Tax, Credit, and Liquidity: Corporate Bond Spreads 1927-1940

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Abstract

We examine corporate bond spreads from 1927 to 1940 (a period dominated by the Great Depression). In spite of major tax reforms, tax spreads remained small. This was due to bondholder migration, capital gains tax effects, and the effect of tax shields on call policies. Credit and liquidity spreads rose for speculative grade bonds during the Great Depression itself. Liquidity and credit spread contagion also occurred. Unemployment, negative economic growth, and disinflation were all associated with wider spreads. Treasury rate changes mostly affected investment grade bonds. Credit and liquidity risk was priced, but with a low premium during recessions.

Which should bondholders fear most: tax increases, issuer default, or declining liquidity? This is the fundamental question of corporate bond pricing, and answers are mixed. Some studies find liquidity to be the main driver of corporate bond prices (e.g. Chen et al. (2007), Friewald et al. (2012), Lin et al. (2011), Friewald and Nagler (2019), and Schwarz (2019)) while others contend that credit risk is the dominant pricing determinant (e.g. Covitz and Downing (2007) and Helwege et al. (2014)). Finally, tax effects are argued to be important by Liu et al. (2007) and Elton et al. (2001). In this paper, we evaluate the relative importance of these effects using a unique, hand-collected set of corporate bond prices for the period 1927 to 1940.

The 1927–1940 period represents the final years of exchange trading of corporate bonds in the US. Bond data during this period are very transparent: the New York Times reports transactions of corporate bonds alongside stock prices. During the 1940s, the corporate bond market migrated to being traded over the counter (OTC).[1] Post 1940, corporate bond prices became increasingly difficult to observe, since they were traded between dealers with no requirement to report to an exchange. This opacity was only removed by the advent of the Trade Reporting and Compliance (TRACE) database in 2002.[2] Biais and Green (2007) note that liquidity in corporate bond markets has declined since the 1930s (in spite of improvements in trading technology) due to the shift to OTC trading.[3]

The bond market during the 1927–1940 period is ideal for addressing the makeup of corporate bond spreads for two reasons. First, the period saw frequent reform of tax rates. Initial fiscal policy, following the 1929 downturn in economic performance, focused on balancing the budget, with the result of sending marginal income tax rates skyrocketing (Eggertsson (2008)). Outside this period, major adjustments of tax rates are mostly associated with wars: both World Wars saw rapid increase in tax rates, with the World War 1 tax rates being reduced back to normal levels during the 1920s.[4] The Revenue Act of 1964, Economic Recovery Tax Act of 1981, and Tax Reform Act of 1986 served to reduce tax rates from their post-Great Depression/World War 2 levels (see Roberts (2014)). With the exception of the World War 1/early 1920s period, all of these other tax-adjustment periods occurred while the corporate bond market traded over the counter (and predated the TRACE database) so corporate bond prices cannot be easily observed. Second, the 1927–1940 period features three large economic downturns, which are empirically important for exacerbating credit (and potentially liquidity) risk. The 1926–1927 recession (which is partially captured at the beginning of the dataset) saw GNP decline by 2.7%, while the Great Depression of 1929–1933 and the 1937–1938 recession saw GNP decline by 45.0% and 10.6%, respectively. By comparison, the Global Financial Crisis of 2007–2009 saw a GNP decline of 2.7%.

The failure of credit markets has been established as a root cause of the economic downturn of the Great Depression of 1929–1933 (Bernanke (1983)). However, relatively little work has been done to examine the behaviour of the corporate bond market during this period. Giesecke et al. (2011) and Giesecke et al. (2014) examine the quantity of defaults

[1] Municipal bonds underwent this migration during the 1920s, and treasury bonds during the 1930s.

[2] The TRACE database, established by the National Association of Securities Dealers (NASD; now Financial Industry Regulatory Authority), required all NASD members to report their trades, so that these could be publicised in order to promote fair pricing of fixed income securities and transparency of the market.

[3] Glode and Opp (2020) note that over the counter markets do, however, have advantages in avoiding duplication of expertise development that may outweigh their liquidity disadvantages.

[4] The World War 2 tax increases were not reversed after the war.

from 1866–2010, but do not consider pricing of individual bonds. Durand (1942), Durand and Winn (1947), and Johnson (1967) fit yield curves for high-grade corporate bonds over the period. Hickman (1958) and Johnson (1967) examine the incidence of defaults during the Great Depression. Using firm level accounting data, Graham et al. (2011) document that highly leveraged firms and firms with low rated debt were more likely to face financial difficulties during the Great Depression. Benmelech et al. (2019) show that firms whose debt rolled over during the Great Depression were more likely to lay off employees. Our paper is thus the first paper to analyse individual bond spreads for the period.

Methodologically, our analysis of bond spreads differs from other corporate bond econometric studies (e.g. Chen et al. (2007), Collin-Dufresne et al. (2001), Dick-Nielsen et al. (2012), Eom et al. (2004), Friewald et al. (2012), Ericsson and Renault (2006)) in that we extract spreads taking account of both callability and tax effects.[5] This methodology is important since the majority of bonds issued during the period are callable (although not convertible), and also this enables us to isolate a bond's tax spread.

First, we examine the behaviour of corporate bond tax spreads. By examining income tax reports, we show that at the same time that taxes rose, there was a migration of bondholders, so that tax rate effects were partly offset by a decline in the average income of bondholders. Corporate income taxes were also adjusted over the period. We show that when the gap between corporate income tax and personal income tax rates widened, callable bonds became more valuable, since the company's optimal exercise policy differed from the policy that would minimise bondholder value of the bond. Further, in a low interest rate environment, capital gains tax effects serve to increase bond values, since (ceteris paribus) bonds are more likely to trade at a premium. All these results combined to make the tax contribution to bond values modest, in spite of huge tax rate movements.

Next we examine credit and liquidity spreads. We calculate the distance to default of the issuers (see Bharath and Shumway (2008)), which provides an estimate of default probability. We also estimate the expected loss given default from post-default bond prices. These allow us to break spreads not driven by tax into a credit component and a residual

[5]Chen et al. (2007) include callable bonds in their study, but use Datastream calculated spreads: yield to maturity for bonds trading below par, or yield to first call for bonds trading above par. Collin-Dufresne et al. (2001), Dick-Nielsen et al. (2012), Eom et al. (2004), and Ericsson and Renault (2006) exclude callable debt. Hickman (1958), Durand (1942), Durand and Winn (1947), Johnson (1967), and Friewald et al. (2012) ignore optionality of bonds.

liquidity component. We show that the Great Depression and 1937–1938 recession saw a steepening of the credit curve, so that the gap between high quality and low quality bonds' credit spreads increased. The effects on liquidity were more mixed: the 1926–1927 recession saw liquidity spreads widen for highly rated bonds, while the Great Depression saw this happen for junk bonds. In contrast, the 1937–1938 recession saw liquidity spreads improve for most bonds. Railroads, who were an overcapitalised industry, and hence very vulnerable to the economic downturn (see Schiffman (2003)), saw liquidity spreads widen during the Great Depression, and credit spreads widen during the 1937–1938 recession.

Despite the exchange traded bond market's superior liquidity, we find liquidity playing an important role in bond pricing, even larger than that found in modern data (see Longstaff et al. (2005) and Huang and Huang (2012)). We also find that, similar to the declines in liquidity during the Global Financial Crisis of 2009–2010 documented by Friewald et al. (2012) and Dick-Nielsen et al. (2012), bond market liquidity declined during two of the three recessions in our sample. The increases in liquidity spreads for the Great Depression are strikingly similar to Dick-Nielsen et al.'s (2012) numbers. Seeing similar behaviour in the bond market in the 1927–1940 period suggests that substantial bond liquidity problems can occur during crises even when bonds are exchange traded.

Jorion and Zhang (2007, 2009) suggest that bonds may suffer from contagion: when one firm defaults or sees its credit spread rise, other firms' credit spreads may increase. We investigate the extent to which heightened co-movement of spreads occurred during the recessions our data cover. We show that credit spreads for speculative grade bonds suffered contagion during the Great Depression and 1937–1938 recession. Railway bonds also had significant credit contagion effects during the 1937–1938 recession. In contrast, liquidity contagion affected investment grade bonds during the 1926–1927 recession, while these bonds co-moved *less* than usual during the 1937–1938 recession.

As well as GNP growth seeing extreme variation over the period, a number of other macroeconomic variables fluctuated considerably. We show that unemployment, along with GNP declines, increased bond spreads. Anticipated deflation (negative inflation) also had a severe effect on bond spreads. The level and slope of the treasury curve had mixed effects, raising spreads for bonds that were going concerns (those with high credit ratings), but having little effect on those bonds that were likely to default (speculative grade bonds).

Finally, we examine bond returns over the period, using a conditional asset pricing model.

We show that credit risk and liquidity risk were both priced. However, these prices of risk declined during recessions. Coupled with our findings about contagion, this suggests a toxic combination of corporate bonds being both riskier, and there being less compensation for bearing that risk.

This paper contributes to a number of literatures. It contributes to the bond pricing literature by establishing a methodology for decomposing bond spreads into tax, liquidity, and credit components. Tax effects have been examined by Liu et al. (2007) and Elton et al. (2001), and the liquidity/credit decomposition has been addressed by many authors.[6] However, we are the first paper to handle these jointly. Second, it contributes to the financial history literature by documenting the behaviour of an important market during the Great Depression period. Third, we provide evidence of the cycle of bond recoveries for our period studied, similar to more recent analysis by Jankowitsch et al. (2012). Fourth, we contribute to the credit risk and contagion literature. Lastly, we contribute evidence on the behaviour of bond liquidity spreads, particularly in response to economic crises (see Friewald et al. (2012) and Dick-Nielsen et al. (2012)).

The layout of the remainder of the paper is as follows. Section 1 describes our methodology. Section 2 describes the data used in this paper. Section 3 presents our main results (concerning taxes, liquidity, and credit spreads), while Section 4 describes our modelling of contagion, macroeconomic variables, and bond returns. Lastly, Section 5 concludes.

1 Methodology

We first discuss the calculation of yield curves, credit/liquidity spreads (CLSs), and tax spreads for bonds. Next we describe decomposing CLSs into credit and liquidity components. Finally we look at techniques used in our extensions: measuring contagion and fitting asset pricing relationships.

[6]See, for example Chen et al. (2007), Dick-Nielsen et al. (2012), Lin et al. (2011), Bao et al. (2011), Covitz and Downing (2007), Helwege et al. (2014), Longstaff et al. (2005), and Ericsson and Renault (2006).

1.1 Treasury and corporate curves

Much of the analysis in this paper works with option adjusted spreads for bonds. To calculate these, we require two inputs: a treasury zero curve, and a process that a particular bond's short rate follows.

To build treasury curves, we use cubic splines to choose the forward curve (where $F(t,T)$ is the forward rate observed at time t for T periods in the future) to minimise the squared pricing errors of non-callable treasuries. We fit curves with knot points at 0.5, 1, 2, 5, 10, 20, and 50 years. Knots are removed so that there is at least one bond between each pair of knots. Pricing errors are scaled by bond duration.[7] Following Waggoner (1997), we also impose a smoothness penalty on the curve so that the curve must not be too curved as maturity increases.[8] As described in Appendix C, we further account for the potential of an exchange premium discussed by Cecchetti (1988).

Corporate curves are built similarly, by creating a spread curve that is added to the contemporaneous treasury curve to price non-callable corporate bonds of a particular credit quality. Here, two tax rates must be considered: income tax and capital gains.[9] If the bond pays coupon c at times t_j, and matures at date T, a bond's price ($BVN(t)$) solves

$$
\begin{aligned}
BVN(t) &= \sum_j c(1-\tau_I)P(t,t_j) + \left[100 - (100 - BVN(t))\tau_G\right] P(t,T) \\
\Rightarrow BVN(t) &= \frac{\sum_j c(1-\tau_I)P(t,t_j) + 100(1-\tau_G)P(t,T)}{1-\tau_G P(t,T)},
\end{aligned}
$$

where τ_I is the income tax rate, τ_G is the capital gains rate, and $P(t,T) = e^{-\int_t^T F(t,s)ds}$ is the time t discount factor for future time T.

One problem with fitting corporate curves is that treasury bonds in our data have matu-

[7]Duration is defined here as the partial derivative of the bond's price with respect to a parallel increase in all the discount rates. Effectively this is a derivative of the bond's price with respect to its CLS.

[8]Specifically, we add a penalty to the least squares fit consisting of

$$
0.1\int_0^1 \frac{\partial F(t,T)}{\partial T^2}dT + 100\int_1^{10} \frac{\partial^2 F(t,T)}{\partial T^2}dT + 100000\int_{10}^{\overline{T}_t} \frac{\partial^2 F(t,T)}{\partial T^2}dT,
$$

where $\overline{T}_t$ is the longest maturity bond being considered. If $\overline{T}_t < 10$, then the third term is discarded, and the second term is integrated between 1 and $\overline{T}_t$ years.

[9]Cecchetti (1988) argues that even partially tax exempted treasuries were generally held by tax exempt investors so tax is not a consideration for treasury bonds.

rities of 30 years or less, while corporate bonds (see Table 2) routinely have longer maturities. To deal with this, we extrapolate the treasury curve by assuming that it obeys the Nelson and Siegel (1987) model, with parameters chosen to match the height and slope of the fitted spline forward curve at the longest maturity for which bonds trade and long term interest rates that converge to the average of ten year zero rates in our sample.[10]

1.2 Credit/liquidity spreads (CLSs)

We assume in this paper that short rates follow a no-arbitrage variant of the Sandmann and Sondermann (1997) model. Here

$$dr^* = \lambda(\theta(t) - r^*) + \sigma dz,$$

where dz is the increment of a Brownian motion. The short interest rate (r) is given by $r = \log(1+\exp(r^*))$. This model has the appealing feature of having finite absolute volatility as $r \to \infty$ (ensuring that interest rates do not explode), but lognormal interest rates as $r \to 0$ (ensuring that interest rates do not become negative). This allows the model to deal with both high quality debt (where r is close to zero) and also junk bonds (where r is very large). Appendix A describes how to price securities in general using the Sandmann and Sondermann (1997) short rate model. Note that by allowing $\theta(t)$ to vary with time, our model is flexible and can generate spreads consistent with the actual treasury curve observed rather than being constrained by an equilibrium model for the treasury curve, as in Liu et al. (2007).

Having created a given corporate spread curve for each date (see Section 1.1), we calculate the volatility of zero rates for 1 and 10 year maturities. The parameters σ and λ are calibrated to match these two levels of volatility (see Appendix D for details).

Using the treasury yield curve and σ and λ parameters for a particular credit class, we

[10] Mechanically, the Nelson and Siegel (1987) forward rate at time t is given by:

$$F(t,T) = \overline{r}\exp\left[e^{-\lambda(T-\overline{T}_t)}\left(\beta_{2t} + \beta_{3t}(T-\overline{T}_t)\right)\right],$$

where $\overline{T}_t$ is the maturity of the longest maturity treasury bond observed at time t. β_{2t} and β_{3t} are chosen so to make the Nelson and Siegel (1987) curve match height and slope of the spline forward curve at maturity $\overline{T}_t$: $\beta_{2t} = \log(F_t(\overline{T}_t)) - \log(\overline{r})$, and $\beta_{3t} = \frac{F_t'(\overline{T}_t)}{F_t(\overline{T}_t)} + \lambda\beta_{2t}$. λ is set to be the mean reversion rate calibrated to the treasury curve (see Appendix D), while $\overline{r}$ is the average of ten year treasury rates over the sample.

can then calculate a CLS for a particular bond. To do this, we price the bond using the treasury curve, increasing the discount rate at each node in the finite difference calculations by a constant spread. We then calibrate this spread to cause the model to produce the same price as the market. As noted in Section 1.1, tax is a consideration for corporate bonds. Because most of the bonds are callable, we must also worry about the effect of corporate income taxes on the firm's decision to call the debt (see Mauer and Lewellen (1987)). Appendix B discusses the specifics of dealing with callability and taxes. Since the calculation of the bond's spread incorporates embedded optionality, the CLS can be seen as an option adjusted spread where tax effects have also been incorporated. Hence the CLS must be either generated by credit risk or illiquidity of the bond in question.

1.3 Tax spreads

Tax spreads are defined as in Liu et al. (2007). First, the bond is priced consistently with the actual tax structure (see Appendix B), using the treasury curve. This gives the bond's price, accounting for tax and optionality, but no other effects (no credit or liquidity spread). Next the bond is priced again, as if all tax rates were zero, and a spread is added to the treasury curve to make this price identical to the taxed price. This spread is the bond's tax spread. Note that these calculations make no use of market prices, but do use σ and λ, since these are used in the valuation of callable bonds.

1.4 Measuring credit risk

To decompose CLSs into credit and liquidity portions, we calculate a probability of default, and then multiply this by an expected loss given default. Lastly, we regress bond credit/liquidity spreads on this credit risk measure to estimate credit spreads.

1.4.1 Default probabilities

Bharath and Shumway (2008) document that the Merton (1974) model provides a useful forecasting tool for default probability in its "naïve" format. The naïve Merton model is implemented as follows. First, a distance to default for a one year horizon is calculated:

$$DD = \frac{\log(VAL/DEBT) - \frac{\sigma_{VAL}^2}{2}}{\sigma_{VAL}}, \tag{1}$$

where $DEBT$ is the book value of the firm's debt, $VAL = DEBT + EQ$ is the total value of the firm, EQ is the market value of equity for the firm, σ_{VAL} is the volatility of the firm's value. In calculating $DEBT$, we halve the book value of long term debt.[11] We calculate firm value volatility as:

$$\sigma_{VAL} = \frac{EQ}{EQ + DEBT}\sigma_{EQ} + \frac{DEBT}{EQ + DEBT}(0.05 + 0.25\sigma_{EQ}),$$

where σ_{EQ} is the volatility of the firm's equity. Finally, a default probability is calculated as $N(-DD)$, where $N(.)$ is the cumulative normal distribution.[12]

1.4.2 Recovery rates

Bonds continued to trade on the NYSE after default during our sample period. We use the price observed at the end of the month in which default occurred as an estimate of the recovery value of the bond.[13] Jankowitsch et al. (2012) note that bond prices are often depressed on the actual date of default relative to subsequent trading, so by using the end of month price instead of the price at date of default we mitigate this effect. We break our sample into investment grade bonds (rating Baa or above) and speculative grade bonds (lower ratings). For each grade, we calculate an Exponentially Weighted Moving Average (EWMA) forecast of recovery rate. If DR is the decay rate for the EWMA, and (DT_j, RR_j) are the set of default dates and realised recovery rates for a particular credit grade, we

[11] We can identify bonds that have a maturity of one year or less from our data. Other non-bond debt is assumed to be long term.

[12] Bharath and Shumway (2008) include a drift term in the numerator of (1) equal to the preceding year's equity return, but when this is implemented with our dataset, it results in periods where almost all firms are predicted to default.

[13] Bonds that had defaulted were listed as "s.f.", or "selling flat". This meant that their traded price no longer included accrued interest, and hence the clean price can be seen as a percentage of principal expected to be recovered.

calculate the predicted recovery rate at time t (PR_t) as

$$PR_t = \frac{\sum_{DT_j<t} e^{-DR(t-DT_j)} RR_j}{\sum_{DT_j<t} e^{-DR(t-DT_j)}}.$$

By setting the value of DR, we can set the half-life of a particular recovery's impact on the expectations of the market. We set DR so that the half-life of a recovery is six months.

1.4.3 CLS decomposition

By multiplying the default probability from Section 1.4.1 by the expected loss given default ($1 - PR_t$), we obtain a measure of the bond's expected loss over the next year:

$$EL_{it} = N(-DD_{it}) \times (1 - PR_t),$$

where DD_{it} is the issuer's distance to default, and PR_t is the predicted recovery rate for a bond of this grade (investment or speculative). This measure, by construction, is for a one year horizon. Since we are agnostic as to how exactly this would determine a bond's spread, we then, at each time, regress individual bond CLSs on individual bond expected losses:

$$\log(1 + CLS_{it}) = \beta_{0t} + \beta_{1t} EL_{it} + \epsilon_{it}, \tag{2}$$

where CLS_{it} is bond i credit/liquidity spread at time t, EL_it is bond i's expected loss at time t, β_{0t} and β_{1t} are time-varying coefficients, and ϵ_{it} is the regression's residual terms. Since credit risk should tend to zero as the expected loss tends to zero, we treat $\beta_{1t} EL_{it}$ as our estimate of the bond's credit risk component at time t. We transform the CLS term in the regression to make the regression more robust to outliers (see Section 2).

1.5 Measuring liquidity

The analysis of Section 1.4.3 provides an estimate of the component of the CLS that is explained by credit risk, and hence implies that the remainder of the spread ($\beta_{0t} + \epsilon_{it}$) is liquidity related. It is helpful to have a measure of liquidity to confirm that this residual "liquidity spread" is indeed correlated with liquidity.

We use two measures for this. The first is turnover (see Section 2). The second is a variant on the "effective tick" described in Goyenko et al. (2009) and Holden (2009). The effective tick uses the fractional part of a bond's price to identify the level of its liquidity. The intuition of this approach is that if traders are using a particular tick size on a day, we would expect to see trade prices being more likely to have a particular fractional part. For example, if a bond's price is quoted in ticks of half dollars, we would see either a trade price of a round dollar amount or with a fractional part of $\frac{1}{2}$, but not $\frac{1}{4}$ or $\frac{3}{4}$. Further, the bid-ask spread on a day will generally equal the day's tick.

The effective tick measure is normally calculated with daily data, using these to generate a distribution of spreads within a given month. The average of these spreads is then divided by the security price. Since we are working with monthly data, we use an EWMA (as described in Section 1.4.2) over previous monthly ticks. We also eschew scaling by bond price, since this conflates credit risk with liquidity: bonds that have very low prices (due to high credit risk) would end up with large effective ticks, labeling them as illiquid.

Our algorithm for effective tick calculation is as follows. First, we divide a particular bond's prices into buckets, based on their fractional parts. We obtain four buckets: bonds whose prices are in whole dollars, bonds whose prices end in $\frac{1}{2}$, bonds whose prices end in an odd quarter ($\frac{1}{4}$ or $\frac{3}{4}$), and bonds whose prices end in an odd eighth.[14] We calculate the empirical estimate of the proportion of observations with tick size TS_j at time t (using an EWMA) as:

$$PTS_{j,t} = \frac{\sum_{u \leq t} e^{-DR(t-u)} \mathbb{1}_j(BV_u)}{\sum_{u \leq t} e^{-DR(t-u)}},$$

where $\mathbb{1}_j(BV)$ is an indicator that returns 1 if price BV has fractional term TS_j. In our work, $TS_1 = \frac{1}{8}$, $TS_2 = \frac{1}{4}$, $TS_3 = \frac{1}{2}$, and $TS_4 = 1$. As in Section 1.4.2, we set DR so that the half-life of an observation is six months.

Following Holden (2009), we then correct for the fact that some observations will be misattributed to other tick sizes (for example, an observation with a price ending in $\frac{1}{2}$ could be caused by a tick size of $\frac{1}{4}$, but where the trade price fell on an even numbered quarter).

[14] Bonds prices in our data are often rounded to the nearest cent, so we see prices ending in 0.13 instead of 0.125 or 0.68 instead of 0.675. We treat these as eighths.

This correction results in probabilities for each tick size of:

$$PTS^*_{j,t} = \begin{cases} \min(\max(2PTS_{1,t}, 0), 1) & \text{if } j = 1 \\ \min\left[\max(2PTS_{j,t} - PTS_{j-1,t}, 0), 1 - \sum_{k=1}^{j-1} PTS^*_{k,t}\right] & \text{if } j = 2 \text{ or } 3 \\ \min\left[\max(PTS_{4,t} - PTS_{3,t}, 0), 1 - \sum_{k=1}^{3} PTS^*_{k,t}\right] & \text{if } j = 4. \end{cases}$$

Lastly, we aggregate the effective tick ET as

$$ET_t = \sum_{j=1}^{4} PTS^*_j \times TS_j.$$

The resulting effective tick provides us with a measure of liquidity at a particular point in time, with lower effective tick signifying higher liquidity. Although this uses our price series, it makes exclusive use of the fractional part of the price, and hence (as noted earlier) avoids spurious correlation with credit risk. By regressing the residual and intercept from (2) on the effective tick for a bond and its turnover, we can gauge whether the part of bond spread unexplained by credit risk is in fact associated with liquidity.

1.6 Measuring contagion

Jorion and Zhang (2007, 2009) find contagion in credit default swap spreads: bad news for one firm can widen credit default swap spreads for other related firms. Similarly, Das et al. (2007) document that there is more clustering in defaults than can be explained by common risk factors. In testing for contagion, we must be careful to check for an actual increase in bonds' comovement with the market, since crisis periods will always be associated with a rise in correlation of individual securities (see Forbes and Rigobon (2002)).

We use the following methodology to test for contagion. First, we use principal components analysis, applied to studentised differences in bond CLSs. Matters are complicated here in that there will be missing observations for individual bonds due either to missing bond prices, or because a given bond is not present at a particular time (either due to not having been issued yet, or having matured/defaulted prior to the date in question). We thus use the Stock and Watson (1998) expectation maximisation algorithm approach to factor estimation, as described in Korajczyk and Sadka (2008).

Having generated a market-wide index for spread changes, we then run the regression:

$$DS_{j,t} = \sum_k \alpha_k X_{k,j,t} + \sum_l \beta_l PC_{1,t} X_{l,j,t} + \eta_{j,t},$$

where $DS_{j,t}$ is the difference in the j-th bond's spread (CLS, credit spread, or liquidity spread) at time t. $PC_{1,t}$ is the level of the market shock (principal component) at time t, and $X_{k,j,t}$ is the kth explanatory variable for changes in spreads, α_k and β_l are coefficients, and η_{jt} is the regression's residual. By including dummies for recessions in these explanatory variables, we can use the β coefficients associated with these recessions to measure the extent to which bond co-movement changes during recessions.

1.7 Asset pricing relationship for returns

We are also interested in whether there is a pricing relationship between exposure to systematic risk. To test this, we posit that the stochastic discount factor is given by:

$$SDF_t = 1 - \sum_{j=1}^{J} \left(b_j FAC_{t,j} + c_j FAC_{t,j} REC_t \right), \tag{3}$$

where FAC_j $(j \in 1, \ldots, J)$ is a set of mean zero factors, REC is a dummy that takes value 1 if the economy is in recession, and 0 otherwise, and b_j and c_j are constants. We form portfolios of bonds, and calculate their vector of excess returns (EXR). We further condition on whether the economy is in recession or not. Hence our moment conditions are given by

$$g(b,c) = E\left((SDF_{t+1}(b,c) EXR_{t+1}) \otimes \begin{bmatrix} 1 \\ REC_t \end{bmatrix} \right) = 0,$$

where $\otimes$ denotes a Kronecker product. We account for the fact that the factors have had their means removed following Cochrane (2005), resulting in a correction analogous to Shanken (1992). We estimate the spectral density matrix as the variance-covariance matrix of six month cumulative errors to account for potential autocorrelation of returns and factors.

2 Data

Bond prices are obtained from the New York Times, and consist of bonds traded on the New York Stock Exchange (NYSE). Although the NYSE faced competition at this time from the curb exchange and other regional exchanges, it was the preeminent exchange for bond trading. Turnover on the curb peaked at 54.9% of NYSE turnover in 1932, however, on average its turnover was 32.7% of the NYSE over the period studied.

Data are collected at a monthly frequency, at end of month, to coincide with the CRSP database for treasury data. We consider only those bonds where there are at least 25 months' observations. For these bonds, we collect information from Moody's manuals on the credit rating, coupon, issue and maturity dates, callability (and call schedule where relevant), credit rating, convertibility, and default date (if any). We also record the firm's industry, and parent company, if it is a subsidiary. We then use a combination of Moody's manuals and Commercial and Financial Chronicle information to source accounting information for the issuing firms. Where the firm has accounting information, we use this. However, if the firm does not have accounting information (signifying that it does not exist as a separate financial entity to its parent), we use the parent's information. Equity prices are taken from CRSP, allowing us to calculate market values of equity, and volatility for equity returns (the latter using daily returns to produce a monthly volatility).

The monthly bond price observations from the New York Times also contain quantities traded for the day. At the end of each year, the newspaper reports the annual volume traded for each bond. We use these, along with the monthly (market-wide) trade volumes reported by the newspaper to disaggregate the annual volumes into monthly (log) volumes using the methodology of Proietti (2006).[15] This allows us to calculate a turnover for each bond by dividing its trade volume by the bond's amount outstanding. Although this measure suffers from noise due to the disaggregation, it provides a second proxy for liquidity to use alongside the effective tick measure described in Section 1.5.

There are 918 bonds for which we have 25 observations or more. We then apply several filters to the data. First, we remove convertible bonds, since their valuation would involve accounting for equity changes as well as interest rate changes, which would be computationally

[15] It is necessary to work with log volumes in the disaggregation to avoid calculating negative volumes for a given month.

expensive. These bonds are relatively uncommon during the 1920s and 1930s, so this filter only eliminates 98 bonds from the sample. Next, we remove bonds issued by financial firms, since we might expect their behaviour with respect to leverage and accounting information to be rather different from other firms. These are also a relatively small part of the market, so this filter removes 8 further bonds. We remove a bond issued by the Ontario (Canada) government. Next we remove bonds with exotic features, such as cash flows tied to revenue or non-deterministic call schedules. This removes 48 bonds. Our analysis stops following bonds after their default (although we use their post-default values to infer recovery rates; see Section 3.3). Of the remaining bonds, seventeen are in default at the start of our sample or from their date of issue, so they are removed. Lastly, we do not consider bonds that do not have credit ratings, or are rated below Caa (most of these are in default, and the remaining sample is too small to analyse). This last filter removes a further two bonds. We are left with a sample of 744 bonds, which are either plain vanilla or callable. For these bonds, we further remove observations where a callable bond's price is above its current call price, since this suggests an arbitrage opportunity for the issuing firm at the next call date.[16] We also remove bonds that have less than six months to run until maturity, since these can lead to extreme values for spreads when the bond's price does not approach par as maturity approaches (the so-called "crisis at maturity" documented by Johnson (1967)). Three bonds have no observations.[17] Finally, we have 740 bonds that have at least one observation. There are 40,771 bond-month observations remaining at this stage. We are able to find accounting/equity information for 573 bonds' issuers, leading to 31,793 bond-month observations with accounting information.

The breakdown of callable and non-callable bonds is given in Table 1. Although, as noted earlier, convertibility is not common at this time, callability is the norm amongst corporate bonds, especially for those not issued by the railway industry. The railway industry makes up almost half of the sample, with the remainder being a mixture of utilities and industrials.

We apply standard filters to the CRSP treasury data that we use to create treasury curves. We remove flower bonds (bonds where the bond can be surrendered as payment of estate tax, effectively giving an embedded put option), callable/puttable bonds, consols,

[16] Durand (1942) notes the large number of these observations over the 1934–1942 period, and similarly excludes them from his analyses.

[17] One bond has no rating prior to defaulting, a second has no observations where the price is below the strike price of its call provision, while the third has no observations in our sample prior to its default.

	All		Accounting	
	Callable	Non-callable	Callable	Non-callable
Rail	178	162	155	144
Non-rail	343	57	237	37

Table 1: Break down of bonds between rail and non-rail issuers, callable and non-callable debt, and accounting information being available (at least partially).

bonds with less than six months to maturity, and bonds with varying coupons. We do include treasury bills when available, since these help us to better fit the short maturity rates.

2.1 Bond characteristics

Table 2 presents summary statistics for the dataset. Annual coupon rates vary between 2.75% and 8%. The average bond pays a coupon of 5%. Coupon rates for new issues generally decline throughout the sample. Time to maturity for our sample is on average 20 years or so. Most bonds during this period are issued with a maturity of 50 years. Some bonds are issued for longer. The most extreme example are the *West Shore Railroad first gold 4s*, which were issued in 1886, maturing in 2361.

Credit/liquidity spreads are calculated according to the methodology described in Section 1 and Appendix B. Note that these remove tax effects as well as option effects. CLSs vary considerably. A few bonds have substantially negative spreads: these are bonds whose prices are such that, if they persist, will soon become arbitrage opportunities for the issuing firms through call exercise. However, the current call price does not admit this (or the bond is not yet callable). At the other end of the spectrum, bonds facing a crisis at maturity may have very large positive spreads. To avoid these outliers dominating the results, in our subsequent regressions, we work with $\log(1 + CLS)$ in place of CLS. For bonds with modest spreads, this has minimal effect, however it substantially reduces the higher spreads (see Table 2).

Tax spreads (see Section 1.3 for calculation details) are generally small. Although bond prices are decreasing in income tax rates, bonds whose coupon rates are higher than treasury rates may see their value increase from capital gains taxes (see Section 1.1 and Appendix B). Further, distortion of exercise policies due to tax shield effects may further increase bond values. As a result, in some cases, tax spreads are actually negative.

	Samp.	N	Min	Max	Mean	Median	Std. Dev.
			Bond characteristics				
Coupon	all	740	2.75	8	4.89	5	0.90
Coupon	a/c	573	2.75	8	4.84	5	0.86
			Bond-time characteristics				
CLS	all	41717	-4.96	370.77	3.78	1.84	8.63
log(1+CLS)	all	41717	-5.09	154.92	3.49	1.82	6.07
Tax spread	all	41766	-2.32	0.98	0.29	0.29	0.19
Maturity	all	41717	0.50	433.91	27.68	21.25	29.35
Mkt. cap	all	32958	0.04	3926.02	231.91	50.26	542.90
Debt/TA	all	39444	0.01	1.62	0.45	0.44	0.17
Tot. Asst. ($m)	all	39457	5.39	5024.34	640.76	312.57	805.86
Equity Vol	all	33045	0.01	8.88	0.58	0.45	0.48
Cash/Debt	all	39450	0.00	4.77	0.08	0.04	0.12
Turnover	all	40370	0.00	207.94	1.05	0.64	2.82
Effective Tick	all	41717	0.17	1.00	0.34	0.31	0.12
CLS	a/c	32568	-4.54	299.40	3.64	1.88	7.27
log(1+CLS)	a/c	32568	-4.65	138.48	3.40	1.87	5.43
Maturity	a/c	32568	0.50	433.91	27.52	21.00	30.32
Mkt. cap ($m)	a/c	32568	0.04	3926.02	232.06	50.15	545.50
Debt/TA	a/c	32568	0.01	1.62	0.43	0.44	0.15
Tot. Asst. ($m)	a/c	32568	5.77	5024.34	650.77	356.91	758.86
Equity Vol	a/c	32568	0.01	8.88	0.58	0.45	0.47
Cash/Debt	a/c	32568	0.00	4.77	0.09	0.05	0.13
Turnover	a/c	32272	0.00	207.94	1.07	0.66	2.84
Effective Tick	a/c	32568	0.17	1.00	0.34	0.31	0.12

Table 2: Summary statistics for the bond dataset. Bond characteristics (coupons) do not vary across a bond's life and so are reported per-bond. Bond-time characteristics do vary across a bond's life, so the unit of observation is a bond at a particular time. Variables with sample "all" are across all data where a CLS can be calculated, while those with "a/c" next to them are only for bond-times where *all* accounting information is available. CLS, log(1+CLS), tax spread, and turnover are measured in percent.

Issuers are generally large. The average total assets is \$651 million. There is considerable variability however, with the smallest total assets being \$5.39 million (St. Louis Rocky Mountain and Pacific Company, end of 1939), and the largest just over \$5 billion (AT&T at the end of 1931). Converting period dollars to January 2020 dollars results in a multiplier of between 14.64 (January 1927) and 20.52 (April 1933). Hence an average firm would be equivalent to a modern firm with roughly \$11 billion total assets.

Accounting performance is mixed. Debt relative to total assets ranges from negligible to over 162% (Fonda, Johnstown, and Gloversville Railroad Company, end of 1939). This latter would be caused by a firm having negative retained earnings that exceed the value at which the equity was initially issued. Hence it would have a negative accounting value of equity, even though the market value of equity would be positive (albeit low, as evidenced by some of the lower values for market capitalisation). The average issuer has 43% debt. Cash holdings vary also. The average firm has cash reserves that cover 9% of the firm's debt, but this has a standard deviation of 13%. Equity volatility (calculated as the standard deviation of the month's daily equity returns for the firm and annualised) ranges from 1% to 888%, with an average of 58%.

The two liquidity measures also show reasonable variability. Effective tick (see Section 1.5) is on average 34 cents, but varies from 17 cents to a dollar. On average a bond issue has around 1.1% of its outstanding amount change hands each month, but this has a standard deviation of 2.8%.

2.2 Defaults

Table 3 summarises the number of defaults each year, along with the mix of bonds trading, organised by credit rating. The top panel shows defaults. The second panel shows the number of each bond rating trading in a given year. When a bond spends part of the year in one class and part in another, the bond is prorated between the two classes. The final panel divides the first panel by the second panel to show the intensity of defaults.

Examining the mix of bonds (middle panel) it becomes apparent that the quality (as measured by rating) declines considerably over the sample period. During the late 1920s, the modal bond class is Aaa, with relatively few bonds being speculative grade (Ba or

Year	All	Aaa	Aa	A	Baa	Ba	B	Caa
Number of defaults								
1927	3*	0	1*	1*	1*	0	0	0
1928	0	0	0	0	0	0	0	0
1929	1	0	0	0	0	0	1	0
1930	2	1	0	0	1	0	0	0
1931	20	0	0	0	4	3	11	2
1932	18	0	0	0	1	7	10	0
1933	40	0	2	2	2	17	12	5
1934	17	0	1	1	3	9	3	0
1935	24	0	1	1	6	11	4	1
1936	11	0	0	0	1	8	2	0
1937	13	0	0	1	1	3	5	3
1938	25	0	3	0	6	5	9	2
1939	14	0	0	0	3	2	7	2
1940	3	0	0	0	0	1	1	1
Number of bonds								
1927	488.8	179.5	94.0	119.5	58.2	33.3	4.2	0.0
1928	545.6	189.0	104.1	131.2	75.2	41.2	5.0	0.0
1929	579.8	203.6	102.4	136.6	78.8	48.8	9.7	0.0
1930	596.5	216.0	98.4	138.5	77.2	49.5	16.1	0.8
1931	601.1	203.6	105.5	124.7	89.1	57.6	20.3	0.3
1932	584.7	144.8	111.0	95.2	110.2	89.8	31.5	2.3
1933	554.6	93.8	99.0	89.7	121.5	105.6	39.2	5.8
1934	519.6	82.1	94.7	91.8	129.7	81.8	35.2	4.4
1935	497.2	78.9	91.8	86.8	130.8	72.8	30.6	5.7
1936	451.7	71.8	83.2	91.5	111.7	62.0	24.9	6.7
1937	419.7	61.2	78.1	90.1	108.1	53.8	22.8	5.8
1938	382.3	48.0	63.6	73.0	100.4	69.8	23.8	3.8
1939	348.0	31.5	49.7	53.3	92.7	89.7	27.5	3.7
1940	321.7	23.2	48.3	42.1	87.8	82.5	33.1	4.6
Implied default intensity (percent)								
1927	0.6*	0.0	1.1*	0.8*	1.7	0.0	0.0	–
1928	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–
1929	0.2	0.0	0.0	0.0	0.0	0.0	10.3	–
1930	0.3	0.5	0.0	0.0	1.3	0.0	0.0	0.0
1931	3.3	0.0	0.0	0.0	4.5	5.2	54.1	600.0
1932	3.1	0.0	0.0	0.0	0.9	7.8	31.7	0.0
1933	7.2	0.0	2.0	2.2	1.6	16.1	30.6	87.0
1934	3.3	0.0	1.1	1.1	2.3	11.0	8.5	0.0
1935	4.8	0.0	1.1	1.2	4.6	15.1	13.1	17.6
1936	2.4	0.0	0.0	0.0	0.9	12.9	8.0	0.0
1937	3.1	0.0	0.0	1.1	0.9	5.6	22.0	52.2
1938	6.5	0.0	4.7	0.0	6.0	7.2	37.9	53.3
1939	4.0	0.0	0.0	0.0	3.2	2.2	25.5	54.5
1940	0.9	0.0	0.0	0.0	0.0	1.2	3.0	21.8

Table 3: First panel reports defaults by class/year. Second panel counts the number of bonds of each class in each year. Bonds spending part of the year in one class and part in another are counted, pro-rata, in both classes. Third panel divides first panel by the second, indicating mortality intensity. Numbers marked with * occur at the start of the sample, for bonds who do not have any spreads reported, and therefore are not included in the total number of bonds.

below) and no bonds being rated Caa.[18] From 1931 onward, however, the number of highly rated bonds declines precipitously, until, by 1933, the modal credit class is Baa (borderline investment grade). The number of speculative bonds grows considerably. By 1940 over a third of all bonds are speculative, in contrast to 7.7% in 1927.

Defaults are (not surprisingly) concentrated in the speculative grade bonds. These begin in earnest in 1931, and peak in 1933. As well as the speculative grade defaults, a number of investment grade bonds default, particularly during the 1932–1935 period. Examining the intensity numbers, clearly the Caa rated bonds have very high default rates. The intensity varies considerably for the other ratings. B rated bonds have 54% mortality in 1931, but mortality is minimal in the late 1920s. Ba rated bonds peak at 16% mortality in 1933, while Baa rated bonds peak at 4.6% in 1935. Overall, the worst years for defaults are 1933 (7.2%) and 1938 (6.5%). Three bonds default in January and February of 1927, with no CLSs calculated for them. These are included for completeness in the first panel of Table 3, and the calculations for the third panel, but are not counted in the second panel.[19] These bonds are helpful in the credit risk analysis of Section 3.3, since they provide information on recovery rates at the start of the sample.

2.3 Tax rates

The Federal government's response to the great depression was, at least initially, to attempt to run a balanced budget (Eggertsson (2008)). The result was a series of sharp increases in tax rates, particularly for middle and higher income households. Figure 1 shows marginal tax rates as a function of income throughout the period. Rates increased initially in 1932, then again in 1934, 1936, and 1940.

The Inland Revenue Service produces, for the period covered, Statements of Income. These provide a breakdown of income reported by source (sorted by total income reported). From this, we can calculate the mean marginal tax rate for an individual earning fully taxable interest. Unfortunately, the income brackets reported do not coincide with the marginal tax income brackets. As a result, we calculate a lower estimate (placing everyone

[18] This is not to say that no bonds had these ratings, since we exclude bonds who have already defaulted.

[19] In two cases, the defaults occurred on 1 January, while in the third case, the default occurred on 1 February, coincident with the bond's maturity, so the bond does not appear in the sample on account of having less than six months to maturity.

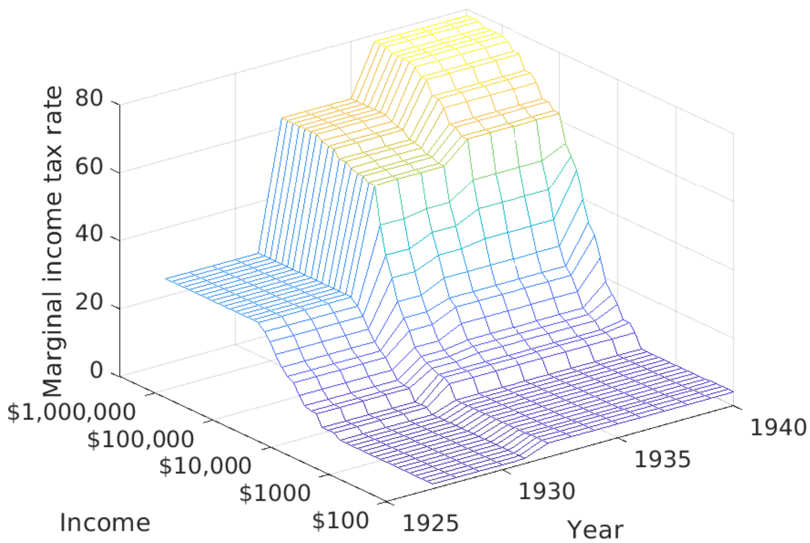

Figure 1: Marginal tax rates as a function of income for the 1927-1940 period. Income is per annum, while marginal tax rate is in percent.

in a reported income bracket at the lowest marginal tax rate for that bracket) and a higher estimate (placing everyone in the bracket at the bracket's highest marginal tax rate). The final marginal tax rate used for that year is the average of these two estimates (see Table 4).

It is interesting to note that in spite of the rapidly increasing tax rates (see Figure 1), actual tax paid on interest remained modest (see Table 4), reflecting a "migration" of bond holders. This phenomenon is discussed further in Section 3.2.

2.4 Macroeconomic data

We obtain Consumer Price Index (CPI) data from the Bureau of Labour Statistics. GNP is obtained from the NBER Macrohistory database at a quarterly level. This is then disaggregated using the Federal Reserve's Industrial Production Total Index, to convert it to a monthly frequency.[20] CPI and GNP are then deseasonalised following the Census Bureau's X-12 ARIMA methodology (see Findley et al. (1998)). These series are then logged and

[20]Disaggregation of macroeconomic time series is performed following Proietti (2006).

Year	Inc (low)	Inc (high)	Inc	Corp	Cap	Tax spread
1927	7.68	8.67	8.18	13.50	12.50	27.67
1928	8.07	9.00	8.54	12.00	12.50	34.64
1929	7.80	8.72	8.26	12.00	12.50	38.45
1930	6.12	7.06	6.59	12.00	12.50	21.42
1931	5.08	5.98	5.53	12.00	12.50	14.05
1932	9.29	9.81	9.55	13.75	12.50	32.31
1933	8.68	9.13	8.90	13.75	12.50	27.39
1934	10.34	10.98	10.66	13.75	12.50	32.30
1935	10.69	11.35	11.02	13.75	12.50	25.01
1936	11.91	14.61	13.26	15.00	12.50	31.41
1937	12.08	14.39	13.23	15.00	12.50	34.92
1938	9.03	9.56	9.30	15.00	12.50	18.67
1939	9.44	10.01	9.73	15.00	12.50	18.20
1940	9.99	10.53	10.26	33.00	12.50	29.01

Table 4: Tax rates for the 1927-1940 period. Inc (low) is average marginal tax rates assuming all income earned in a given income bracket was at the lower end of the bracket, while Inc (high) assumes it was earned at the top of the bracket. Inc represents the average of these two. Corp is the corporate tax rate, while Cap is the capital gains rate. Tax spread reports the average tax spread for a corporate bond traded that year (see Section 1.3), and is measured in basis points.

differenced to produce monthly inflation/growth rates.

To split inflation into expected and unexpected components, we follow Fama and Gibbons (1984) and calculate the ex-post time t real interest rate as the 1-month treasury rate (divided by twelve to rescale to a monthly holding period return) less inflation from time t to time $t+1/12$. We calculate an ex-ante real interest rate for each date using the average of ex-post (scaled) real interest rates for the preceding year. The expected inflation at time t is then the 1-month (scaled) *nominal* treasury rate less the ex-ante 1-month (scaled) real interest rate. Unexpected inflation is realised inflation less expected inflation.

The NBER Macrohistory database provides deseasonalised unemployment numbers from April 1929 to December 1940. To provide rates for the earlier part of the sample, we use Lebergott's (1964) annual series. This is then disaggregated to a monthly series using the NBER's monthly series for unemployment of trade union members (which runs continuously until January 1933). The disaggregated series is then seasonally adjusted. To splice the two series together, the Lebergott/trade union series is then scaled by regressing April 1929-January 1933 numbers on the NBER unemployment series. The intercept and slope of this regression are used to rescale the 1927–1929 numbers.

Lastly, we calculate two measures from the treasury yield curve. The first is the 1 year treasury rate. The second is the 10 year treasury rate less the 1 year treasury rate, which provides a measure of the slope of the treasury curve.

2.5 Forming portfolios

To create portfolios for our asset pricing analysis, we split the bonds two ways. First we split by credit class, pooling the B and Caa rated bonds, since there are too few Caa rated bonds to analyse in isolation. Second we split by maturity. We consider bonds with maturity greater than 0.5 years up to (and including) 15 years as short maturity, greater than 15 years up to (and including) 30 years as medium maturity, and greater than 30 years as long maturity. We thus have 18 portfolios. At date t, a portfolio's return is considered to be the value weighted average return of all bonds in the portfolio at date t that traded at both date t and date $t+1$. We calculate excess returns by removing the time t one-month treasury yield (scaled to a monthly return).

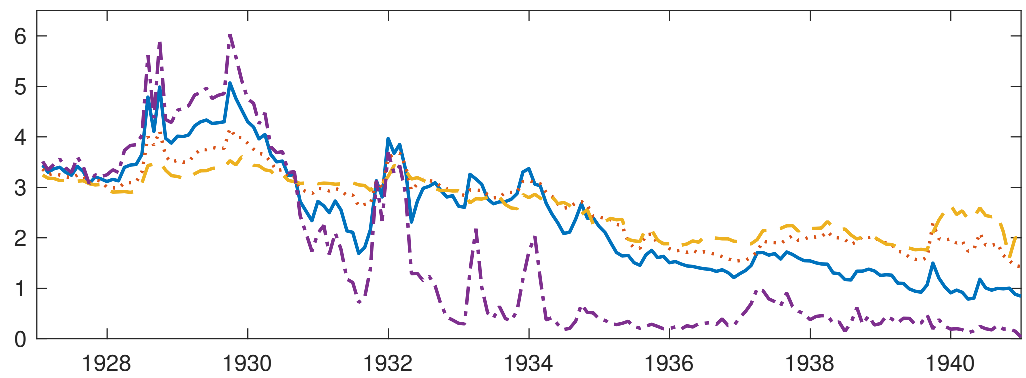

Figure 2: Yield curve for treasury bonds, measured in percent. Dash-dotted line is 1 year rate, solid line is 5 year, dotted line is 10 year, and dashed line is 20 year. These zero curves provide the best overall fit (see Section 1.1) for all treasury bonds on a given date.

3 Main results

We begin by presenting treasury yield curves and corporate spread curves for the period. Subsequently, we break down these spreads into their sources. First, we examine the tax spreads of corporate bonds. We then discuss measurement of credit risk, and the decomposition of CLSs into credit and liquidity components. Finally, we examine variations of spreads (credit, liquidity, or overall) across the period.

3.1 Treasury and corporate curves

Our methodology (see Section 1.1) builds zero curves for treasury bonds, and then spread curves for various credit ratings of bonds. As a prelude to examining individual bond behaviour, we present graphs of these results (see Figures 2–4).

Figure 2 presents zero curves for treasury bonds. Treasury bills first appear in December 1930, so for the earlier part of the sample, the short end of the yield curve are effectively an extrapolation from longer term rates, which are most important for valuing the longer term debt that makes up the bulk of the market. From December 1930 onward, the presence of treasury bills makes the shorter term rates more meaningful.

Treasury rates were relatively high (3.5% with a flat yield curve) in 1927. Rates rose from January 1927 until September 1929, with a downward sloping curve in effect until November

1930. To provide context, the equity market experienced a crash at the end of October 1929. From 1930 onward, rates generally trended downwards. Treasury rates were highly volatile until about 1935. By the end of the period, short term treasury rates were around 50 basis points, while 10-20 year rates were around 2 to 2.5%.

For the Aaa through B rated bonds (see Figure 3), we have fairly extensive data on each trading date. As noted with the early treasury data, short maturity interest rates are not as well identified as the longer maturity part of the yield curve, since most debt is for longer maturities (see Table 2). Hence in our graphs we show 5 year, 10 year, and 20 year spreads.

Perhaps not surprisingly, as we consider lower quality bonds, the spread curves become higher, and also more volatile. Some spread curves have (for short maturities) negative values. For the case of the B rated securities in the early part of the sample, this can be attributed to the very small samples being used to construct the spread curves (see Table 3). For the Aaa rated bonds, later in the sample, it should be noted that the treasury bond market was, by the late 1930s, largely trading over the counter, while the corporate bond market was still exchange traded. Hence, for bonds with minimal credit risk (those still rated Aaa) they might in fact be *more* valuable than corresponding treasury bonds due to the ease with which they could be bought or sold.

Figure 4 shows spread graphs for the lowest (Caa) rated bonds. Here, paucity of data (see Table 3) restricts our attention to the 1930–1940 period. In most cases there are insufficient bonds available to estimate much beyond a flat yield curve. Generally, bonds move fairly rapidly from B to default, so it is rare to see Caa bonds that are still solvent.

In addition to the credit curves themselves, we also generate estimates of volatility (σ) and mean reversion (λ) for the interest rate processes for each credit class (see Appendix D). These are presented in Table 5. Given the use of the Sandmann and Sondermann (1997) model, the volatility can be interpreted as being proportional (e.g. 0.25 means a standard deviation over a year of one quarter of the current interest rate) for low interest rates, and absolute (e.g. 0.25 means a standard deviation of 25%) for high interest rates.

The general trend is that as credit class declines, volatility (σ) increases. Coupled with this, there is a decline (particularly moving from investment grade to speculative grade) in the speed of mean-reversion. For very low quality bonds (Caa rated), the mean reversion is almost zero, suggesting that their movement has a more random-walk (equity like) behaviour. The combination of these two effects is to increase the volatility of long term interest rates.

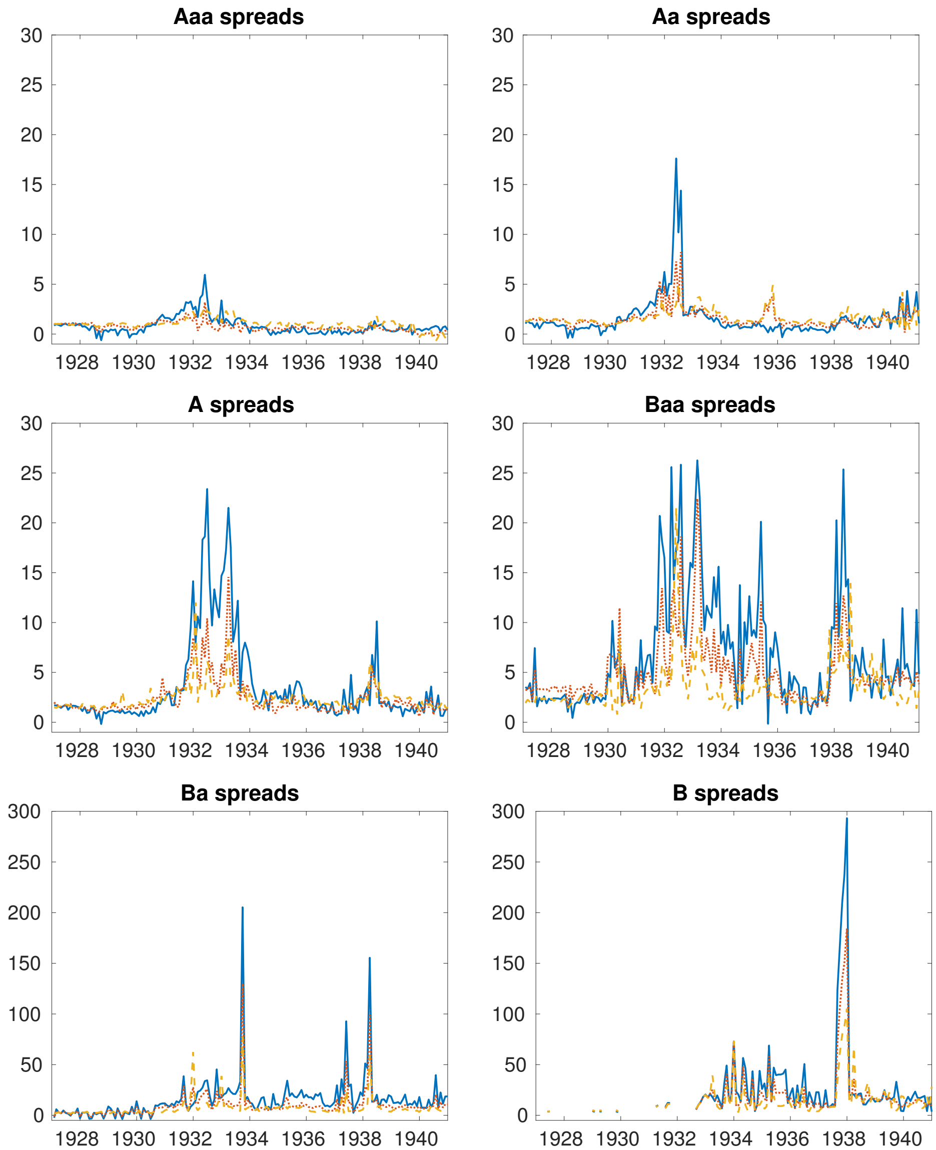

Figure 3: Spread curves for corporate bonds (classes Aaa-B), measured in percent. Solid line is 5 year, dotted line is 10 year, and dashed line is 20 year. These spread curves, when added to the treasury curves (see Figure 2) provide the best overall fit (see Section 1.1) for all bonds of a particular credit class on a given date.

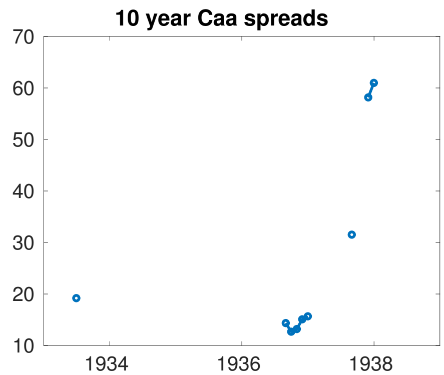

Figure 4: 10 year spread curves for corporate bonds (class Caa), measured in percent. These spread curves, when added to the treasury curves (see Figure 2) provide the best overall fit (see Section 1.1) for all bonds of a particular credit class on a given date. Since there are a very small number of bonds for this credit class, the spread curve is generally quite flat.

Class	σ	λ	$\frac{\sigma}{\sqrt{2\lambda}}$	Class	σ	λ	$\frac{\sigma}{\sqrt{2\lambda}}$
Aaa	0.5735	0.8030	0.4525	Ba	0.7604	0.0230	3.5485
Aa	0.4337	0.2538	0.6087	B	0.8494	0.0218	4.0653
A	1.2143	0.8235	0.9462	Caa	0.0553	0.0021	0.8516
Baa	1.2277	0.5231	1.2004				

Table 5: Volatility (σ) and mean reversion (λ) parameters calibrated to the different bond credit classes over the period 1927–1940. Calibration is discussed in Section 1.1. $\frac{\sigma}{\sqrt{2\lambda}}$ measures the long-term volatility of short-rates implied by this set of parameters.

The third column listed for each model shows the long term (ergodic) volatility of short rates implied by this set of parameters. This highlights that volatility increases considerably as credit quality declines. The only exceptions to this trend are the Caa rated bonds, which record a relatively modest level of long-term volatility. We note that for Caa rated bonds, spreads are sufficiently large that their embedded call options are of minimal value, and so volatility has little effect on the bonds' values.

3.2 Tax spreads

Table 4 shows the tax rates paid by companies and bondholders during the period. The final column displays the average tax spread across all bond prices observed that year. Interestingly, this generally declines over the period. While the tax hikes of 1932, 1934, and 1936 (see Figure 1) increased the tax spreads temporarily, the tax spreads declined precipitously towards the end of the period. This effect can be attributed to two sources: bondholder migration and the effect of other taxes (corporate tax and capital gains tax) on bond values. We examine each effect in turn.

3.2.1 Bondholder migration

As shown in Table 4, the average marginal tax rate paid on interest remained fairly low, in spite of the substantial increases in tax rates shown in Figure 1. To explore this issue more fully, Figure 5 plots percentiles of the income distribution against percentiles of taxable interest earned. For example, a point at (0.7773,0.3526) in 1927 indicates that the bottom 77.73% of households earned 35.26% of the taxable interest income that year.

The most striking aspect of these graphs is the relative lack of curvature. One would expect to find most interest earned by the top 10% (or smaller) income households. However, this is not the case. In 1927, just over half the interest (50.53%) was earned by the bottom 90.18% of the income distribution (those earning less than \$9,000 per year). Wealthy investors certainly earned more interest, but they were sufficiently small in number that they by no means dominated the bondholder population. By contrast, if examining dividends (also reported by the IRS), those earning \$9,000 or less per year in 1927 only earned 19.8% of dividends. Stock ownership was the preferred investment strategy of the wealthy, a quite understandable behaviour, given the large gap between income taxes and capital gains taxes.

Note that this is not to say that bond-holders were necessarily impoverished. To put incomes in context, in 1927, the Shiller house price index (see Shiller (2005)) shows that an average house cost \$5,838 (in 1940, it cost \$5,309, while in 1934, it cost \$4,393).

Comparing the graphs across time, we see that the 1927-1931 period was characterised by an increasing share of interest earned by lower percentiles of the income distribution. Moving from 1931 to 1932, while there was a decline in the fraction earned by the bottom 90%, the curve still lies above the 1927 curve.[21] In 1933, interest was more equally shared (resulting in a migration down the tax curve) while in 1934, equality declined. 1934-1936 sees relatively little movement, however in 1937, there was a large decline in the portion earned by lower income individuals. This corrected itself in 1938, and, after a mild decline in equality in 1939, equality improved in 1940. Most importantly, comparing the top left graph (1927-1931) to the other graphs, generally (with the exception of 1937), these lie to the left of the early periods, reflecting a migration in interest earning to lower income brackets.

Notwithstanding this "relative" migration, absolute incomes declined over the period considered, so that these percentiles generally represented lower absolute levels of income, and hence lower tax brackets. The combination of these two effects was to cause, in spite of rising income tax rates, a decline in the marginal tax paid by the average bondholder.

3.2.2 Coupons, call policies and tax shields

As noted in Sections 2.1 and 1.1, the presence of a capital gains tax can increase the value of bonds that trade at a premium, while deflating the value of those that trade at a discount. As a result, for non-callable bonds, we might expect there to be a negative relationship between tax spread and coupon size relative to interest rates. A call provision on a bond prevents the bond's price from rising above the call provision's strike price. Hence a callable bond would be expected to have a higher tax spread than a corresponding straight bond, since trading at a discount (below par) will make the capital gains tax depress the bond's price further.

Mauer and Lewellen (1987) note that tax shields result in firms exercising their bonds' embedded call options in ways that minimise bond value from the firm's perspective, but

[21] Since the IRS, prior to 1938, amalgamated all incomes below \$5,000 per year, it is difficult to obtain much granularity for incomes below the top 90% during the 1932-1935 period when these make up roughly 90% of the population.

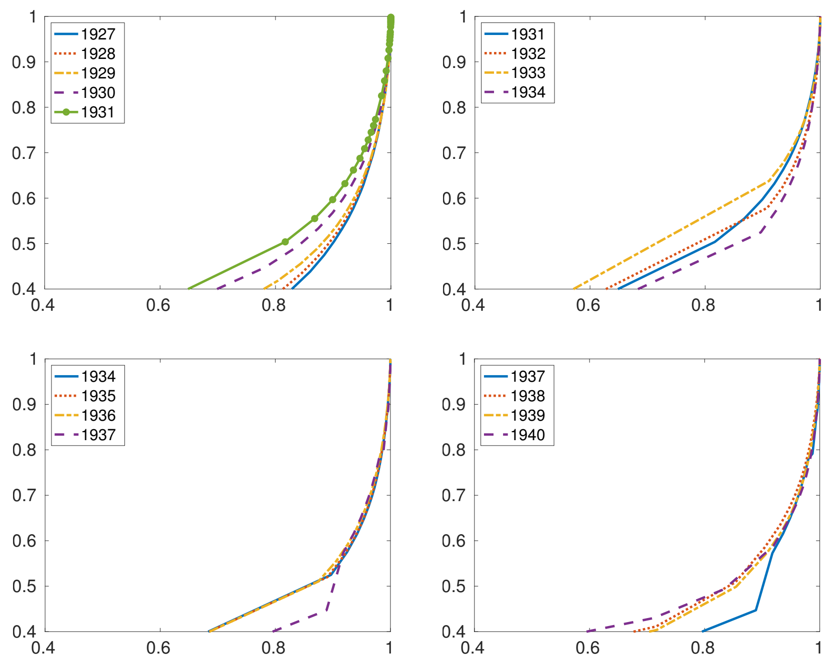

Figure 5: Cumulant of taxpayer population, sorted by income (horizontal axis) plotted against cumulant of interest earned (vertical axis). First graph shows the period 1927-1931, second the period 1931-1934, third graph shows 1934-1937, while last shows 1937-1940. Numbers sourced from Inland Revenue Service Statement of Income reports.

Constant	20.80***	Call	60.32***
	(2.71)		(5.14)
Coup/10y	−13.30***	Call × Coup/10y	−26.18***
	(−3.59)		(−5.89)
Inc	2.18**	Call × Corp	−2.57***
	(2.53)		(−2.92)
Inc × Coup/10y	0.49	Call × Corp × Coup/10y	1.15***
	(1.30)		(3.61)
R^2	0.75		
N	41766		

Table 6: Regression of corporate bond tax spread (in basis points) on level of income tax (Inc; in percent), coupon rate relative to 10 year treasury zero rate (Coup/10y), callability (Call), and corporate income tax rate (Corp; also in percent). Standard errors (reported in parentheses) are clustered by issuing firm and time. ***,**, and * denote significance at the 1%, 5%, and 10% levels, respectively.

do not necessarily minimise bond value from the perspective of a bondholder. This would potentially reduce tax spreads. Here, two aspects of Table 4 come into play here: the modest individual marginal tax rates paid by investors (particularly in 1938-1940) are juxtaposed against growing corporate tax rates (rising from 12% in 1931 to 13.75% in 1932, 15% in 1936, and finally to 33% in 1940). As this gap widens, we would expect to see tax spreads decline for callable bonds.

To formalise these effects empirically, we regress bond tax spreads on coupon rates, callability, and tax rates in Table 6. We scale coupons by the 10 year treasury rate to proxy for the coupon's effect on capital gains. We include a dummy for callability, and interact this with coupon size, corporate tax rates, and the combination of the two. We also include income tax rates, and their interaction with coupons, since bonds with a higher coupon component to their value should be more affected by income taxes.

This regression shows that income tax rates increase tax spreads, since they reduce the value (to bondholders) of coupons paid by the firms. Size of coupon relative to treasury rates has a small (statistically insignificant) positive impact on this effect. Higher coupon rates in isolation decrease tax spreads, since bonds at a premium see their value increase (spreads decrease) and bonds at a discount see their value decrease (spreads increase) from capital gains taxes.

Callability in isolation increases tax spreads since it inhibits the ability of a bond to trade at a premium. This last effect, however, is mitigated by having a higher coupon: callable bonds with high coupons are more likely to be called in the near future, which reduces the magnitude of the capital gains effect on prices (see Appendix B.1). Increasing corporate taxes decreases the tax spread, reflecting the Mauer and Lewellen (1987) effect (the corporate tax and callable interaction term has a negative coefficient).[22] However, as the option moves into the money, this effect decreases (the coefficient for the interaction between corporate tax rate, callability and coupon is positive).

We conclude that declining treasury interest rates would have pushed more bonds into trading at a premium during the latter part of the period, leading to negative (or reduced positive) capital gains effects on tax spreads. The Mauer and Lewellen (1987) effect further mitigated tax effects. The combination of bondholder migration with these effects was to make tax effects on corporate bond prices small, in spite of rising taxes.

3.3 Credit risk

3.3.1 Default probabilities

We calculate probabilities of default using distance to default, as described in Section 1.4.1. To verify that these are working correctly, we perform two analyses. The first fits a logistic regression, predicting monthly defaults. The second compares accuracy ratios.

Table 7 presents the result of the logit analysis. The logit model includes a number of variables that would be expected to do a good job of predicting defaults: bond prices (through the individual bond CLSs), the firm's cash reserves relative to debt, and the bond's credit rating. We also include the rating of the firm's worst rated debt, and the time until a bond next matures, since this may trigger default through an inability to refinance debt. In spite of these competing credit risk variables, the distance to default variable has a very strong t-statistic of 4.73. This is particularly striking because of the inclusion of CLS, which is a very strong predictor of default. It is interesting to note that the credit rating dummies do not come through as being statistically significant in this fit, suggesting that they do not contain information over and above what is contained in prices and accounting information. However

[22]Note that the corporate tax rate is always higher than the income tax rate during our period, so raising the corporate tax rate increases the gap between these two rates.

Constant	-11.37^{***}	(-779.35)	-8.44^{***}	(-264.33)
N(-DD)	5.02^{***}	(4.73)	6.18^{***}	(30.70)
log(1+CLS)	4.17^{***}	(7.38)		
Cash/Debt	-4.24	(-0.60)		
Worst rating	0.74^{***}	(5.62)		
Next maturity	-0.02	(-1.05)		
Aa	0.67	(1.25)		
A	-2.06^{*}	(-1.86)		
Baa	-0.58	(-1.03)		
Ba	-0.12	(-0.19)		
B	0.31	(0.46)		
Caa	2.23^{*}	(1.91)		
R^2	0.30		0.12	
N	32568		88914	

Table 7: Logit model for bond default in the subsequent month. Predictors are $N(-DD)$, probability of default from naïve Merton model, CLS, bond credit/liquidity spread, $Cash/Debt$, ratio of firm cash to debt, $Worst\ rating$, lowest rating of the firm's bonds (where Aaa=1, ..., C=9), and $Next\ maturity$, time (in years) until the firm next has a bond mature. Ratings are dummy variables, where Aaa is excluded. T-statistics are in parentheses, with standard errors clustered across bond and time. R^2 is the McFadden pseudo-R^2. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

the rating of the *worst* rated bond the firm has issued *is* a significant default predictor.

Examining the second column of Table 7, we confirm that variation in $N(-DD)$ by itself does a good job of explaining defaults. Even excluding all the other explanatory variables in the first regression only drops the pseudo-R^2 from 0.30 to 0.12.

The second analysis that we undertake follows Duffie et al. (2007) by calculating the "power curve" for the credit risk measure. A power curve consists of ranking bonds by a given default measure, and then calculating the cumulative percentage of defaults. An ideal indicator would consist of 100% of defaults occurring with the lowest credit measure and none with higher measures. A meaningless measure would be a 45 degree line, where all bonds are equally likely to default, regardless of their scores. By doubling the area under the curve and subtracting 1, we obtain an "accuracy ratio" between 0 (meaningless) and 1 (perfect precision). For predicting the 1 year default probability, $N(-DD)$ has an accuracy ratio of 67.9%. The CLS has 82.2%, the credit rating has 66.7%, the worst rating for the issuer's debt has 75.6%, and cash/debt has 40.6%. Hence our measure of default probability has less

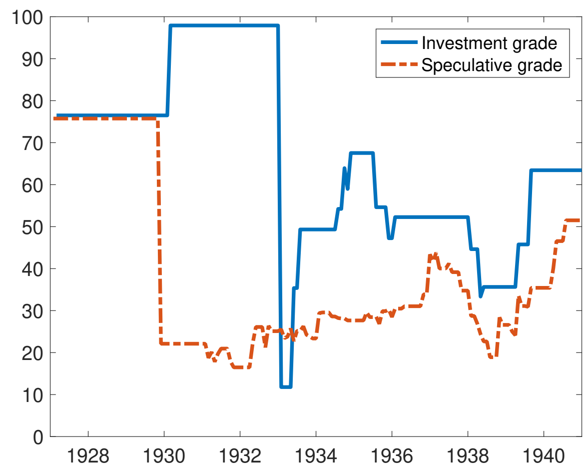

Figure 6: Recovery rates calibrated from observed prices post-default. Individual recovery rates are calculated as price observed at end of month of default. Investment/speculative grade numbers are generated by using an Exponentially Weighted Moving Average fit using prior defaults for the particular class (see Section 1.4.2).

predictive power than bond prices themselves or the worst rating, comparable predictability to the bond's own rating, and better performance than cash/debt ratios.

3.3.2 Recovery rates

The second part of our credit risk analysis entails the calculation of recovery rates (see Section 1.4.2) by examining the price of bonds at the end of the month in which they default.[23] Since this analysis only requires bond prices (and default dates), we use all bonds; including bonds that were otherwise eliminated in our filtering process, such as convertibles.[24]

Figure 6 plots the fitted recovery rates for investment grade and speculative grade bonds for the sample period. The time series presents a stark picture of the evolution of recovery

[23]One concern with this analysis would be that we begin calculating recovery rates in 1927 and there may have been earlier information that investors conditioned their beliefs on. Looking to our overall dataset, we find that two bonds defaulted in 1925, four in 1924, and three in 1923. Of course, these numbers may not reflect overall defaults, since some bonds may have defaulted, and disappeared from the market between their insolvency date and 1927, when we begin collecting data and considering bonds for inclusion in our dataset. Nevertheless, it seems that the 1920s were a relatively quiet period default-wise, and therefore considering investors conditioning their beliefs about recovery on the first defaults observed in 1927 is not unreasonable.

[24]Some concern could be raised regarding the inclusion of financial firms' bonds, however none of this small collection of bonds actually defaulted in this period, so they do not contribute to this analysis.

rates over the period. The cluster of defaults at the start on 1927 saw similar recoveries for the speculative and investment grade bonds concerned. In early 1931, the default of the Aaa rated *New York Central and Hudson River Railroad Company refinancing and improvement gold 4 1/2s (class A)* bonds, saw bondholders take a negligible loss: the price of the bonds at the end of February was 98.25. This could be contrasted to the default, in November 1929, of the B rated *New York State Railways first consolidated gold 4 1/2s, series A due 1952* bonds, where the end of November price was 20. However, subsequently, the Baa rated *Wisconsin Central Railway Company's first general gold 4s* defaulted in January 1933, with a price of $10.25, showing that even investment grade bonds could result in a poor recovery. Later defaults by investment grade bonds in 1933 saw better recovery, and, in general, recovery rates for investment grade bonds were $10–$20 higher than speculative grade bonds for the remainder of the sample period.

Altman et al. (2005), Acharya et al. (2007), and Jankowitsch et al. (2012) note that recovery rates covary negatively with the business cycle, since, during recessions, with many liquidations taking place, it may be difficult to sell a distressed firm's assets for a reasonable price. This pattern can be seen in Figure 6, with substantial declines in speculative bond recovery rates in 1929 and again in 1937 with the start of the Great Depression and the 1937–38 recession (respectively).

To investigate recovery rates further, we regress recovery rates on a range of explanatory variables in Table 8. Given that railroads made up a large part of the market, one might expect to find that these would be prone to diminished recovery rates when there were many defaults in that industry. To that end, we include a variable counting the number of railway defaults in the current and preceding two months. Unfortunately, including this variable means that we cannot evaluate observations at the beginning of 1927, and therefore we are unable to include a dummy variable for the 1926–1927 recession (the only defaults during this period occur at the very beginning of 1927).

The results show that (consistent with Figure 6) investment grade bonds have better recovery than speculative grade bonds. Railway bonds generally see worse losses given default. The Great Depression sees far lower recovery rates, while the 1937-1938 recession has slightly lower recovery rates than normal. Railroads fare better than other firms during the Great Depression but worse (albeit not statistically significantly so) in the 1937–1938 recession. The default intensity coefficient is neither significant, nor of the expected sign:

Inv. Grade	70.67***	(8.53)	70.35***	(8.74)
Spec. Grade	44.55***	(9.49)	44.59***	(9.47)
Rail	−16.14***	(−2.97)	−15.65***	(−3.30)
Rec2627			11.53*	(1.95)
Rec2933	−21.97***	(−4.71)	−22.01***	(−4.69)
Rec3738	−7.74	(−1.32)	−7.78	(−1.32)
Rail*Rec2627			49.53***	(7.32)
Rail*Rec2933	15.27	(1.60)	14.99	(1.59)
Rail*Rec3738	−9.40	(−1.37)	−9.41	(−1.32)
Rail*Default intensity	0.08	(0.18)		
R^2	0.78		0.80	
N	134		137	

Table 8: Regression to explain individual bond recovery rates. Inv. Grade is a dummy variable for Investment Grade bonds, Spec. Grade is a dummy variable for Speculative Grade bonds. Rail is a dummy variable for Railway company bonds. $RecXXYY$ is a dummy variable covering the 19XX–19YY recession. Default intensity counts number of railway bonds that have defaulted in the current and preceding two months. T-statistics are in parentheses, with standard errors clustered on bond and time. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

there seems to be no evidence that railways had lower recovery rates in the presence of clustered railway defaults. The right column of Table 8 removes this variable, allowing the inclusion of the 1926-1927 recession. The new coefficient shows that recovery rates were relatively high during this period, as indicated in Figure 6. Other coefficients remain robust to this respecification of the regression.

3.4 Liquidity

As described in Section 1.4, we use the recovery rates and distances to default to decompose a bond's CLS into credit and liquidity components in Section 3.5. Before analysing these spreads, we confirm that the liquidity spread is indeed correlated with liquidity. For this, we use two liquidity measures. First, we use effective tick (as described in Section 1.5). Second, we use monthly turnover, as described in Section 2. Dick-Nielsen et al. (2012), examining modern data, note that spread measures (such as their imputed round-trip cost) serve as better proxies for liquidity than turnover or zero return measures. Our effective tick measure serves as a proxy for bid-ask spread, since bid-ask spreads are generally highly correlated

	Full sample	Investment grade	Speculative grade
Constant	0.35	0.53***	1.20**
	(1.55)	(3.94)	(2.24)
Effective Tick	3.73***	2.33***	4.61***
	(4.84)	(4.13)	(3.55)
Turnover	1.29	1.72	−10.11**
	(0.73)	(1.44)	(−2.31)
R^2	0.12	0.15	0.12
N	32083	25108	6975

Table 9: Regressions of panel data of bond liquidity spreads (in percent) on effective tick (calculated as described in Section 1.5) and monthly bond turnover (trade volume divided by amount outstanding). T-statistics are in parentheses, clustered on bond and time. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

with tick sizes.

Table 9 presents the results of regressing bond liquidity spreads on effective ticks and monthly turnovers. As the effective tick for a bond increases (the bond becomes less liquid), the liquidity spread increases. Turnover has a statistically significantly negative effect for speculative bonds, indicating that more liquid bonds again have lower spreads. However this effect is not present (insignificant with the opposite sign) for investment grade bonds, or using the full sample (which is dominated by the investment grade bonds). We conclude that the effective tick provides strong support that bond liquidity is correlated with our liquidity spread measure, while the (less reliable) turnover measure provides weak support.

3.5 Spreads

We now move on to examine the behaviour of spreads: the complete CLSs, along with the credit and liquidity spread dichotomy discussed in Sections 3.3 and 3.4.

Table 10 presents regression analysis of the individual bond CLSs. The regression examines the effect of credit class and whether the issuer is a railroad on spreads in general, followed by the effect of each of the three recessions (1926–1927, the Great Depression of 1929–1933, and 1937–1938). The 1926–1927 recession ends in November 1927 (having started in October 1926), the Great Depression spans August 1929 until March 1933, while the 1937–1938 recession starts in May 1937 and ends in June 1938.

	Const.	Rec2627	Rec2933	Rec3738		
Aaa	−0.17	1.16***	0.62***	−1.01**		
	(−1.02)	(7.12)	(3.23)	(−2.20)		
Aa	0.22	0.86***	0.80***	−0.77*		
	(1.35)	(5.02)	(3.76)	(−1.82)		
A	0.67***	0.72***	1.51***	−0.40		
	(3.66)	(3.93)	(3.91)	(−0.82)		
Baa	2.47***	−0.46**	1.93***	0.43		
	(11.63)	(−2.01)	(4.28)	(0.65)		
Ba	5.36***	−2.96***	3.99***	1.61*		
	(15.64)	(−7.17)	(4.89)	(1.75)		
B	9.84***	−6.27***	7.60***	3.08		
	(9.56)	(−8.60)	(4.68)	(0.83)		
Caa	9.49***			15.89***		
	(8.22)			(2.96)		
Rail	1.82***	−1.90***	−0.12	2.04***	R^2	0.46
	(6.76)	(−7.20)	(−0.29)	(2.72)	N	41717

Table 10: Regressions of $\log(1 + CLS)$, measured in percent, on credit class and dummies, and interaction terms with recession dummies. Const. column represents coefficients for dummies themselves. RecXXYY column is for credit class dummies interacted with 19XX–19YY recession dummy. T-statistics are in parentheses, where standard errors are clustered by bond and time. *,**, and *** denote significance at the 10%, 5%, and 1% levels.

The raw dummy terms show the expected pattern: higher rated debt enjoys a lower spread relative to lower rated debt. The distinction between the Aaa, Aa, and A rated classes may only be around 40 basis points, but these gaps widen as credit quality deteriorates. Moving from Baa to Ba entails a 2.89% increase in CLS, while Ba to B creates a 4.48% larger spread. Railway bonds generally have a 1.82% spread over other comparable bonds.

Looking to the recessions, we see that the 1926–1927 recession saw a rise in spreads for Aaa–A rated bonds, and a decline in spreads for lower rated bonds.[25] The overall effect of this was a flattening of the credit curve: a much smaller gap between higher rated bond spreads and lower rated bond spreads. Railway bonds fared better than other bonds, to the point of offsetting their usual 1.8% spread.

The Great Depression had a much worse effect on the bond market. All bond spreads were wider during this period, and, in particular, speculative bond (Ba and below) spreads rose considerably. Railway bond performance was similar to non-recession periods, with a 1.7% extra spread over comparable non-railway bonds.

The railway bonds, however, performed much worse in the 1937–1938 recession. By this stage, problems were widespread in the industry. Schiffman (2003) argues that railroads had initially faced financing problems during the Great Depression due to credit quality requirements imposed in New York state on investments held by banks and trusts. This made refinancing of debt difficult. Although railroads were initially able to reduce costs by deferring maintenance, this became increasingly costly over time. Attempts to stimulate the railroad sector by the Reconstruction Finance Corporation were relatively unsuccessful, with many loan recipients ultimately defaulting. This recession, although not as severe (in terms of bond spreads) as the Great Depression, saw a steepening of the spread curve. Investment grade bond spreads declined, while speculative grade bonds (particularly B and Caa rated bonds) saw their spreads increase substantially.

The spread effects in Table 10 are either due to credit risk or liquidity. Table 11 repeats this analysis, but in this case the first panel reports results for credit spreads, while the second reports results for liquidity spreads.

The credit spread results show that much of the variation in CLS between investment grade credit classes is due to credit risk. The difference in credit spread between Aaa rated bonds and Aa rated bonds is 44 basis points, while the gap between Aa and A rated bonds is

[25]There are no observations of Caa rated bonds during the 1926–1927 recession.

	Const.	Rec2627	Rec2933	Rec3738		
			Credit Spread			
Aaa	−0.66***	0.66***	0.43***	0.01		
	(−5.69)	(5.76)	(3.67)	(0.05)		
Aa	−0.22	0.29**	0.26*	0.13		
	(−1.59)	(2.08)	(1.69)	(0.44)		
A	0.06	0.05	−0.03	0.71**		
	(0.47)	(0.40)	(−0.24)	(2.24)		
Baa	0.99***	−0.74***	−0.32	0.93**		
	(7.38)	(−5.43)	(−0.97)	(2.31)		
Ba	3.38***	−2.97***	3.38***	1.41*		
	(13.04)	(−11.12)	(5.95)	(1.82)		
B	4.51***	−4.48***	3.71***	1.68*		
	(10.15)	(−10.15)	(4.44)	(1.67)		
Caa	3.68**			2.62		
	(2.31)			(1.64)		
Railway	1.41***	−1.41***	−0.78***	1.34***	R^2	0.61
	(9.19)	(−9.35)	(−3.23)	(2.61)	N	32376
			Liquidity Spread			
Aaa	0.49***	0.52***	−0.03	−0.99**		
	(3.96)	(4.19)	(−0.15)	(−2.47)		
Aa	0.32**	0.69***	0.55**	−0.61*		
	(2.09)	(4.49)	(2.04)	(−1.76)		
A	0.57***	0.69***	1.49***	−0.82*		
	(3.93)	(4.73)	(3.60)	(−1.73)		
Baa	1.41***	0.41**	2.16***	0.04		
	(8.63)	(2.19)	(4.18)	(0.12)		
Ba	1.85***	0.08	1.21*	−0.28		
	(6.39)	(0.20)	(1.66)	(−0.41)		
B	4.08***	−0.35	4.26***	−2.20**		
	(6.39)	(−0.55)	(3.12)	(−2.45)		
Caa	7.55***			6.48***		
	(7.46)			(6.41)		
Rail	0.10	−0.23	0.98***	0.13	R^2	0.19
	(0.56)	(−1.26)	(2.63)	(0.35)	N	32376

Table 11: Regressions of credit and liquidity spreads (measured in percent) on credit class dummies, rail dummies, and interaction terms with recession dummies. Const. column represents coefficients for dummies themselves. RecXXYY column is for credit class dummies interacted with 19XX–19YY recession dummy. Numbers in parentheses are standard errors, clustered by bond and time. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

28 basis points. However, this is not true for lower rated debt. Although the credit spreads generally widen (with the exception of the difference between B and Caa rated debt), the gaps are not so large as when considering the entire CLS (see Table 10). For example, moving from a Ba rated bond and a B rated bond only entails an increase in credit spread of 113 basis points, as compared to 4.48% when considering the full CLS. In contrast, much of the CLS premium for railroads (1.82%) can be attributed to credit risk (1.41%).[26]

Turning to the effect of recessions on credit spreads, the 1926–1927 recession shows a similar pattern to the overall CLS: spreads for high quality bonds rose, while those for low quality bonds fell. The Great Depression, in contrast, sees rises in credit spreads for high quality bonds (43 basis points for Aaa rated bonds, and 26 basis points for Aa), very little change for A and Baa bonds, and big increases for Ba and B rated bonds. Contrasting this U-shaped effect with the results in Table 10, we see that large portions of the CLS change for speculative grade bonds cannot be accounted for as credit spread changes, especially for lower rated debt. Railroads fared rather better than their other contemporaries during this period, seeing just over half of their industry spread disappear.

The 1937–1938 recession saw little credit spread effect on Aaa and Aa rated bonds, and modest increases in spreads for lower rated bonds. Comparing these results to Table 10, we see that for investment grade bonds these credit spread shocks are in fact *larger* than the overall CLS spread changes during this period, suggesting (as is confirmed in the second part of Table 11) that liquidity in fact improved during the 1937–1938 recession. The railway premium, however, bucks this trend: the credit spread for railroad bonds (1.34%) is lower than the overall CLS premium (2.04%).

Liquidity spreads (the second half of Table 11) show that, as noted in modern data by Friewald et al. (2012), liquidity premia are larger for lower rated debt. While Aaa, Aa, and A rated debt enjoy similar (low) liquidity premia, the jump from A to Baa entails an increase in liquidity spread of 84 basis points, while moving from Ba to B or B to Caa leads to a bigger increase in liquidity spread than credit spread. Much of the decline in bond value associated with low credit ratings is more concerned with difficulty of trading the bonds as opposed to default risk. Work with modern data, such as Longstaff et al. (2005) and Huang

[26] All credit spreads are (by construction) positive. The negative coefficients for some investment grades are caused by the inclusion, in the regression, of a railway dummy that applies evenly to railways of all credit classes.

and Huang (2012), has shown that the importance of credit risk becomes relatively more important for lower rated bonds, whereas here, we see a more even split of the CLS between the credit and liquidity components.

Looking to the liquidity recession dummies, we see a different pattern to the credit spread recession effects. The 1926–1927 recession saw liquidity spreads widen for all investment grade bonds, by 40 to 70 basis points. The Great Depression saw liquidity spreads increase, but in this case, the effect was disproportionately borne by lower credit quality bonds. Lastly, and most striking, the 1937–1938 recession was associated with an *improvement* in liquidity. Bonds had lower liquidity spreads during this period, especially higher rated bonds. Taking the three sets of results together we now see the explanation for the strong performance of investment grade bonds during this period: credit effects on these bonds were minor, and overall liquidity improvements resulted in their values rising relative to treasuries.[27]

Lastly, the railroad bonds had liquidity spreads that were comparable to other bonds. Neither the 1926–1927, nor 1937–1938 recessions had much effect on their liquidity spreads, although the Great Depression saw a roughly 1% increase in liquidity spreads, more than offsetting their decline in credit spreads.

Dick-Nielsen et al. (2012) calculate liquidity spreads for corporate bonds during the periods 2005Q1–2007Q1 (prior to the Global Financial Crisis) and 2007Q2–2009Q2 (during the Global Financial Crisis). They show that during the GFC, liquidity spreads grew by 4 basis points for Aaa rated bonds, by 41 basis points for Aa rated bonds, 48 basis points for A rated bonds, 89 basis points for Baa rated bonds, and 139 basis points for speculative bonds. Comparing these numbers to our changes for the Great Depression, we see a very similar pattern: Aaa rated bond liquidity spreads did not change, while other investment grade bond spreads rose by 55 (Aa) to 216 (Baa) basis points. Our speculative grade bonds saw an increase of 121 (Ba) to 426 (B) basis points.

Our conclusions are as follows. Liquidity was (as it is now) a very important contributor to spreads for low quality bonds. The 1926–1927 recession was mostly associated with a flattening of the credit curve and heightening of liquidity spreads. The Great Depression was punitive for corporate bonds in terms of both credit spreads and liquidity spreads, but

[27]It should be noted that the liquidity premium is a statement about corporate bond liquidity *relative* to treasury bond liquidity. Since the 1930–1940 period was characterised by the gradual transition of treasuries to an OTC market, some of this "improvement in liquidity" may have been a decline in liquidity for treasuries.

in both cases, more so for speculative bonds. The 1937–1938 recession certainly saw credit spreads heighten, but this was partly offset by liquidity spread declines. Railways generally had higher credit spreads during the latter part of our sample, and especially during the 1937–1938 recession.

4 Extensions

This section examines three further facets of the bond market's behaviour. First, we examine the presence of contagion in credit and liquidity. Next, we try to find which macroeconomic variables affect bond spreads. Lastly, we examine asset pricing effects on expected returns.

4.1 Contagion

Jorion and Zhang (2007, 2009) and Das et al. (2007) note that corporate bonds can exhibit contagion, whereby bonds are more likely to default when other bonds have defaulted. We now turn our attention to whether there is evidence of heightened co-movement of spreads (either through credit spreads or liquidity spreads). In doing this, we follow the methodology outlined in Section 1.6: we generate an index using principal components applied to CLS changes, and then regress spread changes on this index. By including dummy variables for the recessions during the period, we can examine whether bond prices tended to co-move during these periods. Finally, we repeat the analysis using credit spreads and liquidity spreads, gauging whether this heightened co-movement was due to credit or liquidity risk.[28]

Table 12 presents results from analysing CLSs holistically. The market column provides estimates of the average sensitivity of $\Delta \log(1 + CLS)$ to changes in the index for different credit classes during normal times. We can think of these coefficients as similar to "betas" for stocks. Not surprisingly, we see that lower credit classes have higher co-movement with market shocks.[29] Railways also exhibit higher co-movement.

Mirroring our results concerning spreads during the recessions, we see that the 1926–1927

[28]In these cases, we work with indices calculated from credit or liquidity spreads rather than overall CLS spreads.

[29]Note that our methodology for constructing our market index (see Section 1.6) begins by studentising all the series, so the higher co-movement for lower credit classes is not a figment of their dominating the index.

	Const	Index	Rec2627 × Index	Rec2933 × Index	Rec3738 × Index		
Aaa	−0.03	0.00	0.51***	−0.04	−0.45***		
	(−1.28)	(0.11)	(4.52)	(−0.69)	(−4.88)		
Aa	−0.03	0.07*	0.52***	0.01	−0.35***		
	(−1.29)	(1.94)	(3.68)	(0.16)	(−4.56)		
A	0.02	0.27***	0.42***	0.16	−0.44***		
	(0.98)	(4.53)	(3.23)	(1.44)	(−5.00)		
Baa	0.02	0.41***	0.11	0.11	−0.09		
	(1.16)	(10.64)	(1.24)	(1.21)	(−1.21)		
Ba	0.15***	0.61***	0.14	0.25**	0.54***		
	(3.74)	(14.91)	(0.61)	(2.52)	(2.59)		
B/Caa	0.23**	1.01***	−0.59	0.65**	0.17		
	(2.54)	(10.45)	(−0.93)	(2.40)	(0.69)		
Rail	0.07**	0.29***	−0.30*	0.20*	0.57***	R^2	0.29
	(2.38)	(5.36)	(−1.76)	(1.86)	(5.05)	N	28842

Table 12: Regressions of $\Delta \log(1+CLS)$ (in percent), on credit class dummies, rail dummies, and interaction terms with recession dummies and bond spread index. Const. column represents coefficients for dummies themselves. Index is for dummies interacted with index shock. RecXXYY× Index column is for credit class/rail dummies interacted with the index and the 19XX–19YY dummy. T-statistics are in parentheses, where standard errors are clustered by bond and time. *, **, and *** denote significance at 10%, 5%, and 1% levels, respectively.

recession saw a flattening of the "beta curve". Investment grade bonds had higher sensitivity to the market factor and lower quality bonds had lower sensitivities. Further, the railway industry had a lower excess beta relative to other securities. We could thus make the case that for this recession, contagion (i.e. heightened betas) were only associated with investment grade bonds, and mostly concentrated in the Aaa-A rated bonds. The Great Depression, in contrast, saw contagion for all credit classes, except Aaa rated bonds. These effects were particularly acute for lower credit classes. Railways also exhibited contagion. Finally, the 1937–1938 recession saw very little contagion in general. Only Ba rated bonds saw their betas increase, and investment grade bonds saw their betas decline (in the case of A, Aa, and Aaa rated bonds, statistically significantly so). Railways, however, saw a major increase in their betas. Given their large role in the period's bond market, this seems consistent with an industry wide shock taking place (see Section 3.5).

We next move on to separating these effects between credit spreads and liquidity spreads. Table 13 provides this dichotomy. The first panel shows results of credit spreads being regressed on the credit index, while the second half shows results of liquidity spreads being regressed on the liquidity index.

In the first panel (credit contagion), we see that there is definitely a beta curve, with lower rated bonds having higher market sensitivity, but this is not as pronounced as that recorded for the whole CLS (Table 12). Railways also have higher betas. We see evidence of contagion (positive coefficients) for speculative grade bonds during the Great Depression and 1937–1938 recession. There is also evidence of contagion for railways in the 1937–1938 recession.

Findings from Table 12 that were not echoed in the first panel of Table 13 must be found in the second panel. In particular, the contagion for investment grade bonds during 1926–1927 was largely through heightened co-movement of liquidity spreads. Also the negative contagion (reduced co-movement) seen for investment grade bonds during the 1937–1938 recession and railways during the 1926–1927 recession came through liquidity channels.

We conclude that credit contagion occurred for speculative grade bonds during the Great Depression and for speculative grade and railroad bonds during the 1937–1938 recessions. Liquidity effects were more mixed, exacerbating risk for investment grade bonds during the 1926–1927 recession while reducing risk for these bonds during the later 1937–1938 recession.

	Const.	Index	Rec2627 × Index	Rec2933 × Index	Rec3738 × Index		
			Credit Contagion				
Aaa	−0.03	−0.04	−0.13	0.05	−0.03		
	(−0.90)	(−0.47)	(−1.06)	(0.54)	(−0.17)		
Aa	0.01	0.12	−0.18	−0.03	−0.17		
	(0.15)	(0.82)	(−1.02)	(−0.19)	(−0.96)		
A	0.03	0.31**	−0.26	−0.34**	0.18		
	(1.09)	(2.24)	(−1.37)	(−2.15)	(1.03)		
Baa	0.07	0.41***	−0.12	−0.40**	0.17		
	(1.29)	(4.02)	(−0.50)	(−2.06)	(1.52)		
Ba	−0.03	0.25	−0.44	0.47	0.94***		
	(−0.26)	(1.25)	(−1.19)	(1.52)	(4.12)		
B/Caa	−0.05	0.51	−0.92	1.05**	0.82**		
	(−0.23)	(1.49)	(−0.58)	(2.24)	(2.06)		
Rail	0.03	0.16	0.11	−0.07	0.58***	R^2	0.16
	(0.67)	(1.35)	(0.61)	(−0.44)	(4.07)	N	22716
			Liquidity Contagion				
Aaa	0.00	0.05	0.61***	−0.15	−0.66***		
	(0.03)	(0.41)	(3.50)	(−1.04)	(−2.81)		
Aa	−0.04	−0.06	0.59**	0.02	−0.36*		
	(−0.68)	(−0.40)	(2.29)	(0.11)	(−1.73)		
A	0.00	−0.01	0.74***	0.51**	−0.79***		
	(0.02)	(−0.03)	(3.22)	(2.25)	(−3.40)		
Baa	−0.05	−0.05	0.23	0.51*	−0.27*		
	(−0.80)	(−0.44)	(0.81)	(1.93)	(−1.89)		
Ba	0.18	0.34*	0.65	−0.19	−0.40		
	(1.43)	(1.86)	(1.24)	(−0.65)	(−1.38)		
B/Caa	0.17	0.42	1.02	−0.33	−0.72		
	(0.80)	(1.25)	(0.65)	(−0.58)	(−1.60)		
Rail	0.03	0.12	−0.35*	0.32	0.14	R^2	0.07
	(0.49)	(1.06)	(−1.91)	(1.42)	(0.79)	N	22716

Table 13: Regressions of change in credit spread and liquidity spread, measured in percent, on credit class dummies, rail dummies, and interaction terms with recession dummies and bond spread index. Const. column represents coefficients for dummies themselves. Index is for dummies interacted with index shock. RecXXYY× Index column is for credit class/rail dummies interacted with the index shock and the 19XX–19YY dummy. Numbers in parentheses are t-statistics, where standard errors are clustered by bond and time. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

4.2 Macroeconomic variable effects

A natural follow-up question from the analysis of Section 3.5 is to ask why bond spreads respond differently to the different recessions? Using the macroeconomic data described in Section 2.4, Table 14 shows the variation in the state of the economy across the three recessions (along with the non recession periods that intersperse these). Unemployment rises over the earlier part of the sample, hitting its maximum over the period between the Great Depression and the 1937–1938 recession. In contrast, GNP growth is positive (on average) over all the non-recession periods, and is negative during the recession periods (and substantially so during the Great Depression). Expected inflation is negative during the first half of the sample, but then is positive following the Great Depression until the end of the 1937–1938 recession. The last part of the period (1938–1940) has mild deflationary expectations. The expectation of deflation during the Great Depression has been documented by Cecchetti (1992). Consistent with these expectations being accurate, we generally find that unexpected inflation has a mean of close to zero (although the standard deviation is far larger than for expected inflation). However, notably, the unexpected inflation was substantially negative during the 1937–1938 recession, reflecting that the deflation observed during this recession was unanticipated. Interest rates, consistent with Figure 2, decline over the period. The yield curve is downward sloping until the start of the Great Depression, and upward sloping from then on.

Table 15 contains the results from regressing CLS on the macro variables. Unemployment and GNP growth both show a mixed effect on bonds. For top rated bonds (Aaa and Aa), effects of economic slowdown are minimal (or even positive for Aaa rated bonds). In contrast, a rise in unemployment or decline in GNP growth is associated with a rise in spread for bonds rated A or lower. Railways, whose business to a large extent depends on moving freight, also see their spreads rise when the economy slows down.

Turning to inflation, the difference between expected and unexpected inflation is quite stark. Expected inflation sees spreads narrow for all bonds. Unexpected inflation, in contrast, has little effect on bond prices. Looking at Table 14, we see that the Great Depression (1929–1933) is particularly characterised by rampant disinflation (as, to a lesser extent, is the 1926–1927 recession). In contrast, the 1937–1938 recession has (on average) positive expected inflation.

The two yield curve measures suggest that higher treasury rates are bad news for bonds

Period	Recession	UE	GNP	EI	UI	1T	TYS
1/1926–11/1927	Yes	1.01	−0.30	−0.20	−0.05	3.37	−0.16
		0.30	0.55	0.08	0.70	0.16	0.10
12/1927–7/1929	No	1.38	0.57	−0.04	0.10	4.39	−0.90
		0.40	0.47	0.09	0.55	0.72	0.40
8/1929–3/1933	Yes	13.51	−1.06	−0.63	−0.10	2.48	0.72
		8.46	1.27	0.38	0.44	1.57	1.22
4/1933–4/1937	No	17.67	0.93	0.10	0.17	0.49	1.77
		3.65	1.90	0.26	0.71	0.39	0.48
5/1937–6/1938	Yes	15.02	−0.69	0.16	−0.30	0.52	1.46
		3.58	1.71	0.22	0.54	0.21	0.24
7/1938–12/1940	No	15.78	0.74	−0.08	0.05	0.28	1.54
		2.11	1.04	0.15	0.53	0.12	0.22

Table 14: Average levels for macroeconomic variables over subperiods from 1927–1940, with standard deviations reported in parentheses. Macroeconomic variables are Unemployment (UE), monthly Gross National Product growth (GNP), monthly Expected Inflation (EI), monthly Unexpected Inflation (UI), One year Treasury rate (1T), and 10 year to 1 year Treasury Yield Spread (TYS). All variables are measured in percent.

that are going concerns (i.e. investment grade bonds). In contrast, an upward sloping yield curve is good news for railway bonds, and better quality (Ba rated) speculative bonds. A higher one year treasury rate is also good news for Railway bonds. These results seem consistent with higher interest rates having a mixed effect: on the one hand, they can be a signal of heightened economic activity (particularly a positive term premium). On the other hand, higher interest rates result in greater costs for firms. The former effect may be more important for struggling firms, while the latter effect dominates for firms in a healthier financial position.

Table 16 considers the effect of the macroeconomic variables on the credit and liquidity components of the CLS. As in the analyses of Sections 3.5 or 4.1, we would expect the effects seen in Table 15 to be split between the two components.

GNP growth generally decreases both spread components. Liquidity spreads and credit spreads decline when GNP growth is higher for all classes except Aaa (for liquidity spreads) and A (for credit spreads). High unemployment is associated with lower liquidity *and* credit spreads for Aa rated bonds, and (generally) higher spreads for lower rated (Baa) investment grade and speculative grade bonds. The rail coefficients are less consistent between unem-

	Const.	UE	GNP	EI	UI	1T	TYS
Aaa	−0.21	−0.07***	0.01	−1.02***	0.12*	0.34**	0.58***
	(−0.42)	(−4.49)	(0.33)	(−4.01)	(1.87)	(2.22)	(2.66)
Aa	−0.47	−0.03*	−0.03	−1.16***	0.09	0.38**	0.60***
	(−0.88)	(−1.90)	(−0.60)	(−4.47)	(1.55)	(2.34)	(2.69)
A	−2.17***	0.06**	−0.15**	−2.02***	0.14*	0.86***	1.01***
	(−2.75)	(2.20)	(−2.03)	(−5.36)	(1.68)	(3.94)	(3.36)
Baa	−1.83**	0.16***	−0.22***	−1.38***	−0.04	0.90***	0.92**
	(−2.01)	(6.33)	(−3.22)	(−3.78)	(−0.31)	(3.26)	(2.27)
Ba	3.92***	0.32***	−0.34***	−3.60***	0.14	−0.64	−1.77***
	(2.75)	(5.94)	(−6.23)	(−5.97)	(0.66)	(−1.54)	(−2.65)
B/Caa	7.89***	0.16	−0.89***	−4.83**	−0.89*	0.34	0.29
	(3.32)	(1.04)	(−2.80)	(−2.55)	(−1.89)	(0.44)	(0.26)
Rail	1.36	0.22***	−0.16**	0.47	−0.03	−0.65***	−1.35***
	(1.58)	(7.51)	(−2.06)	(1.04)	(−0.29)	(−2.66)	(−4.14)
R^2	0.50	N	41717				

Table 15: Regression of $\log(1 + CLS)$ on macroeconomic variables interacted with credit class of bond and whether bond is issued by railroad (Rail). Macroeconomic variables are Unemployment (UE), monthly Gross National Product growth (GNP), monthly Expected Inflation (EI), monthly Unexpected Inflation (UI), One year Treasury rate (1T), and 10 year to 1 year Treasury Yield Spread (TYS). All variables (including transformed CLS) are measured in percent. Numbers in parentheses are t-statistics, where standard errors are clustered on bond and year. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

ployment and GNP growth. A rise in unemployment worsens both spreads for railways, but a decline in GNP growth sees liquidity spreads worsen while credit spread responses are minor.

This asymmetric behaviour is also prevalent with expected inflation. Higher expected inflation improves liquidity. This is consistent with the observation in Section 3.5 that the 1937–1938 recession (when expected inflation was fairly high) saw low liquidity spreads for corporate bonds. In contrast, the effect on credit risk varies by credit rating. Expected inflation is good news for speculative grade bonds, but bad news for investment grade bonds. For a heavily indebted firm, a rise in inflation makes survival more likely, since it decreases the real value of future debt payments, and hence we might expect credit quality to improve. In contrast, a bond with good credit quality is less likely to be heavily indebted, and so this effect does not occur.

Turning to the interest rate measures, higher rates generally raise liquidity spreads. The asymmetric responses noted in Table 15 come through credit channels, where higher rated bonds see credit spreads widen as rates rise, whereas lower rated bonds see credit spreads narrow. This supports the conjecture that high rates are bad for going concerns, but as signals of better economic conditions are good news for firms whose survival is uncertain (a credit effect).

4.3 Bond returns

Most of the analysis of this paper has focused on spreads of bonds. However, we conclude by examining the behaviour of bond returns. Specifically, we ask the question whether bond returns are priced in terms of sensitivity to market CLSs (or market credit or liquidity spreads) as described in Section 4.1. Further, we are curious as to whether this sensitivity changes during recessions. To do this, we estimate a stochastic discount factor, allowing the recession periods to be a conditioning variable (see Section 1.7). Effectively, we allow the reward for bearing different forms of systematic risk to increase or decrease in recessions.

In this analysis, we form portfolios from bonds, based on credit class and maturity (see Section 2.5). The stochastic discount factor estimation is described in Section 1.7. Factors for the model make use of the Fama-French factors: market return, less our 1 month treasury rate (converted to a monthly holding period return), Small-minus-Big (SMB) and High-

	Const.	UE	GNP	EI	UI	1T	TYS
				Credit spread			
Aaa	−0.99**	−0.02*	−0.04	0.06	0.07	0.34**	0.42*
	(−2.43)	(−1.66)	(−1.57)	(0.49)	(1.20)	(2.48)	(1.87)
Aa	−1.07**	0.04	−0.04	0.08	0.13	0.28	0.12
	(−2.06)	(1.34)	(−0.86)	(0.58)	(1.53)	(1.63)	(0.39)
A	−1.49***	0.05**	0.00	0.45***	0.03	0.46***	0.41
	(−3.06)	(2.20)	(0.01)	(2.65)	(0.40)	(2.90)	(1.49)
Baa	−0.15	0.15***	−0.05	0.36	0.03	−0.11	−0.74
	(−0.28)	(2.89)	(−0.67)	(1.35)	(0.20)	(−0.66)	(−1.63)
Ba	1.77*	0.22***	−0.21***	−2.83***	0.10	−0.29	−0.94*
	(1.95)	(3.99)	(−2.81)	(−5.51)	(0.35)	(−1.04)	(−1.77)
B/Caa	5.21***	0.03	−0.20**	−3.73***	−0.04	−0.69	−0.26
	(2.95)	(0.24)	(−2.07)	(−3.91)	(−0.10)	(−1.10)	(−0.30)
Rail	1.81***	0.12***	0.01	0.24	0.03	−0.71***	−1.12***
	(3.32)	(5.48)	(0.38)	(1.23)	(0.22)	(−4.20)	(−4.19)
R^2	0.67	N	32376				
				Liquidity spread			
Aaa	0.45	−0.07***	0.03	−0.62***	0.04	0.16	0.53**
	(0.91)	(−3.89)	(0.79)	(−2.73)	(0.58)	(1.04)	(2.22)
Aa	−0.03	−0.07**	−0.05	−0.85***	−0.06	0.32	0.80**
	(−0.04)	(−2.16)	(−0.85)	(−3.14)	(−0.51)	(1.55)	(2.14)
A	−0.62	0.01	−0.22**	−2.22***	0.11	0.40	0.67
	(−0.67)	(0.15)	(−2.07)	(−5.88)	(0.76)	(1.50)	(1.53)
Baa	−0.38	−0.02	−0.20*	−1.72***	−0.08	0.66***	1.27**
	(−0.56)	(−0.25)	(−1.87)	(−4.07)	(−0.50)	(2.99)	(2.12)
Ba	0.17	0.11**	−0.14**	−0.73	−0.14	0.27	−0.14
	(0.16)	(2.01)	(−2.37)	(−1.20)	(−0.69)	(0.88)	(−0.26)
B/Caa	3.17	−0.00	−0.19*	−3.08**	−0.41	0.74	0.51
	(1.63)	(−0.02)	(−1.78)	(−2.14)	(−1.59)	(1.24)	(0.81)
Rail	−0.51	0.09**	−0.08	−0.59*	−0.05	0.01	−0.44
	(−0.72)	(2.49)	(−1.53)	(−1.68)	(−0.45)	(0.06)	(−1.45)
R^2	0.20	N	32376				

Table 16: Regression of credit and liquidity spreads (in percent) on macroeconomic variables interacted with credit class and if bond is railway bond. Macroeconomic variables are as described in Table 15. Numbers in parentheses are t-statistics, where standard errors are clustered by bond and time. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

	Coeff.	t-stat	Coeff.	t-stat
CLS	−1.06	−3.23***		
CLS × REC	0.89	1.81*		
Credit spread			−2.01	−4.56***
Credit spread × REC			1.76	2.44**
Liquidity spread			−1.39	−4.97***
Liquidity spread × REC			1.19	1.58
Market	−0.09	−0.71	−0.16	−0.83
Market × REC	−0.03	−0.14	0.05	0.21
SMB	−0.08	−3.82***	−0.11	−4.56***
SMB × REC	0.31	1.86*	0.32	1.30
HML	0.02	0.15	0.07	0.54
HML × REC	0.09	0.40	0.04	0.25

Table 17: Generalised Method of Moments estimates of coefficients for stochastic discount factor (see equation 3). Assets used are excess returns on 18 portfolios sorted on credit class (Caa pooled with B) and maturity (0.5-15 years, 15-30 years, and 30+ years). Recession dummy is included as conditioning information. First two columns represent model with only overall spread factor. Second two columns use credit spread and liquidity spread factors separately. Estimation is as described in Section 4.3. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

minus-Low (HML).We also include our CLS index (as described in Section 1.6). Further, we create analogous indices using our credit spreads and liquidity spreads following the same methodology. Since these latter are untradable (and implicitly have the treasury curve removed from them) we do not adjust these.

The results of this analysis are contained in Table 17. Given the functional form of (3), negative coefficients imply that positive covariance with the factor leads to a rise in expected returns. We note that (consistent with Elton et al. (2001)) the addition of bond factors (in our case, our spread factors) improves on the use of Fama-French factors alone. Indeed, of the three Fama-French factors, only SMB has a significant effect on the Stochastic Discount Factor. Our findings differ from asset pricing results (with modern data) by Bongaerts et al. (2017), in that we find liquidity risk *is* priced. What is most striking, however, is the effect of including the recession conditioning variable. For all the significant factors (Spread, Credit Spread, Liquidity Spread, and SMB), the interaction term with the recession dummy is positive. Hence investors are rewarded for bearing SMB, credit, and liquidity risk during normal (non-recession) periods, but this reward diminishes during recessions. Taken alongside our results from Section 4.1, we see that the recession periods (particularly 1929–1933) were associated with rises in spread co-movement, and hence bondholders would have been bearing greater risk in tandem with a smaller price of risk.

5 Conclusion

Using a hand collected data set of corporate bond prices, we examine bond market behaviour over the 1927–1940 period, spanning three severe recessions. Although this period was characterised by bonds being exchange traded, we document a number of similar behaviours to those observed during the more recent Global Financial Crisis. Credit spreads increased, particularly for low quality bonds. Liquidity also declined for these bonds during the Great Depression. We find that high unemployment, low GNP growth and expected deflation are all associated with widening of bond spreads. Higher treasury rates increase spreads, but mostly for high quality bonds. Contagion was also apparent: speculative bond price co-movement increased during the Great depression and 1937–1938 recession. We also show that liquidity and credit risk factors are priced, but their prices of risk declined considerably during the recessions: risk was greater, and less well compensated.

The 1927–1940 period also saw frequent revisions of tax rates, with large increases in income tax rates. At face value, these should have had a major (negative) effect on corporate bond values. However, three effects mitigated this. First, the group of taxpayers owning bonds and other interest bearing securities changed over the period. Second, declining interest rates led to capital gains taxes reducing tax spreads. Third, the growing wedge between corporate tax rates and income tax rates meant that the value of embedded call options (from the bondholder perspective) declined, partially offsetting the income tax effect.

In conclusion, we revisit our original question from the introduction: what do bondholders fear the most? Our results suggest that the answer is not tax, but rather a relatively even mix of credit and liquidity risk. A decline in financial performance can have a large effect on bond prices, especially for speculative grade debt. At the same time, despite exchange trading, liquidity spreads surged during the Great Depression, similar to recent experience during the Global Financial Crisis.

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Internet Appendix

A Interest rate contingent claim pricing

As noted in Section 1.1, this paper makes use of the Sandmann and Sondermann (1997) model for interest rates. Here

$$dr^* = \lambda(\theta(t) - r^*) + \sigma dz,$$

where dz is the increment of a Brownian motion. The short interest rate (r) is given by $r = \log(1+\exp(r^*))$. In general, we are interested in the case where $\theta(t)$ is allowed to vary in such a way as to cause the model to match a particular spot curve. However, in calibration of volatility (see Appendix D), we consider a simpler version of the model with θ constant.

A.1 Forward equation pricing

For calibration of σ and λ, we use the differential equation

$$\frac{\partial \pi_1}{\partial t} + \lambda(\theta - r^*)\frac{\partial \pi_1}{\partial r^*} - \lambda \pi_1 - \frac{1}{2}\sigma^2 \frac{\partial^2 \pi_1}{\partial r^{*2}} = 0 \tag{4}$$

to solve for the future distribution of r^* ($\pi_1(r^*, t)$), assuming θ is constant. The solution to (4) when $\frac{\partial \pi_1}{\partial t} = 0$ describes the ergodic distribution of r^*. Incorporating $\frac{\partial \pi_1}{\partial t}$ into the equation allows us to iteratively solve for π_1 (see later).

A similar equation is used to derive the state price density of r^*, $\pi_2(r^*, t)$. In calibrating our model to the yield curve, we follow Hull and White (1993) and Daglish (2010), by building a lattice for r^*, assuming mean reversion to be zero, and then shifting interest rates up to match zero coupon bond prices. Here, we solve the differential equation for $\theta \equiv 0$

$$\frac{\partial \pi_2}{\partial t} - \lambda r^* \frac{\partial \pi_2}{\partial r^*} - \lambda \pi_2 - \frac{1}{2}\sigma^2 \frac{\partial^2 \pi_2}{\partial r^{*2}} = -\log\left(1 + \alpha(t) e^{r^*}\right) \pi_2 \tag{5}$$

using the initial condition $\pi_2(r^*, 0) = \delta(r^* - r^*(0))$, where $\delta(.)$ is a Dirac delta function, and $r^*(0)$ is the current short rate. In this setting, $r(t) = \log(1 + \exp(\log \alpha(t) + r^*(t))) \equiv \log(1 + \alpha(t)\exp(r^*(t)))$, allowing $\alpha(t)$ to shift the short rates at time t up or down. The price of a T-period zero coupon bond should satisfy $P(r^*(0), 0, T) = \int_{-\infty}^{\infty} \pi_2(r^*(T), T) dr^*(T)$. This relationship allows us to recursively solve for $\alpha(t)$ given a sequence of zero coupon bond prices.

We solve forward equations (4) and (5) using the Crank and Nicholson (1947) method, working forward from time zero. We discretise r^* over the range r^*_0 to r^*_N ($r^*_k = r^*_0 + (k-1)\Delta r^*$), and t over the range 0 to T to create a set of discrete *nodes* on which the equation will be solved. For most applications in this paper, it is convenient to break the time interval into varying sub-intervals, so as to ensure that bond payments occur exactly on a given time step (see Appendix B). The solution $\hat{\pi}_j(r^*_k, t)$ is defined as

$$\hat{\pi}_j(r^*_k, t) = \int_{r^*_k - \frac{\Delta r^*}{2}}^{r^*_k + \frac{\Delta r^*}{2}} \pi_j(\rho, t) d\rho.$$

Hence the initial condition for the problem is given by

$$\hat{\pi}_j(r^*_k, 0) = \begin{cases} 1 \text{ if } r^*_k = r^*(0) \\ 0 \text{ otherwise.} \end{cases} \tag{6}$$

We define the discretised operator:

$$\mathcal{L}_{\mathcal{F}} \hat{\pi}_j(r^*, t) = \begin{cases} 0 & \text{if } r^* = r^*_0 \\ \lambda(\theta - r^*) \frac{\hat{\pi}_j(r^* + \Delta r^*, t) - \hat{\pi}_j(r^* - \Delta r^*, t)}{2\Delta r^*} & \\ -\frac{\sigma^2}{2} \frac{\hat{\pi}_j(r^* + \Delta r, t) - 2\hat{\pi}_j(r^*, t) + \hat{\pi}_j(r^* - \Delta r, t)}{\Delta r^{*2}} & \\ -\left(\lambda + \log\left(1 + \alpha(t) e^{r^*}\right)\right) \hat{\pi}_j(r, t) & \text{if } r^*_0 < r^* < r^*_N \\ 0 & \text{if } r^* = r^*_N. \end{cases}$$

Here, for $j = 1$, $\alpha(t) \equiv 0$, and for $j = 2$, $\theta = 0$. We then solve for the vector of values $\hat{\pi}_j(r^*, t)$ in terms of the previous time-step $\hat{\pi}_j(r^*, t - \Delta t)$:

$$\frac{\hat{\pi}_j(r^*, t) - \hat{\pi}_j(r^*, t - \Delta t)}{\Delta t} = \mathcal{L}_{\mathcal{F}} \left(\frac{1}{2} \hat{\pi}_j(r^*, t) + \frac{1}{2} \hat{\pi}_j(r^*, t - \Delta t) \right). \tag{7}$$

Equation (7) defines a tridiagonal system of $N + 1$ by $N + 1$ equations that can be solved to calculate $\hat{\pi}_j(r^*, t)$, given $\hat{\pi}_j(r^*, t - \Delta t)$.

For yield curve fitting, we solve for $\hat{\pi}_2$ (i.e. where $\theta = 0$). We can then calculate the t

period zero coupon bond price $P(r^*(0),0,t) = \sum_{r^*} \hat{\pi}_2(r^*,t)$. $\alpha(t)$ is then found by iterating until the model zero coupon bond price is equal to the observed zero coupon bond price. By solving this system repeatedly, the state price density (π_2) can be derived from the initial condition (6).

Alternatively, an arbitrary initial condition for $\hat{\pi}_1$ can be used, and (7) can be applied repeatedly (with $\alpha(t) = 0$) until $|\hat{\pi}_1(r^*,t) - \hat{\pi}_1(r^*,t-\Delta t)|$ converges to zero in order to derive the ergodic distribution of r^* for constant θ.

A.2 Backward equation pricing

Here, for time varying $\theta(t)$,

$$-\frac{\partial f}{\partial t} = \lambda(-r^*)\frac{\partial f}{\partial r^*} + \frac{1}{2}\sigma^2\frac{\partial^2 f}{\partial r^{*2}} - \log\left(1 + \alpha(t)e^{r^*}\right) f, \tag{8}$$

or, for the case of a constant θ

$$-\frac{\partial f}{\partial t} = \lambda(\theta - r^*)\frac{\partial f}{\partial r^*} + \frac{1}{2}\sigma^2\frac{\partial^2 f}{\partial r^{*2}} - \log\left(1 + e^{r^*}\right) f. \tag{9}$$

By applying suitable boundary conditions to (8) or (9), we can price bonds and other contingent claims on r^*. Similar to the forward equation, we discretise the spatial terms of (8) and (9) and define the operator

$$\mathcal{L}_{\mathcal{B}}\hat{f}(r^*,t) = \mathcal{L}'_{\mathcal{B}}\hat{f}(r^*,t) - \log\left(1 + \alpha(t)e^{r^*}\right)\hat{f}(r^*,t),$$

where

$$\mathcal{L}'_{\mathcal{B}}\hat{f}(r^*,t) = \begin{cases} \lambda(\theta - r^*)\frac{-\hat{f}(r^*+2\Delta r^*,t)+4\hat{f}(r^*+\Delta r^*,t)-3\hat{f}(r^*,t)}{2\Delta r^*} \\ +\frac{\sigma^2}{2}\frac{\hat{f}(r^*+2\Delta r^*,t)-2\hat{f}(r^*_N+\Delta r^*,t)+\hat{f}(r^*,t)}{\Delta r^{*2}} & \text{if } r^* = r^*_0 \\ \lambda(\theta - r^*)\frac{\hat{f}(r^*+\Delta r^*,t)-\hat{f}(r^*-\Delta r^*,t)}{2\Delta r^*} \\ +\frac{\sigma^2}{2}\frac{\hat{f}(r^*+\Delta r^*,t)-2\hat{f}(r^*,t)+\hat{f}(r^*-\Delta r^*,t)}{\Delta r^{*2}} & \text{if } r^*_0 < r^* < r^*_N \\ \lambda(\theta - r^*)\frac{3\hat{f}(r^*,t)-4\hat{f}(r^*-\Delta r^*,t)+\hat{f}(r^*-2\Delta r^*,t)}{2\Delta r^*} \\ +\frac{\sigma^2}{2}\frac{\hat{f}(r^*,t)-2\hat{f}(r^*-\Delta r^*,t)+\hat{f}(r^*-2\Delta r^*,t)}{\Delta r^{*2}} & \text{if } r^* = r^*_N, \end{cases}$$

and $\theta = 0$ for solving (8) or $\alpha(t) \equiv 1$ for solving (9). Solution follows by using $\hat{f}(r^*, t + \Delta t)$ to generate $\hat{f}(r^*, t)$:

$$\frac{\hat{f}(r^*, t) - \hat{f}(r^*, t + \Delta t)}{\Delta t} = \mathcal{L}_{\mathcal{B}} \left(\frac{1}{2} \hat{f}(r^*, t) + \frac{1}{2} \hat{f}(r^*, t + \Delta t) \right). \tag{10}$$

This also defines a system of linear equations that are solved to step backwards through time to derive an asset's value. As discussed in Appendix B, by varying the boundary conditions, (8) can be used to price the components of a callable bond's value.

B Corporate bond pricing

Corporate bond valuation is complicated by the presence of three taxes. Bondholders must pay capital gains taxes τ_G on the capital gain that they realise between purchasing the bond and its maturity/call. They must also pay income tax τ_I on coupon payments. Corporations can avoid corporate tax τ_C on their coupon payments, but must pay corporate tax on capital gains due to calling of bonds.

B.1 Replacement bond: bondholder valuation

As in Sarkar (2001), we assume that if a (callable) bond is called, it will be replaced with a bond with identical maturity and coupon, but *uncallable*. We value the replacement bond, incorporating income taxes and capital gains. At maturity, the bondholder will have to pay capital gains tax $\tau_G(100 - BVN)$, where BVN is the value of the bond at *time of purchase*. To correctly value the bond, we use a two step process: first, we calculate the value of the bond ignoring the fact that the current price will reduce the capital gains payment (BVN^*). Here we assume a capital gains tax payment of $100\tau_G$. We then correct for this to find the true value (BVN). We set a terminal condition (at bond maturity date T) of $BVN^*(r^*, T) = 100(1 - \tau_G) + c(1 - \tau_I)$, with periodic payments of $c(1 - \tau_I)$. Coupons are incorporated into the valuation by solving (10) at each time step, and then adding coupons if a time step is a coupon date.[30] The value BVN^* has accounted for a capital gains tax payment of $100\tau_G$ at maturity. However, a buyer at time t knows that this payment (at

[30] As noted earlier, we set our time steps so that coupons fall exactly on timesteps.

maturity) will be offset by an amount $BVN(r^*,t)\tau_G$. Hence the amount a bondholder would actually pay for the bond at time t ($BVN(r^*,t)$) must satisfy:[31]

$$\begin{aligned} BVN(r^*,t) &= BVN^*(r^*,t) + P(r^*,t,T)BVN(r^*,t)\tau_G \\ \Rightarrow \quad BVN(r^*,t) &= \frac{BVN^*(r^*,t)}{1-\tau_G P(r^*,t,T)}, \end{aligned}$$

where $P(r^*,t,T)$ is the present value of \$1 paid at maturity of the bond. To calculate this, we solve (8) subject to the boundary condition $P(r^*,T,T) = 1$.

B.2 Replacement bond: corporate valuation

The issuer's valuation of the replacement (non-callable) bond has two tax considerations (analogous to the bondholder valuation): income effects and capital gains effects. The income effect is that the corporation can claim coupon payments against its income (the net effect of this is to reduce the payment from c to $(1-\tau_C)c$). The capital gains effect is that the issuer will have to pay $\tau_C(BVN - 100)$ at maturity, where BVN is the issue price (the *bondholder* valuation of the bond). If $BVN > 100$, the firm will have made a capital gain (by eliminating a piece of debt with book value BVN by paying \$100), while if $BVN < 100$, the firm will have made a book loss on paying the principal. We handle this in a similar fashion to the bondholder valuation, but in this case, we must use the *bondholder* valuation (BVN) to calculate the capital gain effect (rather than the corporate valuation). We value the replacement bond from the *corporate* perspective initially ignoring capital gains tax, setting the terminal value $CVN^*(r^*,T) = 100 + c(1-\tau_C)$, and setting periodic payments to $(1-\tau_C)c$. To make the adjustment for capital gains, we set

$$CVN(r^*,t) = CVN^*(r^*,t) + P(r^*,t,T)\tau_C(BVN(r^*,t) - 100),$$

where $P(r^*,t,T)$ is as discussed in Section B.1.

[31] A discussion of treatment of taxes for *non-callable* bonds can be found in Liu et al. (2007).

B.3 Callable bond: corporate valuation

Having derived the value (to the issuer) of the replacement bond, we can now derive the optimal call strategy for the issuer. We solve for the issuer's value of the callable bond ($CVO(r^*, t)$) by solving (8), subject to an optimal exercise condition. We assume that the bond was issued at par, so its terminal value is $100 + c(1 - \tau_C)$ and its periodic payments are $c(1 - \tau_C)$ from the issuer's perspective. If callability were instantaneous (no notice was required) then the complementary slackness condition would be:

$$CVO(r^*, t) \leq CVN(r^*, t) - BVN(r^*, t) + K(t) + (100 - K(t))\tau_C,$$

where $K(t)$ is the bond's call price at time t. The right hand side of this equation consists of two parts. The first ($CVN - BVN$) is the cost of servicing the new bond issue, less the money raised from the issue (the negative of the *tax shield* value of the new bond). The second part is the direct cost of calling the bond: the outlay required ($K(t)$), plus the tax due ($(100 - K(t))\tau_C$).[32] The firm would call the bond when the call costs, less the new bond's tax shield value, is equal to the value of continuing to service the old bond.

The presence of notice requirements slightly complicates the analysis (see d'Halluin et al. (2001)). With a notice period of N, the bond will have complementary slackness condition $CVO(r^*, t) \leq PVEC(r^*, t, t+N)$ on any call notice date t, where $PVEC(r^*, t, t+N)$ is the expected value of the cost of calling at date $t+N$ discounted back to time t. $PVEC(r^*, s, t+N)$ is a solution of (8) with boundary condition at the actual call date of

$$PVEC(r^*, t+N, t+N) = CVN(r^*, t+N) - BVN(r^*, t+N) + K(t+N) + (100 - K(t+N))\tau_C.$$

For the case of a *semi-American* callable bond, we need only consider callability at notice date t for each call date $t+N$, and therefore track only one instance of $PVEC$ in solving for CVO. However, for *American* callable bonds, any date (during the call period) is a valid call date. Hence at *every* date during the callable period, $CVO(r^*, t) \leq PVEC(r^*, t, t+N)$.[33]

[32] We assume that all bonds were originally issued at par, so that the firm will realise a capital gain if it calls a bond below par, and a capital loss if it calls a bond above par.

[33] Notice periods vary from bond to bond. We assume that all bonds require a minimum notice period of 30 days, even if none is listed. In addition, from 6 June 1934 onward, the SEC required firms to give 30 days notice prior to issuing notice to bondholders, effectively increasing each bond's notice period by an additional 30 days.

B.4 Callable bond: bondholder valuation

Once the optimal call strategy for the issuer has been found, we can value the callable bond from a bondholder perspective. As is the case in Section B.1, we must account for income and capital gains taxes, and this requires a two step calculation: first ignoring the effect of the current price on the terminal capital gains tax, and then correcting for this. The terminal condition for the first valuation is $BVO^*(r^*, T) = 100(1 - \tau_G) + c(1 - \tau_I)$. To incorporate issuer call policy, we examine all the nodes at which the issuer would have *given notice* to call (as described in Section B.3). Since the bondholder's payout is known with certainty at these nodes, we can find the present value of one dollar paid at *call date*, valued at *time of notice*: $P(r^*, t, t + N)$.[34] Knowing $P(r^*, t, t + N)$, we can then set $BVO^*(r^*, t) = K(t + N)(1 - \tau_G)P(r^*, t, t + N)$, for nodes where notice is given (i.e. where $CVO(r^*, t) = PVEC(r^*, t, t + N)$).

Lastly, we must correct for the fact that the bondholder can apply the price that he/she paid for the bond against its principal payment in calculating the capital gain (as in Appendix B.1). To do this, we track the present value of \$1 paid at maturity *or* call of the bond ($PVMC$). To calculate $PVMC$, we solve (8) with terminal condition $PVMC(r^*, T) = 1$, and setting $PVMC(r^*, t) = P(r^*, t, t + N)$ on any node where the firm gives notice. This allows us to calculate the true bondholder's value (BVO) as:

$$\begin{aligned} BVO(r^*, t) &= BVO^*(r^*, t) + \tau_G PVMC(r^*, t) BVO(r^*, t) \\ \Rightarrow BVO(r^*, t) &= \frac{BVO^*(r^*, t)}{1 - \tau_G PVMC(r^*, t)}. \end{aligned}$$

This *bondholder* valuation of the bond is the price that we compare to the market price in our estimation.

C Treasury bond pricing

Treasury bond pricing can be seen to be a special case of Corporate bond pricing where all tax rates are zero. This follows since the government (the issuer) does not pay tax, and (as argued by Cecchetti (1988)) most holders of government bonds are able to avoid

[34] $P(r^*, s, t + N)$ is the solution to (8) with boundary condition $P(r^*, t + N, t + N) = 1$.

income taxation on even partially tax-exempt bonds. This eliminates consideration of tax shields, and therefore does not require consideration of the replacement bonds. The only complication that is peculiar to treasury bond pricing is the consideration of exchange premia (see Cecchetti (1988)): treasury bondholders were generally able to exchange their matured bonds for an equivalent face value of new treasury bonds, which routinely traded at a premium. Given exchange premium X, the terminal payoff to the treasury bond is $CVO(r^*, T) = BVO(r^*, T) = 100 + X + c$. The government's optimal call policy N periods before a call date is calculated based on $PVEC(r^*, t, t+N) \geq CVO(r^*, t)$, but where the boundary condition for $PVEC(r^*, t+N, t+N) = K(t+N) + X$. BVO^* is calculated as in Section B.4. However, since there are no capital gains considerations, $BVO = BVO^*$.

D Calibration of σ and λ

We calibrate σ and λ to match the observed term structure of yield volatility. Given our fitted yield curves, we can calculate yield volatility for different maturities T. For a given level of r^*, we can calculate the model-implied volatility of the *yield* of a zero coupon bond as:

$$\sigma_T(r^*) = \frac{\partial P(r^*, 0, T)}{\partial r^*} \frac{\sigma}{P(r^*, 0, T)T}.$$

$\frac{\partial P(r^*,0,T)}{\partial r^*}$ can be calculated by pricing a zero coupon bond using (9) to price $P(r^*, 0, T)$ and then calculating $(P(r_0^* + \Delta r^*, 0, T) - P(r_0^* - \Delta r^*, 0, T))/(2\Delta r^*)$. However, since we only observe (empirically) a single level for term T volatility, we must combine this with the ergodic distribution of r^*. Specifically, we follow the technique in Section A.1 to back out the ergodic distribution of r^* (π_1). Finally, we calculate:

$$\bar{\sigma}_T^2 = \int_{-\infty}^{\infty} \pi_1(r^*)\sigma_T^2(r^*)dr^* \simeq \sum_k \hat{\pi}_1(r_k^*)\sigma_T^2(r_k^*). \tag{11}$$

$\bar{\sigma}_T$ is a function of θ, λ, and σ. These three values can be calibrated to ensure (11) matches observed yield volatilities.[35]

[35] In our empirical work, we fix θ as the average of ten year zero coupon bond yields, and use the one year and ten year volatilities to calibrate σ and λ.