Managing the UK National Debt 1694-2018

By MARTIN ELLISON AND ANDREW SCOTT*

We examine UK debt management using a new monthly dataset on the quantity and market price of every individual bond issued by the government since 1694. Our bond-by-bond dataset identifies variations in the market value of debt and so captures investors' one period holding returns, the cost of debt management in the government's intertemporal budget constraint. We find a substantial cost advantage in favour of issuing short bonds, even when considering some of the operational risks implied by cash flows and gross redemptions.
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The substantial deterioration in public finances since the 2007-9 Global Financial Crisis has raised the prominence of government debt and how it should be managed. Whilst there has been considerable debate over the appropriate level of debt, e.g. Reinhart and Rogoff (2009), relatively limited discussion has occurred about what type of debt to issue. In practice, many governments have increased the average maturity of their debt in response to historically low long-term interest rates and a presumption in the academic literature that long bonds are an attractive source of funding.[1] The average maturity of US government debt rose from just under 5 years to nearly 6 years between 2009 and 2018. In Japan the increase was from 5 years to almost 9 years and in the UK it was from 13.5 years to 15 years.

This paper begins by using a newly-constructed database to document the management of the UK national debt from 1694 to 2018. Our database covers the monthly quantity and market price of each bond issued, a granularity that permits a detailed description of the strategies that debt managers have followed in different periods. By focusing on individual bond prices we can calculate one period holding returns which, as emphasised by Hall and Sargent (2011), are the correct measure of funding costs for the government's intertemporal budget constraint. We can also identify changes in the market value of government debt, which allows us to assess the importance of bond price movements in

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[1] See *inter alia* Angeletos (2002), Barro (2003), Nosbusch (2008) and Lustig et al (2009).

ensuring fiscal sustainability over 60 business cycles, 6 major wars and 6 major financial crises. Finally, our bond-by-bond database enables us to examine the detailed cash flows and gross financing requirements that have underpinned UK debt management.

The remit of the UK debt management office to "minimise, over the long term, the costs of meeting the government's financing needs, taking into account risk...", H.M. Treasury (2018), is a useful starting point for appraising the historic management of the national debt.[2] Could debt managers have done better by reducing costs without increasing risks, or by reducing risks without increasing costs? Any attempt at answering this question faces at least two substantive challenges. Firstly, the choice of appropriate measures of costs and risks. Whilst the costs of debt management are relatively easy to summarise in terms of interest payments, measuring the risks associated with debt management is more difficult as it requires taking a stand on what these risks might be. The tendency in the academic literature is to focus on risks that can be measured by the covariance of bond prices with various macroeconomic shocks, whereas debt managers consider a much wider set of concerns, such as 'rollover risk', 'interest rate risk' and 'operational risk'. The second challenge is what would have happened to costs and risks had debt managers pursued alternative issuance strategies. The construction of any counterfactual scenario requires the researcher to define and defend their decisions about how the economy reacts to policy changes. The challenge is particularly acute when modelling the effects of alternative debt management strategies, since they have the potential to influence all macroeconomic variables through their impact on the yield curve.

With these challenges in mind, we use our dataset to perform counterfactuals for a selection of debt management strategies over the period 1915-2018 for which it is possible to estimate the yield curve on government bonds. Our focus is circumscribed to a particular 'operational risk', defined as the risk that issuance receipts will fall short of what is planned due to the fact that the quantity of debt issued has to be decided at least some periods in advance. As a consequence, unexpected yield curve movements between planning and implementation will cause issuance receipts to deviate from what was expected. We capture this using a Value at Risk (VaR) measure based on the historic volatility of the yield curve in our dataset.

In constructing our counterfactual scenarios we follow Hall and Sargent (2010) in making strong exogeneity assumptions that the level and covariance properties of yields do not vary with the volume and maturity of government debt, i.e. that the yield curve is unaffected by issuance. Our main result is that, over long enough periods of time, the upward sloping nature of the yield curve provides a substantial cost advantage to short bonds. Taking our measure of operational risk into account does provide some role for

[2] In the US, the Treasury has similarly always been focussed on funding deficits at the lowest long-run cost to the taxpayer, and in post-war periods it has paid attention to managing and sharing fiscal and interest rate risks between different parties. Alexander Hamilton also considered the need to provide liquid assets to support financial markets, a concern which finds its modern day counterpart in the Treasury's desire to ensure an adequate supply of safe assets. In recent times the Treasury and the Fed have broadened their aims to include assisting with macroeconomic stabilisation, e.g. through quantitative easing. Our framing in terms of the remit of the UK debt management office turns our attention away from the use of debt management to support financial markets and macroeconomic stabilisation. We acknowledge this as an important caveat.

long bonds, but the government should still mainly be issuing short bonds.

Focusing on fiscal insurance, we find that long bond prices have a negative covariance with war shocks but a positive covariance with financial crises. Long bonds hence exacerbate government funding problems during and after crises; we show that issuing long bonds since the Global Financial Crisis has led to higher levels of UK debt than an alternative strategy issuing shorter maturity bonds. In terms of our measure of operational risk, issuing long bonds helps spread financing out over time but this is not the only effect. Because long bonds are more expensive, they generate higher levels of debt and hence increased operational risk due to greater quantities of debt needing to be refinanced each period. Furthermore, long bonds increase operational risk because their prices are more volatile than those of short bonds. This leads to another of our main results, that operational risk has a non-monotonic relationship with maturity and issuing too long maturity bonds can become counterproductive in terms of both cost and risk. Based on our conceptualisation of costs and risks, the very long maturity of UK government debt is sub-optimal in this way.

The paper is organised as follows. Section I outlines our new dataset and its construction, supplementing the well-known narrative of UK public finances with new information on the market value of the individual instruments that have made up government debt over the last 325 years. Central to our analysis is the use of holding period returns to calculate the cost of government funding, so in Section II we derive zero coupon yield curve estimates that take into account the redemption dates and coupon payments of the universe of bonds issued. Section III turns to debt dynamics and an assessment of the role that long bonds have historically played in insuring the government against adverse expenditure shocks. The record of long bonds in providing fiscal insurance in specific episodes of war and financial crisis is the subject of Sections III.A and III.B; a discussion of their potential to insure the government against a broader range of shocks appears in Section III.C. In Section IV we exploit the granular nature of our dataset to consider alternative debt management strategies. We perform counterfactuals in Section IV.A to assess the relative performance of different strategies, focussing on their implications for funding costs in Section IV.B and for operational risk in Section IV.C. The robustness of our findings are considered in Section V, with particular attention to liquidity effects, leveraged issuance strategies and strategies involving buyback. The Online Appendix describes our data sources in detail, and provides further information on call and conversion provisions and how the counterfactuals were calculated.

I. UK government debt 1694-2018

The first issuance of government debt in the United Kingdom is widely dated as beginning in 1694, when King William III used a syndicate of merchants to finance the Nine Years' War. The syndicate went on to become the Bank of England so we begin our analysis of UK government debt from this date.[3] The government did borrow be-

[3]Technically, the debt only became UK government debt in 1707 when the Act of Union joined the Kingdoms of England and Scotland to form the United Kingdom. The initial loan was for £1.2million, at an interest rate of 8% and

fore then but mainly made use of tallies, effectively bills backed up by specific taxes or excise duties falling due over short-term horizons. After 1694 many of the initial loans had design features such as annuities and lotteries that appear unconventional by modern standards, but alongside such borrowing were a number of more conventional bonds paying coupons in perpetuity. By 1752 these perpetual bonds were consolidated in a smaller number of distinct stocks ('consols') offering fixed coupon payments, at which point the bond market took a more recognisably modern form. However, it was not until the early 20th century that the first fixed-term long bonds were issued: marketable debt in the 18th and 19th centuries consisted entirely of consols and short term bills. The first fixed term gilt in our sample period is the 2.75% War Stock and War Bonds 1910, which appears from November 1900.[4]

A. *Quantity of marketable debt*

We obtain data on the quantity of marketable UK government debt outstanding from three separate sources. For 1694-1948, we use the annual *Return relating to the National Debt* presented to the House of Commons by the Financial Secretary to the Treasury, accessed online and from the Parliamentary Papers archive at the Bodleian Library. For 1949-1964, we organise the disparate information in gilt sheets produced by *Mullens & Co.* when acting as broker to the Bank of England, a collection of papers available in the Bank of England archives. From 1965 onwards, the Heriot-Watt *British Government Securities Database* provides all necessary information online. Full details on how our quantity dataset is constructed are contained in Online Appendix A.

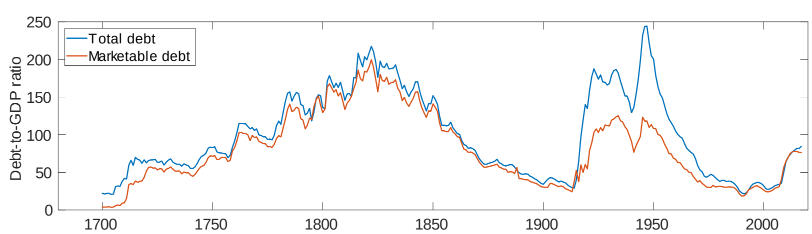

FIGURE 1. FACE VALUE OF TOTAL AND MARKETABLE DEBT OUTSTANDING AS A PERCENTAGE OF GDP.

Figure 1 shows the face value of total marketable debt in our dataset, calculated by summing the face value of all individual gilts outstanding in March of each year from 1700 to 2017 and scaling by GDP. For comparison, we also display the total face value

with a management fee of £4000. It remained on the balance sheet of the Bank of England until its tricentenary in 1994 when it was announced it was to be repaid. For insightful and detailed analysis of UK government debt management over our sample period, see Dickson (1967) for 1688-1756, O'Brien (2008) for 1756-1815, Clark (2001) for 1727-1840 and Allen (2012) for 1919 onwards.

[4]UK government bonds are called "gilts" because the initial paper certificates that acted as proof of purchase had a gilt (or gilded) edge. We use the terms "bonds" and "gilts" interchangeably throughout the paper.

of debt (marketable and non-marketable) from the Bank of England's *A Millennium of Macroeconomic Data* database.[5] The UK government has made use of non-marketable debt to varying degrees, with sizeable international loans from the US government during WWI and WWII eventually being repaid in 2006. The main current forms of non-marketable debt are a range of retail savings products sold by the National Savings Authority, such as investment accounts and premium bonds (a type of lottery).

The overall path of the UK debt to GDP ratio is well-known and reflects the twists and turns of British history.[6] The 1700s sees a series of wars, interspersed with only brief periods of peace when debt was reduced. Wars become increasingly expensive and lead to ever higher levels of debt, which peaks at the end of the Napoleonic Wars in 1815 before starting to fall for almost a century. Debt then experiences a large increase because of WWI; further increases in the 1920s due to weak growth; a further jump because of WWII; a long period of decline until the late 1990s (with various cyclical fluctuations) then a flattening of the trend and signs of a modest increase before a sharper rise in the wake of the 2007/8 Global Financial Crisis. Debt rises acutely after the crisis, reaching around 90% of GDP but ending slightly below the average for the entire sample period.

The fluctuations in our data in Figure 1 reflect only issuance and redemptions of gilts because the UK government has never formally defaulted on any of its marketable debt.[7] There are though a number of 'conversions' in our sample period. UK consols were redeemable by the government when their value rose above par, so on several occasions the government used this as an opportunity to retire gilts paying a high coupon and convert them into gilts paying a lower coupon. This conversion was typically used to reduce the interest payments on debt. Any bondholder not wishing to switch to the lower coupon bond received payment at par. Reinhart and Rogoff (2009) classify one such conversion as a default (the conversion in 1932 of the 1917 War Loan, which had been callable since 1929 and was converted from a 5% stock to a 3.5% stock). Our dataset reflects the conversion regardless of whether or not it is classified as a default – it counts as retirement of an existing bond and the issuance of a new bond.

B. Debt instruments

One aim of our analysis is to consider issues around the government's cash flow and how this links to gross issuance, coupon payments and redemptions. This requires deviating from much of the existing literature, which tends to focus either on the average maturity of debt or the mix between short and long bonds at issuance. We can use our dataset to identify the number and value of each distinct bond the government has issued and redeemed over time. Figure 2(a) uses our dataset to document this feature of UK debt management, in a plot showing the number of distinct gilts outstanding at each point in

[5]GDP data is from the same database, taken from Mitchell (1988) for 1700-1954 and the Office for National Statistics website from 1955.

[6]See Slater (2018) for a historical overview.

[7]The case of non-marketable debt is more complicated, especially regarding US loans. There was an outright default on some WWI loans from the US, connected to Germany's own debt default to the UK, as well as various incidents of suspension of payments and changes to the payment profile for the WWII loans.

time since 1694.[8] As previously noted, the early years saw the issuance of a number of different borrowing instruments that were eventually simplified with the introduction of consols.[9] In the period 1879-1914 the debt structure was relatively unsophisticated, with at most only seven types of gilts being traded in financial markets. Debt management for 1914-1948 was dominated by the need to finance war spending, leading to a sustained rise in the number of distinct gilts outstanding such that by 1930 there were 30 different gilts in circulation. After 1948, even though the main trend is for debt to decline relative to GDP, there is an increase in the number of distinct gilts as the government begins to fill the maturity structure by issuing a variety of short-term and medium-term gilts. Index-linked gilts were first issued in March 1981, which coincides with the number of distinct gilts peaking in excess of 100.

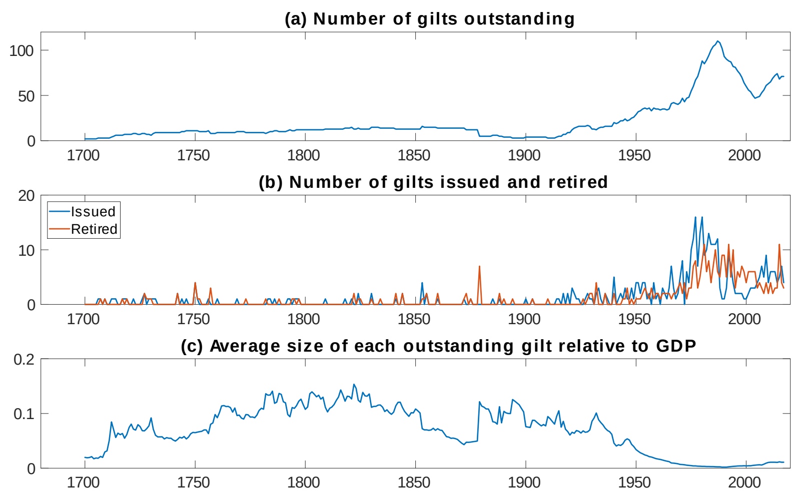

FIGURE 2. DEBT INSTRUMENTS.

Figure 2(b) shows the number of new gilts issued and retired each year, revealing that the rise and fall in the number of gilts outstanding in the 20th and 21st centuries was mainly driven by UK government policy deciding to issue first more and then less different types of gilt. Figure 2(c) shows that governments increased the number of distinct gilts issued by reducing the average size of issuance (relative to GDP) of each gilt. The average size of outstanding gilts has shown a near continuous decline over

[8]For our purposes, a gilt is defined by the 3-tuple of original date of issuance, maturity and coupon rate. For example, if a twenty-year gilt were issued on 1st April 1953 and a ten-year gilt on 1st April 1963 then these would always count as two distinct gilts, despite both having the same redemption date. In some instances, the government issues additional gilts with characteristics identical to a previously-issued gilt. We do not count these 'top ups' as distinct issuance of new gilts.

[9]Consols were first issued in 1752 and last issued when Winston Churchill was Chancellor in 1927. They were finally redeemed by the UK government in 2015, at which time the UK Debt Management Office reported little market appetite for the issuance of new undated bonds.

the sample period, except for a small increase at the end.[10] The increase in number of distinct gilts issued is not then simply a result of fluctuations in the level of debt, but a purposeful change in the behaviour of government debt managers. There are a number of possible explanations for this, e.g. a desire to exploit the whole yield, concerns about refinancing risk if debt issuance is concentrated at certain maturities, fears that prices may be adversely affected by large issues, or wanting to create a market in risk-free securities at a range of different maturities.

Figure 3 uses our dataset to show how the maturity structure of debt has evolved since 1900 (with the first issue of finite maturity debt). The main trend is a move away from a total reliance on consols, first towards a mix of consols and long gilts and then increasing use of short and medium-term gilts. However, by the end of the sample there is still a strong preference for longer gilts, with 60% of gilts outstanding having a maturity of greater than 8 years. In December 2018 the weighted average maturity of UK government debt was 15 years, more than 10 years higher than debt maturity in the US and making the UK the only OECD government with an average debt maturity greater exceeding 10 years.

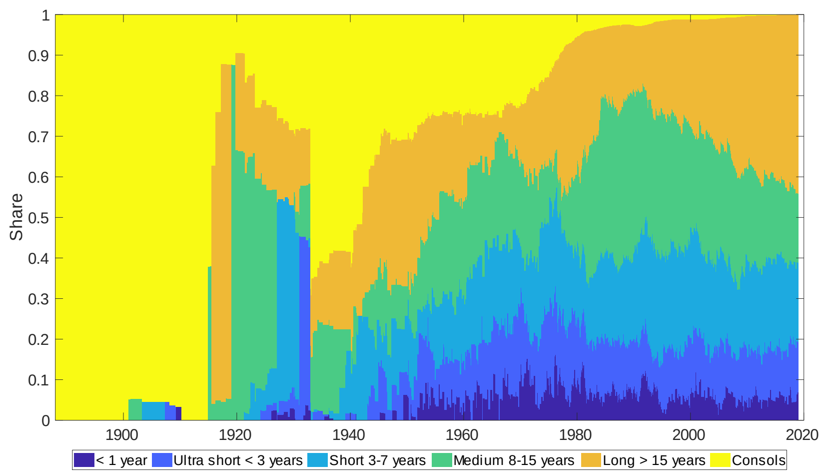

FIGURE 3. PERCENTAGE COMPOSITION OF UK GOVERNMENT DEBT BY MATURITY.

Figure 4 shows a more detailed and dynamic picture of how the structure of UK debt evolves over time, which is useful in considering issues around cash flow and redemptions. If in any specific year there is a gilt outstanding with 8 years left to redemption then that is indicated by a dot at maturity 8. Similarly, if there is a gilt with 20 years

[10]This increase is due to the retirement of the original consols, which by 2015 were small compared to modern day issuance. The redemption of consols also explains why the number of bonds retired spikes upwards at the end of Figure 2(b).

until maturity then a dot is shown at maturity 20. A vertical row of dots from 1-20 would mean that there are gilts outstanding at each of these maturities. The absence of a dot indicates that there is no gilt of that maturity circulating in financial markets in that year. If the government does not tend to buy back their debt until its redemption date then the maturity distribution shows a natural persistence, i.e. a 10 year gilt in 2014 becomes a 9 year gilt in 2015, an 8 year gilt in 2016, and so on. The presence of downward diagonals in Figure 4 illustrates that the UK government tends not to buy back gilts until they mature at their redemption date.[11] The fact that debt managers tend not to buy back debt before redemption means initial issuance pins down future rollover and refinancing risk. Critically, it makes for a very substantial difference to the implications of issuing short or long maturity bonds. In the wake of the recent 2007-9 financial crisis the Bank of England did of course make large scale purchases of UK government debt through its Quantitative Easing programme. However, since on no occasion did the Bank of England buy back *all* the outstanding gilts of a given maturity, this does not affect Figure 4. The other notable feature that the granularity of Figure 4 reveals is how the UK government has increasingly sought to fill "holes" in the maturity structure of debt by issuing gilts at a range of maturities. Combined with Figure 2(c), the narrative is one of switching from issuing undated bonds to an attempt to fill out the maturity structure of debt at all points.

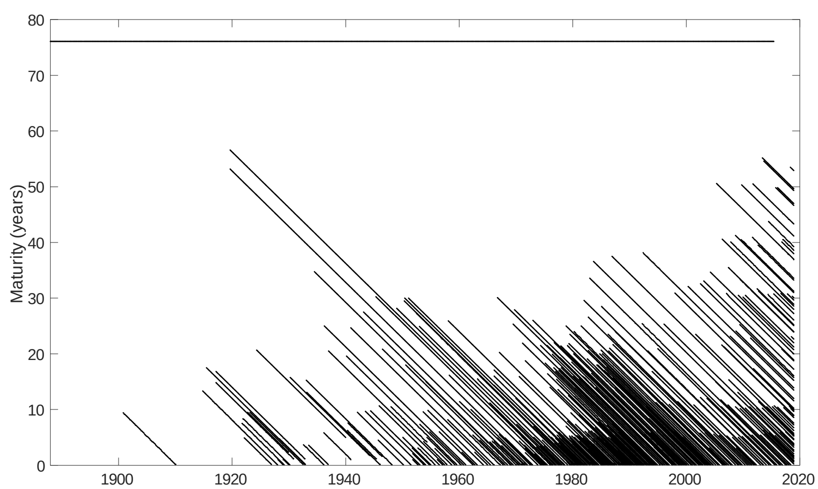

FIGURE 4. MATURITY STRUCTURE OF OUTSTANDING UK GOVERNMENT DEBT.

Note: A black dot indicates that a gilt of a given maturity is outstanding on a specific date. Consols are plotted at 76 years rather than infinity for expositional reasons.

[11] Closer inspection shows that only 8 of the 543 gilts issued over this period were redeemed before maturity. Faraglia et al (2018) report a similar finding for the US.

C. Prices of marketable debt

A key feature of our analysis is a focus on the market value of government debt. The market prices for individual gilts 1729-1887 are derived using the UK 2.5% Consol Yield data from the *Global Financial Data* database, the primary source for which is Neal (1990). For 1888-2009 we use the end-of-month closing prices for UK government gilts published in the *Financial Times*, transcribed from archives held in the British Library and the online *Financial Times Historical Archive*. More recent data was extracted from the online Heriot-Watt *British Government Securities Database*, which itself uses data from the UK Debt Management Office website for April 2001 onwards. Full details of our price data are given in Online Appendix B.

We combine price data with the amount of each gilt outstanding to derive the series for the total market value of UK government debt in Figure 5. For most of the sample period the market value has been below the face value, i.e. the average yield has exceeded the average coupon. In the 18th century gilt prices fluctuated with the changing military fortunes of the UK government, after which the market and face values remain roughly aligned for the next two hundred years. The high inflation period from the mid 1960s to the late 1970s sees the market value of debt go below its face value, whereas the low interest rates of the last 20 years see market values rising above face values. It is noteworthy that the ratio of market to face value of debt in 2018 is at its highest level since our sample began.

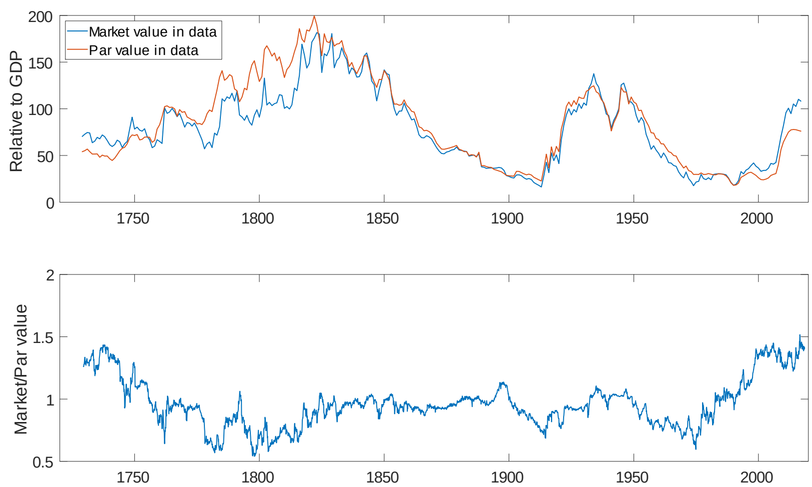

FIGURE 5. MARKET AND FACE VALUE OF DEBT

These market value calculations are based on bond prices which for the most part reflect future coupon and redemption payments for each gilt issues. However, for gilts which are subject to call and conversion provisions the price will also contain an option value component reflecting these provisions. UK gilts are callable by the government at par value, so if their market price rises above par there will be an incentive for the government to redeem them early. Market prices will be depressed if this is likely to happen. Conversely, some gilts issued at the beginning of wars gave investors the option of convertibility should the government raise additional war funding at a higher coupon rate. If conversion is anticipated then these gilts trade at a premium in the market.

The most significant call options exercised by the UK government are Goschen's Conversion of 1888 and the War Loan conversion of 1932. The option for investors to convert to gilts with a higher coupon rate was important in the War Loans issued at the start of World War I. These call and conversion provisions do not distort our calculations of the market value of government debt, holding period returns, fiscal insurance or debt dynamics, as all of the these should factor in the option values. However, the options do need to be taken into account in our estimations of the yield curve which we use in our counterfactual analysis of debt management. We therefore adjust the market prices of gilts subject to call and conversion provisions using the approach of Harley (1976), Klovland (1994) and Cecchetti (1998) when estimating the zero coupon yield curves in Section 3. The idea is to identify option values by comparing the yields on similar gilts with and without call and conversion provisions. Online Appendix C gives full details of how we obtain clean prices in this way.

II. Holding period returns

An important feature of our dataset is that we can measure the cost of the government raising funds by calculating the one period holding returns that investors receive on each gilt. As shown in Hall and Sargent (2011), this is the cost that is relevant in the government's intertemporal budget constraint. The one period holding return is comprised of semi-annual coupon payments and a revaluation term that captures any capital gains or losses the investor makes due to changes in the gilt's market price.

The average annual holding period return for the whole portfolio of UK government debt from 1730 to 2017 is 4.4% in nominal terms and 2.6% in real terms, where the real return is defined *ex post* using the GDP deflator in the Bank of England's *A Millennium of Macroeconomic Data* database as our measure of inflation. The return shows clear shifts between decades and is volatile, ranging from a maximum of +17% to a minimum of -6% per year. Between 1890 and 1918 gilt holders earned an average real return of -0.9% and between 1946 and 1970 a real return of -1.7%. Conversely, between 1919 and 1939 they earned 5.2% in real terms, for 1971-1997 it was 2.1% and for 1997-2017 it was 4.0%. Figure 6 plots coupon payments on marketable debt alongside a five-year moving average of gilt revaluations.[12] In the aftermath of the Napoleonic Wars the difference amounts to 10% of GDP as gilts soar after victory. After WWII our cost of borrowing

[12] As in Figure 11 of Hall and Sargent (2011), the one-year revaluation term is highly volatile (showing swings between +40% and -20% around the Napoleonic Wars). The five-year moving average follows the same general trend but helps isolate the economic magnitude more easily.

series is 3-4% lower. Of note is the period since the financial crisis, with revaluation effects adding an average 1.1% of GDP per year to funding costs since 2010, compared with coupon payments of around 2.1% of GDP.

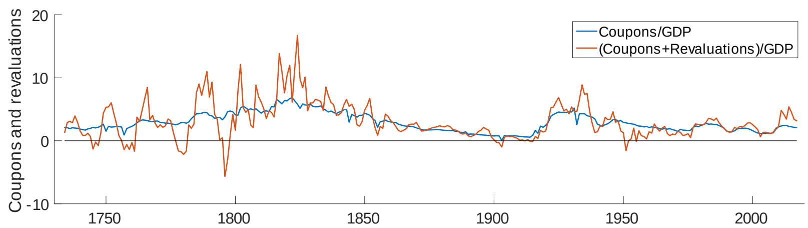

FIGURE 6. COUPON PAYMENTS AND REVALUATIONS OF MARKETABLE DEBT

The information on the holding period returns of specific gilts is useful but difficult to process further because different gilts tend to have different coupons and maturity dates. As an example, consider the 16 year gilt issued in 1994 with a £6.25 coupon (UK Treasury 2010 6.25%) and the 6 year gilt issued in 2004 with a £4.75 coupon (UK Treasury 2010 4.75%). In 2007 both have three years until maturity, but the gilt issued in 1994 will have a higher price because it pays a better coupon. In order to understand the relative merits of different debt maturities we need to abstract from these effects. To do so we use the method outlined in Waggoner (1997) and estimate a zero coupon yield curve based on the market prices of a set of gilts with known coupon payments and redemption dates. The method essentially strips coupons from a bond and treats each coupon as a stand-alone redemption payment of a new and distinct bond whose maturity coincides with the payment date for the coupon. The estimation fits a cubic spline to the zero coupon yield curve, subject to a penalty that imposes additional stiffness at the long end.

Estimates of the zero coupon nominal and real yield curves for 1915-2018 are presented in Figure 7, based on the universe of fixed-term nominal gilts in our dataset with prices cleaned for call and conversion options as described in Section 3 and Appendix C. We cannot go back earlier than 1915 because of missing price data, which rules out reliable estimation of the yield curve. Both nominal and real yields are calculated *ex post*, the nominal yield after revaluations and the real yield net of inflation. For most of the period the nominal and real yield curves slope upwards, reflecting positive term premia, with the volatility of nominal but not real yields increasing with maturity.

III. Fiscal insurance

Proponents of long bonds such as Angeletos (2002) argue that governments should issue long-term debt because it confers the advantages of fiscal insurance. According to the intertemporal government budget constraint, if the price of long bonds falls after

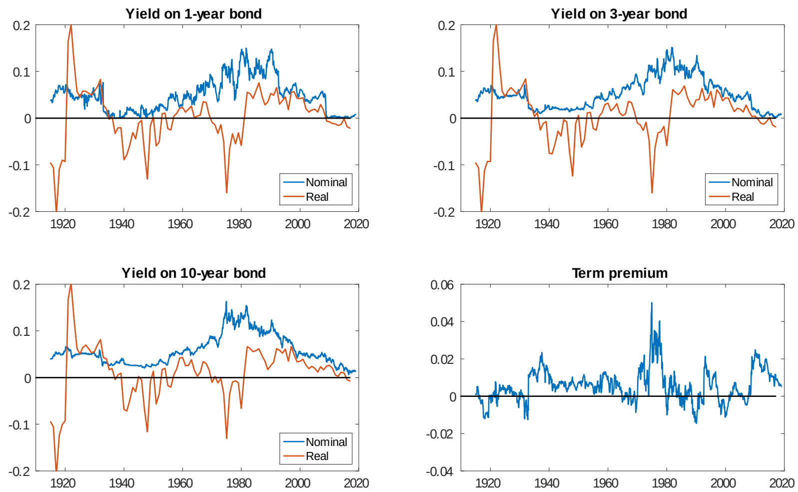

FIGURE 7. SELECTED ZERO COUPON YIELDS

Note: Term premium is difference between yields on 10-year and 3-year bonds.

unfavourable government expenditure shocks then the market value of government debt is partially 'insured' and taxes have to rise by less to maintain fiscal sustainability. Our ability to analyse data on a bond-by-bond basis allows us to examine this mechanism and assess the degree of fiscal insurance provided by bonds of different maturities. Defining $\tilde{B}_t$ and $\bar{B}_t$ as the total real market value of nominal and indexed debt in period t, the ratio of marketable debt to GDP develops according to:

$$\begin{aligned}
\frac{\tilde{B}_t + \bar{B}_t}{Y_t} &= \sum_{j=1}^{n} \tilde{r}^{j}_{t-1,t} \frac{\tilde{B}^{j}_{t-1}}{Y_{t-1}} - \left(\pi_{t-1,t} + g_{t-1,t}\right) \frac{\tilde{B}_{t-1}}{Y_{t-1}} \\
&\quad + \sum_{j=1}^{n} \bar{r}^{j}_{t-1,t} \frac{\bar{B}^{j}_{t-1}}{Y_{t-1}} - g_{t-1,t} \frac{\bar{B}_{t-1}}{Y_{t-1}} \\
&\quad + \frac{NFR_t}{Y_t} + \frac{\tilde{B}_{t-1} + \bar{B}_{t-1}}{Y_{t-1}} \qquad (1)
\end{aligned}$$

where $\tilde{r}^{j}_{t-1,t}$ and $\bar{r}^{j}_{t-1,t}$ are the nominal holding period returns on the real values of nominal and indexed gilts of maturity j and $\tilde{B}^{j}_{t-1}$ and $\bar{B}^{j}_{t-1}$ denote the real value of nominal and indexed bonds of maturity j in period $t-1$. Inflation $\pi_{t-1,t}$ is measured by the growth in the GDP deflator between periods $t-1$ and t, and $g_{t-1,t}$ denotes the growth in real GDP between periods $t-1$ and t. The term NFR_t is the net funding requirement, the quantity of marketable debt the government issues to finance its primary deficit in period t. It is equal to the primary deficit if all funding is raised in the market.

There is fiscal insurance if the holding period returns co-move negatively with the net funding requirement, in which case the government benefits from paying low returns when there is a fiscal deficit. Since the coupon component of holding returns is fixed, this requires that revaluations in bond prices work in the government's favour. The importance of the negative co-movement for fiscal insurance does not depend on governments buying debt back before it matures. If the government redeems all debt at maturity then the relationship between holding period returns and net funding requirement still affects the assessment of funding costs, even though fluctuations in the market price of previously-issued bonds have no implications for the government's cash flow. This is because the co-movement captures the *opportunity cost* of the government issuing bonds of different maturities. If it is negative then holding period returns are temporarily depressed at the time when the government needs to raise funds. In this case there is an opportunity cost to issuing short bonds, since by doing so the government would miss out on issuing long bonds that would lock in the temporarily low holding period returns. However, if the co-movement is positive then holding period returns are temporarily elevated when the government is raising funds, in which case there is an opportunity cost to issuing long bonds. It would be better for the government to issue short bonds, wait until they mature, and issue longer bonds once holding period returns have normalised. Our dataset enables us to see *ex post* whether this has happened and hence assess the extent to which UK government bonds have historically provided fiscal insurance.

A. Wars

The first adverse government expenditure shocks we consider are wars. If bonds provide fiscal insurance then we would expect their market value to fall during wars and recover in times of peace. A cursory glance at British history reveals a near never-ending list of conflicts, with the country involved in some form of military conflict in all but 53 of the years from 1700 to 2018. However, examination of the government expenditure series suggests the following as substantial conflicts in terms of funding : 1740-49 (War of Austrian Succession including King George's War and War of Jenkins' Ear), 1756-1764 (Seven Years' War), 1775-1786 (War of American Independence, Anglo-French War, Anglo-Spanish War, Anglo-Dutch War), 1793-1815 (including War of French Revolution and Napoleonic Wars), 1914-1919 (WWI) and 1939-1946 (WWII). Our dates are based on high levels of government expenditure that include demobilisation costs, so tend to last a year or two longer than conventional dating of conflicts.

The dynamics of government debt in war and peace are reported in Table 1, which follows Hall and Sargent (2011) in using (1) to decompose the change in the debt to GDP ratio into contributions from nominal holding returns (further decomposed into coupon payments and revaluation effects), inflation, GDP growth and the net funding requirement. All these wars led to broadly similar increases in UK debt of around 30% of GDP during the time of the conflict. Comparing across periods of war and peace, (i) the UK government ran budget deficits during wars and tended to be in surplus when there was peace (as per Barro (1979)) (ii) inflation played a larger and more consistent role in containing UK debt in wars, and (iii) the contribution of GDP growth to lowering the debt to GDP ratio was about twice as important during wars.

TABLE 1—DEBT DYNAMICS IN WAR AND PEACE

	Start Debt to GDP	End Debt to GDP	Change in Debt to GDP	Contribution of Nominal Return	- of which coupons	- of which revaluations	Contribution of Inflation	Contribution of GDP Growth	Contribution of New Debt
Wars									
1740-1749	66.1	91.1	25.1	22.7	20.5	2.2	-4.6	-4.2	11.1
1756-1764	70.2	96.5	26.3	21.3	21.3	-0.0	-10.1	-6.8	21.9
1775-1786	84.7	108.0	23.3	33.9	38.1	-4.3	-9.6	-12.2	11.2
1793-1815	93.5	119.5	26.0	85.3	106.7	-21.4	-43.2	-43.2	27.1
1914-1919	16.2	50.6	34.4	3.4	8.7	-5.3	-33.8	0.2	64.6
1939-1946	104.9	127.5	22.6	35.2	22.5	12.7	-44.3	-13.3	44.9
Peace									
1730-1739	70.5	66.1	-4.5	22.0	21.0	1.1	7.7	-7.7	-26.5
1750-1755	91.1	70.2	-20.9	5.5	12.7	-7.2	1.2	-4.5	-23.0
1765-1774	96.5	84.7	-11.8	31.8	30.2	1.6	-6.9	-4.0	-32.6
1787-1792	108.0	93.5	-14.6	30.7	25.0	5.7	-4.5	-14.5	-26.2
1816-1913	119.5	16.2	-103.3	357.7	289.5	68.2	44.7	-192.5	-313.1
1920-1938	50.6	104.9	54.3	93.8	77.5	16.3	15.7	-37.7	-17.5
1947-2017	127.5	108.3	-19.3	137.3	147.2	-9.9	-139.2	-97.1	79.8

Revaluations in gilt prices provide the UK government with some limited fiscal insurance by falling during wars and rising otherwise. The nominal holding period return on UK government gilts decreases in periods of war (3.7% compared to 4.6% during peace), as does the real return (0.7% compared to 3.1%) due to a rise in inflation (3.0% compared to 1.6%). Long maturity gilts are responsible for almost all of the fiscal insurance effect, but their most important role is as a conduit for the contribution of inflation. Whilst there is considerable similarity across the different wars, there are also inevitable differences. The role of inflation in funding wars has become more significant over time and the fiscal insurance from revaluations is particularly unstable across different time periods. In general, wars are financed by deficits that are subsequently offset by peacetime surpluses, at which time holders of long gilts experience low real returns due to high inflation. The evidence points to long gilts only providing the UK government with limited insurance against the fiscal consequences of going to war.

B. Financial crises

A second adverse fiscal shock to consider is a financial crisis, especially pertinent given the surge in UK government debt since 2007. We follow Capie (2014) in identifying the periods of financial crises in the UK as 1825 (run on country banks), 1837 (US crisis and UK balance of payments crisis), 1847 (Bill market crisis), 1857 (US panic, Borough Bank of Liverpool), 1866 (Overend Gurney) and 2007-2009 (Global Financial Crisis). There are many other notable periods of financial instability in the UK, e.g. Barings in 1890, the accepting house crisis in 1914 and the secondary banking crisis 1973-1975, but these are not classified as major financial crises according to the Schwarz (1986) definition as an event which actively threatens the payments system. It is surprising how few financial crises there are over the sample period using this stricter definition. According to Capie (2014) this is because the credit system is still underdeveloped in the 18th century, as evidenced by a low money multiplier keeping the value of deposits close to that of reserves.

The dynamics of UK government debt during crisis and non-crisis years are compared in Table 2, where the three years after the crisis are included as crisis years. Comparing averages, we see that (i) debt increases in crisis years and reduces slightly in non-crisis years, (ii) fiscal policy in crises tends to reduce rather than increase the value of debt as the government runs fiscal surpluses (2007-2009 being the major exception) and (iii) low inflation during financial crises exacerbates the rise in debt relative to GDP. The most revealing feature of Table 2 is the high funding cost associated with gilts during financial crises. The high holding period returns on government debt in crises lead to a worsening of the debt to GDP ratio, with most of that contribution coming from an unfavourable revaluation of long gilts. The real return in periods of financial crisis is 4.8%, compared with 0.3% otherwise. This is only partly caused by a fall in inflation (-0.5% compared to 0.1%), with the rest being due to upward revaluations in gilt prices. Financial crises tend to be followed by low interest rates and increasing gilt prices, as seen in the most recent crisis where UK gilts saw a real rate of return of 4.5%. The upshot is that long gilts increase rather than reduce the national debt during financial crises. Whilst the favourable movements of long bond prices in wars make long bonds useful but limited providers of fiscal insurance against military expenditure shocks, the adverse reaction of their prices during financial crises undermines their ability to insure a government facing a broader range of shocks.

The opportunity cost of issuing long bonds in the immediate aftermath of the Global Financial Crisis of 2007-9 is apparent in the unprecedentedly high ratio of market to face value of government debt at the end of the sample period. Long bond prices tend to rise for several periods after a financial crisis, so if the government immediately issues long bonds then they miss out on even cheaper financing opportunities in the near future. As we shall see in Section V.B, the market value of UK debt in 2018 would have been substantively lower had the UK government issued shorter debt, a challenge to the UK and other countries who responded to the low yields on long bonds by lengthening their debt maturity.

TABLE 2—DEBT DYNAMICS IN FINANCIAL CRISES AND NON-CRISIS TIMES

	Start Debt to GDP	End Debt to GDP	Change in Debt to GDP	Contribution of Nominal Return	- of which coupons	- of which revaluations	Contribution of Inflation	Contribution of GDP Growth	Contribution of New Debt
Financial crises									
1825-1828	180.0	163.5	-16.5	12.4	22.3	-9.9	1.7	-9.4	-21.3
1837-1842	137.3	156.6	19.3	35.7	27.7	7.9	11.7	-4.5	-23.5
1847-1850	125.8	141.6	15.8	23.2	16.2	7.0	10.4	-1.7	-16.1
1857-1860	97.6	93.5	-4.1	11.1	12.5	-1.4	1.7	-6.9	-10.0
1866-1869	69.2	67.7	-1.5	13.3	9.1	4.2	1.4	-5.7	-10.5
2007-2012	40.8	100.6	59.9	21.6	11.3	10.3	-4.6	-2.5	45.3
Normal times									
1730-1824	70.5	180.0	109.5	377.2	332.6	44.6	-41.5	-123.1	-103.1
1829-1836	163.5	137.3	-26.1	47.2	42.2	5.1	9.8	-35.7	-47.5
1843-1846	156.6	125.8	-30.8	12.2	16.1	-3.9	2.2	-30.6	-14.7
1851-1856	141.6	97.6	-44.0	16.4	20.3	-3.9	-16.7	-23.6	-20.1
1861-1865	93.5	69.2	-24.3	9.7	13.4	-3.6	-7.5	-9.9	-16.7
1870-2006	67.7	40.8	-26.9	284.0	286.1	-2.1	-190.0	-172.8	51.9

IV. The potential for fiscal insurance

The above subsections concentrate on two particular episodes of fiscal shocks - wars and financial crises. To consider the potential of long bonds to provide fiscal insurance against a broader range of shocks, consider Figure 8(a) which plots the government's annual primary deficit (as a percentage of GDP) against the corresponding annual percentage revaluation of a 3% Treasury Consol from 1730 (when the console was first issued) to 2014 (after which it was retired). The points to the right of the scatter plot are all for the years of WWI and WWII when the primary deficit was especially high. The correlation between the primary deficit and revaluations of the consol across the whole sample period is very slightly positive and insignificant at 0.006, the incorrect sign for fiscal insurance.

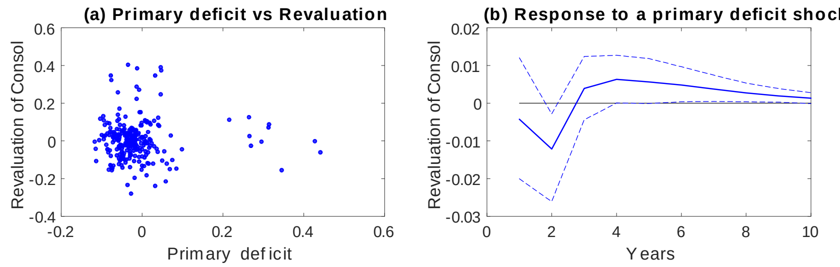

FIGURE 8. PRIMARY DEFICIT AND REVALUATION OF 3% TREASURY CONSOL 1730-2014

The correlations between the primary deficit and revaluations of the consol strengthen if we consider correlations at leads and lags, which suggests that a simple bivariate vector autoregression analysis may be insightful. Figure 8(b) presents the resulting impulse response function, showing how the consol is revalued after a one percentage point shock to the primary deficit as a percentage of GDP when wars are excluded from the estimation sample. Identification is achieved by assuming that shocks to the price of consols have no contemporaneous effects on the primary deficit and the lag length of the vector autoregression is 4. Confidence intervals of 95% are shown. It is difficult to identify shocks by contemporaneous zero restrictions with annual data so our results should be treated with caution, but the tentative conclusion from Figure 8(b) is that long gilts are unlikely to provide the UK government with significant fiscal insurance. Gilt prices move in the right direction after a primary deficit shock, but the movement is transitory and only borderline significant.[13]

V. Alternative debt management strategies 1915-2018

As trailed in the introduction, an advantage of constructing our dataset on a gilt-by-gilt basis is that we can perform counterfactuals to consider alternative debt management policies. We have data on the quantity of government debt issued and redeemed every month, and we have the monthly holding period returns on nominal debt of any desired maturity for 1915-2018 from the zero coupon yield curve estimates in Section 3. Armed with an estimate of the yield curve and the cash flows associated with debt issuance, we can investigate what counterfactually would have happened to the UK national debt under different issuance strategies.

[13]Our long sample period is both an advantage and a disadvantage. The lengthy historical span with so many business cycles, conflicts and financial crises allows for a rich understanding of how debt and debt management interact. However, over such a lengthy period there are likely to be structural breaks that may affect our results, especially those derived from structural vector autoregressions. Estimating the same vector autoregression over different subperiods nonetheless confirms that the covariance between bond prices and primary deficit shocks is very unstable and rarely strongly negative.

A. Counterfactuals

We create multiple counterfactual scenarios that are differentiated by the maturity of debt the government issues.[14] The simplest counterfactuals assume the government concentrates all of its issuance in zero coupon nominal bonds of a specific maturity and never buys them back early, e.g. the government only ever issues 3, 5 or 10 year bonds and redeems them at maturity. Subsequent counterfactuals permit a wider range of maturity options, as well as issuing a mix of bonds of different maturities, and allowing the government to redeem bonds early. In performing the counterfactuals, we follow Hall and Sargent (2010) in making a strong exogeneity assumption that yields do not vary with the volume and maturity structure of government debt, i.e. that the yield curve is unaffected by issuance.

There are two channels through which debt structure is likely to influence yields. The first channel is the general equilibrium effects in Aiyagari et al. (2002), Angeletos (2002) and Buera and Nicolini (2004), where issuance policy changes the market value of debt and so affects equilibrium taxes, consumption and rates of return. In our counterfactuals we abstract from these effects by assuming that changes in debt have no impact on the yield curve, and so do not trigger changes in the market value of debt or real outcomes. This is clearly limiting, although the magnitude of general equilibrium effects is often rather limited in the structural models of Angeletos (2002) and Buera and Nicolini (2004). The second channel is a market microstructure argument that the government will face adverse price effects if it tries to issue too much debt at a particular maturity, see Guibaud, Nosbusch and Vayanos (2013). Such liquidity effects imply that changing the composition of debt issuance will affect yields. We return to this issue in Section VI.A, but note for now that the empirical evidence of Lou et al. (2013), Breedon and Turner (2018), Greenlaw et al. (2018) and Song and Zhu (2018) suggests that the relationship between issuance and yields is not linear, differs across maturities and is relatively modest.

B. Funding costs

We measure the funding costs associated with each scenario by the total holding period returns on the counterfactual portfolios of government debt we create. Since these will typically differ from the historic costs, the question arises as to how to interpret the difference. We present results in which any cost savings are used to reduce debt issuance at the next available opportunity, and any excess in cost is covered by issuing additional government debt. In both cases the difference in funding costs is reflected in the counterfactual market value of debt. We could alternatively have assumed that any differences in cost are offset by adjusting the government's primary budget balance, i.e. by changing counterfactual taxes or government expenditure. In this case the difference in costs would be reflected in lower or higher primary balances, whilst the counterfactual market

[14]The detailed construction of our counterfactuals is described in Online Appendix D.

value of debt follows its historic level. We re-interpret our results in these terms at the end of this section.

Table 3 reports the evolution of debt in counterfactuals for 1914-2017 and various subsamples. To ease comparability, we present debt levels relative to GDP, under the maintained assumption that inflation and GDP growth are independent of issuance strategy. Presenting in this way has the added advantage of also allowing equation (1) to show the factors that have propelled the market value of debt in both the counterfactuals and the original data. In Table 3 the market value of debt relative to GDP would have been 23.6% lower in 2017 had the government over the period 1914-2017 only issued 3-year zero coupon bonds that were redeemed at maturity. The debt to GDP ratio would have been 12.7% lower if only 5-year bonds were issued over this period, and 12.6% higher if issuance had been based solely on 10-year bonds. We conclude that issuance policies concentrating on long bonds lead to higher one period holding returns and hence higher funding costs than policies based on short bonds, an obvious implication of the yield curve tending to slope upwards over most of the sample period.

Whilst the yield curve is on average upward-sloping over the whole sample period, there is considerable variation in its behaviour in different subperiods. Table 3 and Figure 9 hence examine the robustness of our results across a range of subsamples. The cost advantages of short bonds extend to the four subsamples in Table 3, except 1946-1970 for which issuing long bonds is marginally more cost-effective. Figure 10 extends the subsample analysis by graphically presenting which of the 3, 5 and 10 year issuance strategies leads to the lowest cost for counterfactuals for any start and end date. The preponderance of red confirms that short bonds lead to lower costs for the majority of periods, with only the 1970s being a period where issuing longer bonds regularly dominates. Of special note is the most recent period 1997-2017, for which the counterfactuals suggest that the UK policy of issuing long maturity gilts led to a substantial increase in the market value of debt. Long-term interest rates fell after the Global Financial Crisis, triggering unfavourable revaluation effects and extra costs in the form of high one period holding returns on long gilts. These would have been avoided had the government issued shorter maturity bonds, as in our Section III.B discussion that there is an opportunity cost to issuing long bonds when their prices are rising.

Part of the reason why costs are low when issuing short bonds is that the yield curve usually slopes upwards, with a term premium making the average yield at the short end less than that at the long end. The superior performance of short bonds is though about more than just cheapness of their average yield. Issuing only 3-year bonds also outperforms an alternative strategy in which the government issues 3, 5 or 10 year bonds depending on which maturity has the lowest yield at the time funds need to be raised. Over the whole sample period 1914-2017, the alternative strategy delivers a counterfactual final market value of debt to GDP of 61.8%, compared to 46.2% for the strategy always issuing 3-year bonds. The low cost of the short bond strategy is therefore not purely due to the upwards-sloping nature of the yield curve.

In our counterfactuals we assume that changes in the costs of funding feed through into the level of debt. Alternatively, we could keep debt levels constant and see what

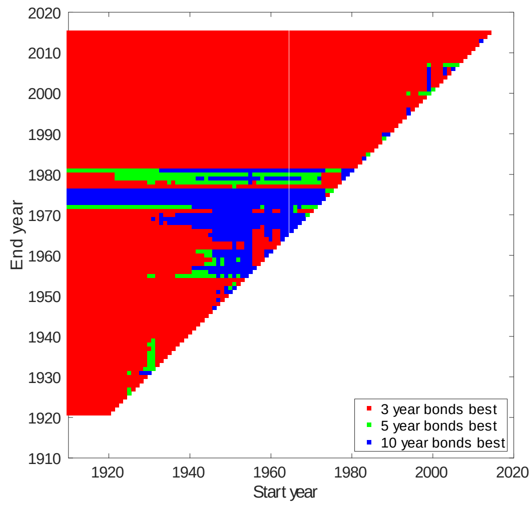

FIGURE 9. COMPARISON OF COUNTERFACTUALS ISSUING 3, 5 AND 10 YEAR BONDS.

Note: For any period characterised by a start year on the horizontal axis and an end year on the vertical axis, a red dot indicates that funding costs are minimised when issuing 3 year bonds. If the dot is green then issuing 5 year bonds minimises costs; if the dot is blue then 10 year bonds are best.

variations in funding costs imply for the government's primary deficit. For example, a back of the envelope calculation suggests that a 23.5% lower debt to GDP ratio at the end of the short bond counterfactual 1914-2017 is roughly equivalent to an improvement in the annual primary deficit of $23.5/104 = 0.23\%$ of GDP. In other words, if the UK government had issued 3-year bonds for the whole period 1914-2017 then it could have reduced taxes or increased government expenditure by 0.23% of GDP each year, without increasing the national debt at the end of 2017.

C. Operational risk

Our counterfactuals suggest that the UK government would have benefitted from reduced funding costs over the period 1914-2017 had it issued only 3-year debt. A switch to issuing shorter maturity bonds would therefore respond to the UK Debt Management Office's stated objective to "minimise, over the long term, the costs of meeting the government's financing needs." What is less clear is how to interpret the counterfactuals when the stated objective is followed by the caveat "taking into account risks." Issuing large quantities of bonds at a specific maturity may make redemption profiles lumpy, which leads to concerns that the government will find itself issuing large quantities of bonds at a time when yields are especially unfavourable, or that the government may be unable to sell enough bonds to finance its activities. Issuing across a range of maturities could potentially lessen such risks, whilst issuing long bonds helps postpone gross redemptions.

There is no single measure that captures all the risks involved in debt management. To proceed, we restrict our attention to the "operational risk" that arises because issuance has to be decided at least some periods in advance, which exposes the government to the possibility that issuance receipts may fall short of what is planned, in which case it may need to resort to more expensive sources of funds to finance its operations. At a minimum, any measure of such operational risk should (i) be increasing in the total market value of debt to be issued on a given date, (ii) be increasing in the volatility of the yield curve at the maturities where debt is issued, and (iii) recognise that shortfalls in issuance receipts are likely to be more problematic than excesses. To quantify operational risks in our counterfactuals, we offer a measure inspired by the concept of Value at Risk from the finance literature. It satisfies properties (i), (ii) and (iii) above, but we make no claim that our measure comprehensively captures all the risks involved in a particular debt management strategy. We are, though, encouraged by Bolder and Deeley (2011) describing how the Funds Management Department of the Bank of Canada uses a similar Cost at Risk measure in their debt-strategy model.

Our measure of operational risk is explicitly based on implementation lags in debt issuance policy. We quantify the distribution of issuance receipts using the properties of the zero coupon yield curve estimates from our dataset. If the face value of debt issuance has to be decided one month in advance then it is the variance and covariance of one-period ahead forecasts of the yield curve at different horizons that determine the distribution of issuance receipts.[15] To account for shortfalls being more problematic, we measure the prospective shortfall in issuance receipts that occurs if yield curve movements are in their 5th most unfavourable percentile over the implementation lag of the policy. In parallel with measures of Value at Risk from the finance literature, our measure satisfies our minimum criteria (i) and (ii) by ensuring that risk is increasing in issuance and yield curve volatility, and (iii) by penalising shortfalls more than excesses in receipts. We report our risk measure relative to GDP, so for example a 1.5% level for the 5% Value at Risk measure means there is a 5% probability that a government deciding issuance in advance will face a shortfall in receipts of at least 1.5% of GDP.

The trade-off between funding costs and our measure of operational risk is plotted in Figure 10(a), which shows combinations of average debt and average Value at Risk achieved over the period 1914-2017 in counterfactuals where the government always issues zero coupon nominal bonds of a given maturity and does not redeem them until maturity. Policies based on issuing bonds of an integer number of years to maturity are shown by large dots labelled 1, 2, 3 and so on. Smaller dots are for policies that issue non-integer maturities such as 2.5 years. Figure 10(a) has a U-shape, with our measure of operational risk first falling and then rising as maturity increases.[16] That risk is non-

[15]Since the yield curve at any given maturity exhibits close to unit root behaviour, we approximate the volatility of one-period ahead forecasts by the unconditional volatility of one-period changes in the yield curve. Accounting for the covariance between one-period ahead forecasts at different horizons captures any role that curvature may play in the dynamics of the yield curve.

[16]The pattern is robust to assuming an implementation lag of more than one period in the Value at Risk measure. Longer implementation lags lead to higher Value at Risk but still produce a U-shape.

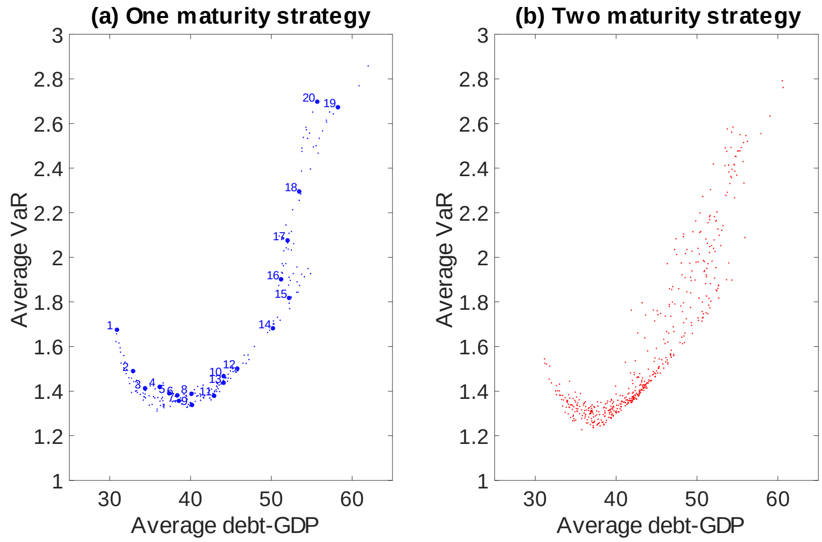

FIGURE 10. COMBINATIONS OF AVERAGE DEBT-TO-GDP AND VALUE AT RISK WITH DIFFERENT ISSUANCE STRATEGIES 1914-2017

monotonic with respect to maturity may appear surprising at first, since the expectation might be that operational risk always falls as the government increases the maturity of debt it issues. To the left of the minimum of the U-shape this reasoning applies and risk does fall with maturity, but to the right of the minimum the logic is reversed and risk rises with maturity. Two factors lie behind the reversal. Firstly, lengthening the maturity of government debt when the yield curve is upward-sloping leads to higher overall debt levels, which translate into more operational risk as there are greater absolute quantities of debt to refinance each period. Secondly, prices of long bonds are more volatile than prices of short bonds so issuing longer debt is inherently more risky.

Figure 10(b) extends the counterfactual analysis by allowing the government to issue fixed proportions of two different maturities of zero coupon nominal bonds each time it needs to raise funds, maintaining the assumption that bonds are not redeemed until they reach maturity. There are now many smaller dots, each corresponding to a counterfactual with two maturities of bonds and a fixed proportion in which they are issued. We are interested in minimising costs after taking into account risk, so Figure11 plots the convex hulls of Figure10 to map the frontiers that minimise average Value at Risk for a given average debt level. Also included is the frontier when the government issues fixed proportions of three different maturity bonds, although the gains relative to issuing only two bonds are not large.

The lowest Value at Risk in counterfactuals with only one bond requires the government to always issue zero coupon nominal gilts of maturity 5 years. The minimum Value at Risk with two bonds occurs when the government issues debt in fixed proportions of 80% short (22 months) and 20% long (137 months), for an average implied maturity at

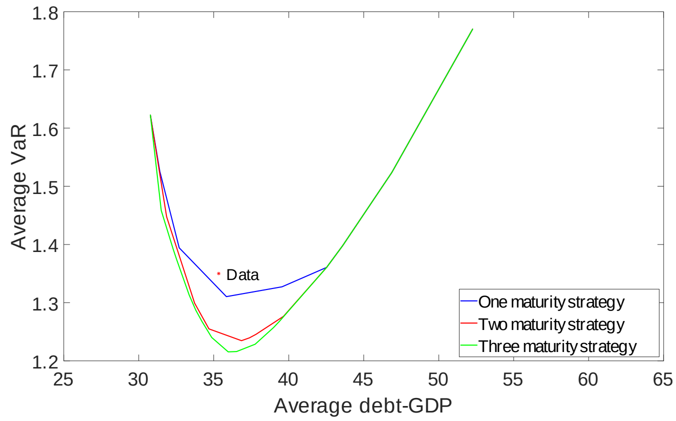

FIGURE 11. LOWER BOUNDS ON AVERAGE VALUE AT RISK FOR GIVEN AVERAGE DEBT TO GDP RATIOS 1914-2017

issuance of around 4 years. With this combination, average debt is 35.8% of GDP and the average Value at Risk is 1.23% of GDP. If we interpret the convex hulls in Figure 11 as efficiency frontiers then the performance of the actual issuance strategy over the period 1914-2017 has *ex post* been sub-optimal. By switching to a different issuance strategy, the UK government could have reduced its risk exposure without compromising on costs, or alternatively could have lowered costs without taking on additional risk.

VI. Liquidity, leverage and buyback

Our counterfactuals raise a number of additional issues. One is liquidity and the possibility that issuing large quantities of debt in a limited range of maturities may drive bond prices against the government more than we account for in our counterfactuals. This is potentially important, although liquidity effects are similarly absent in the usual arguments advocating long bonds. Another issue is the prescription in the optimal debt management literature that the government may need to take highly leveraged positions to better exploit movements in the yield curve and reap the benefits of fiscal insurance. The same literature also typically assumes that the government buys back and re-issues the entire debt stock each period, not just the bonds that are maturing. Excluding buyback as a debt management option may make our conclusions misleading. In this section, we examine the sensitivity of our findings to these additional issues.

A. Liquidity

The concern over adverse liquidity effects is that yields may move so much with issuance that all the cost gains in the counterfactuals are wiped out. This is a recurring theme in our discussions with debt management offices, although it often reflects a desire to spread issuance across multiple maturities rather than an argument *per se* for issuing long rather than short bonds. In the absence of robust empirical evidence on how yields respond to issuance, we take an agnostic approach by calculating an upper bound on how large liquidity effects would need to be to completely offset the gains displayed in the counterfactuals. The value of nominal debt to GDP for 2017 in the data is 69.8% and in the 3-year bond counterfactual it is 46.2%. The question is how much the yield curve would need to move to nullify the implied gain of 23.5% of GDP.

To calculate the upper bound on permissible liquidity effects, note that the yield to maturity ytm_t^j of a nominal gilt of face value £100 that matures in j months satisfies

$$ytm_t^j = \left(\frac{100}{P_t^j}\right)^{\frac{1}{j/12}} - 1$$

where P_t^j is the bond's current market price. In the counterfactuals it was assumed that the government receives the full amount P_t^j for each £100 it promises to pay in j months, irrespective of the volume of debt issued. To allow for issuance to affect costs, we introduce a premium x on the yield the government has to pay when it raises funds. Instead of P_t^j the government only receives $\tilde{P}_t^j < P_t^j$ for each £100 of debt it issues, where

$$\tilde{P}_t^j = 100 \left[\left(\frac{100}{P_t^j}\right)^{\frac{1}{j/12}} + x \right]^{-j/12}$$

The question now becomes one of how large the premium on the yield can be before the gains in the counterfactuals are wiped out. The critical break-even value of x for the 3-year counterfactual is 78 basis points and for the 5-year case it is 36 basis points. The 10-year counterfactual performs worse than the historic UK debt management even without liquidity effects, so adding them only worsens things still further.

A liquidity premium of 78 basis points is substantial in the context of the 5.3% average one-period holding return on 3-year gilts over the period 1914-2017. However, so too is the increase in issuance required by the policy that only issues 3-year bonds. For the same period, the average annual issuance of debt with maturity 3 ± 1 years (to allow for debt that was not issued with maturity of exactly 3 years) amounts to 0.9% of GDP, whereas in the counterfactual with only 3-year bonds the average annual issuance rises to 13.6% of GDP. Therefore, in order for 3-year bonds to outperform actual UK policy for the period we require that the elasticity of the yield curve with respect to issuance is less than $\Delta Q/Q \times ytm/\Delta ytm = ((13.6 - 0.9))/0.9 \times 530/78 = 96$. In practical terms, this means a doubling of issuance should lead to an increase in yields of no more than $530/96 = 5.5$ basis points. Breedon and Turner (2018) evaluate the costs of the UK government both buying and issuing large quantities of gilts. They report in their Table A2.1 that a doubling in the value of issuance moves yields by a maximum of $3.300 \times \log(2) = 2.3$ basis points, lower than the critical value calculated above.

The impact of liquidity premia on debt management frontiers is visible in Figure 12, where the distance from the data to the frontier reduces as we allow for ever larger price effects from issuance. We find that a 100 basis points premium on the yield to maturity

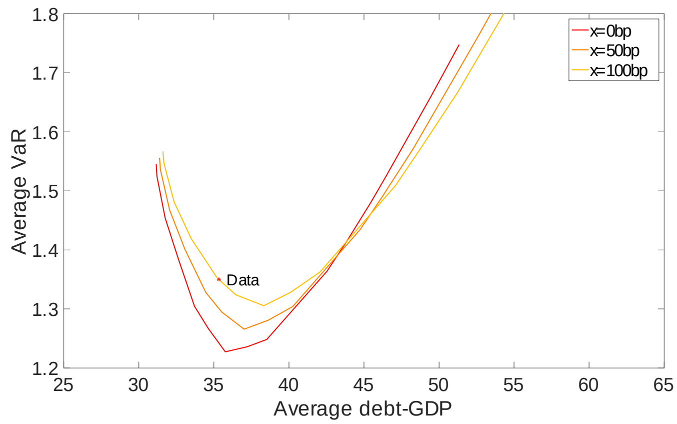

FIGURE 12. LIQUIDITY EFFECTS AND DEBT MANAGEMENT FRONTIERS 1914-2017

is sufficient to place the actual data on the efficiency frontier when issuing bonds of two maturities.

B. Leverage

The low funding costs associated with 3-year bonds raises the possibility that the government could reduce costs still further by taking leveraged positions in debt markets. Leverage also has the potential to reduce risk by gearing up the limited shifts in the yield curve that underpin fiscal insurance, as emphasised by Buera and Nicolini (2004). To investigate the implications of leverage, we return to the counterfactuals in which the government issues two bonds of different maturities in fixed proportions. We model leverage by allowing the government to issue a negative quantity of one of the bonds, i.e. the proportions of each bond are $-z$ and $1 + z$ respectively, where $z > 0$. The results appear in Figure 13, which reproduces the red efficiency frontier from Figure 11 as the baseline case for counterfactuals with two bonds and no leverage.

Over-issuance facilitates two types of outcome that were previously unattainable. In the south east of Figure 13 the government can lower its Value at Risk exposure without increasing the average debt to GDP ratio. These outcomes are achieved by the government over-issuing long bonds, although the benefits here are somewhat illusionary since all the new outcomes are dominated by ones attainable without leverage. Of greater interest are the new possibilities in the north west of Figure 13, which arise when the government over-issues short debt. By adopting this strategy, the government is able to reduce the average debt to GDP level below anything possible with non-leveraged strategies. Because the yield curve is usually upward-sloping, the government can reduce average debt by over-borrowing in short bonds and saving the excess receipts in long bonds. The drawback is that these new outcomes are associated with a very high Value at Risk, as the leveraged strategy exposes the government to operational risk on both its

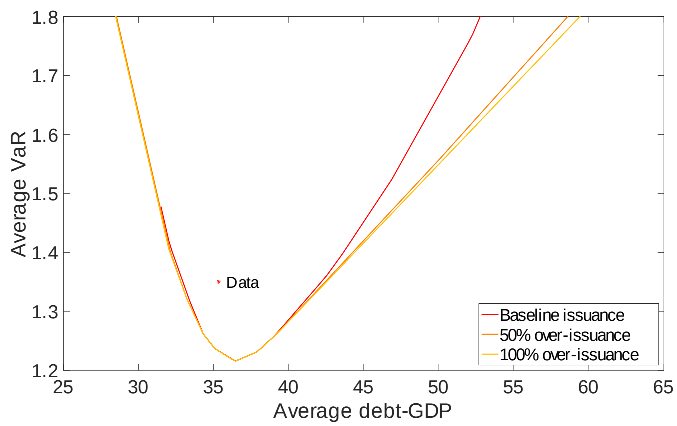

FIGURE 13. LEVERAGE AND DEBT MANAGEMENT FRONTIER 1914-2017

borrowing and its savings. Since the objective of debt management includes a requirement to take account of risks, we conclude that the government should avoid leverage and instead focus on strategies that favour the issuance of short bonds. If liquidity effects are important then leverage becomes even less attractive as a debt management strategy.

C. Buyback

The counterfactuals presented so far assume that the government does not repurchase any of the bonds it issues until they reach maturity. This is in line with practical debt management in the UK, where only very few of the gilts in our sample period were redeemed early.[17] If markets are incomplete, Faraglia et al. (2018) show that the no buyback assumption affects the timing of cash flows and creates a “lumpiness” in the profile of redemptions that may hamper the ability of long bonds to provide fiscal insurance. In this subsection, we therefore examine whether the desirability of short bonds is lessened if the government buys bonds back one year after issuance.

Table 4 reports the evolution of debt in counterfactuals with buyback. In comparison with our previous results in Table 3, there are only a few cases in which the buyback strategy outperforms no buyback. Most notable of these is the period 1946-1970, where buyback strategies prevail irrespective of whether the government issues 3, 5 or 10 year bonds. Not surprisingly, this is also the period in which issuance of long bonds was preferable in the counterfactuals without buyback. Long bonds offer fiscal insurance in this period, and buyback increases their ability to provide that insurance by ensuring that they dominate the maturity structure of government debt. More generally, the periods in which buyback is better are closely aligned with periods when long bonds are best,

[17] From the perspective of the consolidated government budget constraint, the large scale asset purchases made under the Bank of England’s Quantitative Easing Programme could be interpreted as buyback of previously-issued debt. The absence of detailed data on the assets purchased precludes further gilt-by-gilt analysis at this stage.

hence the relative performance of 3, 5 and 10 year bond strategies is as before without buyback. As such, issuing and buying back 10 year bonds in the most recent period 1998-2017 remains particularly undesirable, underlining again the expensive nature of long bonds after a financial crisis.

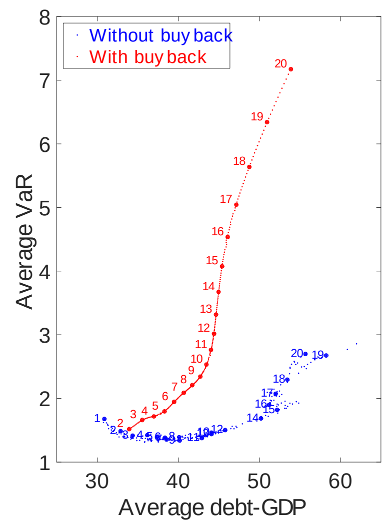

FIGURE 14. BUYBACK AND DEBT MANAGEMENT FRONTIERS 1914-2017

Allowing the government to repurchase bonds also has other disadvantages for debt management in terms of heightened operational risk. Buyback leads to a substantial increase in debt issuance each period, which may impact upon yields and the government's ability to finance its operations. Our Value of Risk measure surges if we assume that buyback decisions have to be made in advance. This is clear in Figure 14, where buyback introduces significant extra operational risk under all issuance strategies. Allowing for liquidity effects would reduce the performance of buyback strategies even further.

VII. Conclusion

Managing the national debt is a formidable task for any government. In this paper, we offer assistance by documenting the history of UK debt management since 1694. Central to our contribution is the detail in our new dataset, which has 81701 monthly observations of individual gilt prices and 87772 monthly observations of individual gilt quantities. This is the first time that archives at the House of Commons, Bank of England, Heriot-Watt University and the *Financial Times* have been brought together with other historic data to provide a comprehensive account of debt management in a format that is amenable to macroeconomic analysis. The granular coverage of our quantity and price database is important as it provides in-depth information on the market value of debt and the one period holding returns on bonds of different maturities, both of which are key concepts in the government's intertemporal budget constraint. The data is also comprehensive enough to identify the issuance receipts, coupon payments and gross redemptions that make up the funding profile of the government. Knowledge of one period holding returns means we can accurately measure the costs of alternative funding strategies. The cash flows from receipts, coupons and redemptions provide the backdrop for an evaluations of the historic performance of UK debt management.

We find there are large cost advantages to issuing short bonds. The degree and regularity with which the yield curve slopes upwards means that long bonds should only play a minority role, even when the case for issuing long bonds is strengthened by taking into account some of the risks involved. The cost advantages of short term debt are substantial, a recurring feature over long periods and various sub-samples. This is borne out by our counterfactual scenarios, which suggest that UK government debt in 2017 would have been around 24% of GDP lower had the government only issued 3-year bonds throughout the 20th century and early 21st century. Long bonds do have some advantages. Their prices tend to fall in response to military expenditure shocks connected to major wars, which reduces the market value of debt and eases pressures on taxation. However, this effect is relatively modest and not generic across all government expenditure shocks. In particular, long bonds appreciate in value in periods of financial crisis, leading to increases in the market value of government debt and exacerbating budgetary concerns. Since the recent Global Financial Crisis, high holding period returns on long gilts have driven the ratio of the market to face value of UK debt to its highest levels since our data began. The frequency at which maturing debt needs to be refinanced is lessened by issuing long bonds. However, the relationship between the maturity and the quantity of debt maturing is non-monotonic because long bonds are expensive to issue and so lead to higher overall levels of government debt. Although long bonds reduce the proportion of debt that matures each period, they increase the absolute quantities of debt maturing each period. The operational risk from refinancing is minimised when the government issues 2 and 11 years bonds in the proportion 3:1, an average implied maturity at issuance of around 4 years. The non-monotonicity between operational risk and maturity suggests that it is possible to go too long with debt, issuing in a range where both cost and risk are increasing. Our measures of operational risk suggest this appears to be the case in the UK, which is the only OECD country with an average debt maturity in excess of 10 years.

The UK is clearly an exceptional case, given its lengthy maturity of government debt and its record of never having defaulted on marketable debt. It could be argued that issuing of long bonds is more attractive for other countries with a history of defaults. Whilst plausible, this does not undermine our finding that there is a cost in terms of interest payments and operational risk in pushing out the maturity of government debt. This remains an important insight, given that default risks are not always the reason why long term debt is advocated. What our database does show is an upward-sloping yield curve giving substantial cost disadvantages to long bonds. It also suggests a greater need to focus on cash flows and gross redemptions if we are to better map the concerns over risk of debt management. Improved measures of risk are also undoubtedly desirable. Even so, the cost advantages of issuing at the short end of the maturity profile and the non-monotonic relationship between operational risk and maturity suggest that increasing the maturity of government debt may not be optimal. Our conclusions question the empirical relevance of the optimal debt management literature's preference for long bonds and the current UK practice supporting the longest average maturity government debt portfolio in the world. At the heart of our reasoning are term premia that favour issuing short debt and covariance properties of long debt that provide only limited fiscal insurance. Any explanation for why the UK government maintains such a long average maturity of debt and issues so many different maturities cannot rely on stochastic properties of the yield curve. It must instead focus on risks specific to the microstructure of bond markets, which as yet remain ill-defined in the literature.

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TABLE 3—DEBT DYNAMICS IN COUNTERFACTUALS WITHOUT BUYBACK

	Start Debt to GDP	End Debt to GDP	Change in Debt to GDP	Contribution of Nominal Return	- of which coupons	- of which revaluations	Contribution of Inflation	Contribution of GDP Growth	Contribution of New Debt
Actual issuance									
1914-2017	0.0	69.8	69.8	155.3	148.9	6.4	-135.5	-82.8	132.8
1914-1945	0.0	78.3	78.3	27.3	20.0	7.3	-10.4	-9.4	70.8
1946-1970	78.3	24.0	-54.3	30.7	44.7	-14.0	-57.9	-40.8	13.7
1971-1997	24.0	28.2	4.2	57.8	52.8	5.0	-53.2	-17.0	16.7
1998-2017	28.2	69.8	41.5	39.5	31.4	8.1	-14.1	-15.4	31.5
3-year zero coupon bonds									
1914-2017	0.0	46.2	46.2	156.5	0.0	156.5	-155.2	-87.9	132.8
1914-1945	0.0	75.1	75.1	22.9	0.0	22.9	-9.5	-9.2	70.8
1946-1970	78.3	36.1	-42.2	55.0	0.0	55.0	-64.9	-46.1	13.7
1971-1997	24.0	21.7	-2.3	51.2	0.0	51.2	-54.5	-15.8	16.7
1998-2017	28.2	45.4	17.1	10.8	0.0	10.8	-12.0	-13.2	31.5
5-year zero coupon bonds									
1914-2017	0.0	57.1	57.1	181.4	0.0	181.4	-162.5	-94.6	132.8
1914-1945	0.0	78.2	78.2	27.5	0.0	27.5	-10.4	-9.8	70.8
1946-1970	78.3	35.4	-42.9	54.2	0.0	54.2	-64.7	-46.1	13.7
1971-1997	24.0	25.6	1.6	56.5	0.0	56.5	-54.9	-16.7	16.7
1998-2017	28.2	50.3	22.1	17.2	0.0	17.2	-12.7	-14.0	31.5
10–year zero coupon bonds									
1914-2017	0.0	82.4	82.4	240.6	0.0	240.6	-180.8	-110.2	132.8
1914-1945	0.0	85.3	85.3	40.0	0.0	40.0	-13.2	-12.4	70.8
1946-1970	78.3	33.8	-44.5	53.3	0.0	53.3	-65.0	-46.5	13.7
1971-1997	24.0	32.5	8.5	66.4	0.0	66.4	-56.4	-18.3	16.7
1998-2017	28.2	62.0	33.8	32.1	0.0	32.1	-14.2	-15.6	31.5

TABLE 4—DEBT DYNAMICS IN COUNTERFACTUALS WITH BUYBACK

	Start Debt to GDP	End Debt to GDP	Change in Debt to GDP	Contribution of Nominal Return	- of which coupons	- of which revaluations	Contribution of Inflation	Contribution of GDP Growth	Contribution of New Debt
Actual issuance									
1914-2017	0.0	69.8	69.8	155.3	148.9	6.4	-135.5	-82.8	132.8
1914-1945	0.0	78.3	78.3	27.3	20.0	7.3	-10.4	-9.4	70.8
1946-1970	78.3	24.0	-54.3	30.7	44.7	-14.0	-57.9	-40.8	13.7
1971-1997	24.0	28.2	4.2	57.8	52.8	5.0	-53.2	-17.0	16.7
1998-2017	28.2	69.8	41.5	39.5	31.4	8.1	-14.1	-15.4	31.5
3-year zero coupon bonds									
1914-2017	0.0	52.5	52.5	169.4	0.0	169.4	-158.4	-91.3	132.8
1914-1945	0.0	76.8	76.8	25.2	0.0	25.2	-9.9	-9.4	70.8
1946-1970	78.3	35.7	-42.6	54.7	0.0	54.7	-64.9	-46.2	13.7
1971-1997	24.0	23.3	-0.7	53.0	0.0	53.0	-54.2	-16.2	16.7
1998-2017	28.2	49.0	20.8	15.6	0.0	15.6	-12.5	-13.8	31.5
5-year zero coupon bonds									
1914-2017	0.0	67.7	67.7	196.4	0.0	196.4	-163.8	-97.7	132.8
1914-1945	0.0	80.0	80.0	30.3	0.0	30.3	-10.9	-10.2	70.8
1946-1970	78.3	34.0	-44.3	52.6	0.0	52.6	-64.5	-46.1	13.7
1971-1997	24.0	27.2	3.2	57.3	0.0	57.3	-53.9	-16.9	16.7
1998-2017	28.2	57.2	29.0	25.6	0.0	25.6	-13.4	-14.8	31.5
10-year zero coupon bonds									
1914-2017	0.0	112.6	112.6	258.6	0.0	258.6	-169.2	-109.6	132.8
1914-1945	0.0	82.9	82.9	34.6	0.0	34.6	-11.8	-10.8	70.8
1946-1970	78.3	27.4	-50.9	43.7	0.0	43.7	-63.0	-45.3	13.7
1971-1997	24.0	43.1	19.1	80.8	0.0	80.8	-57.7	-20.8	16.7
1998-2017	28.2	76.4	48.1	48.4	0.0	48.4	-15.1	-16.7	31.5