments come from [Bayley \(1882\)](#) for the period from 1790-1871 and from [U.S. Department of the Treasury \(2015\) Monthly Statements of the Public Debt](#) for the period from 1872-1960.

The quantity data are quarterly from 1776 to 1871 and monthly thereafter. All quantity entries record the quantity outstanding on the last business day of the period. The quantities outstanding from 1790 to 1871 are imputed from the issue and redemption series reported by [Bayley \(1882\)](#). We cross-checked these quantities against quantity outstanding series reported in [Register's Office \(1886\)](#). After 1871 our source for quantity outstanding series is the [U.S. Department of the Treasury \(2015\) Monthly Statements of the Public Debt](#). The

---

<sup>40</sup>Only data from publicly available data sets are posted on the GitHub page.

<sup>41</sup>See <http://www.crsp.com/products/research-products/crsp-us-treasury-database>.

call data are from *Annual Reports of the Secretary of Treasury* for various years. Data on Treasury securities held in government accounts are from *Banking and Monetary Statistics 1914-1941* prior to 1941 and from *Treasury Bulletin* thereafter.<sup>42</sup>

We require data on greenback-gold dollar exchange rates to estimate the greenback and real yield curves. For the gold-to- greenback exchange rate, we use Greenback price data from [Mitchell \(1908\)](#)<sup>43</sup> for the period from 1862-1878 during which greenbacks and gold dollars both circulated. For the gold-to-goods exchange rate, we combine several series. For the period from 1800-1860, we use the wholesale price index from [Warren et al. \(1932\)](#). For the period from 1860-1913, we use the General Price Level Index from the *NBER Macroeconomics Database*<sup>44</sup>. For the period from 1913-2020, we use the Consumer Price Index from the U.S. Bureau of Labor Statistics. Finally, we use the GDP series from [Officer and Williamson \(2021\)](#).

## A.2 Exclusion of Bonds

The estimation of the non-linear state space model of gold bond prices defined in section 3.2 excludes all bonds that paid coupons and/or principals in any denomination other than gold. It also excludes short term Treasury notes that the US issued during the War of 1812. [Bayley \(1882\)](#) lists these notes as the Treasury Notes of 1812, Treasury Notes of 1813, Treasury Notes of March 1814, Treasury Notes of December 1814, and the Small Treasury Notes of 1815. These notes were used for payments well after their earliest redemption date and so probably earned a convenience yield. It also excludes the Panama Canal bonds, which we were not able to price consistently with the rest of the bonds, suggesting that they they have a different pricing kernel.

For the estimation of the non-linear state space model of greenback bonds defined in section 5.1 we exclude the following bonds, which [Bayley \(1882\)](#) documents had ambiguous denominations for the repayment of the principal: the “Five-Twenties of March 1864”, the “Five-Twenties of June 1864”, the “Five-Twenties of 1865”, the “Consols of 1865”, the “Consols of 1867”, and the “Consols of 1868”.

## A.3 Construction of cash-flows

In order to estimate the yield curve, we need to construct the currency flows promised by each bond. For many of the early bonds in the sample, both the coupon dates and the maturity date have ambiguity because the bond information is imprecise and because it unclear whether newspaper prices are ex or cum dividend. For the coupon dates, we used

---

<sup>42</sup>See [Board of Governors of the Federal Reserve System \(1943\)](#) and [Register’s Office \(1886\)](#).

<sup>43</sup>See Table 2

<sup>44</sup>See <https://www.nber.org/research/data/nber-macrohistory-iv-prices>

Table 1: Summary of Data Sources

Series	Period	Frequency	Source
Bond prices	1776-1839	M	<a href="#">Razaghian (2002)</a> , <a href="#">Sylla et al. (2006)</a> and <i>Global Financial Data</i> .
	1840-1859	M	<a href="#">Razaghian (2002)</a> , <i>The New York Times</i> , and <i>Global Financial Data</i>
	1860-1925	M	<i>Commercial &amp; Financial Chronicle</i> , <i>Global Financial Data</i> , <i>Merchant's Magazine</i> , <i>The New York Times</i> , <i>US Treasury Circulars</i> , and <a href="#">Martin (1886)</a> .
	1925-1960	M	<i>CRSP US Treasury Database</i> .
Quantities	1790-1871	Q	<a href="#">Bayley (1882)</a> .
	1872-1960	M	<a href="#">U.S. Department of the Treasury (2015)</a> .
Contract Info.	1790-1960		1790-1871 from <a href="#">Bayley (1882)</a> .
			1872-1960 from <a href="#">U.S. Department of the Treasury (2015)</a> .
Gold/Goods	1800-1860	M	Wholesale Price Index (Warren/Pearson)
Exchange Rate	1860-1913	M	U.S. Index of the General Price Level (NBER Macrohistory: Series NBER 04051)
	1913-2020	M	CPI (BLS)
GDP	1790-2020	A	<a href="#">Officer and Williamson (2021)</a>
Gold/Greenbacks	1862-1878	M	Yale SOM ICF dataset
Exchange Rate			

<sup>1</sup> Repository for bond time series: <https://github.com/jepayne/US-Federal-Debt-Public>

the following rule. If [Bayley \(1882\)](#) lists exact coupon dates, then we use those dates. Otherwise, we identify the coupon dates from cyclical decreases in the price series at the frequency of coupon payment. We interpret these decreases as the price impact of the coupon payment.

For the maturity dates, we used the following rules. For bonds with an explicit maturity date, we set the maturity to that date. For the three Hamilton bonds (which [Bayley \(1882\)](#) lists as *Six Per Cent Stock of 1791*, *Deferred Six Per Cent Stock of 1791*, and the *Three Per Cent Stock of 1791*), which were issued as annuities but ultimately redeemed early, we impose that investors had perfect foresight about the early redemption and set the maturity date to be date at which greater than 90% of the outstanding bonds had been redeemed. For bonds with a redemption window, we calculate the minimum of the date at which 90% of the outstanding bonds had been redeemed and date at which the bonds started to trade at par value. We then set the maturity date to be closest coupon payment date to that minimum calculation. For bonds that converted into different bonds, we set the maturity date to be maturity of the bond into which it is converted.

#### **A.4 Construction of Recession bands**

For the 1796-1914 period we use recession dates from [Davis \(2006\)](#). These are derived solely from the [Davis \(2004\)](#) annual industrial production index. The Davis index incorporates 43 annual series in the manufacturing and mining industries in a manner similar to the Federal Reserve Board’s present-day industrial production index. For this reason, we regard it as an improvement over earlier more qualitative approaches of dating pre-World War I business cycles. Since the data used to date peaks and troughs is annual, the methodology is quite simple: A year immediately preceding an absolute decline in the aggregate level of Davis’s industrial production index defines a peak, and the last consecutive decline following a peak defines a trough ([Davis, 2006](#)). For the 1915-present period we use recession dates from the NBER.

## **B Historical Time Line**

The text references many changes to monetary and financial regulation. In this section, we collect those events into a historical timeline, which is shown in table 2. The time line is broken up into a collection a collection of banking “eras”. The first era is from 1791-1836, during which the First and Second Banks of the US operated alongside state banks. The second era is from 1837-1962, during which state banks could automatically gain bank charters without a congressional review process, often referred to as the “free banking” era. The third era is from 1863-1913, during which the federal government chartered national

banks that issued bank notes backed by US federal government debt. The fourth era is from 1913-1933, during which the Federal Reserve Bank was introduced to act as lender-of-last resort to the banking sector. The fifth era is from 1934-1980, during which the New Deal financial regulations were in place. The sixth era is from 1980s-2009, during which the New Deal financial regulations were gradually unwound. Finally, there is the era from 2010 to the present day, during which the Dodd-Frank Act another financial crisis legislation are in place.

Table 2 Time Line of Monetary and Financial Events

---

1791	• Congress charters the First Bank of the US. The bank is privately owned. It operates as a commercial bank but also has the special privileges of acting as banker for the federal government (storing tax revenue and making loans) and being able to operate across states. It shares responsibility with state banks for bank note issuance. It influences state bank money and credit issuance by setting the rate at which it redeems state notes collected as tax revenue into gold.
1792	• Coinage Act of 1792. Authorizes the US to issue a new currency, the US gold dollar.
1811	• Charter of the First Bank of the US expires and is not renewed.
1812-5	• War of 1812. Convertibility to bank notes to gold is suspended. Government issues Treasury Notes to finance the war.
1816	• Congress charters the Second Bank of the U.S.
1819	• Panic of 1819. Cotton prices fall, farms go bankrupt, and banks fail.
1832	• Jackson vetoes bill to recharter Second Bank.
1833	• Jackson removes federal deposits from Second Bank of the US
1834	• Coinage Act of 1834. Changes the ratio of silver to gold from 15:1 to 16:1.
1836	• Charter of the Sector Bank of the US expires and is not renewed. The Second Bank becomes a private corporation.

---

1837	• “Free Banking” Era begins. Michigan Act allows the automatic chartering of banks (without requiring explicit approval from state legislature) that issue bank notes backed by specie (gold and silver coins). Over the next few years, other states pass similar laws.
1837	• Panic of 1837. Sharp decrease in real estate prices leads to large bank losses. In New York, every bank suspends payment in gold and silver coinage. Many banks fail.
1857	• Coinage Act of 1857. Foreign coins can longer be legal tender.
1857	• Panic of 1857. Railroad company stocks drop sharply. Ohio Life Insurance and Trust company fails, which prompts a collapse in stock prices and widespread failures across mercantile firms.
<hr/>	
1861-5	• Civil War.
1862	• Legal Tender Act. Authorizes the federal government to use nonconvertible greenback paper dollars to pay its bills.
1863-4	• The National Bank Acts. The National Currency Act (1863) and The National Bank Act (1864) establish a system of nationally chartered banks and the Office of the Comptroller of the Currency. National banks can issue national bank notes up to 90% of the minimum of par and market value of qualifying US federal bonds. Limit on aggregate national bank note issuance is \$300 million. Banks must pay a 1% annual tax per on outstanding national bank notes backed by US federal bonds. State banks must start paying a 2% annual tax on state bank notes.
1865-6	• Additional National Bank Acts. State banks must start paying a 10% annual tax on state bank notes.
1870	• Limit on aggregate national bank note issuance increases to \$354 million.
1873	• Bank panic of 1873. Widespread failure of railroad firms leads to stock market crash and bank failures. Jay Cooke and Company goes bankrupt.
1875	• Congress repeals limit on aggregate national bank note issuance.

1879	US Treasury starts to promise to convert greenbacks to dollars one-for-one.
1893	Bank panic. A combination of falling commodity prices, oversupply of silver, and a fall in US Treasury gold reserves prompted a run on bank deposits.
1896	Cross of Gold Speech. Democratic presidential candidate William Jennings Bryan gives a speech in favor of allowing unlimited coinage of silver into money demand (“free silver”).
1900	Tax on national bank notes backed by US federal bonds paying coupons less than or equal to 2% is reduced to 0.5% per annum.
1900	Gold Standard Act. The gold dollar becomes the standard unit of account (further restricting the possibility of “free silver”).
1907	Panic of 1907. The Knickerbocker Trust Company collapses prompting a bank run. J.P. Morgan organizes New York bankers to provide liquidity to shore up the banking system.
<hr/>	
1913	Federal Reserve Act. Establishment of the Federal Reserve Bank to act as a reserve money creator of last resort during financial panics.
1914-8	World War I.
1917	2nd Liberty Loan Act establishes a \$15 billion aggregate limit on the amount of government bonds issued.
1929	Stock market crash and start of the Great Depression.
1929	US issues first Treasury Bill.
<hr/>	
1933	Banking Act (“Glass-Steagall Act”). Establishes the Federal Deposit Insurance Corporation (FDIC). Separates commercial and investment banking. Introduces cap on deposit interest rate (“Regulation Q”).
1933	President Roosevelt issues an Executive Order requiring people and businesses to sell their gold to the government at \$20.67 per ounce.
1934	Gold Reserve Act.
1934	National Housing Act. Establishes the Federal Savings and Loan Insurance Corporation (FSLIC).



1935	The last national bank notes are replaced by Federal Reserve notes.
1938	Amendment to the National Housing Act established the Federal National Mortgage Association (FNMA), commonly known as Fannie Mae.
1939-45	World War II.
1942	The Treasury and Federal Reserve agree to fix the yield curve on Treasury securities.
1944	Bretton Woods Agreement.
1951	Treasury-Fed Accord ends the fixed yield curve on Treasury securities and establishes the Fed's policy independence from fiscal concerns.
1968	Housing and Urban Development Act of 1968. Creates the Government National Mortgage Association (GNMA), commonly known as Ginnie Mae.
1966	Fed applies Regulation Q to impose deposit rate ceiling for the first time.
1971	US effectively terminates the Bretton Woods system by ending the convertibility of the US dollar to gold.
1977	Congress issues the Fed with the dual mandate to "promote effectively the goals of maximum employment, stable prices, and moderate long term interest rates".
<hr/>	
1980	Depository Institutions Deregulation and Monetary Control Act of 1980 starts to phase out Regulation Q.
1986-1989	Savings and loan crisis.
1994	Riegle-Neal Interstate Banking and Branching Efficiency Act. Allows banks to operate across states.
1999	Gramm-Leach-Bliley Act. Repeals provisions of the Glass-Steagall Act that prohibited a bank holding company from owning other financial companies.
2007-9	Great Financial Crisis.
<hr/>	
2010	Dodd-Frank Wall Street Reform and Consumer Protection Act.

## C Additional Theory

### C.1 Inferring risk premia from the US-UK yield spread

The yield-to-maturity on an annuity with gold coupon payments  $\bar{m}$  and price  $p_t$  is the rate  $\bar{y}_t$  that solves:

$$p_t = \sum_{j=1}^{\infty} \exp(-\bar{y}_t)^j \bar{m} \quad (\text{C.1})$$

Let  $\bar{q}_t := \exp(-\bar{y}_t)$ . In lemma 1 in Appendix C.2, we show that combining equation (C.1) with definition of  $q_t$  gives the following expression for the yield-to-maturity:

$$\bar{q}_t = 1 - \frac{1}{\sum_{j=0}^{\infty} q_t^{(j,g)}}$$

Let lowercase letters represent US prices and yields and let capital letters represent UK prices and yields. Then from corollary 1 in Appendix C.2, we have that the difference between the US and UK consol yields is:

$$\bar{y}_t - \bar{Y}_t \approx \frac{\sum_{j=0}^{\infty} (q_t^{(j,g)} - Q_t^{(j,g)})}{\left(\sum_{j=0}^{\infty} q_t^{(j,g)}\right) \left(\sum_{j=0}^{\infty} Q_t^{(j,g)}\right)} \quad (\text{C.2})$$

where  $\bar{y}_t$  and  $q_t^{(j,g)}$  are yields-to-maturity and zero-coupon prices in the US and  $\bar{Y}_t$  and  $Q_t^{(j,g)}$  are yield-to-maturity and zero-coupon prices in the UK. If, for simplicity, we impose the following structure on the pricing kernel:

$$p_t^{(i,j)} = \mathbb{E}_t \left[ \left( \frac{S_{t+j}}{S_t} \right) \left( \frac{e_{t+j}^{(g)}}{e_t^{(g)}} \right) \xi_{t+j}^{(i)} \bar{m}_{t+j}^{(i)} \right]$$

where we have implicitly assumed that there is no convenience yield on UK or US debt. If, in addition, we impose that haircut risk is zero in the UK implies, then the spread between US and UK zero-coupon bond prices is given by:

$$\begin{aligned} & q_t^{(j,g)} - Q_t^{(j,g)} \\ = & \mathbb{E}_t \left[ \frac{S_{t+j}}{S_t} \right] \left( \underbrace{\mathbb{E}_t \left[ \frac{e_{t+j}^{(n)}}{e_t^{(n)}} \right]}_{\text{Expected gold inflation in US}} \underbrace{\mathbb{E}_t [\xi_{t+j}]}_{\text{US haircut probability}} \underbrace{\left( 1 + \text{Cov}_t \left( \frac{S_{t+j}}{S_t}, \frac{\xi_{t+j}}{\mathbb{E}_t \left[ \frac{S_{t+j}}{S_t} \right]} \right)}_{\text{Risk premium on US haircut risk}} \right)}_{\text{Risk premium on US haircut risk}} \right) - \underbrace{\mathbb{E}_t \left[ \frac{E_{t+j}^{(n)}}{E_t^{(n)}} \right]}_{\text{Expected gold inflation in UK}} \end{aligned}$$

If gold inflation expectations were similar in the US and UK during the gold standard<sup>45</sup>, then we can interpret the difference between the US and UK consol yields in figure 3 as reflecting the risk premium on US federal debt.

**Estimating haircut risk:** In principle, we could attempt to use UK yields to estimate haircut risk. However, we face the major challenge of only observing the prices of UK consols. This means that, to make progress, we would need to impose a one-dimensional functional parameterisation of  $\mathbb{E}_t[\xi_{t+j}]$ . Here is one way to do this. Suppose that government haircuts are governed by a two-state Markov Chain with default as an absorbing state. Let  $\mathbf{p}_t$  be bondholders' perceived probability of default in period  $t$  and assume that they use the two-state Markov Chain to forecast future cash-flows. For simplicity, suppose that upon default, government bonds pay 0. These assumptions imply  $\mathbb{E}_t[\xi_{t+j}] = (1 - \mathbf{p}_t)^j$ . In addition, suppose that bondholders' are risk-neutral in the sense that  $\text{cov}_t\left(\frac{S_{t+j}}{S_t}, \xi_{t+j}^{(i)}\right) = 0$ . In this special case, we have:

$$q_t^{(j,n)} - Q_t^{(j,g)} = \underbrace{\mathbb{E}_t \left[ \frac{e_{t+j}^{(n)}}{e_t^{(n)}} \right]}_{\text{Expected gold inflation in US}} \underbrace{(1 - \mathbf{p}_t)^j}_{\text{US haircut probability}} - \underbrace{\mathbb{E}_t \left[ \frac{E_{t+j}^{(n)}}{E_t^{(n)}} \right]}_{\text{Expected gold inflation in UK}}$$

which we could combine with equation (C.2) to estimate a haircut probability  $\mathbf{p}_t$ . Of course, this particular example imposes strong assumptions and ignores the possibility of varying convenience yields on US and UK federal debt. We leave the complicated task of resolving the estimation of haircut risk to future work.

## C.2 Connection Between Yields on Finite-Horizon Zero-Coupon Bonds and Yield-To-Maturity

Some analysts have expressed historical long-term interest rates as yields-to-maturity rather than zero-coupon yields. In this appendix, we discuss the connection between the different types of yields. A yield-to-maturity (a.k.a. an internal rate of return) is defined as a fixed discount rate,  $\bar{y}^{(i,n)}$ , that equates the currency  $n$  bond price to the present discounted value of its promised currency  $n$  payments. Thus, the dollar  $n$  yield-to-maturity on bond  $i$  with payments in currency  $n$  and maturity  $J^{(i)}$  is the rate  $\bar{y}_t^{(i,n)}$  that solves:

$$p_t^{(i,n)} = \sum_{j=1}^{J^{(i)}} \exp\left(-\bar{y}_t^{(i,n)}\right)^j \bar{m}_{t+j}^{(i,n)}$$

---

<sup>45</sup>We have not estimated inflation expectations during the 19th century in the UK, but this seems like a reasonable prior given that both countries were on the gold standard.

To compare to the zero-coupon prices, let  $\bar{q}_t^{(i,n)} := \exp(-\bar{y}_t^{(i,n)})$ . The bond price can be expressed in terms of  $\bar{q}_t^{(i,n)}$  as:

$$p_t^{(i,n)} = \sum_{j=1}^{J^{(i)}} \left(\bar{q}_t^{(i,n)}\right)^j \bar{m}_{t+j}^{(i,n)}. \quad (\text{C.3})$$

**Lemma 1.** *Consider a bond with  $J^i = \infty$  and  $\bar{m}_{t+j}^{(i,n)} = \bar{m}^{(n)}$  (i.e. a fixed coupon annuity in currency  $n$ ). Denote the yield-to-maturity on such a bond by  $\bar{y}_t^{(n)}$  and the associated price by  $\bar{q}_t^{(n)} := \exp(-\bar{y}_t^{(n)})$ . Then  $\bar{q}_t^{(n)}$  can be expressed in terms of zero-coupon yields as:*

$$\bar{q}_t^{(n)} = 1 - \frac{1}{\sum_{j=0}^{\infty} q_t^{(j,n)}} \quad (\text{C.4})$$

*Proof.* From equation (C.3), we have that the price of the fixed coupon annuity is:

$$\bar{p}_t^{(n)} = \sum_{j=1}^{\infty} \left(\bar{q}_t^{(n)}\right)^j \bar{m}^{(n)} = \bar{m}^{(n)} \sum_{j=1}^{\infty} \left(\bar{q}_t^{(n)}\right)^j = \bar{m}^{(n)} \left(\frac{1}{1 - \bar{q}_t^{(n)}} - 1\right)$$

We also have the expression:

$$\bar{p}_t^{(n)} = \sum_{j=1}^{\infty} \bar{q}_t^{(j,n)} \bar{m}^{(n)} = \bar{m}^{(n)} \left(\sum_{j=0}^{\infty} \bar{q}_t^{(j,n)} - 1\right)$$

where  $\bar{q}_t^{(0,n)} = 1$ . Equating the expressions gives that:

$$\frac{1}{1 - \bar{q}_t^{(n)}} = \sum_{j=0}^{\infty} \bar{q}_t^{(j,n)}$$

and rearranging gives the desired result.  $\square$

**Corollary 1.** *Let lowercase letters represent US prices and yields and let capital letters represent UK prices and yields. Then the difference between the US and UK consol yields is*

$$\bar{y}_t - \bar{Y}_t \approx \frac{\sum_{j=0}^{\infty} \left(q_t^{(j,g)} - Q_t^{(j,g)}\right)}{\left(\sum_{j=0}^{\infty} q_t^{(j,g)}\right) \left(\sum_{j=0}^{\infty} Q_t^{(j,g)}\right)}$$

*Proof.* Using equation (C.4), we have that:

$$\bar{y}_t = \log(\bar{q}_t^{(n)}) = \log\left(1 - \frac{1}{\sum_{j=0}^{\infty} q_t^{(j,n)}}\right) \approx -\frac{1}{\sum_{j=0}^{\infty} q_t^{(j,n)}}$$

and so:

$$\begin{aligned} \bar{y}_t - \bar{Y}_t &\approx -\frac{1}{\sum_{j=0}^{\infty} q_t^{(j,n)}} + \frac{1}{\sum_{j=0}^{\infty} Q_t^{(j,n)}} \\ &= \frac{\sum_{j=0}^{\infty} (q_t^{(j,g)} - Q_t^{(j,g)})}{\left(\sum_{j=0}^{\infty} q_t^{(j,g)}\right) \left(\sum_{j=0}^{\infty} Q_t^{(j,g)}\right)} \end{aligned}$$

□

Equation (C.3) indicates that the yield-to-maturity on a coupon-bearing bond is some kind of *weighted average* of zero-coupon yields, with cash-flow payments serving as weights. For the case of an annuity, the average is unweighted and reduces to equation (C.4). Because a principal payment is typically substantially larger than the coupon payments, the maturity-related zero-coupon yield gets the largest weight in the average. As a result, a yield-to-maturity on a  $J$ -maturity bond can approximate a  $J$ -period zero-coupon yield, although the quality of approximation depends on details of a bond's promised payment stream. The only exact equality is that a yield-to-maturity on a  $j$ -period zero-coupon bond coincides with the  $j$ -period zero-coupon yield,  $y_t^{(j,n)}$ .

## D State-Space Model of Inflation Expectations

We estimate inflation expectations between 1794-2020 by applying a univariate state-space model with drifting coefficients and stochastic volatility. The underlying data are our combined inflation series described in Appendix A.1. During the temporary suspension of gold convertibility (1862-1879), the General Price Level Index expresses greenback inflation, so we convert it into gold inflation by using the gold/greenback exchange rate  $P_t$ . The estimates in the paper are based on quarterly inflation, however, our key findings are robust to estimating the model using monthly or annual inflation.

Let  $\pi_{t+1}$  denote the logarithm of quarterly price change between period  $t$  and  $t+1$ . We model this variable with the following state-space model with stochastic volatility, changing long-run mean and (infrequently) changing persistence parameter:

**Assumption 6.** Quarterly inflation  $\pi_t$  obeys a state-space model:

$$\begin{aligned} \pi_{t+1} &= \alpha_t + x_t^\pi + \sigma_{\pi,t} \varepsilon_{\pi,t+1} & \varepsilon_{\pi,t+1} &\sim \mathcal{N}(\mathbf{0}, 1), \quad \forall t \geq 0 \\ x_{t+1}^\pi &= \rho_t x_t^\pi + \sigma_x \varepsilon_{\pi,t+1} \end{aligned} \quad (\text{D.1})$$

where  $x_t^\pi$  is a hidden state with a given initial  $x_0$ . Parameters  $\alpha_t$  and  $\sigma_{\pi,t}$  follow random walks:

$$\begin{aligned} \alpha_{t+1} &= \alpha_t + \sigma_\alpha \varepsilon_{\alpha,t+1} & \varepsilon_{\alpha,t+1} &\sim \mathcal{N}(\mathbf{0}, 1) \\ \log \sigma_{\pi,t+1} &= \log \sigma_{\pi,t} + \sigma_{\sigma_\pi} \varepsilon_{\sigma_\pi,t+1} & \varepsilon_{\sigma_\pi,t+1} &\sim \mathcal{N}(\mathbf{0}, 1) \end{aligned}$$

while the persistence parameter  $\rho_t$  follows a random walk with infrequent shocks:

$$\rho_{t+1} = \begin{cases} \rho_t + \sigma_\rho \varepsilon_{\rho,t+1} & \varepsilon_{\rho,t+1} \sim \mathcal{N}(\mathbf{0}, 1) & \text{if } t = k\Delta \text{ for } k \in \mathbb{N} \\ \rho_t & \text{otherwise} \end{cases}.$$

Our baseline estimates set  $\Delta = 4$ , i.e., the persistence of quarterly inflation can change once every year. Model (D.1) posits that  $j$ -period ahead logged inflation,  $\sum_{i=1}^j \pi_{t+i}$ , is a normal random variable, implying that  $j$ -period ahead gross inflation,  $\Pi_t^{(j,n)}$ , is log-normal. Using the model-implied conditional mean and variance of  $\sum_{i=1}^j \pi_{t+i}$ , one can derive an estimate for  $\mathbb{E}_t \left[ \exp \left( -\pi_t^{(j,n)} \right) \right]$  that goes into formula (3.2). We estimate this model using the same HMC-NUTS sampler that we use for our yield curve model.

**Priors:** We use independent Gaussian priors for  $\sigma_x$  and the initial parameters  $\alpha_0$  and  $\rho_0$ :

$$\sigma_x \sim \mathcal{N}(0, 0.5), \quad \alpha_0 \sim \mathcal{N}(0, 1), \quad \rho_0 \sim \mathcal{N}(0, 0.5)$$

For the initial standard deviation  $\sigma_{\pi,0}$ , we use a log-normal prior  $\sigma_{\pi,0} \sim \log \mathcal{N}(0.015, 0.01)$ . For the standard deviations  $\sigma_\alpha$ ,  $\sigma_{\sigma_\pi}$ , and  $\sigma_\rho$ , we use a *common* exponential prior with the rate parameter tuned so that *a priori* the probability that  $\sigma_i > 0.3$  is lower than 5%. The prior mean is 0.1.

**Results:** The posterior distributions of conditional moments implied by this model are depicted in Figure 12. The top panel shows conditional inflation expectations: color grey refers to long term expectations (permanent component of inflation), color blue represents inflation expectations one year ahead. The grey line in the bottom plot depicts the posterior median estimate for the model implied 5 year ahead conditional inflation volatility. We plot

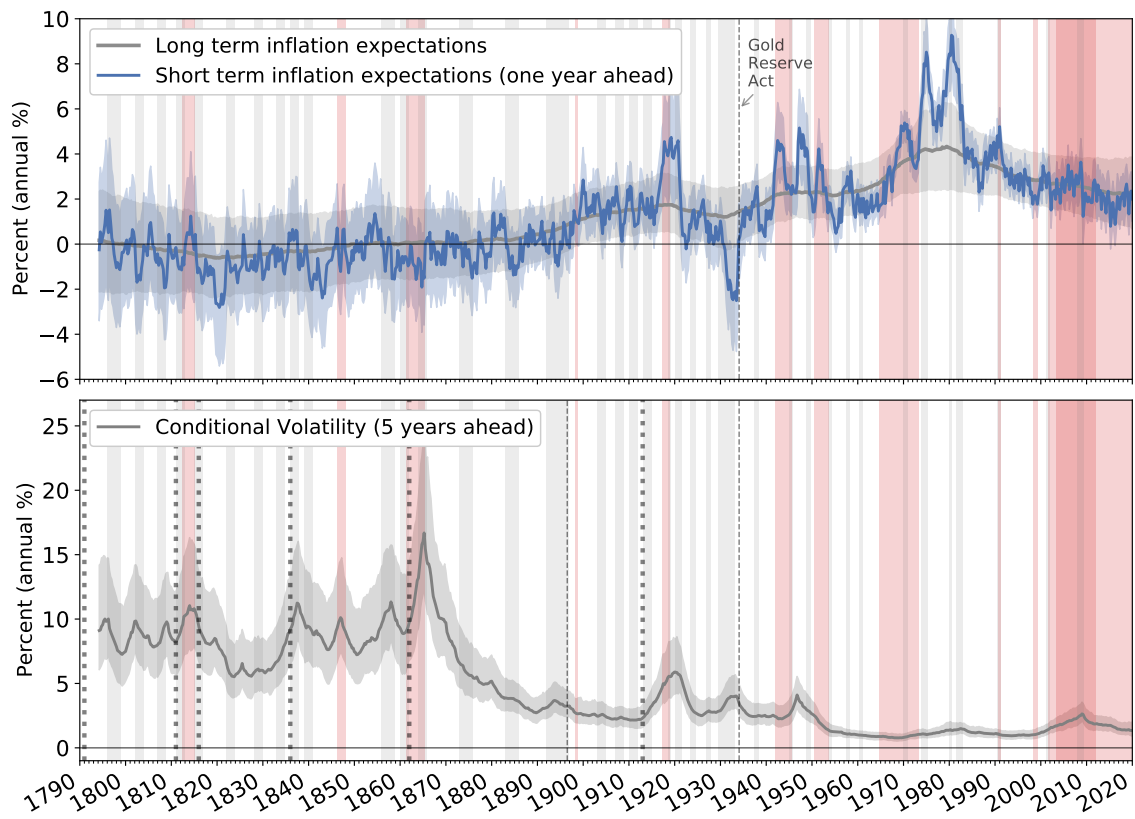


Figure 12 Smoothed Conditional Moments of Inflation

*Top plot:* The solid grey line depicts the posterior median estimate for the permanent component of inflation. The solid blue line depicts the posterior median estimate for period  $t$  one year ahead inflation expectations implied by our statistical model. Bands around the posterior medians depict 90% interquartile ranges. *Bottom plot:* The solid grey line depicts the posterior median estimate for the 5-year-ahead smoothed, annualized conditional inflation volatility. The solid purple line depicts the posterior median estimate for the 5-year-ahead smoothed conditional root mean square statistic. The light bands around the posterior medians depict 90% interquartile ranges.

the *annualized* conditional volatility defined as

$$\sigma_{\pi,t}^{(j)} := \sqrt{\frac{1}{j} \left( \mathbb{E}_t \left[ \exp \left( 2\pi_t^{(j)} \right) \right] - \mathbb{E}_t \left[ \exp \left( \pi_t^{(j)} \right) \right]^2 \right)}.$$

The purple line in the bottom plot depicts the posterior median estimate for the 5-year-ahead smoothed conditional root mean square statistic—a measure of conditional second moment of inflation—used by [Cogley and Sargent \(2015\)](#) to quantify ‘price instability’ (as opposed to unpredictability). In this case, the conditional root mean square statistic can be written as

$$crms_{\pi,t}^{(j)} := \sqrt{\frac{1}{j} \mathbb{E}_t \left[ \exp \left( 2\pi_t^{(j)} \right) \right]}.$$

## E Additional Detail on Gold Yield Curve Model

### E.1 Posterior distribution of our pricing model

Our nonlinear state space model of gold bond prices can be written as:

$$\begin{aligned} \tilde{p}_t^{(i)} &= \langle \mathbf{q}(\lambda_t, \tau), \bar{\mathbf{m}}_t^{(i)} \rangle + \sigma_m^{(i)} \varepsilon_t^{(i)} && \text{gold bonds} \\ \lambda_{t+1} &= \bar{\lambda}_t + \varrho(\lambda_t - \bar{\lambda}_t) + \Sigma_t^{\frac{1}{2}} \varepsilon_{\lambda,t+1} && \text{yield curve params} \\ \log \sigma_{t+1} &= \log \sigma_t + \Xi_{\sigma} \varepsilon_{\sigma,t+1} && \text{stochastic volatility} \\ \bar{\lambda}_{t+1} &= \begin{cases} \bar{\lambda}_t + \bar{\Xi} \varepsilon_{\bar{\lambda},t+1}, & \text{if } t = k\Delta \text{ for } k \in \mathbb{N} \\ \bar{\lambda}_t & \text{otherwise} \end{cases} && \text{long-run mean} \end{aligned}$$

with  $\varepsilon_t^{(i)} \sim \mathcal{N}(0, 1) \quad \forall i, \quad \varepsilon_{\lambda,t} \sim \mathcal{N}(\mathbf{0}, \mathbb{I}_3)$   
 $\varepsilon_{\bar{\lambda},t} \sim \mathcal{N}(\mathbf{0}, \mathbb{I}_3) \quad \varepsilon_{\sigma,t} \sim \mathcal{N}(\mathbf{0}, \mathbb{I}_3), \forall t \geq 1$

where  $\tilde{p}_t^{(i)}$  denotes the *observed* period- $t$  price of bond  $i$  in terms of gold. The posterior distribution of this model is obtained by adding up the Gaussian log-likelihoods associated with the independent shocks and combine them with priors described below.

**Priors:** Assumptions 2 and 3 give rise to a flexible model of the gold denominated yield curve process that is pinned down by a small set of hyper-parameters. We specify a prior on  $\tau$  and the initial (time 0)  $\lambda$  vector that effectively determines an ‘average yield curve’ for the whole sample period. We use log-normal prior for  $\tau$  and independent log-normal priors for the three entries of the initial  $\lambda$  vector that implies the prior distribution for the initial yield curve shown in the left panel of Figure 13. Our prior imposes a flat ‘average



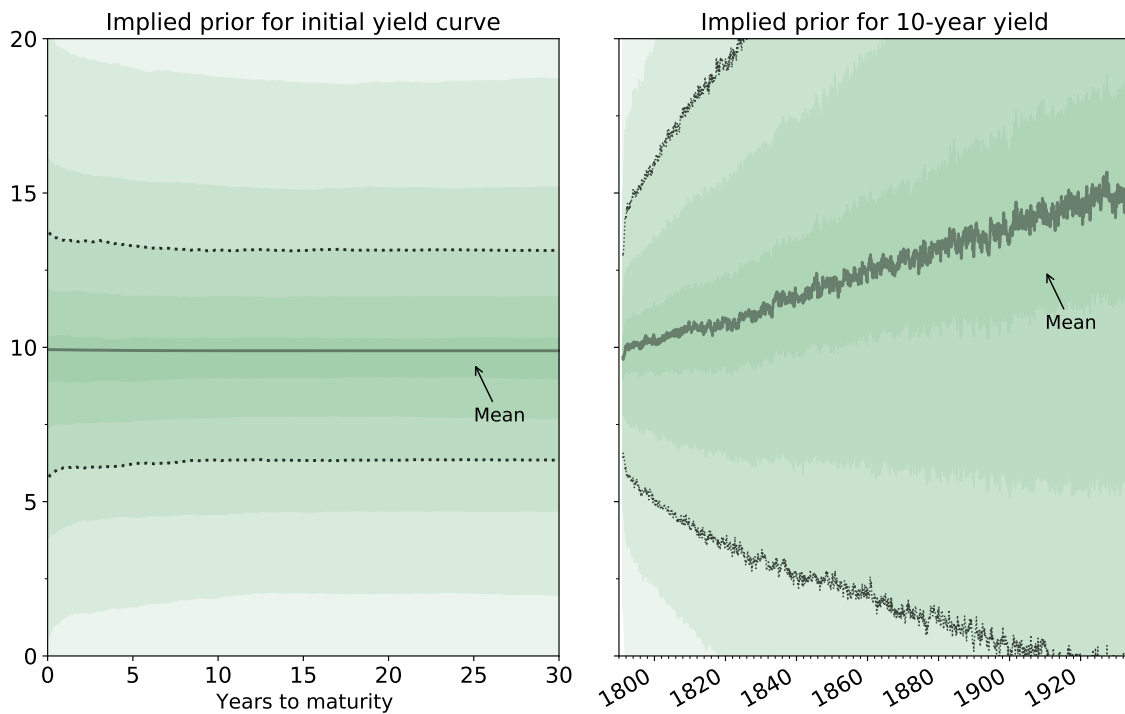


Figure 13 Implied Prior Distribution of the Initial Yield Curve and the 10-year Zero-Coupon Yield.

The solid grey lines depict the mean, dotted lines depict the 25% and 75% percentiles of the prior distribution. Shaded areas represent interquartile ranges so that dark areas are indicative of concentrated prior probability.

yield curve,” i.e., for all maturities the prior mean is 10% with standard deviation of around 5%. More precisely, the underlying priors are:

$$\begin{aligned}\lambda_{0,0} &\sim \log \mathcal{N}(10 - \underline{\beta}, 6), & \lambda_{1,0} &\sim \log \mathcal{N}(10 - \underline{\beta}, 6), \\ \lambda_{2,0} &\sim \log \mathcal{N}(10 - \underline{\beta}, 15), & \tau &\sim \log \mathcal{N}(60, 60).\end{aligned}$$

While the “average yield curve” influences our posterior distribution in the early part of the sample, it is much less influential later due to the random walk component in  $\lambda_t$ . The right panel of Figure 13 illustrates how the prior mean and “prior coverage bands” for the 10-year yield grow over time. How much our prior for  $\lambda_0$  affects the posterior distribution for later periods depends mainly on our priors on  $\{\bar{\lambda}_t\}$ ,  $\varrho$ , and  $\{\Sigma_t\}$  that we specify as follows:

- For the correlation matrix  $\Omega$  we use the LKJ prior with a concentration parameter  $\eta = 5$ , which is a unimodal but fairly vague distribution over the space of correlation matrices. For  $\eta$  values larger than 1, the LKJ density increasingly concentrates mass around the unit matrix, i.e., favoring less correlation.<sup>46</sup>
- For the initial standard deviations  $\sigma_0$  we use independent log-normal priors:  $\sigma_{i,0} \sim \log \mathcal{N}(0.05, 0.1)$ .
- We use *common* exponential priors on the standard deviation in the diagonal of  $\Xi_\sigma$ , with the rate parameter tuned so that *a priori* the probability that  $\sigma_\sigma^{(i)} > 0.15$  is lower than 5%. The prior mean is 0.05.
- We use independent normal priors on the entries of  $\varrho$ . The prior mean is chosen as a diagonal matrix with diagonal entries [0.8, 0.8, 0.8] while we set standard deviation of 0.3 for all 9 entries of  $\varrho$ .
- We use independent log-normal priors for the three entries of the initial  $\bar{\lambda}_0$  (permanent component of  $\lambda$ ):

$$\bar{\lambda}_{0,0} \sim \log \mathcal{N}(10 - \underline{\beta}, 6), \quad \bar{\lambda}_{1,0} \sim \log \mathcal{N}(10 - \underline{\beta}, 6), \quad \bar{\lambda}_{2,0} \sim \log \mathcal{N}(10 - \underline{\beta}, 15)$$

- We use *common* exponential priors on the standard deviation in the diagonal of  $\bar{\Xi}$ , with the rate parameter tuned so that *a priori* the probability that  $\bar{\sigma}^{(i)} > 0.15$  is lower than 5%. The prior mean is 0.05.

We use *common* exponential priors on the standard deviation of pricing errors,  $\sigma_m^{(i)}$ , with the rate parameter tuned so that *a priori* the probability that  $\sigma_m^{(i)} > 30$  is lower than 5%. Prior mean is 10.

---

<sup>46</sup>See Lewandowski et al. (2009). The LKJ distribution is defined by  $p(\Omega|\eta) \propto \det(\Omega)^{\eta-1}$ . For  $\eta = 1$ , this is a uniform distribution.

## E.2 Methodological Contribution

*Alternative to Particle Filtering:* Estimating the model in Section 3.2 involves a complicated filtering problem due to the non-linear nature of bond prices and the existence of stochastic volatility. A standard approach to such non-linear filtering problems is to use some version of particle filtering. However, thanks to the length and other complexities of our data set, the well-known drawbacks of particle filters, such as sample degeneracy and impoverishment, become particularly acute in our case. We deploy an alternative strategy and approach the problem as a high-dimensional statistical model by “treating latent variables as parameters.”<sup>47</sup> From this viewpoint, the model has more than 7,500 parameters. To cope with such a high-dimensional parameter space, we use Hamiltonian Monte Carlo with a “No-U-Turn Sampler” of Hoffman and Gelman (2014), along with subsequent developments described in Betancourt (2018). The basic idea of the method is to use slope information about the log-likelihood to devise an efficient Markov Chain Monte Carlo sampler. This method can attain a nearly i.i.d. sample from the posterior by proposing moves to distant points in the parameter space through (an approximately) energy conserving simulated Hamiltonian dynamic.

*Bond-specific pricing errors for classification:* In theory, idiosyncratic bond characteristics, such as denomination, flexible maturities, and conversion options, would require custom pricing formulas for each bond. In practice, such a procedure is impractical while it is a priori unclear that all features are equally important for bond pricing. To decide which bond characteristics warrant special treatments, we devise a “cost-benefit analysis” tool in the form of bond-specific pricing errors: starting with presuming that all bonds can be priced with a common time-varying pricing kernel, we look for patterns in the estimated pricing errors, the idea being that misjudgments in our bond classification would show up as large, cluster-specific relative pricing errors. This approach helped us identify two types of bonds that require special treatment: (i) greenback-denominated bonds, and (ii) bonds that are close to maturity. As for the greenback bonds, we devise custom pricing formulas detailed in Subsection 5.1.<sup>48</sup> As for bonds with short maturity, we suspect the large relative pricing errors are due to a liquidity premium that emerges from the relative ease in which such bonds could be used for transactions. We deal with this misclassification by dropping prices of bonds that are less than one year to maturity from the sample that we use to estimate our yield curve. In Subsection 4.2 we use the residual pricing errors on these bonds

---

<sup>47</sup>We use quotation marks because in the Bayesian paradigm there is no clear distinction between latent variables and parameters.

<sup>48</sup>Similarly, we found evidence that special treatment is needed for the 5-20s whose principal denomination was ambiguous during and after the Civil War. We drop these bonds from our sample and leave the construction of 5-20s-specific pricing formulas for future research.

as a proxy for the liquidity premium on money-like federal liabilities.

*Computational issues:* While **Stan** might seem an obvious choice for the task at hand—it is a well-developed software that efficiently implements the HMC-NUTS sampler—non-trivial features of our data set make it inconvenient for our purposes. Some of the main technical difficulties we face are: (1) the number of observed assets changes over time, (2) each bond has a payoff stream of varying length, (3) periods without price observations, (4) the set of bond-specific pricing errors that are relevant at a given period  $t$  changes over time in a complicated fashion, etc. To tackle these difficulties, we code the log posterior function of our model from scratch and feed it into the `DynamicHMC.jl` package by [Papp et al. \(2021\)](#) which is a robust implementation of the HMC-NUTS sampler mimicking many aspects of **Stan**. An important advantage of this package is that it allows the user to provide the Jacobian of the log-posterior manually. Not having to rely on automatic differentiation for a model with 7,500+ parameters cuts running time by several orders of magnitude. In most cases, we use the recommended (default) tuning parameters for the NUTS algorithm.

### E.3 Laboratory Experiment

Our parameterisation can capture a wide range of yield curve shapes. However, as was shown in Figure 1, we want to infer yield curve parameters from relatively few price observations, with most observed prices being for long term bonds. How can we recover short yields? To show how pooling information over time can help with this matter, we conduct a “laboratory experiment”: taking a particular yield curve process (in line with our state space model in Subsection 3.2) as given, we use it to price four bonds with known characteristics (maturity, coupons, pricing error), then perform our econometric procedure, and compare our posterior yield estimates to the true values that generated our artificial data. We investigate two scenarios:

**Case 1:** long term bonds with maturity dates that are distributed relatively evenly over the sample period

**Case 2:** there is an extended period without bonds that mature in less than 10 years

We create bonds that are “representative” of our sample in the sense that they are long term. Here information about short yields must be recovered from prices of bonds that were originally long term but are now approaching maturity.

The rows of Figure 14 depict the outcomes of the two scenarios. The red lines are the true 1-year (middle column) and 10-year yields (right column) that were used to generate prices of the four bonds, the characteristics of which are depicted in the left column. The

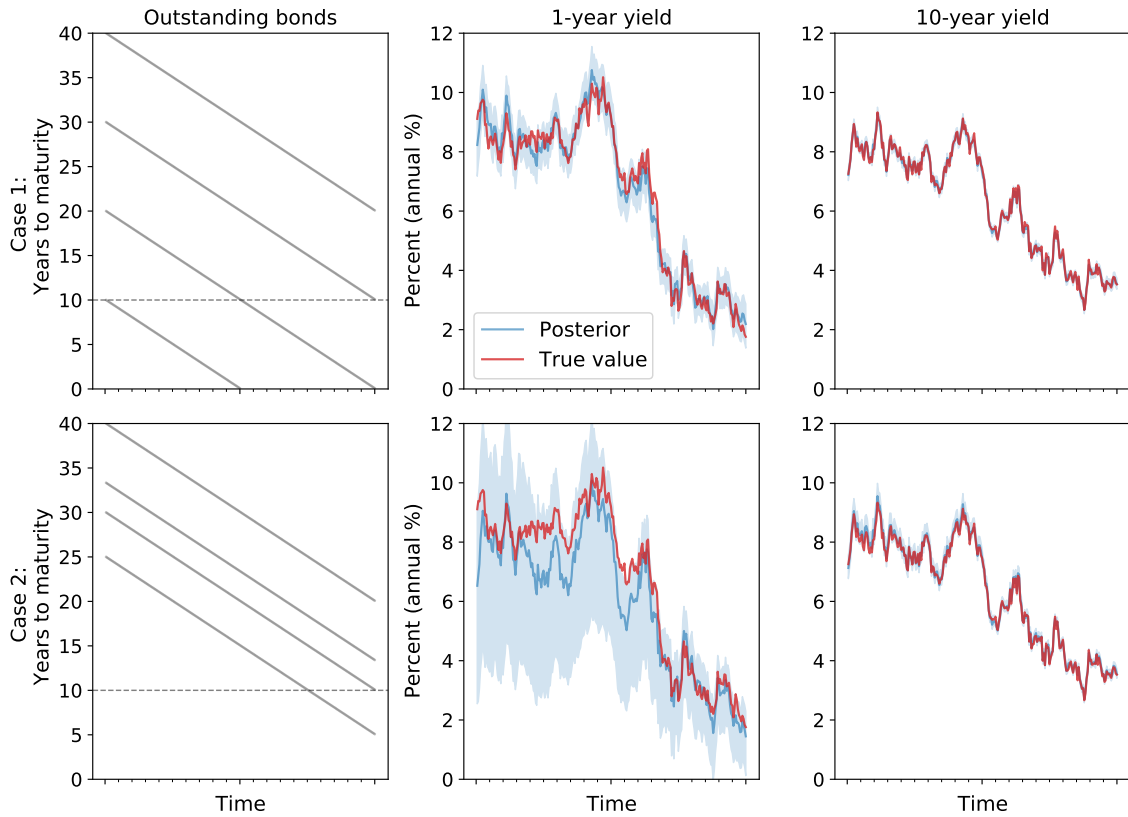


Figure 14 Comparison of Posteriors to True Values.

Artificial samples with 4 bonds ( $T = 20$  year). **Case 1: [top row]** (i) 6 % (semi-annual), 10 year maturity,  $\sigma_m^{(i)} = 3$ ; (ii) 3 % (semi-annual), 20 year maturity,  $\sigma_m^{(i)} = 2$ ; (iii) 5 % (semi-annual), 30 year maturity,  $\sigma_m^{(i)} = 1$ ; (iv) 2 % (semi-annual), 40 year maturity,  $\sigma_m^{(i)} = 4$ . **Case 2: [bottom row]** (i) 6 % (semi-annual), 25 year maturity,  $\sigma_m^{(i)} = 3$ ; (ii) 3 % (semi-annual), 33 year maturity,  $\sigma_m^{(i)} = 2$ ; (iii) 5 % (semi-annual), 30 year maturity,  $\sigma_m^{(i)} = 1$ ; (iv) 2 % (semi-annual), 40 year maturity,  $\sigma_m^{(i)} = 4$ .

blue lines depict the posterior median and the shaded blue area depicts the 90% interquantile range of the posterior distribution. Even though we have few price observations for bonds with short maturity, the algorithm nevertheless does a good job of recovering the true 1-year yield under the first scenario (Case 1). That is, at least when the common pricing kernel assumption is a good description of the data, observing a few long term bonds can be sufficient to recover the short end of the yield curve as long as the maturity dates of the observed bonds are distributed relatively uniformly over time. This is what our model’s ability to pool information buys us.

To illustrate this point, Case 2 represents a scenario when all four bonds mature beyond 20 years and shorter term securities are not issued in the meantime,<sup>49</sup> so our model has little chance to utilize information about short yields. The result is depicted in the bottom row of Figure 14. As can be seen, the algorithm can still recover the true 10-year yield (it can observe bonds close to 10-years in the second half of the sample) but it has much more trouble trying to recover the 1-year yield. The posterior 90% interquantile range is large, and the posterior median departs significantly from the true value for many periods. This illustrates that the structure of our Nelson-Siegel parameterisation does not automatically generate tight posteriors. We do need some observations of prices for short maturity bonds to recover the yield curve.

## F Statistical Fits

We argue that our common discount function assumption—accompanied with our flexible parametric statistical model—provides a reasonable summary of the available bond price data. A number of observations justify this claim: (1) mean pricing errors are generally small for all bonds that we include in the estimation of gold dollar yield curves, and (2) yield-to-maturities of observed bonds concentrate around our estimated par yield curves. In addition, in Section G, we compare our estimates to existing series and show that our estimates line up at the maturities and time intervals for which we have reliable alternative series.

### F.1 Small pricing errors across bonds

An important aspect of our approach is the assumption of bond-specific pricing errors. This allows the algorithm to decide if certain bonds are likely to violate our common discount function assumption. The black crosses in Figure 15 depict *mean absolute pricing errors* for each bond included in the analysis. They are computed as the time average of the absolute

---

<sup>49</sup>This scenario describes the last decade of the eighteenth century well, during which we observe only the three “Hamilton bonds.”

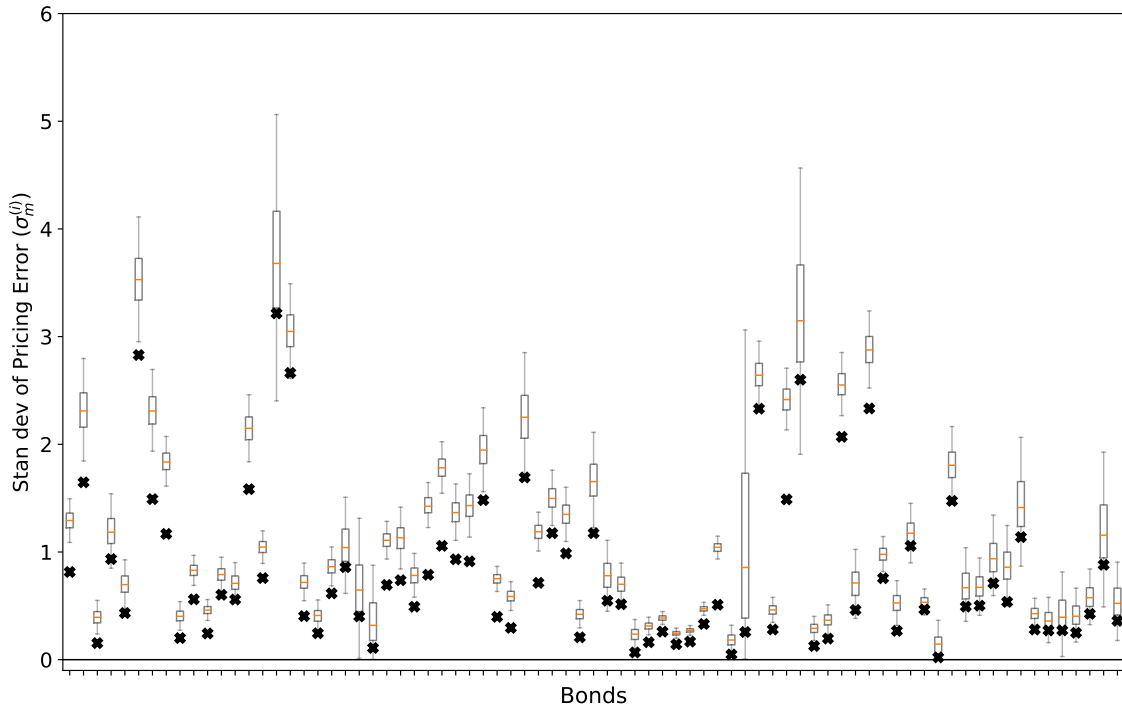


Figure 15 Posterior Distributions of Bond-Specific Pricing Error Variances

Each boxplot represents the interquartile range (IQR) and median (orange line) of the posterior distribution of  $\sigma_m^{(i)}$ —that is the standard deviation of the bond-specific pricing error—for each bond used in the estimation. Black crosses represent *mean absolute price errors* computed from the difference between observed and model-implied prices for each bond.

difference between observed prices and posterior median price forecasts. We see that our gold dollar yield curve estimates the prices of the included bonds fairly well with similar errors across the different bonds. This is a sign of a good in-sample fit and the fact that imposing a common discount function provides a reasonably good description of the gold dollar bonds with maturities larger than 1 year.

Similarly, the estimated standard deviations of bond-specific pricing errors,  $\sigma_m^{(i)}$ , are also small. The boxplots in Figure 15 depict summary statistics of the corresponding posterior distributions. The relative magnitude of these estimates is indicative of how influential certain bonds are on the estimated yield curve. Our algorithm assigns relatively less “weight” to bonds with large estimated  $\sigma_m^{(i)}$  values. Figure 15 shows that the set of bonds with relatively little influence more or less coincides with the bonds with the highest mean absolute pricing error.

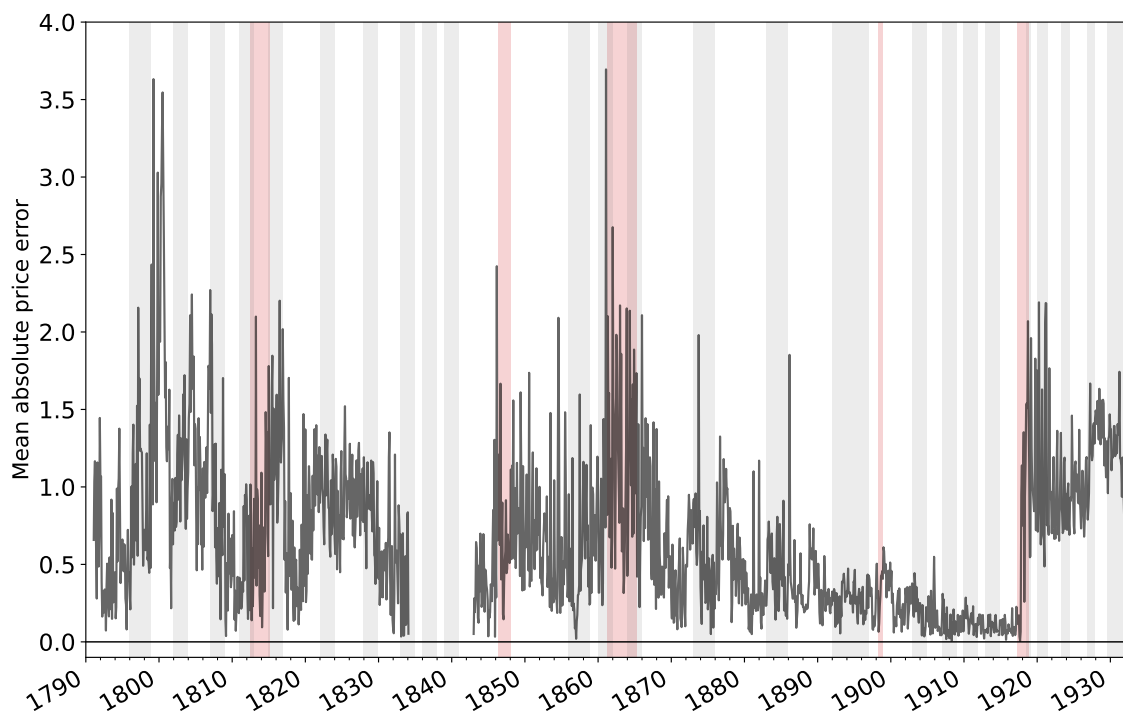


Figure 16 Time Series of Mean Absolute Pricing Errors

The black line depicts the cross-sectional average (over bonds for each month) of the absolute difference between observed prices and posterior median price forecasts. The light gray intervals depict recessions as dated by Davis (2006) for the 1796-1914 period and NBER recessions thereafter. The light red intervals depict wars (from left to right: the War of 1812, the Mexican-American War, the Civil War, the Spanish-American War, and World War I).

## F.2 Small pricing errors over time

Figure 16 depicts the cross-sectional average (over bonds for each month) of pricing errors, as measured by the absolute difference between observed prices and posterior median price forecasts. The largest errors are associated with the War of 1812, the Civil War, and the First World War. This suggests that we have most difficulty simultaneously pricing cross-section of bonds simultaneously during wartimes.

## F.3 Small pricing errors across maturities

Figure 17 replicates our “short rate disconnect” plot (see Figure 4) with a finer set of maturity bins. It shows that yield errors tend to average out for all maturity bins that we included in the estimation. The left panel in Figure 18 depicts distributions of errors for the specified maturity bins, illustrating the same point from a different angle. The left box



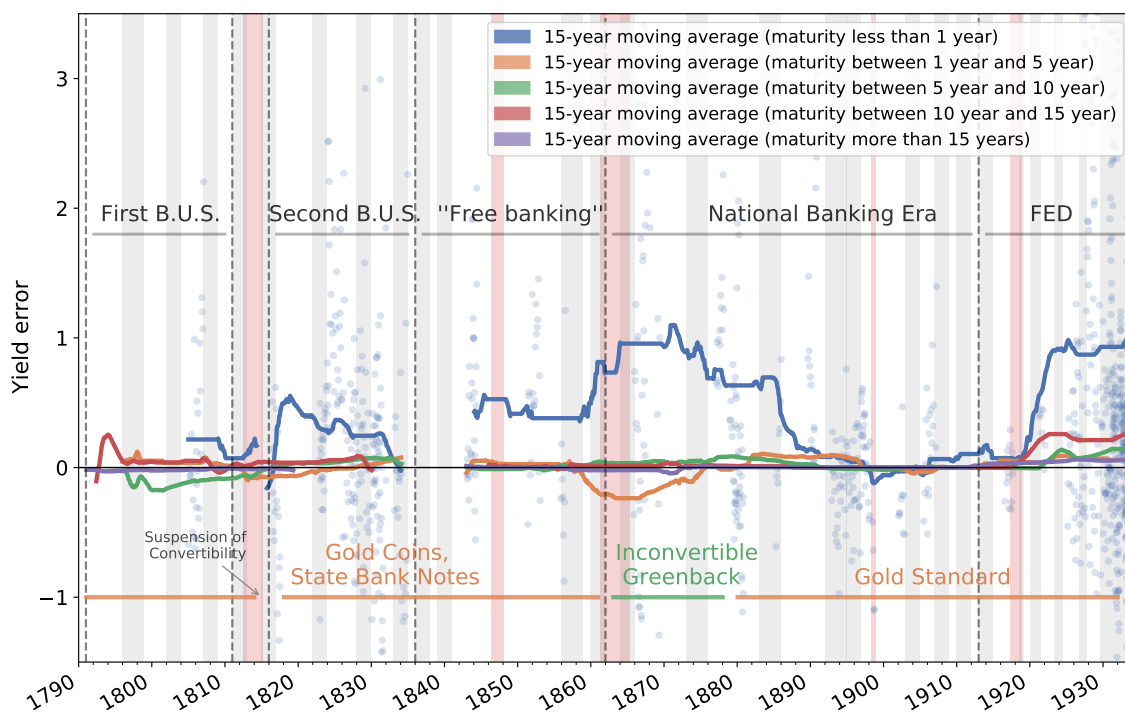


Figure 17 Short Rate Disconnect for Different Maturity Bins

represents maturities that we exclude from the estimation (0-1 years), the rest of the boxes correspond to the included maturity bins. Again, we see that on average our parametric yield curve specification fits observed prices well. The right panel in Figure 18 shows the mean absolute pricing errors at different maturities. We do not see systematic differences in the pricing errors at different maturities. We take this as evidence that our parametric specification captures the most important “local variations” across maturities.

#### F.4 Observed yields-to-maturities are close to estimated par yield curves

Another argument why our estimates are plausible is based on the fact that the Congress and the Treasury often aimed to set coupon rates on new bonds so that initially they would sell at par. That outcome would make their yields-to-maturities equal their coupon rates. This practice implies that we should expect observed yield-to-maturities to be close to the so called *par yield curve*; a curve that shows the required coupon rate for any bond with maturity  $j$  to sell at par. This object is a non-linear, one-to-one function of the zero-coupon yield curve, therefore, we can use our estimated model to see how well observed yield-to-

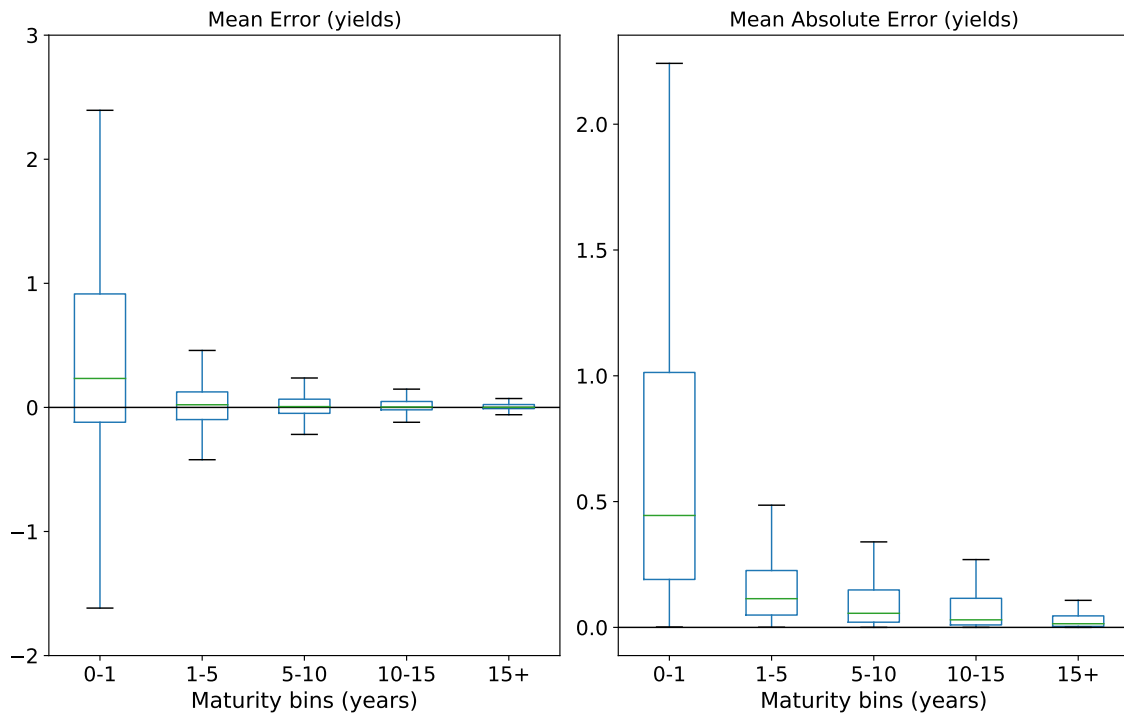


Figure 18 Mean Absolute Pricing Errors at Maturities.

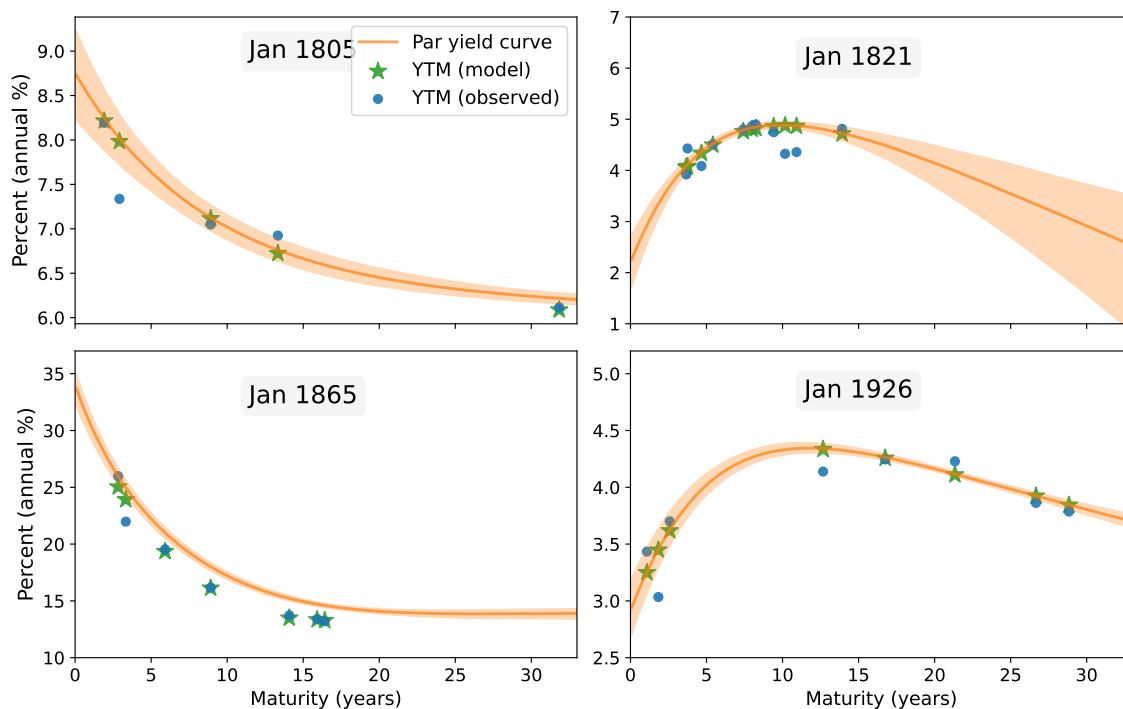


Figure 19 Par Yield Curve Estimates vs. Yield-to-Maturities.

The solid orange lines depict the median of our posterior for the gold dollar par yield yield curve at four specific dates (in gray boxes). The light orange bands around the posterior median depict the 95% interquartile ranges. Blue dots represent observed yield-to-maturities for bonds that are outstanding at the given period. Green stars depict model implied yield-to-maturities for the same bonds—computed from the posterior median price forecasts.

maturities line up with the estimated par yield curves at least in “non-emergency” periods when issuing new bonds at par was feasible.

The subplots of Figure 19 depict estimated par yield curves (orange lines) at dates that are more or less representative of certain sub-periods of our sample. Observed and model implied yield-to-maturities for the outstanding bonds are represented by blue dots and green stars, respectively. The close proximity of the dots and stars is indicative that the fit of our model is quite good across the whole maturity spectrum: our model is able to replicate a wide variety of yield curve shapes and succeeds in capturing the fact that yields at the long end of the maturity spectrum is often lower than yields at medium horizons irrespective of how short-term yields behave.<sup>50</sup> Moreover, comparing the blue dots to the estimated par yield curves illustrate that the Congress’ objective to sell bonds at par was often achieved (see the subplots for 1805, 1821 or 1926).

<sup>50</sup>In other words, allowing for a “hump” in the yield curve is often necessary.

Changes in market conditions, however, frustrated this objective during important episodes in US history. Thus, at times of financial distress during the War of 1812 and the Civil War, Treasury debt sold at deep discounts; and during disagreements between the President and the Congress, like those in the 1890s, the Treasury issued bonds with coupon rates exceeding current yields, so that bonds sold at a premium.<sup>51</sup> Indeed, the bottom left subplot in Figure 19 shows that in the last months of the Civil War, the par yield curve systematically deviated from the blue dots even though the model implied yield-to-maturities (stars) closely approximates the observed yield-to-maturities (dots).

In remarks at a 2010 Minneapolis Fed conference, Professor V.V. Chari offered an “accounting tail wags the dog” explanation of why Congresses often wanted only to market new bonds that would sell “at par”.<sup>52</sup> Chari’s explanation was that Congresses viewed themselves as stuck with Alexander Hamilton’s peculiar accounting rules that told them to measure total government debt by simply adding up *undiscounted* par values of all outstanding debts, ignoring coupon values. That accounting system could provide good approximations to the value of debt only if bonds traded at or near par values.

## G Comparison to Other Historical Estimates

### G.1 Our long yields line up with available series

The 10 year yield is the part of the yield curve that has attracted the most attention from historians so there are some previous estimates that can be used for comparison. A widely respected series is the “Federal Government Bonds: Selected Market Yields” series of [Homer and Sylla \(2004\)](#), computed as the coupon rate on US federal bonds that have approximately 10 years to maturity and were trading close to par. Figure 20 depicts our estimates of ten-year gold dollar zero-coupon yields along with the US long term yield series of [Homer and Sylla \(2004\)](#).

Evidently, our estimates typically follow the [Homer and Sylla \(2004\)](#) series, except that we estimate substantially higher yields during the War of 1812 and the Civil War. In particular, our ten-year gold yield estimate reaches a peak of 16% near the end of the Civil War, which is substantially higher than the [Homer and Sylla \(2004\)](#) series peak of 6% at the

---

<sup>51</sup>In 1895, after a run drained 40% of the Treasury’s Gold Reserve Fund, President Grover Cleveland sought to issue debt to purchase the gold needed to replenish these reserves. But proponents of bimetallism in Congress blocked new borrowing. Accepting advice from J.P. Morgan’s lawyers, the Cleveland Administration bypassed Congress and used some Civil War-era legislation to issue 30-year bonds bearing 4 percent coupons, at a time when the 10-year zero-coupon yield was below 3 percent. The controversy surrounding the issuance of these bonds helped inspire William Jennings Bryan’s “Cross of Gold” Speech at the 1896 Democratic Convention. See [Chernow \(2001, ch5\)](#) for details.

<sup>52</sup>Chari was responding to the content of a draft version of [Hall and Sargent \(2011\)](#), which documented differences between the US government accounting method and an alternative mark-to-market method.

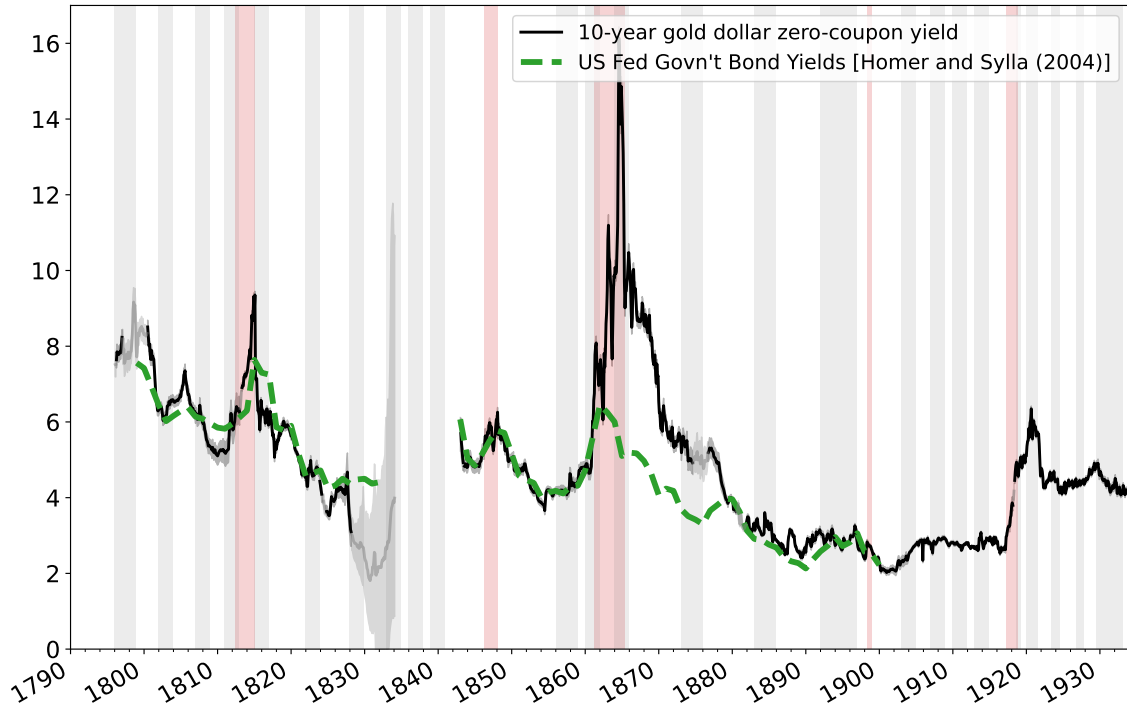


Figure 20 Comparison to the Long-run Yield of [Homer and Sylla \(2004\)](#)

The solid black line depicts the mean of our posterior estimate for the 10-year, gold denominated, zero coupon yield. The dashed grey line depicts the mean of our posterior estimate for the 10-year, dollar denominated, zero coupon yield. The grey bands around the posterior mean depict the 95% interquartile range. The dashed green line depicts the 'Federal Government Bonds: Selected Market Yields' series from Table 38 of [Homer and Sylla \(2004\)](#). The light gray intervals depict recessions as dated by [Davis \(2006\)](#) for the 1796-1914 period and NBER recessions thereafter. The light red intervals depict wars (from left to right: the War of 1812, the Mexican-American War, the Civil War, the Spanish-American War, and World War I).

start of the war. The following observations suggest that our estimate of yields during this period is more plausible than those of [Homer and Sylla \(2004\)](#).<sup>53</sup> Starting in 1862, all US Treasury bonds could be purchased with greenback dollars, including bonds with coupons and principal payments denominated in diverse units of account, some in greenbacks, others in gold dollars. The value of the greenback fluctuated with battlefield and political news, and all Treasury bond prices deviated substantially from par. For example, during the summer of 1864, when re-election of President Abraham Lincoln was in doubt, 100 greenback dollars could be purchased for as few as 40 gold dollars. Consequently, during that time Treasury bonds that promised to pay 6 percent coupons in gold dollars could be purchased for 40 percent of par, implying long-term yields in excess of 15 percent.<sup>54</sup>

We find it reassuring that our estimate aligns with [Homer and Sylla \(2004\)](#) during “non-emergency” periods because there are good reasons to think that their estimates should be a good approximation to the 10 year yield. Their approach calculates an average yield to maturity for 10 year bonds, which should be similar to the 10 year zero-coupon yield when the yield curve is relatively flat.<sup>55</sup> Except during and after the Civil War, the average duration of outstanding bonds was close to 10 years and the average market trading price is close to par and [Homer and Sylla \(2004\)](#) have a large data set.<sup>56</sup> For these reasons, we consider the general congruence between our estimated 10-year yields and “long-term federal government bond yields” in [Homer and Sylla \(2004\)](#) as a reassuring check on the plausibility of our findings. In Appendix G.2, we report comparisons to other historical estimates and discuss why they might differ from our gold denominated zero-coupon yields.

---

<sup>53</sup>[Homer and Sylla \(2004\)](#) themselves caution against using their estimates for the Civil War period stating on page 303, “. . . the tables of bond yields for the years 1863 to 1870 do not provide a reliable picture of long-term interest rates.” This is because there were no federal bonds trading with a gold price of par and so they are forced to estimate the yield as the gold coupon rate for bonds trading with a greenback price of par. We can capture greater variation in the yield curve because we use the universe of US Treasury bonds at monthly frequency whereas [Homer and Sylla \(2004\)](#) use the subset of these bonds that are trading at par.

<sup>54</sup>In his State of the Union Address on December 9, 1868, President Andrew Johnson said: "It can not be denied that we are paying an extravagant percentage for the use of the money borrowed, which was paper currency, greatly depreciated below the value of coin. This fact is made apparent when we consider that bondholders receive from the Treasury upon each dollar they own in Government securities 6 per cent in gold, which is nearly or quite equal to 9 per cent in currency; that the bonds are then converted into capital for the national banks, upon which those institutions issue their circulation, bearing 6 per cent interest; and that they are exempt from taxation by the Government and the States, and thereby enhanced 2 per cent in the hands of the holders. We thus have an aggregate of 17 per cent which may be received upon each dollar by the owners of Government securities." Our estimate of the ten-year gold dollar zero-coupon yield in December 1868 is 8 percent; our calculations do not include interest earned by national banks and don't account for the tax exemption.

<sup>55</sup>We discuss the relationship between the zero-coupon yield curve and the yield to maturity in Appendix C.2.

<sup>56</sup>Bonds typically traded close to par because the government set coupon rates to ensure an issue price of par.

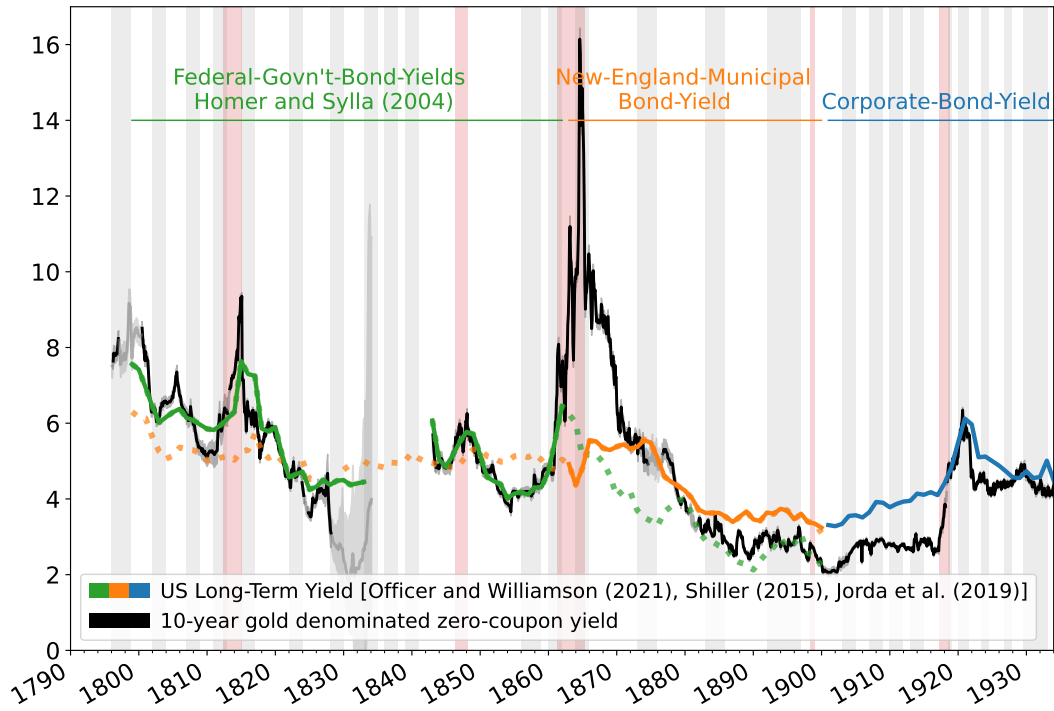


Figure 21 Alternative Long-Term Yield Estimates.

The solid black line depicts the median of our posterior estimate for the 10-year, gold denominated, zero coupon yield. The grey bands around the posterior mean depict the 90% interquartile range. The green line (bold and dotted) depicts the ‘US Government Bond Yield’ series from [Homer and Sylla \(2004\)](#). The orange line (bold and dotted) depicts the New England Municipal Bond Yield reported by [Homer and Sylla \(2004\)](#). The blue line depicts the Corporate Bond Yield reported by [Homer and Sylla \(2004\)](#). The bold green-orange-blue line depicts the ‘composite’ bond series used by [Officer and Williamson \(2021\)](#). The light gray intervals depict recessions and the light red intervals depict wars.

## G.2 Comparison to Other Historical Estimates

The [Homer and Sylla \(2004\)](#) series depicted in figure 20 is not the long-term US bond series that is commonly used in the economic history literature. Instead, researchers<sup>57</sup> have typically used a ‘composite series’ that combines the [Homer and Sylla \(2004\)](#) estimates for the period from 1798-1861 with the yield-to-maturity on the New England Municipal bond for the period 1862-1899 and the yield-to-maturity on corporate bonds for the period 1900-1940.<sup>58</sup> Figure 21 plots this composite series alongside our 10-year yields. Our estimates diverge post 1861 when the composite series stops using US federal debt prices. We estimate a much higher long-term yield during the war and a lower long-term yield in the late 19th century. Possible sources for these discrepancies are that federal debt carried a greater default risk during the Civil War and that, after the war, National Banking Era protocols stimulated demands for federal bonds as reserves against National Bank Notes.

## G.3 Comparison to Other Short Term Yields

Figure 22 depicts our estimates for 1-year gold denominated zero-coupon yields alongside a short term yield series used by [Officer and Williamson \(2021\)](#) and [Jordà et al. \(2019\)](#).<sup>59</sup> We have more difficulty estimating the 1-year yields than the 10-year yields because some periods have very few price observations for bonds that are close to maturity. This is reflected in sizes of 95% interquantile ranges for 1-year zero-coupon yields in figure 22. We are most concerned about the period 1790-1815 when our only price observations are for the consol bonds that Alexander Hamilton issued to refinance the Revolutionary War debts.<sup>60</sup> By contract, the Hamilton consols had no maturity dates. Because the federal government ended up repurchasing and retiring all of these bonds, our perfect foresight assumption means that we treat them as finite maturity bonds.<sup>61</sup> This allows us to estimate a yield

---

<sup>57</sup>For example, [Officer and Williamson \(2021\)](#), [Shiller \(2015\)](#), [Jordà et al. \(2019\)](#), and [Hamilton et al. \(2016\)](#).

<sup>58</sup>It is not obvious that during the 19th century municipal debt was a safer investment than federal debt. Until the 1934 Gold Reserve Act, the federal government had never defaulted. In contrast, eight states and one territory defaulted in 1830s and 1840s and ten states defaulted in 1870s and 1880s. These state defaults are discussed in [McGrane \(1935\)](#) and [English \(1996\)](#).

<sup>59</sup>The figure depicts the series labeled as “Surplus Funds (Contemporary Series).” The Series involves the short-term lending or borrowing of surplus funds, that is, funds that are considered excess by the lending institution and are required for immediate temporary use by the borrowing entity.

<sup>60</sup>[Bayley \(1882\)](#) calls these bonds: *The Six Percent Stock of 1790*, *The Deferred Six Percent Stock of 1790*, and *The Three Percent Stock of 1790*.

<sup>61</sup>The time to maturity in figure 1 shows the time until the bonds were bought back by the government. The Act authorizing the issuance of the 1790 Stocks provided for a committee comprised of the president of the Senate, Chief Justice, Secretary of State, Secretary of the Treasury, and Attorney General to use surplus revenue to repurchase these stocks at market prices, if not exceeding par. Between 1791 and 1824, nearly all of the outstanding Six Percent and Deferred Six Percent Stocks were repurchased. By 1832, nearly all of the outstanding Three Percent Stock was repurchased. See [Bayley \(1882, pages 33, 110\)](#).



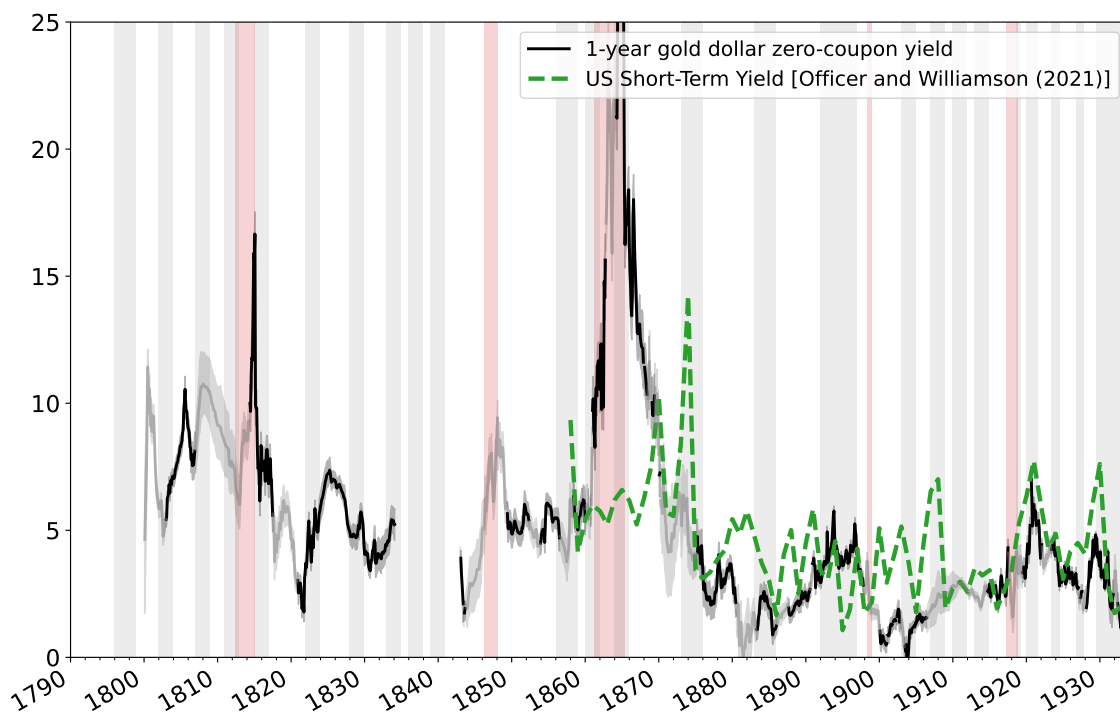


Figure 22 Short-Term Yields.

The solid black line depicts the mean of our posterior estimate for the 1-year, gold denominated, zero coupon yield. The dashed grey line depicts the mean of our posterior estimate for the 10-year, dollar denominated, zero coupon yield. The grey bands around the posterior mean depict the 95% interquartile range. The green dotted line depicts the US short term yield series (surplus funds, contemporary) used by [Officer and Williamson \(2021\)](#) and [Jordà et al. \(2019\)](#). The light gray intervals depict recessions as dated by [Davis \(2006\)](#) for the 1796-1914 period and NBER recessions thereafter. The light red intervals depict wars (from left to right: the War of 1812, the Mexican-American War, the Civil War, the Spanish-American War, and World War I).

curve, but we are faced with two problems: investors may not have anticipated that the bonds would be repurchased and when, and “times-to-repurchase” were typically greater than 10 years, providing us with little information about the short end of the yield curve. For these reasons, we drop data from 1790-95 and treat the short yield curve during 1790-1815 with caution.

Our short term yield series substantially departs from popular alternative series, especially during the Civil War when we estimate substantially higher yields, peaking at approximately 44% in July 1864. Anecdotal evidence indicates that Union short-term debt paid very high yields during the Civil War. For example, [Homer and Sylla \(2004, page 302\)](#) report that in 1860 the Treasury had issued one-year notes at rates of 10-12% and had rejected bids ranging from 15-36%. One-year yields are negative in the early 1880s and

close to zero in the early 1890s. What parts of our data most influence our inferences about these negative yields? It is that these negative yields help price both the *Four Percent Loan of 1907* and the *Four and One-Half Percent Loan of 1891*.<sup>62</sup> Economic events that may or may not be sources of these low gold yields during the early 1880s are that financial markets were highly volatile, that the US government was using surpluses to repurchase bonds, and that the US had just returned the gold standard in January 1879 (see [Noyes, 1909](#), pp. 79-80).

**Aside:** Comparing our yield estimates to that of [Homer and Sylla \(2004\)](#) sheds new light on an economic history literature that, starting with [Evans \(1985, 1987\)](#), has concluded that during the 19th century there was no strong association between interest costs and deficits. To conclude that, previous papers used the composite series in Figures 21 and 22. Our analysis indicates that those series substantially underestimates increases in yields on US federal debt during episodes of large 19th century government deficits. One way to reconcile our analysis with this literature would be to argue that yields on US municipal and corporate bonds were not highly correlated with surpluses even though yields on US federal bonds were. We leave a detailed analysis of 19th century municipal and corporate yields for future work.

## H Additional Details on Greenback Yield Curve Estimation

### H.1 State Space Model of Exchange Rates

We model the joint dynamics of exchanges using a bivariate state-space model with time varying long-run mean and persistence parameter:

**Assumption 7.** Joint dynamics of exchange rates  $v_t := \{P_t, e_t^{(g)}\}$  obey a state-space model:

$$\begin{aligned} v_{t+1} &= \mu_t + x_t + F\varepsilon_{v,t+1} \\ x_{t+1} &= A_t x_t + K\varepsilon_{v,t+1} \end{aligned} \quad \varepsilon_{v,t+1} \sim \mathcal{N}(\mathbf{0}, \mathbb{I}_2), \forall t \geq 0$$

where  $x_t$  is a 2-vector hidden state with a given initial  $x_0$ ,  $F$  and  $K$  are  $2 \times 2$  matrices with  $F$  being lower triangular. Parameters  $\mu_t$  and  $A_t$  follow drift-less random walks with shocks

---

<sup>62</sup>These are the names used in [Bayley \(1882\)](#). We initially imposed non-negativity constraints in the estimate of the yield curve. This led to small pricing errors for the *Four Percent Loan of 1907* but large pricing errors for the *Four and One-Half Percent Loan of 1891* in the early years of the 1880s. Relaxing the non-negativity constraint significantly reduced the pricing errors on the *Four Percent Loan of 1907* without increasing other errors. We take this as suggestive statistical evidence that the yield curve went negative in the early 1880s, but further investigation is required.

that arrive every  $\Delta$  months:

$$\mu_{t+1} = \begin{cases} \mu_t + \Xi_\mu \varepsilon_{\mu,t+1} & \text{if } t = k\Delta \text{ for } k \in \mathbb{N} \\ \mu_t & \text{otherwise} \end{cases},$$

$$\text{vec}(A_{t+1}) = \begin{cases} \text{vec}(A_t) + \Xi_A \varepsilon_{A,t+1} & \text{if } t = k\Delta \text{ for } k \in \mathbb{N} \\ \text{vec}(A_t) & \text{otherwise} \end{cases},$$

where  $\Xi_\mu$  and  $\Xi_A$  are positive definite diagonal matrices and shocks  $\varepsilon_{\mu,t}$  and  $\varepsilon_{A,t}$  are Standard Normal for  $\forall t \geq 1$ . For convenience, we collect the parameters of the exchange rate model into the vector:

$$\theta_t := [\mu_t', \text{vec}(A_t)', \text{vec}(F)', \text{vec}(K)']'.$$

**Priors:** We use independent Gaussian priors for all entries in  $\theta_0$  except  $F$ .

- For entries of the initial long-run mean vector  $\mu_0$  and matrix  $K$ , we set the mean of the Gaussian prior to the point estimates coming from estimating a time-invariant version of the model in Assumption 7 using data for 1862-1863. We set the standard deviations so that the prior allows for reasonably large deviations from these point estimates.<sup>63</sup> This procedure guarantees that the prior distribution concentrates on sensible parameter values, but because the estimation is based on a short stretch of data, the location of the parameters is only weakly restricted.
- For entries of the initial persistence matrix  $A_0$  we set a prior that assumes mildly positive auto-correlations for both entries of  $x_t$  while being agnostic about the cross-terms.<sup>64</sup> Observe that we do not explicitly restrict  $A_t$  to be a stable matrix, but use a prior that pushes the initial  $A_0$  matrix in the direction of the “stable region.”
- Parameter matrix  $F$  is lower-triangular that we parameterize as follows. First, we decompose the covariance matrix  $FF'$  into correlation coefficients and marginal variances  $FF' = \Xi_F \Omega_F \Xi_F'$ , where  $\Xi_F$  is a diagonal matrix containing the marginal standard deviations and  $\Omega_F$  is the corresponding correlation matrix. Matrix  $F$  can be written as  $F = \Xi_F L \Omega_F$ , where  $L \Omega_F$  is the lower-triangular Cholesky factor of  $\Omega_F$  such that  $(L \Omega_F)(L \Omega_F)' = \Omega_F$ . For the standard deviations in the diagonal of  $\Xi_F$  we use log-normal priors (independent across components):  $\sigma_F^{(1)} \sim \log \mathcal{N}(0.02, 0.01)$  and

<sup>63</sup>In particular, we set  $\mu_0[1] \sim \mathcal{N}(1, 1)$ ,  $\mu_0[2] \sim \mathcal{N}(1.23, 1)$ , and  $K[1, 1] \sim \mathcal{N}(0.03, 0.05)$ ,  $K[2, 1] \sim \mathcal{N}(-0.04, 0.05)$ ,  $K[1, 2] \sim \mathcal{N}(0.0, 0.05)$ ,  $K[2, 2] \sim \mathcal{N}(0.03, 0.05)$ .

<sup>64</sup>In particular, we set  $A_0[1, 1] \sim \mathcal{N}(0.9, 0.1)$ ,  $A_0[2, 1] \sim \mathcal{N}(0, 1)$ ,  $A_0[1, 2] \sim \mathcal{N}(0, 1)$ ,  $A_0[2, 2] \sim \mathcal{N}(0.9, 0.1)$ .

$\sigma_F^{(2)} \sim \log \mathcal{N}(0.04, 0.01)$ . For the Cholesky factor  $L\Omega_F$  we use the LKJ prior with concentration parameter  $\eta_F = 2$ .

- We assume that  $\Xi_\mu$  and  $\Xi_A$  are diagonal matrices, i.e., shocks to the components of  $\mu_t$  and  $A_t$  are independent. For their standard deviations we use a *common* exponential prior (independent across components) with the rate parameter tuned so that *a priori* the probability that  $\sigma_i > 0.06$  is lower than 5%. The prior mean is 0.02.

## H.2 Model for Greenback Yield Curve

We write our complete model of bond prices in the following compact form:

$$\begin{aligned}
 \hat{p}_t^{(i)} &= \left\langle \mathbf{q}(\lambda_t, \tau), \bar{\mathbf{m}}_t^{(i)} \right\rangle + \sigma_m^{(i)} \varepsilon_t^{(i)} && \text{gold bonds} \\
 \hat{p}_t^{(i)} &= \left\langle \mathbf{q}(\lambda_t, \tau) \odot \mathbf{z}(\theta_t), \bar{\mathbf{m}}_t^{(i,d)} \right\rangle + \sigma_m^{(i)} \varepsilon_t^{(i)} && \text{greenback bonds} \\
 \lambda_t & \text{ from Assumption 3} && \text{yield curve parameters} \\
 \theta_t & \text{ from Assumption 7} && \text{expectation parameters} \\
 \text{with } \varepsilon_t^{(i)} & \sim \mathcal{N}(0, 1) \quad \forall i, \forall t \geq 1
 \end{aligned}$$

where  $\hat{p}_t^{(i)}$  denotes the *observed* period- $t$  price of bond  $i$  in terms of gold. We believe that Assumptions 5 and 7 impose much more stringent restrictions on the data than our assumptions supporting the estimation of the gold dollar yield curve. To defend our baseline gold dollar yield estimates against the influence of these less trusted assumptions, we choose not to estimate the above model in one step. Instead, we proceed in two steps:

1. *Gold yield curve:* Using prices on gold dollar bonds and priors described in Appendix E.1, draw a random sample from the posterior distribution of the gold yield curve model. Approximate the joint posterior distribution of  $\{\lambda_t\}$  and  $\tau$  with a (correlated) Gaussian distribution.
2. *Greenback yield curve:* Treat the joint posterior distribution of  $\{\lambda_t\}$  and  $\tau$  as a “second-stage” prior—along with priors for  $\theta_0$ ,  $\Xi_A$  and  $\Xi_\mu$  described in Appendix H.1—and combine it with prices on greenback dollar bonds and the observed series of exchange rates  $\{v_t\}$  to characterize the “second-stage” posterior of  $\{\theta_t\}$ ,  $\{x_t\}$ ,  $\Xi_A$ ,  $\Xi_\mu$ , and  $\{\sigma_m^{(i)}\}$ .

**Aside: Did bondholders’ beliefs change?** Following [Cogley and Sargent \(2005\)](#) and [Cogley \(2005\)](#), we interpret time-variation in  $\theta_t$  as bondholders’ “changing beliefs” induced by shifts in fiscal-monetary policy rules. During and after the Civil War, the direction of US monetary-fiscal policies recurrently either shifted markedly or seemed to be on the

verge of swerving onto another course. We cope with this situation by positing a shifting law of motion for the relative value of greenback dollars. We assume that financial market participants understood that policies were drifting and sought to adapt their beliefs accordingly. The vector  $\theta_t$  represents their period- $t$  beliefs about the currency price processes. We assume that the pricing formulas hold on a date-by-date basis, i.e., although agents keep updating their beliefs, they treat the updated  $\theta_t$  as if it would remain constant forever. [Kreps \(1998\)](#) incorporates such behavior in his ‘anticipated utility’ model.

### H.3 The Evolution of Exchange Rate Expectations

Figure 23 shows expected gold/green back exchange rate paths at different dates during the Civil War. On each plot, a black line shows the path of the gold/greenback exchange rate,  $P_t$ , up until a particular date, the gray line shows the continuation of the realized gold/greenback exchange rate after that date, and the orange line shows our estimates of investors’ expectations about paths of the gold/greenback exchange. Evidently, throughout the War (1861-65), investors expected a rapid return to the gold standard in the post war period. This was true even during the large drops in the value of the greenback that occurred in 1863 and 1864 in response to bad news from the war front. Thus, even in the face of very high greenback inflation during the War, expectations of a rapid resumption of greenback convertibility at par seemed to prevail. However, after the War, bond holders became less optimistic about a rapid return to gold.

It is enlightening to stare at the post-war panels with a copy of [Dewey \(1922, pp. 340-345\)](#) in hand and to seek explanations for this pattern there in terms of fiscal-monetary decisions made by the Congress and Treasury. [Dewey \(1922, pp. 340-352\)](#) described unfoldings of political struggles about how and whether to service or to tax bond holders or outright to default on US bonds. After describing tentative steps initially taken in early 1866 to retire greenbacks, Dewey tells how Congress postponed measures designed to return to the gold standard. On page 340 he writes “... a great opportunity was lost, for public sentiment in the winter of 1866 would have sustained a more rapid contraction; the country at large was expecting it, and the deed might have been accomplished if Congress had had enough courage.” Our estimates indicate that by the mid-1870s investors thought that discrepancies between gold and greenback prices would persist almost indefinitely.

## I Does the slope predict recessions?

Figure 24 depicts the yield on 5-year government bonds minus the yield on 1-year government bonds. We refer to this as a term spread. A positive term spread indicates an upward sloping yield curve (i.e., longer maturity bonds have higher rates), while a negative term

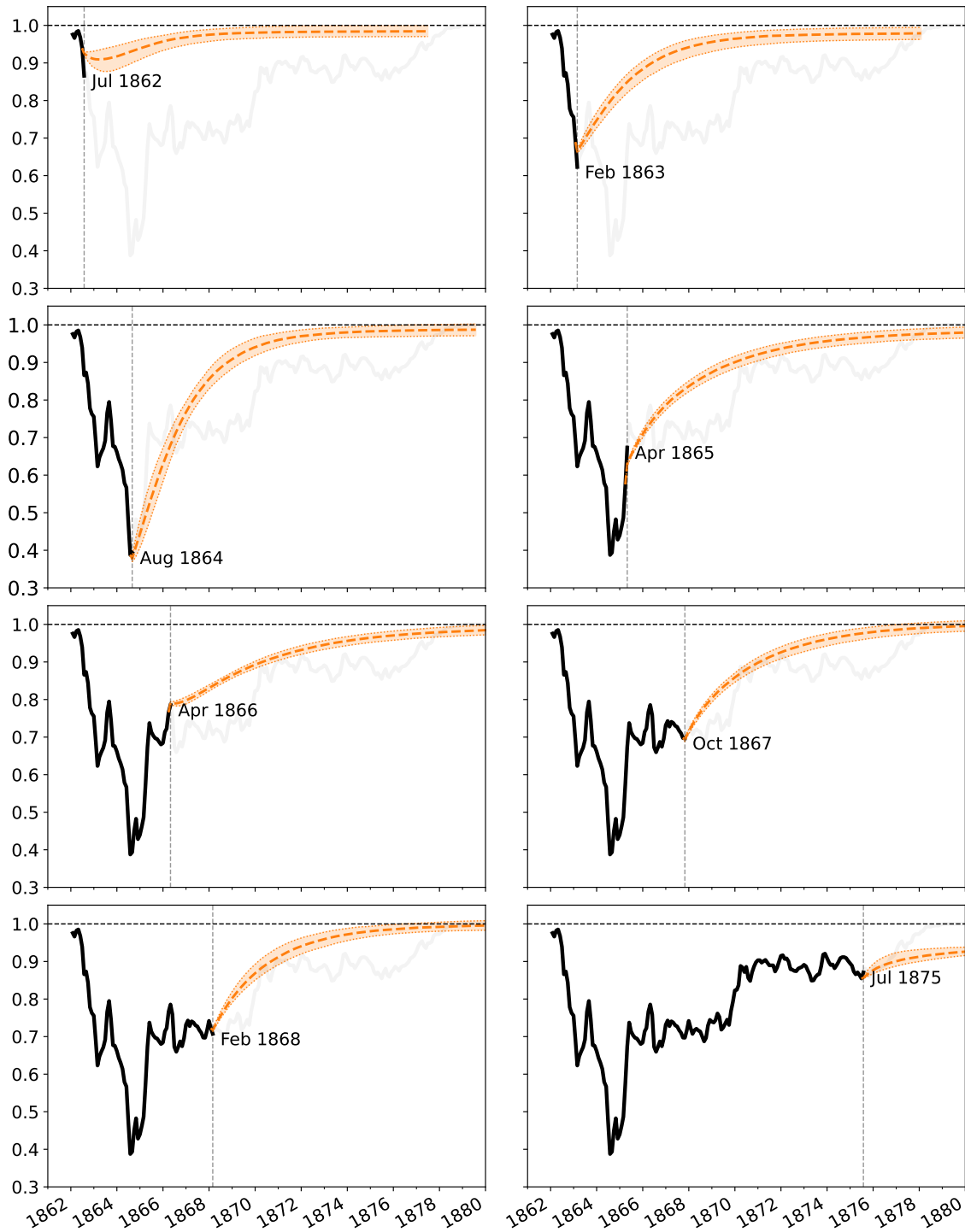


Figure 23 Evolution of Gold/Greenback Exchange Rate Expectations

On each plot, the black line shows the path of the gold/greenback exchange rate,  $P_t$ , up until a particular date. The gray line shows the continuation of the realized gold/greenback exchange rate after highlighted date. The dashed orange line shows our model's estimate of investors' expectations about the path of the gold/greenback exchange. The orange shaded area is the 90% interquartile range.

spread indicates an inverted yield curve (i.e., shorter maturity bonds have higher rates). Yield curves were typically upward sloping throughout the 19th century, with notable inversions during the War of 1812, the early 1830s, the Mexican-American War, the Civil War, and in the late 1890s.

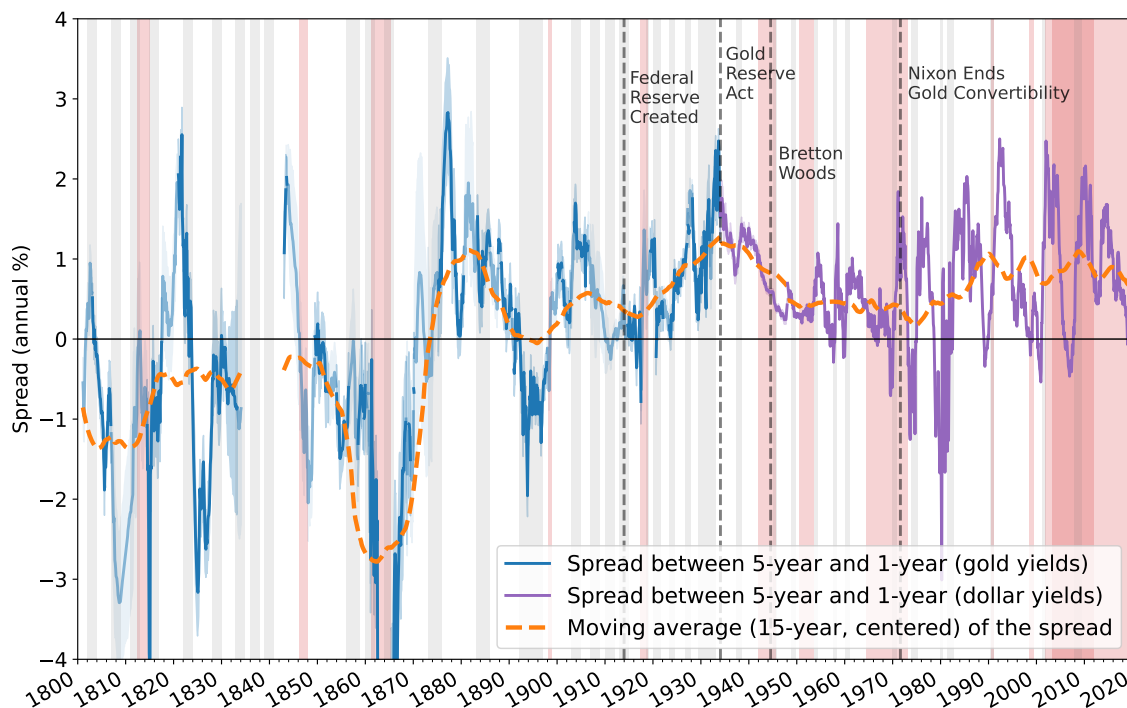


Figure 24 5 Year – 1 Year Yield Spread

The solid blue line depicts the yield on 5-year, gold denominated, zero coupon US government bonds minus the yield on 1-year, gold denominated, zero coupon US government bonds. The pale blue bands around the posterior mean depict the 95% interquartile range. The purple line depicts the same yield spread for dollar denominated bonds (after the US leaves the gold standard). The light gray intervals depict recessions as dated by Davis (2006) for the 1796-1914 period and NBER recessions thereafter. The dark gray intervals depict NBER recessions. The light red intervals depict wars (from left to right: the War of 1812, the Mexican-American War, the Civil War, the Spanish-American War, and World War I).

A large literature has used yields to help predict real GDP growth.<sup>65</sup> Our yield curve estimates open the way to extend such work back into the 19th century. As a preliminary step, our table 3 below emulates table 2 from Ang et al. (2006). It reports the coefficient  $\beta_k^{(j)}$  and  $R^2$  for the regression:

$$g_{t+k} = \alpha_k^{(j)} + \beta_k^{(j)}(y_t^{(10)} - y_t^{(j)}) + \varepsilon_{t+k,k}^{(j)}$$

<sup>65</sup>See Stock and Watson (2003) for a critical literature review.

where  $g_{t+k}$  is the annual percentage growth of real GDP over the next  $k$  years and  $y_t^{(j)}$  denotes the annualized  $j$ -year zero coupon yield for  $j \in \{1, 5\}$ . Notice that an upward sloping yield curve appears to be positively correlated with future economic growth during the 19th century even though no central bank existed to engage in “active” monetary policy.<sup>66</sup>

In table 3, we report the coefficients from the regression of the change in the spread on GDP growth and find additional suggestive evidence that 19th century spreads have some predictive ability.

Table 3 Forecasts of real GDP growth from term spreads

Horizon	1797-1860				1866-1933				1950-2000			
	Term spread maturity											
	10y - 1y		10y - 5y		10y - 1y		10y - 5y		10y - 1y		10y - 5y	
$k$ -years	$\beta_k^1$	$R^2$	$\beta_k^5$	$R^2$	$\beta_k^1$	$R^2$	$\beta_k^5$	$R^2$	$\beta_k^1$	$R^2$	$\beta_k^5$	$R^2$
1-year	0.23	0.040	0.42	0.018	0.07	0.000	0.46	0.002	1.28	0.230	3.54	0.159
	(0.12)		(0.37)		(0.32)		(0.80)		(0.46)		(1.66)	
3-year	0.79	0.084	1.63	0.051	0.31	0.002	1.00	0.003	1.56	0.103	2.71	0.028
	(0.31)		(0.99)		(0.81)		(1.83)		(0.72)		(1.13)	

The table reports the coefficient  $\beta_k^{(j)}$  and  $R^2$  for the regression  $g_{t+k} = \alpha_k^{(j)} + \beta_k^{(j)} (y_t^{(10)} - y_t^{(j)}) + \varepsilon_{t+k,k}^{(j)}$  where  $g_{t+k}$  is the annual percentage growth of real GDP over the next  $k$  years and  $y_t^{(j)}$  denotes the annualized  $j$ -year zero coupon yield. We annualize the yields by taking the arithmetic average for each year. Newey and West heteroskedasticity- and autocorrelation-consistent standard errors with lag order one in parentheses.

Table 4 replicates table 3 but uses the change in the spread rather than the level of the spread.

## J Additional Figures

<sup>66</sup>However, from 1897 until 1913, Republican Secretaries of the Treasury more and more violated the letter of the 1844 Independent Treasury Act by *de facto* conducting open market operations intended to lean against the wind.



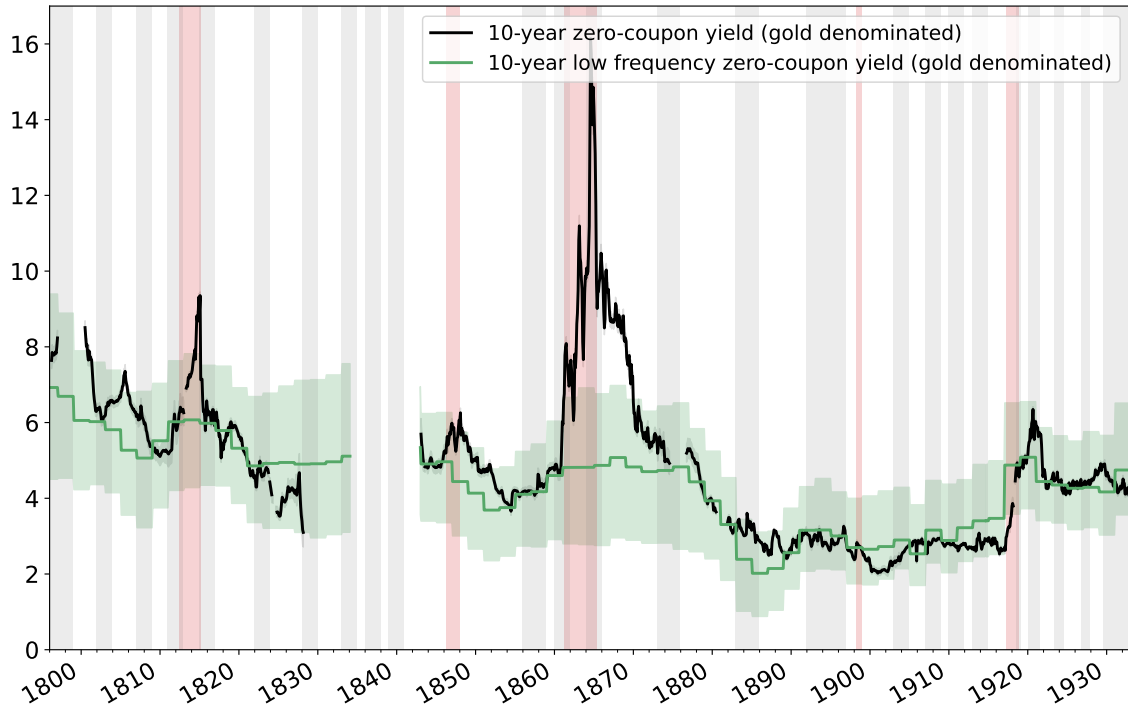


Figure 25 Low Frequency Zero Coupon Yield.

The solid black line depicts the mean of our posterior estimate for the 10-year, gold denominated, zero coupon yield. The grey bands around the posterior mean depict the 95% interquartile range. The solid green line depicts the mean of our posterior estimate for the low frequency component of the 10-year, gold denominated, zero coupon yield. The light green bands around the posterior mean depict the 95% interquartile range. The light gray intervals depict recessions as dated by [Davis \(2006\)](#) for the 1796-1914 period and NBER recessions thereafter. The light red intervals depict wars (from left to right: the War of 1812, the Mexican-American War, the Civil War, the Spanish-American War, and World War I).

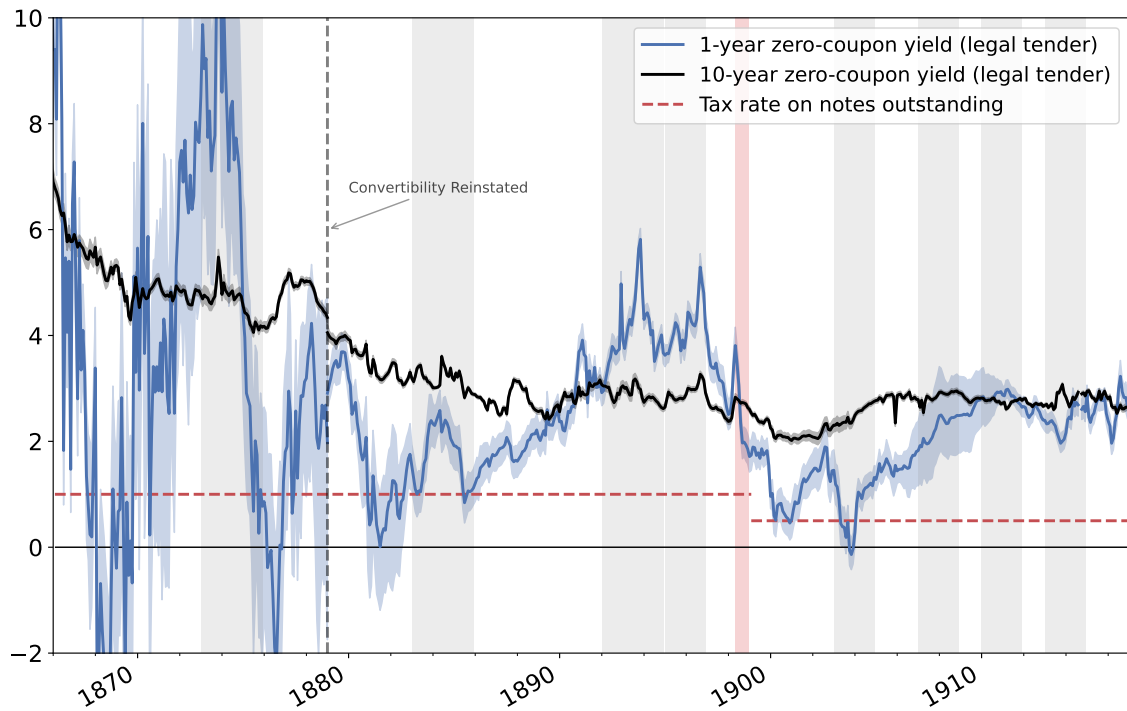


Figure 26 Comparison to Tax Rates on Outstanding Bank Notes

The red dashed line depicts the tax rate on note issuance. The solid black line depicts the mean of our posterior estimate for the 10-year, legal tender, zero coupon yield. The grey bands around the posterior mean depict the 95% interquantile range. The solid blue line depicts the mean of our posterior estimate for the 1-year, legal tender, zero coupon yield. The light blue bands around the posterior mean depict the 95% interquantile range. The black dashed line depicts the tax rate on note issuance. The light gray intervals depict recessions as dated by Davis (2006) for the 1796-1914 period and NBER recessions thereafter. The light red intervals depict wars (from left to right: the War of 1812, the Mexican-American War, the Civil War, the Spanish-American War, and World War I).

Table 4 Forecasts of real GDP growth from first differenced term spreads

Horizon	1797-1860				1866-1933				1950-2000			
	Term spread maturity											
	10y - 1y		10y - 5y		10y - 1y		10y - 5y		10y - 1y		10y - 5y	
$k$ -years	$\beta_k^1$	$R^2$	$\beta_k^5$	$R^2$	$\beta_k^1$	$R^2$	$\beta_k^5$	$R^2$	$\beta_k^1$	$R^2$	$\beta_k^5$	$R^2$
1-year	-0.20 (0.13)	0.015	-0.42 (0.31)	0.011	-0.01 (0.61)	0.000	0.37 (1.53)	0.001	1.06 (0.32)	0.128	3.81 (1.22)	0.136
3-year	0.57 (0.30)	0.022	0.54 (1.03)	0.003	0.63 (1.55)	0.003	3.27 (3.64)	0.010	2.32 (0.66)	0.166	5.99 (2.28)	0.100

The table reports the coefficient  $\beta_k^{(j)}$  and  $R^2$  for the regression  $g_{t+k} = \alpha_k^{(j)} + \beta_k^{(j)} \left( \left( y_t^{(10)} - y_t^{(j)} \right) - \left( y_{t-1}^{(10)} - y_{t-1}^{(j)} \right) \right) + \varepsilon_{t+k,k}^{(j)}$  where  $g_{t+k}$  is the annual percentage growth of real GDP over the next  $k$  years and  $y_t^{(j)}$  denotes the annualized  $j$ -year zero coupon yield. We annualize the yields by taking the arithmetic average for each year. Newey and West heteroskedasticity- and autocorrelation-consistent standard errors with lag order one in parentheses. \*\*\* 1%, \*\* 5%, and \* 10% significance.

## References

- Ang, A., Piazzesi, M., and Wei, M. (2006). What does the yield curve tell us about GDP growth? *Journal of econometrics*, 131(1-2):359–403.
- Bayley, R. A. (1882). *The National Loans of the United States, from July 4, 1776, to June 30, 1880*. Number 246. US Government Printing Office.
- Betancourt, M. (2018). A conceptual intro to Hamiltonian Monte Carlo.
- Board of Governors of the Federal Reserve System (1943). *Banking and Monetary Statistics, 1914-1941*. Board of Governors of the Federal Reserve System, Washington D.C.
- Chernow, R. (2001). *The House of Morgan: An American Banking Dynasty and the Rise of Modern Finance*. Grove Press.
- Cogley, T. (2005). Changing beliefs and the term structure of interest rates: Cross-equation restrictions with drifting parameters. *Review of Economic Dynamics*, 8(2):420–451. Monetary Policy and Learning.
- Cogley, T. and Sargent, T. J. (2005). Drifts and volatilities: monetary policies and outcomes in the post WWII US. *Review of Economic Dynamics*, 8(2):262–302.
- Cogley, T. and Sargent, T. J. (2015). Measuring price-level uncertainty and instability in the United States, 1850-2012. *The Review of Economics and Statistics*, 97(4):827–838.

- Davis, J. H. (2004). An annual index of U.S. industrial production, 1790–1915. *The Quarterly Journal of Economics*, 119(4):1177–1215.
- Davis, J. H. (2006). An improved annual chronology of u.s. business cycles since the 1790s. *The Journal of Economic History*, 66(1):103–121.
- Dewey, D. R. (1922). *Financial History of the United States, Eighth edition*. Longmans, Green, and Co., New York.
- English, W. B. (1996). Understanding the costs of sovereign default: American state debts in the 1840's. *The American Economic Review*, 86(1):259–275.
- Evans, P. (1985). Do large deficits produce high interest rates? *The American Economic Review*, 75(1):68–87.
- Evans, P. (1987). Interest rates and expected future budget deficits in the united states. *Journal of Political Economy*, 95(1):34–58.
- Hall, G. J. and Sargent, T. J. (2011). Interest Rate Risk and Other Determinants of Post-WWII US Government Debt/GDP Dynamics. *American Economic Journal: Macroeconomics*, 3(3):192–214.
- Hamilton, J. D., Harris, E. S., Hatzius, J., and West, K. D. (2016). The Equilibrium Real Funds Rate: Past, Present, and Future. *IMF Economic Review*, 64(4):660–707.
- Hoffman, M. D. and Gelman, A. (2014). The No-U-Turn sampler: Adaptively setting path lengths in hamiltonian monte carlo. *Journal of Machine Learning Research*, 15(47):1593–1623.
- Homer, S. and Sylla, R. E. (2004). *A History of Interest Rates*. Rutgers University Press.
- 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.
- Kreps, D. M. (1998). *Anticipated Utility and Dynamic Choice (1997)*, page 242–274. Econometric Society Monographs. Cambridge University Press.
- Lewandowski, D., Kurowicka, D., and Joe, H. (2009). Generating random correlation matrices based on vines and extended onion method. *Journal of Multivariate Analysis*, 100(9):1989 – 2001.
- Martin, J. G. (1886). *Martin's Boston Stock Market: Eighty-eight Years, from January 1, 1798, to January, 1886*. The author.

- McGrane, R. C. (1935). *Foreign Bondholders and American State Debts*. New York: The Macmillan Company.
- Mitchell, W. C. (1908). *Gold, Prices, and Wages under the Greenback Standard*. University of California, Berkeley, California.
- Noyes, A. D. (1909). *Forty Years of American Finance: A Short Financial History of the Government and People of the United States Since the Civil War, 1865-1907*. GP Putnam's Sons.
- Officer, L. H. and Williamson, S. H. (2021). Explaining the measures of worth. *Measuring Worth*.
- Papp, T. K., Aluthge, D., JackRab, Widmann, D., TagBot, J., and Piibeleht, M. (2021). tpapp/dynamichmc.jl: v3.1.0. Julia package version 3.1.0.
- Razaghian, R. (2002). Financial credibility in the united states: The impact of institutions, 1789-1860. Data made available through the International Center for Finance at Yale University.
- Register's Office, U. T. (1886). *Statement of Receipts and Expenditures of the Government (by Warrants) from July 1, 1855, to June 30, 1885 and Statement of Principal of Public Debt from 1791 to 1836 by Issues and Redemptions, and From January 1, 1836, to June 30, 1885 by Warrants*. Government Printing Office, Washington DC.
- Shiller, R. J. (2015). *Irrational Exuberance, 3rd edition*. Princeton University Press, revised and expanded third edition edition.
- Stock, J. H. and Watson, M. (2003). Forecasting output and inflation: The role of asset prices. *Journal of Economic Literature*, 41(3):788–829.
- Sylla, R. E., Wilson, J., and Wright, R. E. (2006). Early U.S. security prices. <http://eh.net/databases/early-us-securities-prices>.
- U.S. Department of the Treasury (1869-2015). *Monthly Statement of the Public Debt*. U.S. Treasury Department.
- Warren, G. F., Pearson, F. A., Stoker, H. M., et al. (1932). Wholesale prices for 213 years, 1720 to 1932.