A history of large-scale asset purchases before the Federal Reserve

Benjamin Chabot and Gabe Herman

Introduction and summary

The Federal Reserve's preferred policy instrument—the overnight federal funds rate—approached zero at year-end 2008. With the zero lower bound constraining additional policy accommodation through traditional channels, the Federal Reserve began a series of large-scale asset purchases (LSAPs). The goal of the Fed's LSAP strategy is to place downward pressure on yields of a wide range of longer-term securities, foster mortgage markets, and encourage a stronger economic recovery.[1] While a consensus has emerged that LSAPs have lowered yields on U.S. Treasury bonds and other long-maturity, high-duration assets (thus increasing their prices),[2] considerable uncertainty remains as to the magnitude of these yield changes and the exact channels by which central bank purchases influence yields.[3] Much of this uncertainty stems from the fact that researchers have only a few examples of large open market purchases of government-guaranteed bonds to study. Central banks have traditionally preferred to implement monetary policy by altering short-term interest rate targets rather than utilize their balance sheets as a policy tool. Most of what we know about the effectiveness of LSAPs and the magnitude of their effects, therefore, come from evaluations of the small number of episodes when central banks wished to stimulate their economies but the traditional tool—the short-term policy rate—was constrained by the zero lower bound of nominal interest rates.[4]

In this article, we assemble a new historical database of monthly U.S. Treasury bond prices, contract terms, and amounts outstanding between 1870 and 1913. These new data allow us to look beyond the traditional empirical sample of LSAPs by examining the numerous large open market operations conducted by the U.S. Department of the Treasury during this pre-Fed era. During this period, the Treasury engaged in many refundings and open market sinking fund purchases[5] that resulted in dramatic changes in the quantity and duration of aggregate Treasury bonds outstanding. These refundings and sinking fund purchases provide us with an opportunity to measure the effects of changes in the amount and duration of Treasury bonds on equilibrium yields.[6] We compare the price response of high- and low-duration bonds to changes in the amount and aggregate duration of Treasury bonds outstanding, and find purchases of Treasury securities made by the U.S. Treasury Department narrowed the yield spread between Treasury bonds with high interest rate risk (the risk of an investment's value changing on account of interest rate changes)[7] and those with low interest rate risk.

Benjamin Chabot is a financial economist and Gabe Herman is an associate economist in the Economic Research Department at the Federal Reserve Bank of Chicago.

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LSAP channels

Theory suggests LSAPs can lower equilibrium bond yields through three channels, which we label *scarcity*, *duration*, and *signaling*. The *scarcity* channel, which is sometimes referred to as the portfolio-balance channel, is associated with the preferred habitat literature pioneered by James Tobin, Franco Modigliani, and Richard Sutch.[8] Because of differences in asset risk characteristics or regulation, some investors prefer to hold certain assets and are reluctant or unable to hold alternative assets. For example, regulatory restrictions force money market funds to hold short-maturity assets, while insurance companies may prefer to hold long-maturity assets that match the duration of their liabilities; moreover, a bank that wishes to hedge the duration and negative convexity[9] embedded in its mortgage portfolio will prefer to short sell[10] long-maturity Treasury securities. Therefore, different classes of financial assets are not perfectly substitutable in investors' portfolios and changes in the relative supply of preferred assets may alter their equilibrium prices and yields.

There is every reason to believe that pre-1913 investors also preferred to hold certain bonds because of differences in asset risk characteristics or regulatory restrictions. The National Banking Acts of 1863 and 1864, for instance, provided regulatory incentives for national banks located outside "reserve cities" to deposit a portion of their reserves in reserve city national banks.[11] These deposits could then be lent in the secured overnight call market[12] where U.S. Treasury bonds were considered premium collateral, which required a smaller haircut[13] than other securities. While most data on overnight lending are unavailable, the New York Superintendent of Insurance required insurance companies doing business in the state to report the collateral accepted and haircuts demanded to secure overnight loans appearing on their year-end balance sheets. An 1872 sample of this year-end insurance data confirms the favored status of government bond collateral (and especially low-duration government bonds): Insurance companies lent overnight against Treasury bond collateral with an average haircut of 11.2 percent, which was much lower than an average haircut of 23.2 percent on all collateral.[14]

National banks were also required to hold Treasury bonds as collateral against bank note issuance or government deposits. The funding needs of each bank and the price and risk characteristics of each Treasury bond issue determined how appealing a given Treasury bond was as collateral. For example, a high-coupon Treasury bond trading above face (par) value would secure more funding when it was pledged as collateral in the interbank call market (where bonds were haircut from market value) than when it was pledged as collateral for bank note issuance or government deposits (for which legal requirements valued all government bonds at the minimum of par or market value). Therefore, a high-coupon, low-duration bond was better collateral for a bank that funded in the wholesale call market than a bank that funded via bank note issuance and government deposits. These differences were indeed reflected in the use of outstanding Treasury bonds as collateral. If we define high-duration Treasury bonds as bonds of this type with durations above the median duration of all Treasury bonds outstanding, 44 percent of the market value of all Treasury bonds was in high-duration bonds at year-end 1872. Despite accounting for four-ninths of all Treasury bonds outstanding, high-duration bonds accounted for only 18.3 percent of Treasury bonds posted as collateral for overnight loans from insurance companies.[15] However, high-duration bonds accounted for 82.2 percent of Treasury bonds posted to secure bank note issuance.[16]

Legal differences in circulation privileges, taxes, and option-induced[17] convexity likely resulted in less-than-perfect substitutability among bonds in the portfolios of certain investors during the pre-Fed era. When bonds are not perfectly substitutable, the scarcity channel implies that LSAPs can raise the prices of the purchased assets and similar assets but will have a limited effect on the prices of dissimilar assets. However, there are reasons to believe that LSAPs' effect on asset prices through the scarcity channel is *not* monotonic. If open market purchases remove too much supply from a segmented basket of assets, the resulting decrease in liquidity (the ease at which an asset can be converted into cash) may make the remaining assets unattractive to investors who previously preferred to hold them. This concern is reflected in the current Federal Reserve policy to limit aggregate system open market account holdings of each Treasury bond issue to no more than 70 percent of outstanding issuance.[18]

The *duration* channel also arises from the existence of preferred habitat investors, and it likely existed during the pre-Fed era. Unlike the scarcity channel where asset purchases should only affect the prices of the purchased assets and similar assets, the removal of interest rate risk or duration risk[19] from the market via LSAPs should affect the risk premium of all assets in proportion to their sensitivity to interest rate changes. In the model of Vayanos and Vila (2009), for example, the presence of preferred habitat investors who are willing to accept lower returns to hold assets in a preferred maturity neighborhood creates profitable trading opportunities for other risk-averse investors—called arbitrageurs—who are willing to trade assets of any maturity. These willing traders can earn excess profits by holding assets that are out of favor with preferred habitat investors and short selling the assets that are in favor with those investors. The preferred habitat investors' trading strategy exposes arbitrageurs to aggregate interest rate risk for which they must be compensated. In this framework, LSAPs can lower the equilibrium risk premium embedded in bond yields by removing aggregate duration risk from the portfolios of arbitrageurs.

The final channel, which we call the *signaling* channel, is based on the insight that increases in central bank open market purchases can be interpreted as a signal of a more accommodative policy stance.[20] If this signal results in a lowering of investors' expectations for the future path of policy rates, open market purchases can lower the yield on longer-term assets by lowering expectations of future short-term interest rates. The United States had no central bank during our period of study, and the entity that conducted open market sales and purchases—the Treasury—did not (and perhaps could not) target any policy rate. Because the Treasury did not target a policy rate, our time period is an ideal laboratory to identify the effects of altering the duration and scarcity of Treasury bonds outstanding without a signaling channel confounding our measurements.

Data: The market price and amount outstanding of U.S. Treasury debt in 1870–1913

We document the large-scale asset purchases of the pre-Fed era by collecting information about the amount outstanding and cash flow characteristics of each Treasury bond in existence between 1870 and 1913. Our main source is the U.S. Department of the Treasury's *Monthly Statement of the Public Debt* (MSPD) database.[21] The statements in this database report the amounts outstanding of each bond issue on or near the last day of the month. Also included in the statements are a number of bond characteristics necessary for specifying each bond's promised cash flow—such as the coupon rate, the month(s) in which the interest payments are made, the schedule of final maturity payments, and the terms of any embedded options. During our period of study, a majority of United States bonds contained call option clauses granting the government the right, but not the obligation, to retire all or part of the issue outstanding for a particular price after a vesting date but before the bond's maturity date (if it had one). For most bonds, the MSPD database includes the date on which the government's call option vests. In cases where information from the MSPD database was unclear, we determined option characteristics by locating the contract language of the bonds in De Knight (1900).

We collect price data from the New York Stock Exchange (NYSE) closing bid and ask prices reported in the *Commercial & Financial Chronicle*, the *New York Times*, and the *New York Tribune*. Because some debt issues were not regularly quoted on the NYSE, we were able to find NYSE price quotations for only 77 percent of the monthly bond listings that appeared in the MSPD. We replaced the missing 23 percent of bond prices with model-generated prices by fitting a term structure of interest rates (yield curve)[22] and implied volatility[23] to the observable bonds via the Hull–White model described in the next section.

Measuring the duration of U.S. Treasury debt in 1870–1913

Using the market prices, amounts outstanding, and cash flow characteristics of U.S. Treasury bonds from the data sources described in the previous section, we compute the Macaulay duration of each bond each month to form a monthly time series of the aggregate duration risk of U.S. Treasury bonds during our sample period.

Option-free bonds with observable market prices

We begin by computing the Macaulay duration of each option-free bond. When a bond has an observable market price and a nonstochastic cash flow, Macaulay's duration is as follows:

$$\text{1)}\quad Dur = \sum_{t=1}^{T} \frac{\frac{(t)CF_t}{(1+ytm)^t}}{P},$$

where P is the bond's price, CF_t the bond's cash flow at time t, and ytm is the bond's yield to maturity measured at the same frequency as the coupon payments.

Bonds with embedded options or no market price

Fifty-eight percent of the bonds in our database have embedded options, which grant the Treasury the right, but not the obligation, to retire the bond at par after a vesting date but before the bond's final maturity date. Options alter the duration of a bond by transforming the bond's cash flow into a function of stochastic future interest rates. We use the Hull–White model to compute the option-adjusted durations of bonds with embedded options.[24]

The Hull–White model is a single-factor no-arbitrage model of the term structure of interest rates in which the short-term rate is assumed to evolve via a stochastic differential equation with mean reversion. Given an initial zero-coupon yield curve (zero curve),[25] we can use the model to compute the value and duration of an option-embedded bond as a function of the volatility of the short-term rate and the degree of mean reversion. To implement the Hull–White model, we require an initial zero-coupon yield curve and the volatility and degree of mean reversion for the short-term rate. None of these initial parameters are directly observable during our time period,[26] but we can calibrate each by fitting a zero curve, implied volatility, and mean-reversion parameter to best match observable bond prices.

We select a time-invariant coefficient of mean reversion and, for each month in our data set, an implied volatility and a linear zero curve (level and slope coefficients) to best fit the observable bond price data.[27] The result is a monthly time series of estimated zero curves and implied volatilities. With these parameter estimates in hand, we use the Hull–White model to compute the option-adjusted duration for each bond with an embedded option and generate the model-implied price and duration for the option-free bonds with missing price data.

Aggregate duration risk of U.S. Treasury debt in 1870–1913: Ten-year-equivalent debt outstanding

With duration estimates and amounts outstanding in hand, we compute a monthly time series of ten-year-equivalent U.S. Treasury debt outstanding. A ten-year equivalent is a common measurement for interest rate risk in a portfolio. To express a portfolio's interest rate risk in ten-year-equivalent units, we first compute how much the portfolio's dollar value will change for a given change in yields and then compute how many bonds with ten-year duration one would have to hold to experience the same change in portfolio value. Thus, the ten-year-equivalent U.S. Treasury debt outstanding is

$$2)\quad 10yearEq = \Sigma_{n=1}^{N}\left(\frac{Dur_n}{3650}\right)MV_n,$$

where N is the number of bonds in the portfolio, Dur_n is the duration in days of the nth bond, and MV_n is the market value of the nth bond.

Figure 1 graphs the outstanding U.S. Treasury bonds' par value (the size) and ten-year-equivalent value (representing the aggregate interest rate risk) over the period 1870–1913. As we will discuss in more detail in the next section, when the ten-year-equivalent value rises, it indicates that aggregate interest rate risk borne by holders of Treasury bonds has increased. Aggregate interest rate risk can rise because the Treasury issues more risky bonds in total that must be held by the public (for example, during the 1893–99 period in figure 1) or because the existing bonds become more sensitive to interest rate changes (for example, during the 1876–79 period in figure 1).

LSAPs: 1870–1913

The refunding of the U.S. Civil War debt in the late 1870s, the bond issuance associated with the return to the gold standard in 1879, the sinking fund open market purchases of the 1880s, and the deficit funding of the 1890s all provide examples of dramatic changes in the duration or amount of U.S. Treasury bonds outstanding.[28]

The refunding of Civil War debt replaced low-duration bonds with an almost equal amount of high-duration bonds (a reverse Operation Twist[29]) and more than doubled the ten-year-equivalent size of outstanding U.S. Treasury bonds held by the public (see figure 2, panel A).

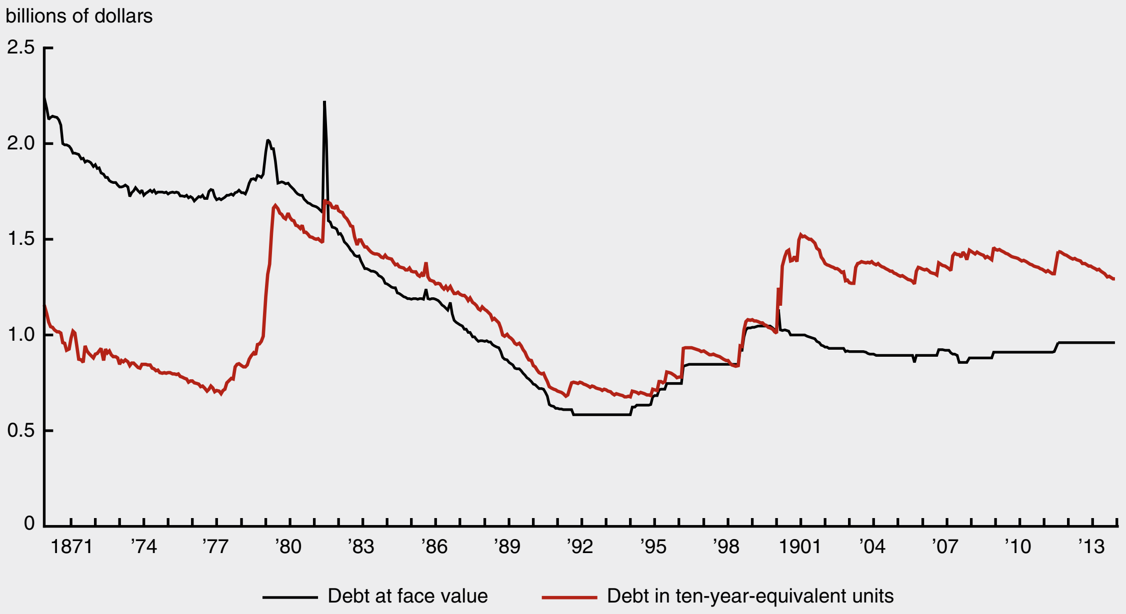
The Civil War was largely financed by the issuance of legal tender notes (greenbacks) and the flotation of a series of bond offerings known to the market as the 5-20s and 10-40s. The 5-20s and 10-40s paid a 6 percent coupon maturing in 20 and 40 years, respectively, with embedded government call options vesting after five and ten years, respectively.

By 1876, long-term interest rates on U.S. Treasury bonds had fallen well below 6 percent, and the Treasury took advantage of the lower prevailing rates by issuing option-free 4.5 percent, 15-year bonds in 1876 and 4 percent, 30-year bonds in 1877 at prices above par.[30] The Treasury used the proceeds from these bond sales to retire the high-coupon 5-20s and 10-40s by exercising the call options embedded in them. Because the 5-20s and 10-40s had coupons well above both prevailing and forward interest rates, their embedded call options were deeply *in the money*[31] and these bonds had lower durations compared with the new 15- and 30-year bond issuances that replaced them.

The funding act that passed on February 25, 1862, instructed the Secretary of the Treasury to set aside the annual surplus from custom revenues for the establishment of a sinking fund to retire at least 1 percent of outstanding U.S. debt per annum by making open market purchases or by exercising embedded call options. There was no attempt to comply with the law during the Civil War and subsequent Treasury Secretaries used their own interpretations to largely ignore the sinking fund provision during the Depression of 1873 and the periods of bond issuance associated with the resumption of the gold-standard convertibility in

FIGURE 1

The size and interest rate risk of U.S. Treasury bonds, 1870–1913



Notes: The data are month-end values. A ten-year equivalent is a common measurement for interest rate risk in a portfolio. This figure only includes positive duration obligations of the U.S. Treasury. Zero-duration liabilities, such as Treasury notes (cash in circulation), coinage, and pension funds, appear on the Treasury's *Monthly Statement of the Public Debt* but have no effect on the ten-year-equivalent size of the U.S. portfolio and are excluded from the face value calculations. See the text for further details.

Sources: Authors' calculations based on data from the U.S. Department of the Treasury, *Monthly Statement of the Public Debt* database; De Knight (1900); and New York Stock Exchange quotations in the *Commercial & Financial Chronicle*, *New York Times*, and *New York Tribune*.

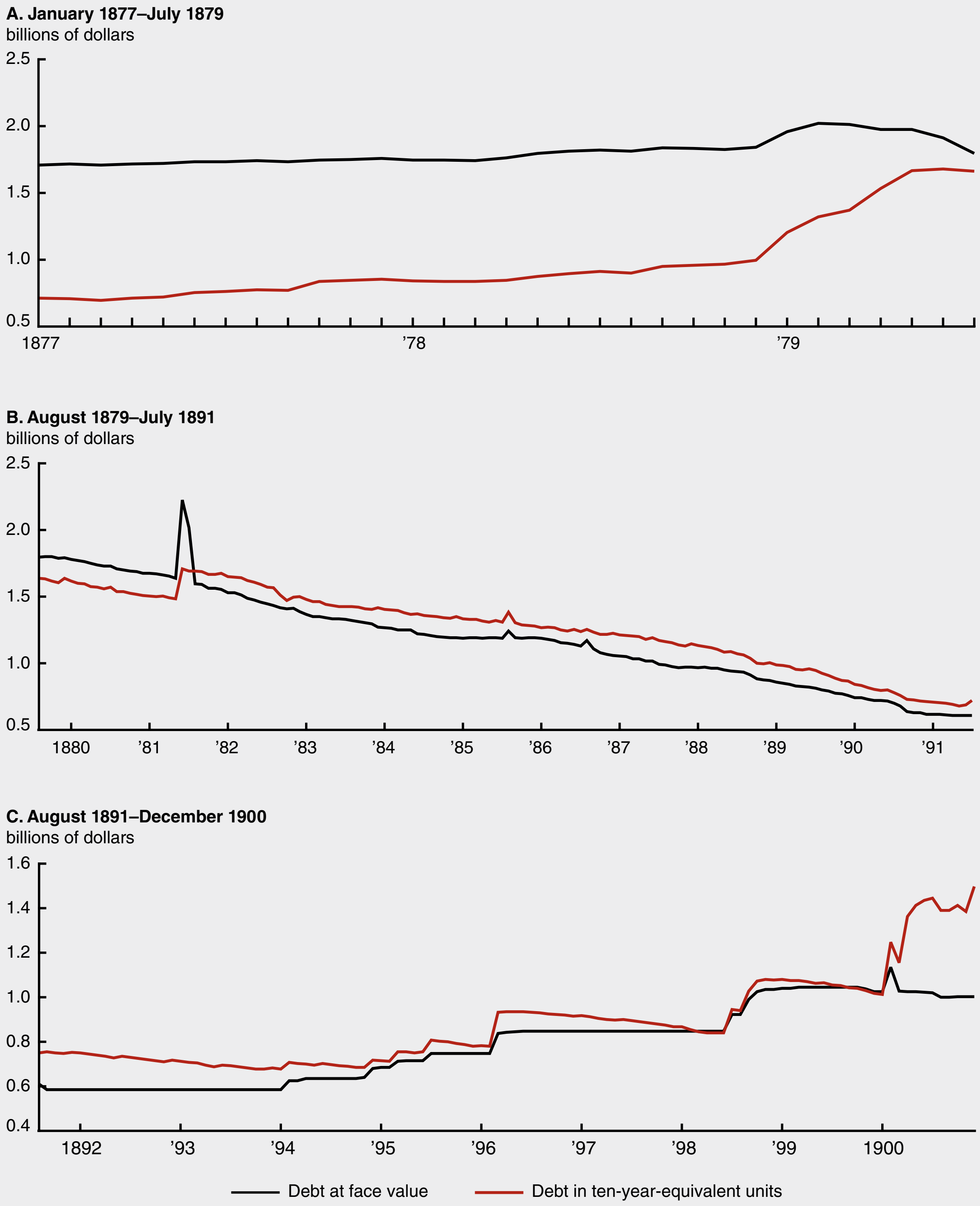
January 1879. The issuance of new debt in the first half of 1879 resulted in a dramatic increase in the ten-year-equivalent duration (and, hence, the aggregate interest rate risk) of outstanding debt (see figure 2, panel A).[32]

Between 1879 and 1890, however, the Treasury enjoyed large fiscal surpluses and Treasury Secretaries regularly employed the sinking fund to retire outstanding Treasury debt.[33] The Treasury retired debt by making open market purchases or exercising call options in 79 percent of the months over the period August 1879 through July 1891. By July 1891, the cumulative effect of making these purchases and exercising the call options had reduced the par value of Treasury bonds in the hands of the public by 68 percent and the ten-year-equivalent duration of outstanding Treasury debt by 59.4 percent.

With one exception, the sinking fund purchases resulted in a nearly monotonic decline in both the duration and face value of Treasury bonds held by the public during the 1880s. The exception was a refunding of maturing debt in 1881, which increased the aggregate duration of outstanding Treasury debt by almost 15 percent while leaving the supply of Treasury bonds virtually unchanged. A 5 percent bond matured on May 1, 1881, and three separate 6 percent coupon bonds matured on either June 30 or July 1, 1881. With interest rates on both secured overnight loans and long-term Treasury bonds close to 3 percent, the Treasury offered holders of these maturing bonds the choice of converting their bonds into 3.5 percent perpetual bonds callable at the pleasure of the government (that is, bonds without maturity dates that may be retired by the Treasury Department when it exercises their call options).[34] Because of the uncertainty about how many bondholders would accept the conversion offer, the Treasury issued short-term refunding certificates that were redeemed in September 1881. These certificates added zero duration risk but accounted for the two-month spike in the face value of outstanding Treasury bonds, as shown in figure 2, panel B. The conversion offer was accepted by approximately 90 percent of bondholders. While this conversion had virtually no effect on the total amount of Treasury debt outstanding, the introduction of callable perpetual bonds with coupons only 50 basis points above market rates dramatically increased the interest rate risk held by the public.

FIGURE 2

The size and interest rate risk of U.S. Treasury bonds, by subperiods



Notes: The data are month-end values. A ten-year equivalent is a common measurement for interest rate risk in a portfolio. This figure only includes positive duration obligations of the U.S. Treasury. Zero-duration liabilities, such as Treasury notes (cash in circulation), coinage, and pension funds, appear on the Treasury's *Monthly Statement of the Public Debt* but have no effect on the ten-year-equivalent size of the U.S. portfolio and are excluded from the face value calculations. The refunding of Civil War debt is covered in panel A. The refunding of 1881 and sinking fund purchases are covered in panel B. The deficit funding of the 1890s and the refunding of 1900 are covered in panel C. See the text for further details.

Sources: Authors' calculations based on data from the U.S. Department of the Treasury, *Monthly Statement of the Public Debt* database; De Knight (1900); and New York Stock Exchange quotations in the *Commercial & Financial Chronicle*, *New York Times*, and *New York Tribune*.

By October 1891, sinking fund purchases had reduced the face value of Treasury bonds outstanding to $585.4 million. However, the recessions of 1890 and 1893 eliminated the budget surpluses the Treasury had relied upon for debt purchases. The Treasury was forced to reenter the market in 1894 and float bonds to replenish its rapidly dwindling stock of gold. Between 1894 and 1898, the Treasury issued option-free ten-year and 30-year bonds and a 20-year bond callable after ten years. By November 1898, the cumulative effect of these issues had raised the face value of Treasury bonds outstanding by 78 percent and the ten-year-equivalent duration of outstanding Treasury debt held by the public by 59 percent (see figure 2, panel C).

By 1900, long-term interest rates had declined to less than 2 percent. The Treasury took advantage of these low rates by issuing a 30-year, 2 percent coupon bond at an initial yield to maturity of 1.82 percent. The majority of this bond offering was issued in a voluntary exchange for outstanding 5 percent coupon bonds due in 1904, 4 percent coupon bonds due in 1907, and callable 2 percent perpetual bonds. By replacing these low-duration bonds with a high-duration bond, the 1900 refunding acted like a reverse Operation Twist, which effectively increased the ten-year-equivalent interest rate risk held by the public by 39.5 percent in just three months.

Constructing a test portfolio of high-duration bonds minus low-duration bonds

A number of open market operations are apparent in figure 1 (p. 144). Periods without new issuance of Treasury debt resulted in a decline in the duration of Treasury bonds held by the public with no corresponding change in the amount of bonds outstanding that could serve as collateral. Likewise, the federal government's refunding of maturing debt with new long-term bond issuance resulted in jumps in the duration of Treasury debt held by the public without a corresponding change in bonds outstanding. Finally, the federal government's open market sinking fund purchases resulted in a decrease in both the amount outstanding and duration of Treasury bonds held by the public. These operations allow us to disentangle changes in duration risk of outstanding Treasury debt from changes in the amount of Treasury bonds available as collateral.

We evaluate the relative importance of changes in the aggregate duration and total supply of Treasury bonds by constructing a portfolio of high-duration bonds minus low-duration bonds. We construct this portfolio by sorting all bonds with observable market prices in each time period into a basket of high-duration bonds or one of low-duration bonds based on whether the bond's duration is above or below the median duration of the set of bonds in existence on that date. The portfolio of high-duration bonds minus low-duration bonds is then formed by computing the difference between the holding-period returns of the basket of equally weighted high-duration bonds and the basket of equally weighted low-duration bonds. We refer to this test portfolio as the high-minus-low (HML) portfolio.

We can use the return on the HML portfolio to measure the relative importance of changes in aggregate duration and local supply of Treasury bonds outstanding. If there is a duration-risk premium, it should be apparent in the return of the HML portfolio. High-duration bonds expose their investors to more interest rate risk. Therefore, the price of high-duration Treasury bonds should be more sensitive to changes in the aggregate duration of Treasury bonds held by the public. That said, because of the more volatile market price of high-duration Treasury bonds, they often require larger haircuts and are considered worse collateral than low-duration Treasury bonds. We would expect, all else being equal, high-duration Treasury bonds to be less sensitive than low-duration Treasury bonds to changes in the total supply of Treasury bond collateral available to the market.[35]

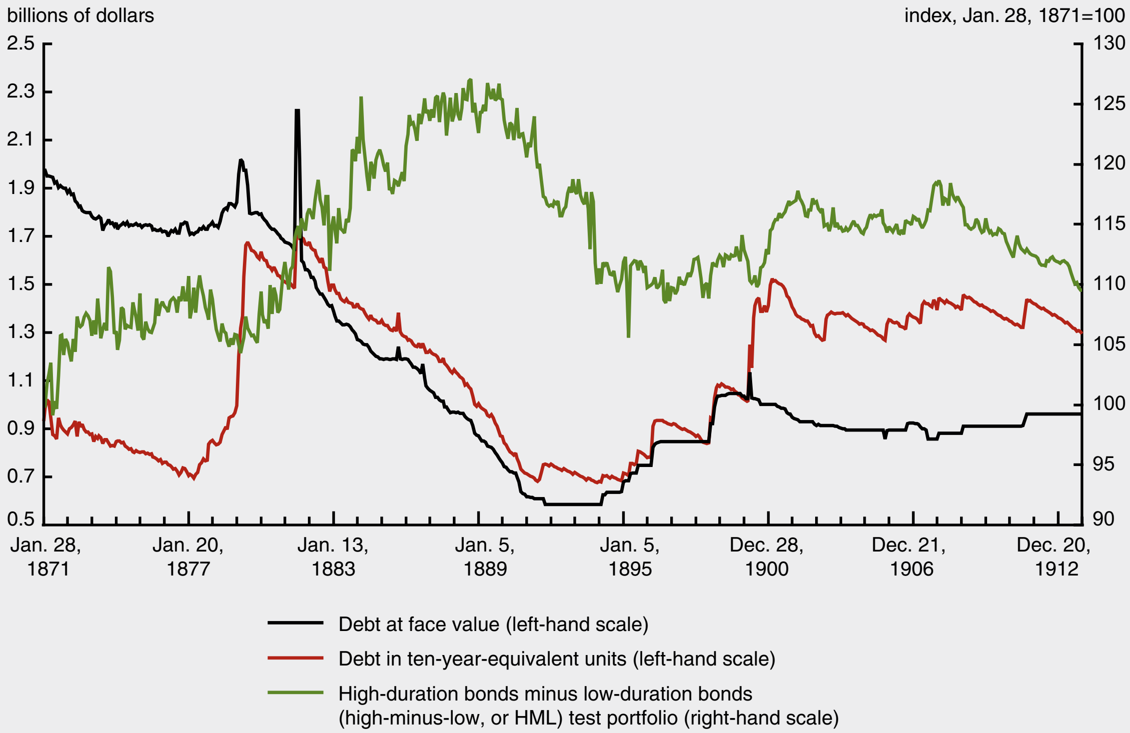
Figure 3 plots the index of cumulative holding-period returns of the HML portfolio. Consistent with a positive term premium,[36] the high-duration bonds outperformed the low-duration bonds by an average of 22 basis points per year over our sample period. However, there were long periods where high-duration bonds dramatically outperformed or underperformed low-duration bonds, and these swings in their relative performance often coincided with changes in the amount (as represented by the face value measure in figure 3) or duration (as represented by the ten-year-equivalent measure) of outstanding Treasury bonds. For example, high-duration bonds outperformed low-duration bonds during the 1880s—when both the supply and aggregate duration risk of Treasury bonds held by the public dramatically declined—and underperformed low-duration bonds in the 1890s—when the supply and aggregate duration risk of Treasury bonds held by the public increased. This is evident in figure 3, which shows an increase in the HML portfolio index during the 1880s and a decrease in the 1890s.

Measuring the effects of historical LSAPs

The numerous refundings and sinking fund purchases between 1870 and 1913 provide us with a unique laboratory in which to measure the sensitivity of bond prices (and yields) to changes in the quantity or duration of outstanding Treasury debt. Moreover,

FIGURE 3

The size and interest rate risk of U.S. Treasury bonds and the HML portfolio index, 1871–1913



Notes: The data are collected every 28 days because of the HML test portfolio, which relies on prices that are collected from the *Commercial & Financial Chronicle* (a weekly publication) that published Friday prices. A ten-year equivalent is a common measurement for interest rate risk in a portfolio. This figure only includes positive duration obligations of the U.S. Treasury. Zero-duration liabilities, such as Treasury notes (cash in circulation), coinage, and pension funds, appear on the Treasury's *Monthly Statement of the Public Debt* but have no effect on the ten-year-equivalent size of the U.S. portfolio and are excluded from the face value calculations. See the text for further details.

Sources: Authors' calculations based on data from the U.S. Department of the Treasury, *Monthly Statement of the Public Debt* database; De Knight (1900); and New York Stock Exchange quotations in the *Commercial & Financial Chronicle*, *New York Times*, and *New York Tribune*.

the magnitude of the change in the size or duration of outstanding Treasury bonds due to pre-1913 LSAPs dwarfs that of the change in the size or duration of them due to the modern LSAPs. Pre-1913 interest rates were not constrained by a zero lower bound, and the Treasury did not target a short-run policy rate. Together, these facts make the period between 1870 and 1913 an ideal era for studying the sensitivity of bond prices to changes in the aggregate duration of Treasury bonds or their quantity available as collateral without the confounding effects of policy rate signaling by a central bank. However, the small number of Treasury bonds in existence during the pre-1913 era makes it difficult, if not impossible, to identify price changes due to the traditional scarcity channel of bond purchases. Recall that the effects of the scarcity channel should only be reflected in the prices of similar, substitutable securities. Researchers studying modern LSAPs measure the scarcity channel by carefully selecting bonds with cash flow characteristics that are practically identical to those of the bonds purchased by the central bank.[37] During the period between 1870 and 1913, the Treasury seldom had more than a handful of different bonds outstanding at any given time, and these bonds differed greatly with respect to embedded options, maturity, and coupon rate. As a result, close substitutes are hardly ever available. We can nonetheless infer the existence of preferred habitat investors by examining the effects of changes in the total supply and aggregate duration of Treasury bonds on the holding-period returns of high- and low-duration bonds.

We measure the effects of changes in the total supply and aggregate duration of U.S. Treasury bonds by estimating the following monthly regression:

$$3)\quad Ret_{HML\_Dur} = \alpha + \beta_1(\%\Delta AggDur) + \beta_2(\%\Delta FV) + \beta_3(\Delta\%HD) + \beta_4(Ret_{all\_bonds}) + \varepsilon,$$

where Ret_{HML_Dur} is the holding-period return on the HML portfolio; $\%\Delta AggDur$ is the percentage change in aggregate ten-year-equivalent duration outstanding; $\%\Delta FV$ is the percentage change in the aggregate face value of U.S. Treasury bonds outstanding; $\Delta\%HD$ is the change in the proportion of high-duration Treasury bonds outstanding relative to all Treasury bonds outstanding, with the proportion defined as $(FV_{HDbonds}/FV)$, where $FV_{HDbonds}$ and FV are the face value of bonds with durations above the median and the face value of all bonds, respectively; and Ret_{all_bonds} is the holding-period return on the equally weighted portfolio of all U.S. Treasury bonds outstanding. The α and β coefficients are free parameters to estimate; the βs measure the sensitivity of the HML portfolio return to changes in our variables of interest. And ε is the error term.

The variable $\%\Delta AggDur$ is our measure of the duration channel. The coefficient on $\%\Delta AggDur$ tells us the difference in sensitivity of high-duration bonds and low-duration bonds to changes in the aggregate duration risk of Treasury bonds held by the public. If pre-1913 investors required compensation for holding duration risk in Treasury bonds in proportion to the quantity of duration in the bonds held by the public, we would expect high-duration bonds to be more sensitive to increases in the ten-year-equivalent size of Treasury bonds outstanding than low-duration bonds and also anticipate the coefficient on $\%\Delta AggDur$ to be negative.

The variables $\%\Delta FV$ and $\Delta\%HD$ are our measures of the scarcity channel. To the extent that low-duration bonds are preferred for collateral purposes, increases in the aggregate amount of Treasury bond collateral outstanding should decrease the price of low-duration bonds more than that of high-duration bonds; we would, therefore, expect the coefficient on $\%\Delta FV$ to be positive. Likewise, if the total supply is fixed, an increase in the relative proportion of high-duration bonds should decrease the price of plentiful high-duration bonds and raise the price of scarce low-duration bonds; we would, therefore, expect the coefficient on $\Delta\%HD$ to be negative.

Finally, we include the holding-period return on the market portfolio of all bonds to control for the fact that the high-duration bonds are more sensitive, by construction, to shifts in the yield curve.

Our regression estimates can be found in table 1. The results in table 1 confirm that changes to the aggregate duration and total supply of Treasury bonds outstanding altered equilibrium prices. The coefficients on both aggregate duration and face value have the predicted sign and are economically and statistically

TABLE 1

Regression results

	1	2
α	0.0003 (1.10)	0.0001 (0.12)
$\%\Delta AggDur$	−0.0336** (−2.43)	−0.0353*** (−2.59)
$\%\Delta FV$	0.0470*** (2.91)	0.0466*** (2.93)
$\Delta\%HD$	0.0074* (1.86)	0.0073* (1.86)
Ret_{all_bonds}		0.1235*** (3.23)
R^2	0.0095	0.0171

*Significant at the 10 percent level.
**Significant at the 5 percent level.
***Significant at the 1 percent level.
Notes: The two regressions take the following form:

$$Ret_{HML\_Dur} = \alpha + \beta_1(\%\Delta AggDur) + \beta_2(\%\Delta FV) + \beta_3(\Delta\%HD) + \beta_4(Ret_{all\_bonds}) + \varepsilon.$$

See the text for details on the variables. The results in the first column are for the regression run without the return on all bonds. The results in the second column are for the regression run with the return on all bonds. The Newey–West *t* statistics are in parentheses.
Sources: Authors' calculations based on data from the U.S. Department of the Treasury, *Monthly Statement of the Public Debt* database; De Knight (1900); and New York Stock Exchange quotations in the *Commercial & Financial Chronicle*, *New York Times*, and *New York Tribune*.

significant. Our point estimates suggest that removing 10 percent of the aggregate duration risk held by the public increased the price of interest-rate-sensitive high-duration bonds by 35 basis points relative to that of low-duration bonds (table 1, regression 2, $\%\Delta AggDur$ coefficient). Likewise, a 10 percent decrease in the face value of all Treasury bond collateral available to the market raised the price of the low-duration bonds (serving as good collateral) by 47 basis points relative to that of high-duration bonds (table 1, regression 2, $\%\Delta FV$ coefficient). Both of these results are consistent with a model featuring preferred habitat investors who value low-duration bonds for collateral purposes and arbitrageurs who require compensation for bearing duration risk in proportion to the aggregate amount of duration risk held by the public.

The coefficient on $\Delta\%HD$, however, is *not* consistent with the preferred habitat model. With the total supply and aggregate duration of Treasury bonds outstanding held constant, a 10 percent increase in the proportion of bonds with above-median duration actually increased the price of high-duration bonds relative to that of low-duration bonds (table 1, regression 2, $\Delta\%HD$ coefficient). This result is inconsistent with the theory. In our opinion, the most likely explanation is that while our sorting procedure does a good job of identifying which bonds have more duration risk or are likely to be substitutes for collateral purposes, our procedure is too coarse to capture the effects of the scarcity channel, where changes in the local supply of Treasury bonds will only manifest themselves in the prices of the purchased assets and close substitutes. Unlike today's market where the breadth of Treasury offerings assures us that very similar Treasury bonds always exist, the pre-1913 Treasury market seldom had more than four U.S. Treasury bond issues trading at any given time. Therefore, when a refunding alters the proportion of Treasury bonds with high duration, we are not measuring the relative change in price of a Treasury bond very similar to the new Treasury bond issue; rather, we are looking at the relative change in price of a bond that most likely differs in coupon rate, convexity, years to maturity, and the terms of its embedded option. Because changes in total Treasury bond collateral or aggregate duration of Treasury debt outstanding would affect the prices of all Treasury bonds, these sorting constraints are less likely to affect the coefficients on face value of total collateral or aggregate duration. In light of the face value and duration results, we think the most likely explanation of our result for the coefficient on $\Delta\%HD$ is that the pre-1913 Treasury bond offerings were too sparse for us to measure the scarcity channel.

Conclusion

There are few examples of central banks employing their balance sheets for policy purposes in the past 50 years or so. If one looks at periods before the Federal Reserve, however, large-scale asset purchases and operations like Operation Twist are far more common than previously thought. Between 1870 and 1913, the U.S. Department of the Treasury engaged in a number of refundings and sinking fund purchases, which altered the duration risk and amount of Treasury bond collateral in the hands of the public. While the pre-1913 purchases were not conducted with an eye toward stimulating the economy through reaching new equilibrium bond prices, their effects on the size and duration risk of the aggregate portfolio of Treasury bonds held by the public were very similar to those of modern central bank LSAPs.

The changes in Treasury bond yields due to Treasury bond purchases suggest a duration channel was present in the pre-1913 bond market. Sinking fund purchases or refundings that removed duration from the aggregate portfolio of Treasury bonds held by the public resulted in a narrowing of the yield spread between high- and low-duration Treasury bonds, consistent with a decrease in the term premium on high-duration bonds.

While open market purchases of Treasury bonds lowered equilibrium bond yields through the duration channel, the price effect of the removal of bonds from the portfolios of the public was not unambiguously positive. Models of segmented markets where quantities affect equilibrium prices imply that Treasury bonds provide a service that cannot be replicated by privately produced assets. Most likely, this service is the provision of a safe and liquid asset to serve as collateral. While all Treasury bonds are safe in terms of default risk, high-duration bonds that expose their owners to more interest rate risk are less valuable for collateral purposes. With the amount of aggregate duration held constant, a decrease in the face value of aggregate Treasury bonds outstanding was associated with a decrease in the price of high-duration bonds relative to their less risky low-duration counterparts.

The behavior of bond prices between 1870 and 1913 is consistent with a segmented bond market in which participants valued safe and liquid bonds and required a duration-risk premium to hold high-duration assets. In such a setting, open market purchases that alter the amount or interest rate risk of Treasury bonds held by the public can stimulate the economy by generating changes in equilibrium bond yields.

NOTES

[1]For further explanations of LSAPs and the Federal Reserve's rationale in making them, see www.federalreserve.gov/faqs/what-are-the-federal-reserves-large-scale-asset-purchases.htm. Recent empirical studies that examine LSAPs' effectiveness include Krishnamurthy and Vissing-Jørgensen (2011, 2012), Gagnon et al. (2011), D'Amico and King (2013), Hamilton and Wu (2012), Hancock and Passmore (2011), Joyce et al. (2011), Neely (2013), Christensen and Rudebusch (2012), and Bauer and Rudebusch (2014).

[2]See Krishnamurthy and Vissing-Jørgensen (2011), Fuster and Willen (2010), Hancock and Passmore (2011), and Wright (2011). In this article, a bond's duration (that is, its Macaulay duration) is a measure of its sensitivity to changes in interest rates (equation 1 shows how the Macaulay duration is calculated). Moreover, duration is an approximation of the percentage change in a bond's price for a 100 basis point change in its yield to maturity. The greater an asset's duration is, the higher its sensitivity to interest rates changes—meaning that the asset's price fluctuations due to interest rate changes will be more pronounced. Hence, duration risk is a measure of interest rate risk—which is the risk that an investment's value will be altered because of a change in the absolute level or shape of the yield curve (that is, the line plotting the interest rates of assets of the same credit quality but with differing maturity dates at a certain point in time).

[3]For the differences in magnitude of yield changes, see Williams (2013, table 1). For details about the channels by which central banks' LSAPs influence asset yields, see Krishnamurthy and Vissing-Jørgensen (2013).

[4]These episodes include the Federal Reserve's large open market purchases of bonds since 2008 and the Bank of England's large open market purchases since 2009; the Bank of Japan's large open market purchases since 1987; and the Federal Reserve's Operation Twist in the 1960s, which involved the sale of short-maturity bonds and purchase of long-maturity bonds (for details, see Alon and Swanson, 2011).

[5]A refunding is the process of redeeming an outstanding bond issue at its maturity with the proceeds of a new debt issue. A sinking fund is a fund set up by a government agency (or corporation) for the purpose of periodically acquiring outstanding bonds via redemption or open market purchases (to retire debt).

[6]Equilibrium values (for bond yields, prices, etc.) are the values that equalize a bond's supply with its demand.

[7]For more on interest rate risk, see note 2.

[8]See Tobin (1965, 1969) and Modigliani and Sutch (1966).

[9]A bond's convexity is a measure of the sensitivity of the bond's duration to changes in its yield to maturity. A negative convexity indicates that the duration of a bond rises as its yield to maturity increases (and its price decreases); a positive convexity indicates that the duration of a bond rises as its yield to maturity decreases (and its price increases).

[10]Short selling, or shorting, is the selling of a security that the seller does not own but has promised to deliver later (usually to the party from which the seller borrowed it). It is motivated by the belief that a security's price will decline—which would enable the short seller to make a profit when the security is bought back at a cheaper price.

[11]For more on reserve cities and the National Banking System as a whole, see Champ (2011).

[12]A call market is an overnight lending market where borrowers pledge collateral for a secured loan repayable on demand (which is called a call loan). See Griffiss (1923) for a description of the U.S. call market before the Federal Reserve.

[13]In a collateralized loan, the haircut is the percentage by which the collateral asset's market value is reduced to provide a cushion against the possibility that the collateral will decline in value before the loan can be repaid. For example, if a security with a $100 market value can secure an $80 loan, the asset has a 20 percent haircut.

[14]Authors' calculations based on a sample of 86 percent of all call loans appearing on insurance balance sheets reported in the State of New York, Insurance Department (1873).

[15]Ibid.

[16]Authors' calculations based on data from the Office of the Comptroller of the Currency (1872).

[17]An option is a contract giving its owner the right, but not the obligation, to buy or sell a particular asset at a specified price on or before a specified date. In the case of our sample Treasury bonds, many granted the Treasury the option to buy back the bonds at face value.

[18]See www.newyorkfed.org/markets/lttreas_faq.html.

[19]For a definition of duration risk (which is related to interest rate risk), see note 2.

[20]Bauer and Rudebusch (2014).

[21]The MSPD database is available at http://treasurydirect.gov/govt/reports/pd/mspd/mspd.htm.

[22]For a definition of yield curve, see note 2.

[23]The implied volatility is a level of volatility that sets the model-implied price of an option equal to the observed market price.

[24]See Hull and White (1996, 2000).

[25]A zero-coupon interest rate is the yield to maturity on a bond with a single cash flow payment at its maturity. The zero-coupon yield curve is the line plotting the interest rates of zero-coupon bonds with differing maturity dates at a certain point in time.

[26]In the modern era, the zero-coupon yield curve is directly observable from the market prices of zero-coupon STRIPS (Separate Trading of Registered Interest and Principal of Securities), and only the volatility and mean-reversion parameters of the Hull–White model are calibrated to the observable bond price data. However, there was no STRIPS market during our period of study, and the number of existing coupon bonds was always too sparse to identify a unique zero curve.

[27]Specifically, we search over a grid of level, slope, and volatility to find the values that minimize the Euclidean distance between the prices implied by the Hull–White model and the observable market prices.

[28]Unless otherwise indicated, all the numerical values related to Treasury bonds reported in this section are from authors' calculations based on data from the sources in figure 1. Similarly, unless otherwise indicated, the historical details provided here are based on the authors' interpretations of the information from those sources.

[29]For more on Operation Twist of the 1960s, see note 4.

[30]The 4.5 percent, 15-year bonds due in 1891 began trading at a price of 111.25 percent of par; and the 4 percent, 30-year bonds due in 1907 began trading at a price of 105.5 percent of par.

[31]An option is considered in the money when the option grants the option holder the right to sell an asset at a price above current market value or to buy it at a price below market value.

[32]See Ross (1892, pp. 79–85) for a history of the sinking fund of 1862.

[33]Ibid.

[34]The NYSE overnight call rate on loans backed by government bond collateral was in the range of 2.5–3 percent in the month before the conversion, and the secondary market yields on option-free Treasury bonds maturing in ten and 16 years were 2.85 percent and 3.06 percent, respectively.

[35]Griffiss (1923) and Chabot (2011) discuss the importance of the collateralized lending market before 1913.

[36]The term premium is the excess return that investors require to hold a long-term bond rather than a series of short-term bonds (this compensation is required because long-term bonds face higher interest rate risk than short-term bonds).

[37]See, for example, the CUSIP (Committee on Uniform Securities Identification Procedures) level matching of D'Amico and King (2013). For details on CUSIP, see www.sec.gov/answers/cusip.htm.

REFERENCES

Alon, Titan, and Eric Swanson, 2011, "Operation Twist and the effect of large-scale asset purchases," *FRBSF Economic Letter*, Federal Reserve Bank of San Francisco, No. 2011-13, April 25.

Bauer, Michael D., and Glenn D. Rudebusch, 2014, "The signaling channel for Federal Reserve bond purchases," *International Journal of Central Banking*, forthcoming.

Chabot, Benjamin, 2011, "The cost of banking panics in an age before 'too big to fail,'" Federal Reserve Bank of Chicago, working paper, No. WP 2011-15, November 28.

Champ, Bruce, 2011, "The National Banking System: A brief history," Federal Reserve Bank of Cleveland, working paper, No. 07-23R, revised May 2011, available at www.clevelandfed.org/research/workpaper/2007/wp0723r.pdf.

Christensen, Jens H. E., and Glenn D. Rudebusch, 2012, "The response of interest rates to US and UK quantitative easing," *Economic Journal*, Vol. 122, No. 564, November, pp. F385–F414.

D'Amico, Stefania, and Thomas B. King, 2013, "Flow and stock effects of large-scale treasury purchases: Evidence on the importance of local supply," *Journal of Financial Economics*, Vol. 108, No. 2, May, pp. 425–448.

De Knight, William F. (preparer), 1900, *History of the Currency of the Country and of the Loans of the United States from the Earliest Period to June 30, 1900*, 2nd ed., Washington, DC: Government Printing Office.

Fuster, Andreas, and Paul S. Willen, 2010, "$1.25 trillion is still real money: Some facts about the effects of the Federal Reserve's mortgage market investments," Public Policy Discussion Papers, Federal Reserve Bank of Boston, No. 10-4, November 18.

Gagnon, Joseph, Matthew Raskin, Julie Remache, and Brian Sack, 2011, "The financial market effects of the Federal Reserve's large-scale asset purchases," *International Journal of Central Banking*, Vol. 7, No. 1, March, pp. 3–43.

Griffiss, Bartow, 1923, *The New York Call Money Market*, Johns Hopkins University, dissertation, June.

Hamilton, James D., and Jing Cynthia Wu, 2012, "The effectiveness of alternative monetary policy tools in a zero lower bound environment," *Journal of Money, Credit and Banking*, Vol. 44, No. 1 supplement, February, pp. 3–46.

Hancock, Diana, and Wayne Passmore, 2011, "Did the Federal Reserve's MBS purchase program lower mortgage rates?," *Journal of Monetary Economics*, Vol. 58, No. 5, July, pp. 498–514.

Hull, John C., and Alan D. White, 2000, "The general Hull-White model and super calibration," New York University, working paper, No. FIN-00-024, August.

__________, 1996, "Using Hull-White interest rate trees," *Journal of Derivatives*, Vol. 3, No. 3, Spring, pp. 26–36.

Joyce, Michael A. S., Ana Lasaosa, Ibrahim Stevens, and Matthew Tong, 2011, "The financial market impact of quantitative easing in the United Kingdom," *International Journal of Central Banking*, Vol. 7, No. 3, September, pp. 113–161.

Krishnamurthy, Arvind, and Annette Vissing-Jørgensen, 2013, "The ins and outs of LSAPs," paper at Federal Reserve Bank of Kansas City Economic Policy Symposium, Global Dimensions of Unconventional Monetary Policy, Jackson Hole, WY, August 22–24, revised September 16, 2013.

__________, 2012, "The aggregate demand for Treasury debt," *Journal of Political Economy*, Vol. 120, No. 2, April, pp. 233–267.

__________, 2011, "The effects of quantitative easing on interest rates: Channels and implications for policy," *Brookings Papers on Economic Activity*, Vol. 43, No. 2, Fall, pp. 215–265.

Modigliani, Franco, and Richard Sutch, 1966, "Innovations in interest rate policy," *American Economic Review*, Vol. 56, Nos. 1–2, March 1, pp. 178–197.

Neely, Christopher J., 2013, "Unconventional monetary policy had large international effects," Federal Reserve Bank of St. Louis, working paper, No. 2010-018D, revised August 2013.

Office of the Comptroller of the Currency, 1872, *Annual Report of the Comptroller of the Currency*, Washington, DC: Government Printing Office, December 2, available at http://fraser.stlouisfed.org/docs/publications/comp/1870s/1872/compcurr_1872.pdf.

Ross, Edward Alsworth, 1892, *Sinking Funds*, Publications of the American Economic Association, Vol. 7, Nos. 4–5, Baltimore: Press of Guggenheimer, Weil & Co., July and September.

State of New York, Insurance Department, 1873, *Fourteenth Annual Report of the Superintendent of the Insurance Department*, Part 2, *Life & Casualty Insurance*, Albany, NY: Weed, Parsons & Co.

Tobin, James, 1969, "A general equilibrium approach to monetary theory," *Journal of Money, Credit and Banking*, Vol. 1, No. 1, February, pp. 15–29.

__________, 1965, "The monetary interpretation of history," *American Economic Review*, Vol. 55, No. 3, June, pp. 464–485.

Vayanos, Dimitri, and Jean-Luc Vila, 2009, "A preferred-habitat model of the term structure of interest rates," National Bureau of Economic Research, working paper, No. 15487, November.

Williams, John C., 2013, "Lessons from the financial crisis for unconventional monetary policy," panel discussion by president and CEO of the Federal Reserve Bank of San Francisco at the NBER Conference, Boston, October 18, available at www.frbsf.org/our-district/press/presidents-speeches/williams-speeches/2013/october/research-unconventional-monetary-policy-financial-crisis/.

Wright, Jonathan H., 2011, "What does monetary policy do to long-term interest rates at the zero lower bound?," National Bureau of Economic Research, working paper, No. 17154, June.