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Does the yield curve's ability to predict future output and recessions differ when interest rates are low, as in the current global environment? In this paper we build on recent econometric work by Shi, Phillips, and Hurn that detects changes in the causal impact of the yield curve and relate that to the level of interest rates. We explore the issue using historical data going back to the 19th century for the United States and more recent data for the United Kingdom, Germany, and Japan. This paper is similar in spirit to Ramey and Zubairy (2018), who look at the government spending multiplier in times of low interest rates.

Keywords: low interest rates, policy, predictive content of the yield curve.

JEL Codes: E32, N10, G01.

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I. Introduction

Does the yield curve's ability to predict future output and recessions differ when interest rates are low, as in the current global environment? Despite a variety of work that examines the predictive content of the yield spread accounting for the level of rates (Ang, Piazzesi, and Wei, 2006), monetary policy (Cooper, Fuhrer, and Olivei, 2020) and the persistence of inflation (Benati and Goodhart, 2008) this question remains open. The question recently arose again as the yield curve inverted in the late summer and early fall of 2019. As it turns out, this inversion did foreshadow a recession in 2020, though some may think that the advent of COVID-19 made this example a coincidence; so perhaps the question remains open after all. In fact, the monetary policy response to the pandemic makes the question particularly relevant, with expectations of an extended period of rates at the effective lower bound, quantitative easing, and suggestions that yield curve control—the direct targetting of longer rates—could be used as a pollicy tool (Belz and Wessel, 2020). In this paper we build on recent econometric work that detects changes in the causal impact of the yield curve and relate that to the level of interest rates. We explore the issue using several historical data sets going back to the 19th century for the US and more recent data for the UK, Germany, and Japan. Though using very different techniques and asking different questions, this paper is similar in spirit to Ramey and Zubairy (2018) who look at the government spending multiplier in times of low interest rates.

In our data set, the US has had two extended periods of low interest rates: in the 1930s and 1940s, and in the years during and following the Great Recession. These episodes stand out in Figure 1, which plots the two short rates we use, the commercial paper rate and the target fed funds rate. Ramey and Zubairy (2018) look for episodes when interest rates are near the zero lower bound or times of "extended monetary accomodation," which they define as either very low rates or when rates "stay constant rather than follow the Taylor rule." They find that this happens in two periods: 1932Q2–1951Q1 and 2008Q4–2015Q4. We compare the predictive content of the yield curve in and out of these low rate periods, and although the exact results depend on the time period and data set used, in general the yield curve shows predictive power even in low rate environments.

The rest of the paper is structured as follows: Section II describes the SPH technique for assessing causality, and describes the data used. Section III describes the results, Section IV extends the results to several international data sets, and Section V concludes.

II. Testing for predictive content

An old stylized fact in economics is that the yield curve helps to predict future economic growth (Kessel 1965, Harvey 1988, and Estrella and Hardouvelis 1991 are early important papers in this area), but in recent decades, the evidence has become quite strong that the predictive content of the yield curve changes over

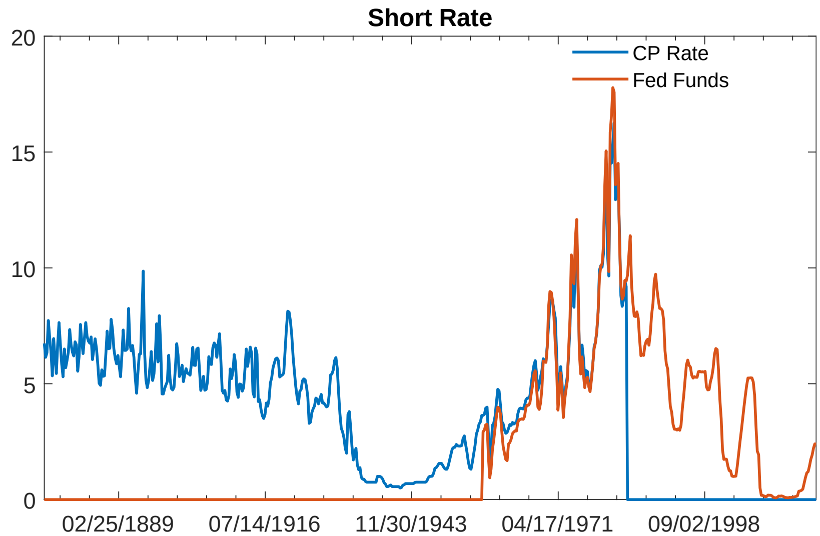

Figure 1. Short Rates

time (Haubrich and Dombrosky 1996, Dotsey 1998). Exactly why the predictive content changes is unclear, in part because the mechanism behind the predictive ability has remained elusive despite some interesting attempts to understand it (Rendu de Lint and Stolin 2003, Kurman and Otrok 2013). Bordo and Haubrich (2008a,b) have suggested that the monetary regime may play a role, Giacomini and Rossi (2006) provide evidence that changes in monetary policy have led to breakdowns in predictive accuracy, and Benati and Goodhart (2008) show that changing inflation persistence is important. The recent concern about low interest rates fits into this tradition, but in one sense is rather surprising, as many of the earliest papers explicitly account for the impact of short-term interest rates: Estrella and Hardouvelis (1991) find the yield curve still has power even when adding the federal funds rate or the 3-month Treasury rate. Plosser and Rowuenhorst (1994) find that the slope of the term structure has information beyond short-term rates. Ang, Piazzesi, and Wei (2006) find that the predictive content of the spread resides in the short rate, but Bordo and Haubrich (2008b) add in a short rate separately and find that the yield curve still matters. Timing the changes in yield curve behavior has been difficult, however, making it hard to align with regime shifts, low interest rates, or other factors. Recently, however, Shi, Phillips and Hurn (2018) have developed a sophisticated recursive method for testing when the yield curve has predictive content, using Wald tests for Granger (1969) causality in a VAR, and this provides a more precise standard to compare with macroeconomic events and regimes.

A. The SPH technique

Shi, Phillips, and Hurn propose a new time-varying Granger causality test, in which they estimate a vector autoregression (VAR)[1] on a window that moves through the data set. The test can identify multiple breaks between periods with and without Granger Causality. The major contribution, of course, is developing a time-varying test with good statistical properties, but they also compare three different types of window: an increasing window, a rolling window, and a rolling recursive window. The rolling window has the best statistical properties, so that is the one we use. We compute the test statistics and critical values by adapting the Matlab program for the paper provided by Shi. The rolling window size suggested by Shi, Phillips, and Hurn, is 20 percent of the data set, and we follow their advice.

SPH describe the test as a sup-Wald test, as it looks at the distribution of the supremum (least upper bound) of the Wald test on the evolving window. The Wald (1943) test is a standard test of the restrictions on the VAR coefficients, the square of the regression coefficient divided by the estimated variance. In this case, the test involves setting some coefficients to zero under the null hypothesis of no Granger causality. The econometric difficulty is judging when the Wald statistic is large enough to detect changes in Granger causality over time—interested readers should consult the SPH paper for details.[2] We use the fact that Phillips has produced a test and calculated the 5 percent error levels that allow us to estimate when the Granger causality switches on and off.

Shi, Phillips and Hurn compare three different windows. The forward expanding window, championed by Thoma (1984) (though he calls it a rolling window), expands the window by adding successive observations, making the window larger as later observations are included. The rolling window, used by Swanson (1998), keeps the window the same size by dropping observations at the beginning as later observations are added (hence the term rolling). Shi, Phillips, and Hurn also propose a rather complicated recursive evolving window, but their simulations show that the rolling window has the best properties in the sense of having the highest successful detection probablity, and being more accurate in assigning a switch-off date for the causality. In addition, though the rolling window has a somewhat higher false detection proportion, the difference is negligible when the sample size reaches 200, a bound our sample easily exceeds (and the successful detection proportion (SDP) further improves with sample size).

[1] As opposed to VaR, which is Value at Risk.

[2] Rossi (2005, 2013) has developed similar tests that Shi, Phillips, and Hurn argue have trouble identifying breaks near the end of the sample. With our concern about the recent content of the yield curve, we prefer the SPH approach.

B. Data

Shi, Phillips and Hurn test for Granger causality of the yield spread on aggregate output. They use a four-variable VAR with data at both quarterly and monthly frequencies. The SPH paper uses data from 1980, but in fact, their data set extends back to 1957 (Q1, or January), and, with our interest in historical regimes, we use the longer series and extend it out to 2019 (Q1 for quarterly and August for monthly data). For quarterly data, the four variables used in the VAR are the real GDP gap (actual real GDP minus real potential from the CBO), inflation calculated as the log difference of core CPI (mulitplied by 400 for quarterly data), the effective fed funds rate, and the difference between the secondary market 3-month T-bill rate and 10-year government bond yield (Long-Term Government Bond Yields: 10-year: Main (Including Benchmark) for the United States from the OECD), with the immediate source of all variables being the FRED database at the St. Louis Federal Reserve Bank. As an alternative, we also look at the year-over-year growth in real GDP. The monthly data use the annual growth rate of industrial production (IP) and multiplies the monthly log difference in core CPI by 1200.

To apply this procedure to historical data, we apply the analysis to a subset of the quarterly data set of Balke and Gordon (1986), which covers 1875-1983 extended with the data from Ramey and Zubairy (2018), which brings the data up to 1998. The current constraint is that 1998 is when the series for six-month commerical paper stops. To follow Shi, Phillips and Hurn as closely as possible, we use a gap measure (real GNP less trend real GNP), inflation from the GNP deflator (quarterly log differences times 400), the commercial paper rate as a short-term interest rate substituting for the policy rate (prior to the Federal Reserve System, there was no official policy rate, and even using the discount rate in the early years of the System has its difficulties), and the corporate bond-commercial paper spread from Balke and Gordon as the term spead.

Looking at early data provides a richer set of monetary regimes, including the gold standard and a time without a central bank, but it also presents challenges. Chief among these is that a risk-free Treasury yield curve is not reliably available, both because Treasury bills did not become standard until the 1920s, and because it was not obvious that even longer-term Treasuries were the risk-free benchmark—for most of the 19th century, railroad bonds had at least as great a claim. Following Balke and Gordon, we use the spread between the yields on corporate bonds and the commercial paper rate. Though neither yield is risk free, it is hoped that their risk premiums will be roughly comparable; for more discussion see Bordo and Haubrich (2008a). Figure 2 plots both spreads, and for the quarter century in which they overlap, the correlation between them is 92 percent. Over this period there is not an obvious interest rate that can count as the monetary policy rate; indeed, for much of the period, the United States did not have a central bank. We use the short rate as a rough equivalent, as a proxy for the stance of conditions in the money market. Using one short rate as both the "policy" rate and in the yield spread is a departure from Shi, Phillips, and Hurn, but the high correlation between policy rates and short-term rates in the money market makes us confident that the problem is not large.

For periods of low rates, we use the definition of Ramey-Zubairy (2018), 1932:Q2 to 1951:Q1 and 2008:Q4 to 2015:Q4, translated for monthly data as 1932 April to 1951 March, and 2008 October to 2015 December. Our monthly data continue until August 2019, but the FOMC increased the lower bound of the target federal funds range above zero on December 16, 2015, so we judge the Ramey-Zubairy ending date as appropriate. The US experience with yield curve control lasted from 1942 to 1951, with caps on Treasury bills ending in July 1947 and caps on longer rates expiring with the Treasury-Fed Accord of February 1951 (Garbade, 2020). Thus the yield curve control period is contained in the period of low rates, and we cannot distinguish between their effects.

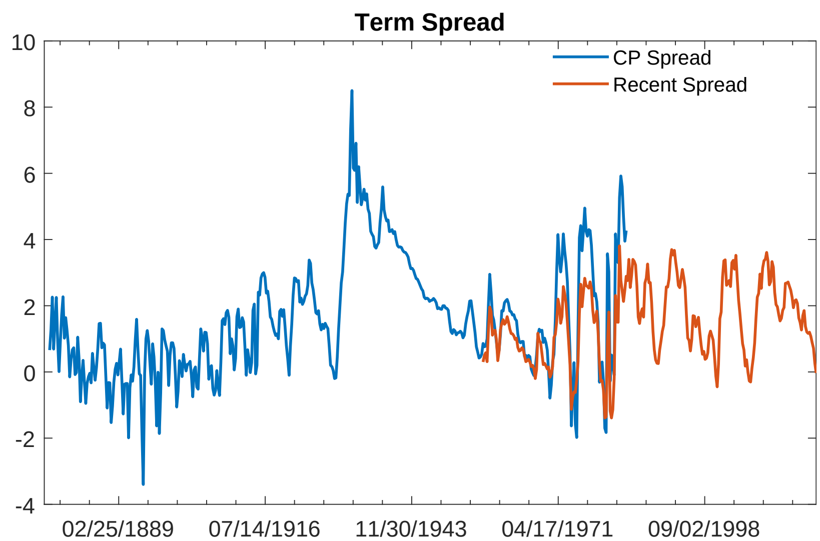

Figure 2. Corporate Commercial Paper and 10-Year 3-Month Spread

Again, as an alternative, we use year-over-year growth in real GNP.

It is also possible to form a long series of monthly data, although at this point we have not been able to extend it up to the present. Monthly industrial production data begin in 1919, and that forms the start of our data. For the short rate and the policy rate, we use the discount rate from the Federal Reserve Bank of New York, available since 1914. Before the New Deal reforms, discount rates at Federal Reserve district banks varied, but New York, as the financial center of the nation, is the most obvious single rate to choose. This series continues up until January of 2003, when the adjustment credit program, which was extended at a below market rate, was replaced by the primary credit program, whose rate was set above the federal funds rate. This was not a change in the stance of monetary policy, but rather in the administration of the discount window. For long rates we use long-term Treasury bonds, putting together several surprisingly consistent series. Finally, for inflation we use the NSA CPI, again available back to 1919. This gives a near-century of monthly data, from 1919 to 2003.

Figure 1 plots the two short rates used: the commercial paper rate and the target fed funds rate. Two periods of exceptionally low rates stand out: the 1930s and 1940s, and the recent post-crisis period. The short rate appears to have greater high-frequency volatility in the pre-war years, but greater low-frequency volatility in the post-war years. Figure 3 plots the inflation rate, which is measured by the deflator in the early days and the core CPI in the later days. Although the measures differ, they track closely. Notice that pre-World War II, inflation was more variable, and deflation was not uncommon. Four periods with low inflation or deflation stand out. The years 1879 to 1897 mark the period from the resumption of the gold standard until the inflation created by the massive gold strikes in South Africa, Alaska, and Colorado. It is one of the periods of "good deflation" as defined by Bordo, Redish and Landon Lane (2009), where output increased despite prices falling, as the gold standard provided a nominal anchor. The years 1921 to 1937 stretched from the Federal Reserve's discovery of the scissors effect of open market operations until the recovery from the Great Depression started in 1937. These years encompassed most of the interwar period, where the anchor of the gold standard operations led to the bad deflation associated with the Great Depression. The years 1951 to 1967 mark the period from the Treasury-Fed Accord to the advent of the Great Inflation in 1968, when the Bretton Woods system still provided a link to gold. And lastly, the period from the mid-1990s to the present saw the Great Moderation, where the anchor was not the gold standard but the credibility of the fiat regime under Alan Greenspan. It was followed by the financial crisis of 2008 and its aftermath.

III. Results

This section applies the SPH sup-Wald test to several data sets to find periods of causality between the yield curve and different measures of aggregate output. It then checks for a relationship between such causality and the interest rate environment, classifying periods as either showing Granger causality or not, or having low interest rates or not, and assesses significance on the classification by a simple χ^2 test on a contingency table.

A. Recent data

For the recent period 1957-2019 we apply the heteroskedastic version of the sup-Wald test with a rolling window, looking for periods where the term spread Granger causes the real GDP gap, year-over-year real GDP growth, or industrial production. In choosing the window size, we again follow SPH, and set the

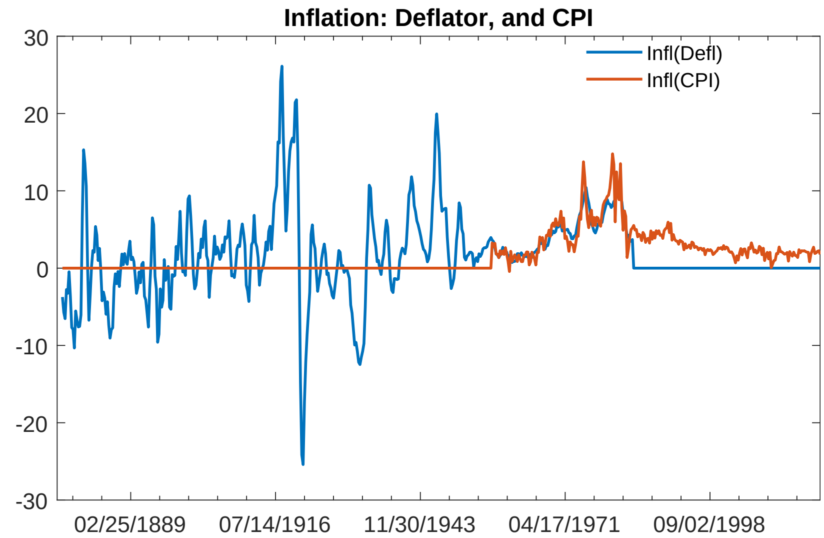

Figure 3. Inflation

fraction of the sample used for the rolling window, f_0 to 0.2, which means that in the recent quarterly data set, the window is set at 0.2x249=50 quarters, or just over 12 years. For the monthly data the same fraction is used, giving a window of 150 months or again a little over 12 years.

First, consider the results for the quarterly data. Figure 4 shows the changing causality from the spread to the real GDP gap, over the years 1957 Q1-2019 Q1. Since the size of the window is 50 quarters, the statistic starts only in 1969. The figure shows the test statistic sequence, the 5 percent critical value, NBER recessions, and yield curve inversions (vertical lines). The statistic achieves significance in 1969 Q1 to 1970 Q2, and in 1981 Q1-Q3,with the numbers getting close in 2001.

The test statistic using year-over-year real GDP growth, shown in Figure 5, shows a similar pattern to the gap series, but it has seveal additional detected periods of causation. In addition to 1969 Q4–1970 Q1 and 1980 Q4–1981 Q4, which correspond closely to dates in the gap series, it finds Granger causality in 2007 Q1 and 2010 Q4 to 2011 Q3. There are also a few close calls in the mid-1990s and mid-2000s. Table 1 lists the periods of Granger causality for the quarterly data.

The monthly data, shown in figures 6 and 7 provides a somewhat different perspective. Using monthly (annualized) industrial production numbers there are more periods of causality: monthly growth from May to November of 1981, September of 1998, and a variety of months between 2012 and 2019. The year-over-year growth numbers show causality as early as May 1976 and show a variety of other months, particularly in the mid- to late-2000s. Table 3 provides the de-

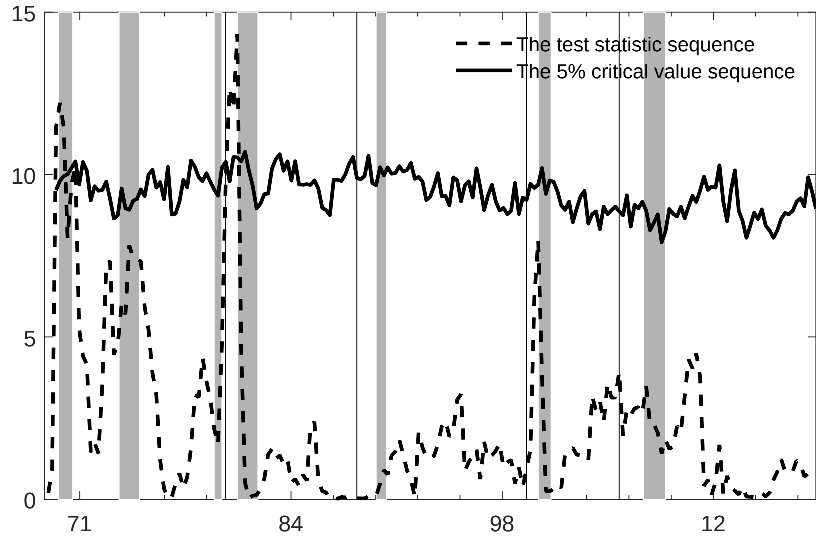

Figure 4. Spread to Gap, SPH data

tails. Unlike the quarterly results, it does not find causality around 1969 (though the test statistic is a bit elevated then), but like them it finds significance around the double-dip recession of 1980-81, around 2005-6, and after the financial crisis, which the quarterly approaches split on.

Table 1—Periods of Granger Causality, 1957-2019 Quarterly Data

10-yr 3-m spread to Gap	yoy RGDP
1969 Q4–1970 Q2	1969 Q4–1970 Q1
1981 Q1–Q3	1980 Q4–1981 Q4
	2007 Q1
	2010 Q4–2011 Q3

Source: FRED, Authors' calculations

If we consider the Ramey and Zubairy periods of extended monetary accommodations or zero lower bounds, we in general do not find overlap with periods of causality, except briefly for the case of industrial production in 2012 and 2013. In fact, periods exhibiting Granger causality from the yield curve to output are rather sporadic. The situation is a bit different if we consider periods of low inflation, as there are periods of causality in the mid-to-late 1990s, the 2000s, and post-crisis.

We can, in fact, address the issue of connection between causality and low rate environments more formally. A given time period (month or quarter) can be classified in two ways: whether it is in a period where the yield curve shows causality to output or not, and whether it is in a period of extended monetary accommodation (according to Ramey and Zubairy) or not. This naturally leads to a 2x2 contingency table and a χ^2 test for independence. Table 2 panel A reports the results for the GDP gap for the 1957-2019 quarterly sample. The χ^2 is insignificant, suggesting independence, or that periods where the yield curve Granger causes output are independent of the degree of monetary accommodation. An alternative way to view the results is Cramer's V statistic, which can be thought of as a measure of correlation between categorical variables, as it takes on values between 0 and 1. For the gap, it measures 0.07. Causality is rare whatever the interest rate environment. There is a bit more causality in the Ramey-Zubairy low rate periods using year-over-year real GDP growth, where the $\chi^2 = 3.56$, p = 0.965, and a Cramer's V of 0.134. Those results for year-over-year growth are reported in panel B. Standard statistical practice (McDonald, 2014) suggests that the χ^2 will be inaccurate and overstate significance if any expected entries of the table are less than 5 or the total sample less than 1000. Since both conditions obtain in many of our tables, we also report two exact tests, Barnard's and Boschloo's, to correct for this. They show results similar to the χ^2.

The results are quite different for the monthly industrial production data, reported in Tables 3 and 4, where there is a more substantial overlap between periods of causality and of excessive monetary accommodation. There, independence is rejected at a significant level, with a χ^2 value (df=13) of 25.4, $p = 0.020$. Cramer's V, a measure of correlation for contingency tables, comes in at 0.206, showing some correlation between low rate periods and causality periods. Using year-over-year growth also rejects independence: here, there are substantial periods of causality in both low and high interest rate environments. The χ^2 statistic is 24.0, with a p-value of 0.031 and a Cramer's V of 0.201.

B. Results for older data

The longer quarterly series, 1875-1998, shows both interesting parallels and differences. Table 5 lists these periods of Granger causality from the yield spread to the output gap and RGDP growth. Figure 8 shows the results for the gap and Figure 9 shows the corresponding results for year-over-year real growth (GNP until 1983, GDP from 1984 to 1998). Both charts show an extended period of Granger causality from the late 1930s to the middle 1950s, with shorter episodes at the start of World War I and in the 1970s. Note that causality occurs despite there being no full-fledged yield curve inversions (with this spread measure) in the Ramey-Zubairy period of low rates. Recall that the initial window of 20 percent of the data set works out to 24 years, so unfortunately we cannot address the causality of periods in the 1800s. Likewise, the data set ends in 1997, and so consideration of the Great Recession period is also precluded.

Table 2—Contingency Table: 1957-2019 Quarterly Data

Panel A: Spread to Gap

Actual frequencies

	Low rate	High rate	total
Granger periods	0	6	6
non-Granger	29	164	193
total	29	170	199

$\chi^2 = 1.06$, df=10, p=0.999,
Barnard p=0.378, Boschloo p=0.549
Cramer's V: 0.073

Panel B: Spread to YOY GDP growth

Actual frequencies

	Low rate	High rate	total
Granger periods	4	8	12
non-Granger	25	161	186
total	29	161	198

$\chi^2 = 3.56$, df=10, p=0.965,
Barnard p=0.067, Boschloo p=0.069
Cramer's V: 0.134

Source: FRED, authors' calculations. Degrees of freedom adjusted for estimated variance, per Cramér (1955), section 15.2

Using the output gap results in a fair number of episodes of Granger causality from the spread. The test statistic exceeds the 5 percent bound in 1903, in 1914 –1915 Q1, a long period from 1938 to 1956, and again from 1977 to 1979. If instead of the gap, we use year-over-year real GNP growth, there are intriguing similarities and differences. Figure 9 shows shorter causality episodes in 1914, 1915, and 1916, again in 1921, and a long episode from 1938 to 1954, followed by a short episode in 1955 and two brief episodes in 1975 and 1976.

Note that the most extensive period of causality, 1938:Q4 to 1956:Q2, overlaps extensively with the period of extended monetary accommodation of Ramey and Zubairy, 1932:Q2 -1951:Q1. The long period of causality showing up in both output series, from 1938 to the mid-1950s, also overlaps with the low inflation environment of the 1950s. Again we can test for independence between the monetary regime and yield curve causality, and Table 6 reports the contingency table for the 1876-1998 data. In contrast to the shorter data set, in this case independence is decisively rejected, and it appears that periods of causality are more likely in a time of monetary accomomdation. The correlation from Cramer's V is 0.67 for the data using the gap as a measure, and 0.54 for year-over-year growth.

Table 3—Periods of Granger Causality, 1957-2019 Monthly Data

10-yr 3-m spread to monthly IP growth	yoy IP growth
	1976 May
1981 May–Nov	1981 May–Aug
1998 Sep	1993 Jul, Oct
	1994 May–Jun
	1995 Feb–1997 Mar
	1997 May–2000 Mar
	2001 April
	2001 Aug –2004 Apr
	2004 Oct–Nov
	2005 Jan–Feb, Apr
	2005 Jul–2007 Feb
	2007 Jul–2009 Mar
	2009 Jul–2010 Feb
	2010 Jun–2011 Sep
	2011 Dec
2012 Sep–Nov	2012 Sep–2013 Feb
2013 Jan–Feb	
2013 Apr–2014 Mar	2013 April–2014 Feb
2015 Nov–Dec	
2016 Mar–May	
2016Sep–2017 Sep	
2019 Mar–Aug	

Source: FRED, Authors' calculations

C. Older Monthly Data

The longer monthly data set provides a near-century of monthly data, from 1919 to 2003. As before, 20 percent of the sample (in this case seventeen years) are held out at the beginning to initiate the rolling window, so the results do not begin until 1938. Figure 10 shows the results using year-over-year growth in industrial production, and Figure 11 shows the results using month-to-month growth. Both figures show causality from the yield curve to output at the end of the sample, with that for year-over-year IP growth starting around 1990 and month-to-month growth starting a decade earlier. As seen in Table 7 there are some earlier periods of causality, particularly in the late 1950s and late 1960s. In contrast to the quarterly output results, there is scant causality indicated from the late 1930s through the mid-1950s. Thus, there is little, in fact, no, overlap with either the Ramey-Zubairy period of extended monetary accommodation or with periods of

Table 4—Contingency Table: IP 1957-2019 Monthly Data

Panel A: Monthly IP growth

Actual frequencies

	Low rate	High rate	total
Granger periods	19	30	49
non-Granger	68	484	552
total	87	514	601

$\chi^2 = 25.4$, df=13, p=0.020,
Barnard p=2.3x10^{-5}, Boschloo p=8.2x10^{-6}
Cramer's V: 0.206

Panel B: Year-over-year IP growth

Actual frequencies

	Low rate	High rate	total
Granger periods	48	144	192
non-Granger	39	361	400
total	87	505	592

$\chi^2 = 24.0$, df=13, p=0.031,
Barnard p=3.7x10^{-5}, Boschloo p=2.5x10^{-6}
Cramer's V: 0.201

Source: FRED, Authors' calculations

low inflation: recall their early period ends in 1951. In contrast to some of the quarterly results, the χ^2 tests reported in Table 8 suggest, if anything, a negative correlation between low rates and causality: $\chi^2 = 173.3, df = 13, p = 3.9x10^{-30}$ for the monthly IP changes, and $\chi^2 = 91.5, df = 13, p = 7.1x10^{-14}$. In contrast to the previous results, this indicates that the yield curve has less predictive content in low rate environments.

IV. Other countries

Other developed countries have also had periods of low interest rates and low inflation under different monetary regimes, and we look at those cases as additional sources of information. We look at the UK, Germany, and Japan. The UK has the financial system most similar to the US, and Germany and the UK were the two European countries where the yield curve showed predictive power in Chinn and Kucko (2015). Any discussion of low inflation and low interest rate environments must include Japan, for which there is also some evidence that the yield curve has predictive content (Nakaota and Fukuta, 2013). We take monetary regimes for these countries based on Benati (2008).

The UK adopted an inflation target in October of 1992, and inflation, which had been persistent (both under Bretton Woods and after) nearly became white noise, at least until the finanical crisis (Benati 2008). Since then inflation ap-

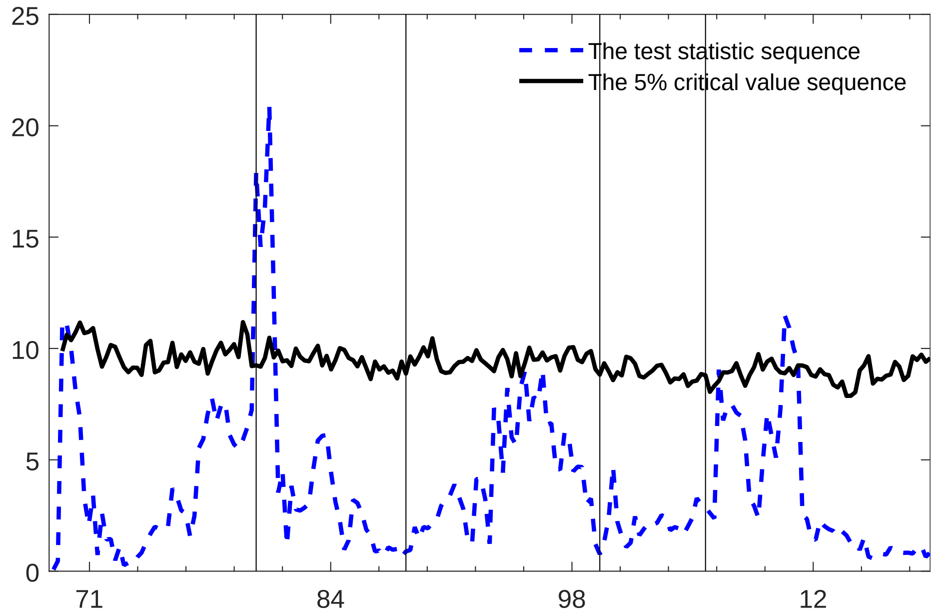

Figure 5. Spread to Real GDP Growth (YOY), SPH Data

pears to fluctuate around a slowly moving trend that has varied from above 3 percent to below 1 percent over the period (Forbes, Kirkham and Theodoridis, 2017). Germany, the poster child of a hard money low inflation regime, also saw a decrease in inflation persistence with reunification in 1990, though it was less dramatic (Benati 2008). Since the financial crisis, trend inflation has fallen, but the persistence has risen (Ciccarelli and Osbat 2017). Japan, despite having quite low levels of inflation, displayed quite high levels of inflation persistence, with inflation looking quite similar to a random walk (Benati 2008). Okimoto (2018) finds a regime of extremely low interest rates from 1995 to 2012 where inflation was steady but negative, followed by an inflation targeting regime since 2012 with low but positive inflation. Japan also instituted a form of yield curve control in September 2016. Figures 12, 13, and 14 show inflation and the monetary policy rate for the UK, Germany, and Japan.

While the UK has consistent series for the policy rate and a long-term interest rate going back to the 17th century, consistent prices and industrial production are more difficult to obtain, with monthly industrial production in a continuous series going back to 1946 and the retail price index, extending back only to 1948. For Germany, the main data constraints are again IP and prices, which both start in 1960. For Japan, the consistent series also start in 1960, though data for yields and recessions go back somewhat further. Figure 15 shows the test statistic for the UK, Figure 16 shows Germany, and Figure 17 shows Japan. Table 9 lists the periods of Granger causality for the UK, Germany, and Japan.

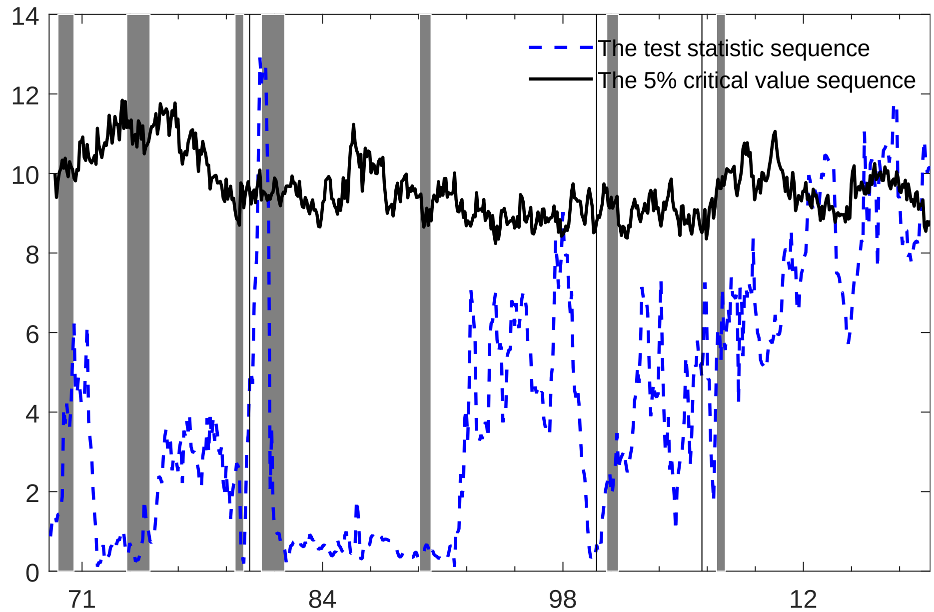

Figure 6. Spread to IP Growth (Monthly, Annualized), SPH Data

These are monthly series, so for the UK, the data runs from 1948-2017 for 824 monthly observations; with the standard 0.2 fraction for the rolling window, the rolling window is just over 13 years and the figure starts in 1961. The test exceeds the critical value only in 2013-2015, but comes close in 2006 and in 1988. In Germany and Japan, where the data start in 1960, the post-window period starts in 1971. In Germany, the test statistic shows causality for most months after mid-2016, but nothing before. Japan has many periods of causality from the 1970s through the 2000s, but they end in the early years of the Great Recession.

To look for overlap with periods of low interest rates, we look for periods where the monetary policy rate was half a percent (0.5 percent) or less. For the UK, this was from April until January 2017, for Germany it was from May 2013 to June 2018, and for Japan, from October 1995 until January 2007, and again from November 2008 to July 2018 (in all three cases, to the end of our data set). Table 10 reports the contingency table for the overlap and the associated χ^2 value and Cramer's V statistic. The UK and Germany strongly reject independence of Granger causality and low rates, not suprisingly because evidence of causality only shows up in the recent low rate environment. Japan shows many more episodes of causality, in periods of moderate and low rates, and independence cannot be rejected.

Table 11 lists the start of recessions (as determined by the ECRI) in the UK, Germany, and Japan and associated yield curve inversions.

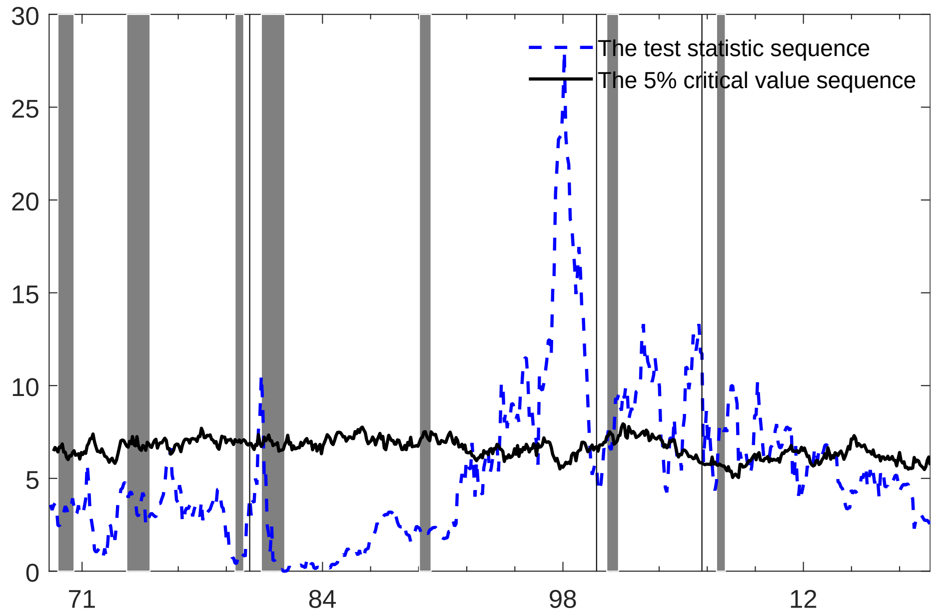

Figure 7. Spread to IP Growth (YOY), SPH data

V. Conclusion

Although it wasn't our main objective, this work confirms that the predictive content of the yield curve varies over time, across countries, and even across data sets. More importantly, in many episodes of low interest rates, whether by our informal definition or that of others, such as Ramey and Zubairy's, the yield curve has predictive power. While the results depend on the exact time period, interest rate and output measure, it also appears that causality from the yield curve to output is in fact more likely in low interest rate environments. The initial draft of this paper was written before the COVID-19 outbreak, and it was a matter of some concern whether the inversion in the summer of 2019 presaged a recession; although a recession did occur, the question remains of whether the conjunction is just a coincidence.

Our results raise as many questions as they answer: If the level of rates matters, does it matter why rates are low, whether inflation expectations are anchored under a gold standard or a price level target, are explicitly pegged, or held down by forward guidance or quantitative easing? Do aspects of inflation matter–such as persistence? What is the economic mechanism that lies behind the observed Granger causality in times of very different monetary policy? These are questions for another day, though perhaps our results can contribute to the answers.

Table 5—Periods of Granger Causality, Balke-Gordon-Ramey Data

Baa-CP Spread to	Gap	RGNP growth
	1903 Q1	
	1914 Q4–1915 Q1	1914 Q4–1915 Q3
		1916 Q3
		1921 Q1–Q3
	1938 Q2	
	1938 Q4–1956 Q2	1938 Q3–1954 Q4
		1955 Q3
	1977 Q3–1979 Q4	1975 Q4
		1976 Q4
Quarterly Data 1876-1997		

Source: Balke and Gordon 1986, Ramey and Zubairy 2018, Authors' calculations

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Table 6—Contingency Table: Aggregate Output, 1876-1997 Quarterly data

Panel A: Gap

Actual frequencies

	Low rate	High rate	total
Granger periods	51	34	85
non-Granger	25	280	305
total	76	314	390

$\chi^2 = 113.7$, df=10, p=$9.5x10^{-20}$,
Barnard p=4.2x10^{-21}, Boschloo 2.2x10^{-16}
Cramer's V: 0.540

Panel B: Year-over-year Growth

Actual frequencies

	Low rate	High rate	total
Granger periods	47	26	73
non-Granger	29	288	317
total	76	314	390

$\chi^2 = 115.4$, df=10, p=4.4$10^{-20}$,
Barnard p=3.0x10^{-21}, Boschloo p=2.2x10^{-16}
Cramer's V: 0.544

Source: FRED, authors' calculations

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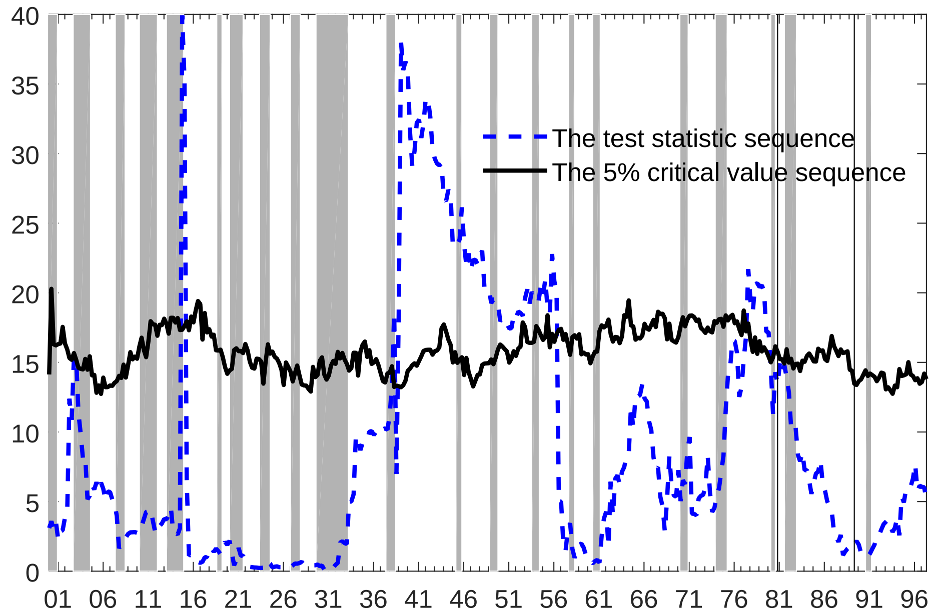

Figure 8. Spread to Gap, Balke-Gordon-Ramey Data

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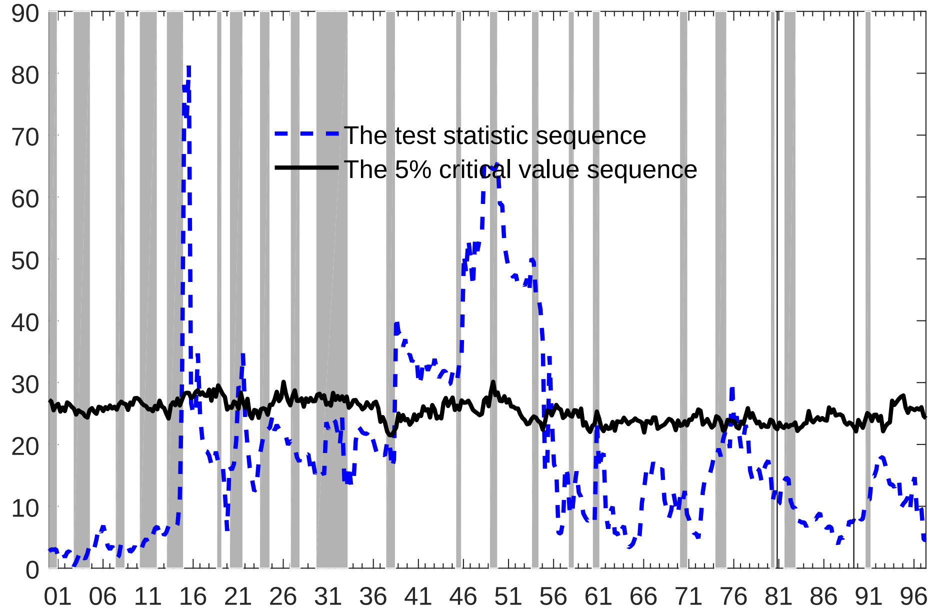

Figure 9. Spread to YOY GDP Growth, Balke-Gordon-Ramey Data

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Table 7—Periods of Granger Causality, 1919-2003 monthly Data

10-yr 3-m spread to monthly IP growth	yoy IP growth
1953 Apr–1958 Jun	1955 Oct–1956 Jan
	1957 Dec
	1958 May–Oct
	1958 Dec–1960 Jan
1962 May–Oct	1962 Mar–Oct
	1963 Jul
1967 Jan–1969 Dec	1967 Nov
	1968 Jan–Feb
	1976 May–1981 Oct
1980 Nov–Dec	
1981 Feb–Aug	
1983 Jan–2000 Jul	
	1992 May–1997 Aug
	1997 Dec–2002Dec
2000 Oct	
2001 Nov–2002 Feb	
2002 May	
2002 Jul–Dec	

Source: FRED, author's calculations

Data Appendix

We extend the B-G data set as follows.

1) Us the CP and Baa as far as it goes, 1998. Source: Federal Reserve H-15, 6-MONTH PRIME COMMERCIAL PAPER - AVERAGE DEALER OFFERING RATE QUOTED ON DISCOUNT BASIS.

2) Real GNP. Use BG till 83. Take natural logs to get YOY growth. From 83 on, use the Ramey RGDP data, taking logs to get YOY growth. Specifically, the 1984 growth should use the Ramey 83 data. The reason is that the growth rates of the two series match pretty well, even if the levels dont, and in this way we avoid the jump when the series splice together.

3) Gap: Same thing. Take $ln(rgdp)ln(Trend)$ from BG as long as you can, and then $ln(rgdp) - ln(rgdp_pott6)$.

4) Inflation, again use the deflator from BG till 83, then use Ramey (again YOY log diffs), again using Ramey 83 levels to compute 84 growth.

Table 8—Contingency Table: IP, 1919-2003 Data

Panel A: Monthly IP growth

Actual frequencies

	Low rate	High rate	total
Granger periods	0	337	337
non-Granger	186	284	470
total	186	621	807

$\chi^2 = 173.3$, df=13, p=$3.9x10^{-30}$,
Barnard p=$4.7x10^{-33}$, Boschloo p=2.2x10^{-16}
Cramer's V: 0.46

Panel B: Year over Year IP growth

Actual frequencies

	Low rate	High rate	total
Granger periods	0	229	229
non-Granger	177	392	569
total	177	621	798

$\chi^2 = 91.5$, df=13, p=$7.1x10^{-14}$,
Barnard p=$1.1x10^{-17}$, Boschloo p=2.2x10^{-16}
Cramer's V: 0.34

Source: FRED, authors' calculations

At this point, the constraint is the six-month commercial paper rate, which ends in 1998.

We produce an "early" monthly data set as follows.

1) Industrial production is monthly since January 1919, from FRED.

2) CPI, not seasonally adjusted, from FRED, since 1913.

3) For the policy rate (alternatively the short-term interest rate) we use the discount rate at the Federal Reserve Bank of New York. Prior to the New Deal reforms, discount rates were not uniform across the districts, but New York, as the financial center, has a certain priority (even post-New Deal reforms, there are occasional brief differences between district banks). This is available from November 1914 until 1969:7 from the St. Louis FRED database, series M13009USM156NNBR, and then the general discount rate from FRED until January of 2003:1, when the adjustment credit program, which was extended at a below market rate, was replaced by the primary credit program, whose rate was set above the federal funds rate. This was not a change in the stance of monetary policy, but rather in the administration of the discount window.

4) For the long interest rate, we start with the Yield on Long-Term United States Bonds, from the NBER Macro History Database, m13033a start-

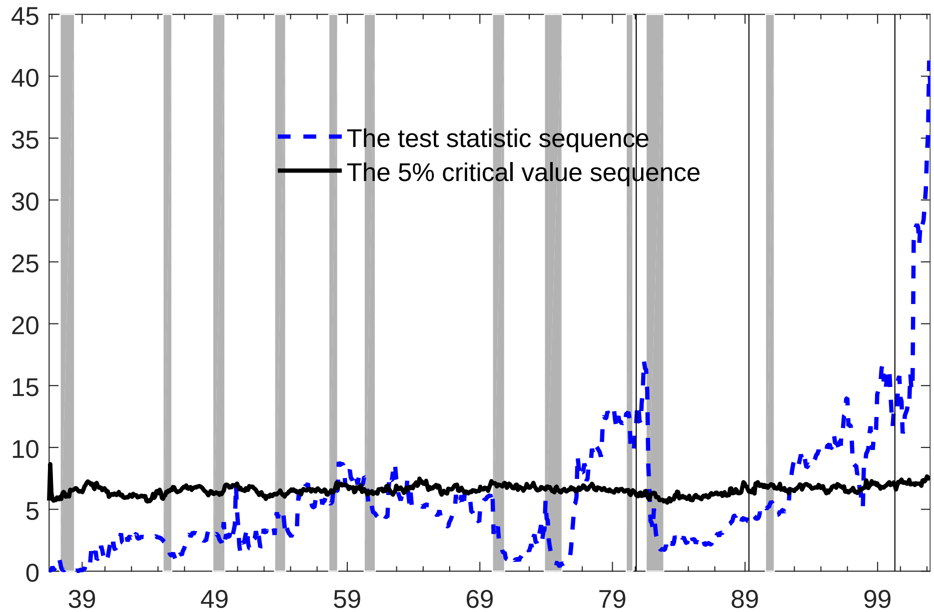

Figure 10. Spread to YOY Growth in IP, Older Monthly Data

ing in January 1919. Starting in December 1935 this is replaced with the COMPOSITE YIELD ON U.S. TREASURY BONDS WITH MATURITY OVER TEN-YEARS from the Federal H-15 discontinued series. For the months between January 1925 and November 1935, the NBER and H15 rates match exactly, but diverge somewhat after that. That series ends in June of 2000 (2000:6) and we continue with the 10-year Treasury constant maturity rate, which has a correlation of 0.988 over the period during which both series exist (April 1953 to June 2000).

The intersection of available dates gives us a data set running from January 1919 to January 2003. at 84 years, this is substantially longer than the 58 years that the more recent monthly data covers, and also allows insight to the early period of low inflation and low interest rates.

British Data: Annual growth of industrial production, found at FRED: (for consistency, log difference x1200) `https://fred.stlouisfed.org/series/IPIUKM`

Change in the RPI, from the UKs Office of National Statistics: The RPI is the constraint on our data, as it only goes back to June 1948.

`https://www.ons.gov.uk/economy/inflationandpriceindices/timeseries/czbh/mm23`

Policy rate the CB rate from the UK from the GFD data. In 1948 the data are monthly, but in September 1968 it changes to daily, so for the recent data use a monthly average of daily rates.

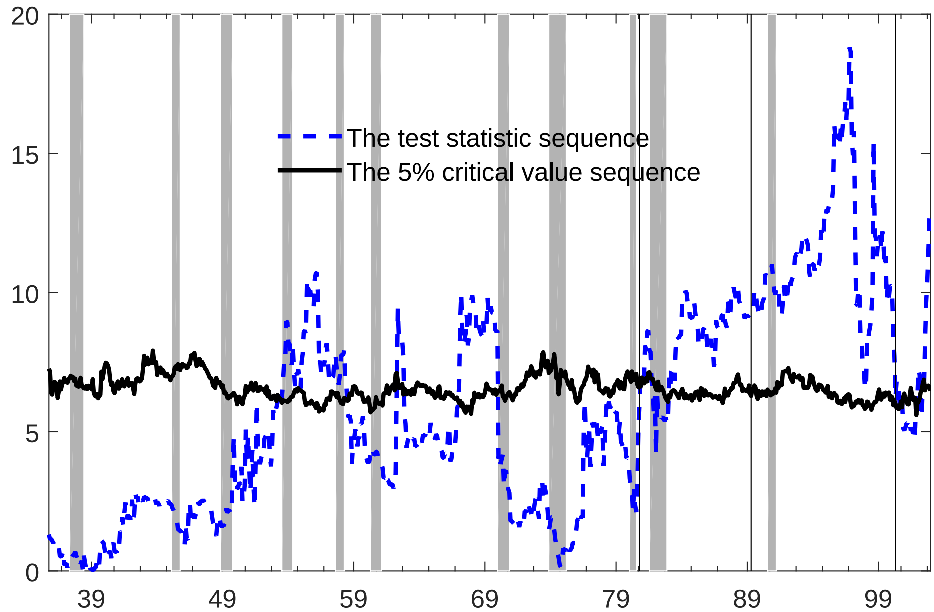

Figure 11. Spread to MTM Growth in IP, Older Monthly Data

Yield curve: 10-year rate minus 3-month rate, from the GFD data. The 3-month rate turns weekly in May of 1973, and then daily in January of 1975. So again take monthly averages. 10-year yields are already daily as of 1948. So again take monthly averages. Recession from ECRI (2020).

German Data: Germany: Industrial production, from FRED, since 1960

`https://fred.stlouisfed.org/series/DEUPROINDMISMEI` Inflation, from FRED, since 1960

`https://fred.stlouisfed.org/series/CPALTT01DEM659N`

Spread: 10-year minus 3-month, from GFD data. 10-year becomes daily in October 1982. 3-month becomes daily in 1998; as before, use monthly averages.

Policy rate: again from GFD, it is daily even in 1960. In January of 1999 the policy rate should become the MRO rate from the European Central Bank. Monthly data from `https://www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates/html/index.en.html`

In June 2000 the ECB switched from fixed to variable rate tenders, and back again to fixed in October 2008.

Recessions from the ECRI (2020).

Japanese Data: Inflation: use the IMF numbers from Haver. Industrial production: `https://fred.stlouisfed.org/series/JPNPROINDMISMEI` Policy Rate: BoJ discount rate, from GFD Yield Spread: 10-yr less 3-mo, GFD. 10-year yields start daily in October 1982, and 3-month yields start daily in January 1998; monthly averages.

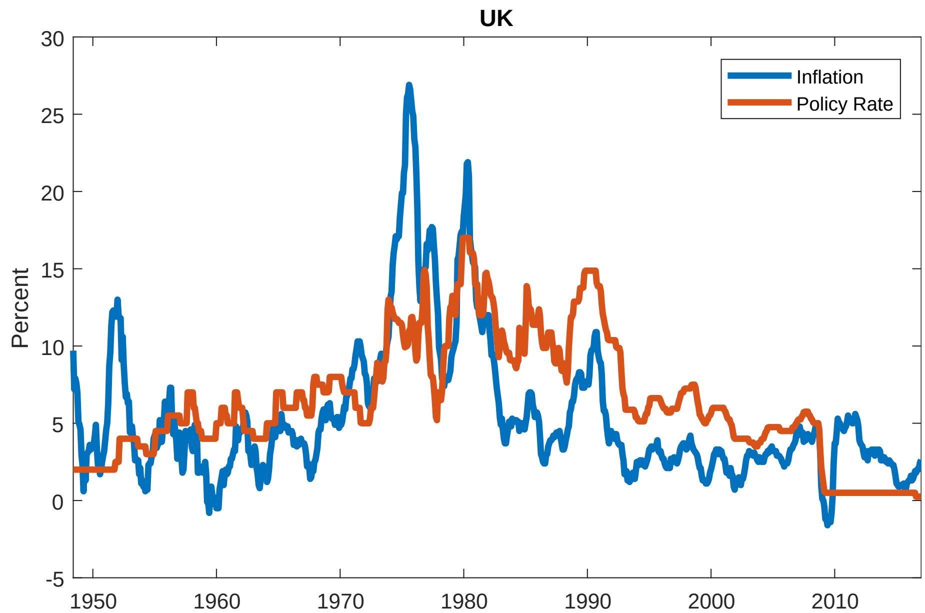

Figure 12. UK Inflation and Policy Rate

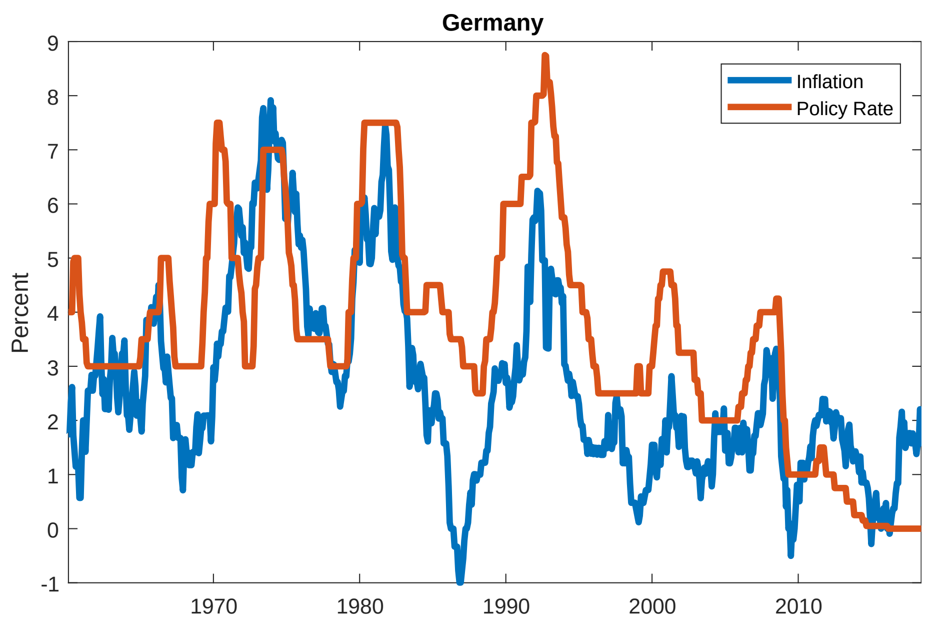

Figure 13. German Inflation and Policy Rate

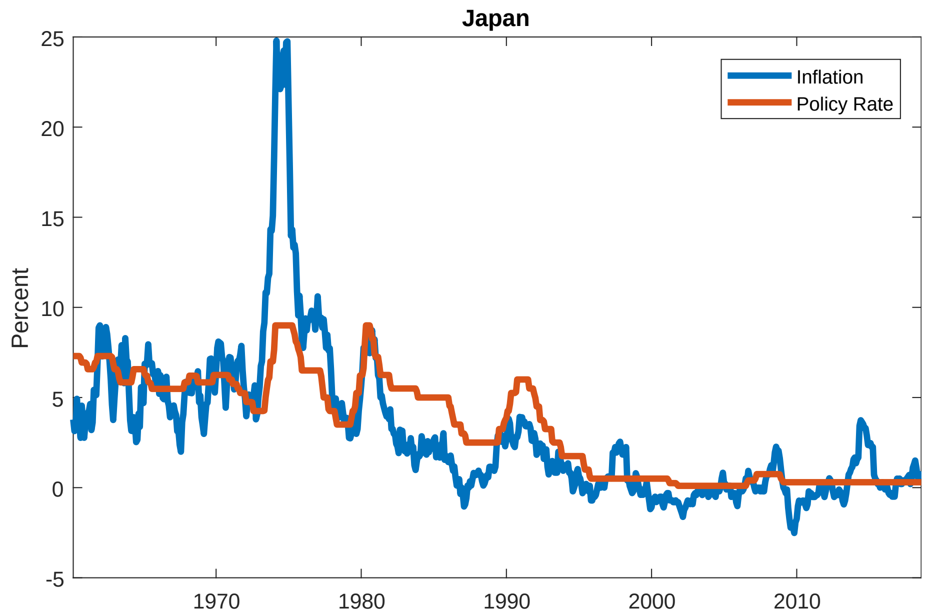

Figure 14. Japanese Inflation and Policy Rate

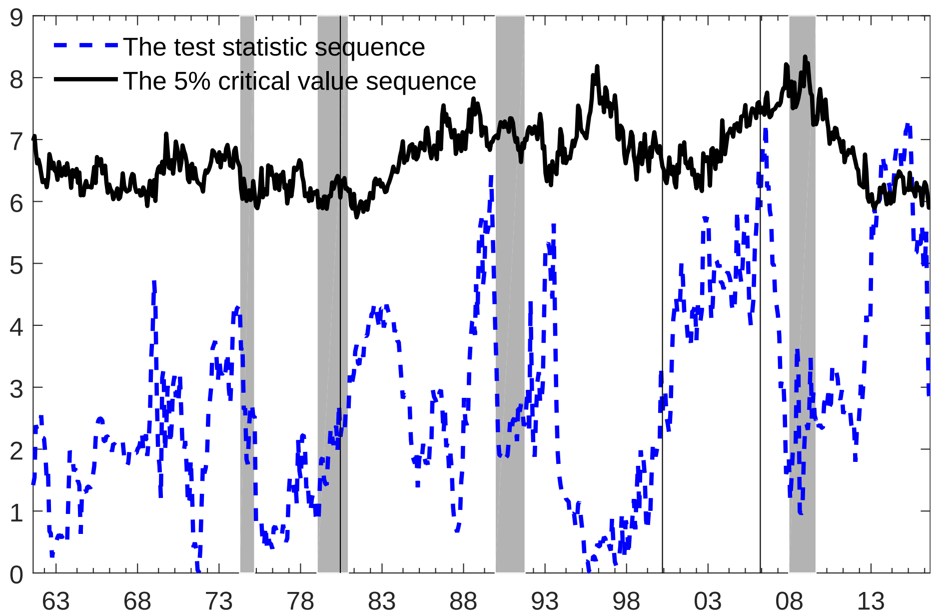

Figure 15. UK Spread to Growth in IP

Table 9—Periods of Granger Causality, International Data

10-yr 3-m spread to UK	Germany	Japan
		1977 Feb–1979 Dec
		1980 Mar
		1987 Feb–1988 Dec
		1989 Apr–1990 May
		1992 Jan–Jun
		1999 Feb
		2001 Feb–2004 Apr
		2004 Jul–Aug
		2004 Oct–2005 Jan
		2005 March–Jun
		2005 Aug–2006 Jun
		2006 Sep–2007 Apr
		2007 Aug–2008 Mar
2013 Aug		
2014 Jan–2015 Nov		
	2016 May, July	
	2016 Sep–2017 Jan	
	2017 Jul–2018 Jun	

Source: GCSI, authors' calculations

Table 10—Contingency Table: IP, International data

Panel A: UK

Actual frequencies

	Low rate	High rate	total
Granger periods	24	0	24
non-Granger	81	554	635
total	105	554	659

$\chi^2 = 131.4$, df=13, p=$1.1x10^{-21}$,
Barnard p=2.0x10^{-21}, Boschloo p=2.2x10^{-16}
Cramer's V: 0.45

Panel B: Germany

Actual frequencies

	Low rate	High rate	total
Granger periods	19	0	19
non-Granger	43	499	542
total	62	499	561

$\chi^2 = 158.3$, df=13, p=$4.4x10^{-27}$,
Barnard p=5.7x10^{-21}, Boschloo p=2.2x10^{-16}
Cramer's V: 0.53

Panel C: Japan

Actual frequencies

	Low rate	High rate	total
Granger periods	66	91	157
non-Granger	187	218	405
total	253	309	562

$\chi^2 = 0.78$, df=13, p=0.999,
Barnard p=0.515, Boschloo p=0.390
Cramer's V: 0.04

Source: FRED, authors' calculations

Table 11—ECRI Recessions and Yield Curve Inversions, Monthly Data

ECRI Peak	Yield inversion	Trend CPI inflation	Exchange rate regime
	UK		
1974 (Sept.)	Dec. 1973		Discretion
1979 (June)	April 1979		
1990 (May)	Dec. 1988		
2008 (May)	Nov. 2006		Inflation Targeting
	Germany		
1966 (March)	na		Bretton Woods
1973 (Aug.)	na		Interim
1980 (Jan.)	Dec. 1979		
1991 (Jan.)	Dec. 1989		Reunification
2001 (Jan.)	na		EMU
2008 (April)	na		
	Japan		
1960 (Feb.)	na		Bretton Woods
1963 (Oct.)	na		
1967 (July)	na		
1970 (May)	na		Bretton Woods
1973 (Feb.)	na	2.39	Post-Bretton Woods
1976 (Dec.)	na	2.52	
1979 (Feb.)	na		
1981 (July)	na		
1985 (Jan.)	na		Post-Great Inflation
1988 (Feb.)	(May 1986)		
1990 (Mar.)	Nov. 1989		
1994 (Dec.)	na		
1997 (Mar.)	na		
2000 (Aug.)	na		
2004 (Jan.)	na		
2005 (April)	na		
2006 (April)	na		
2007 (Aug.)	na		
2010 (Feb.)	na		
2012 (Mar.)	na		
2014 (Mar.)	na		Deflation
2015 (April)	na		
Monthly Data			

Source: ECRI, FRED, GFD, authors' calculations, earliest inversion within 6 quarters of recession's start (business cycle peak) 10-year 3-month bond spread. Trend inflation is 21-quarter moving average centered on ECRI peak.

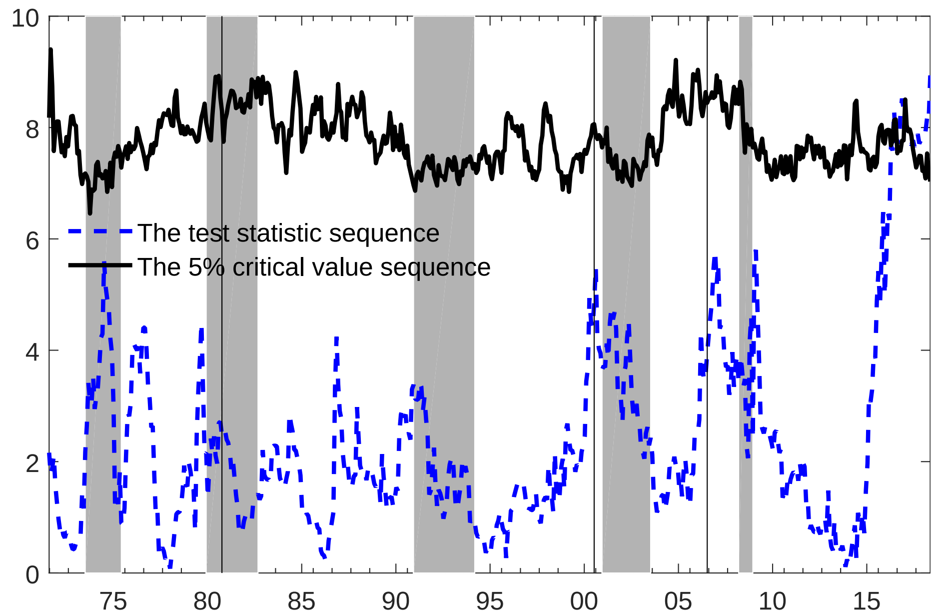

Figure 16. Germany Spread to Growth in IP

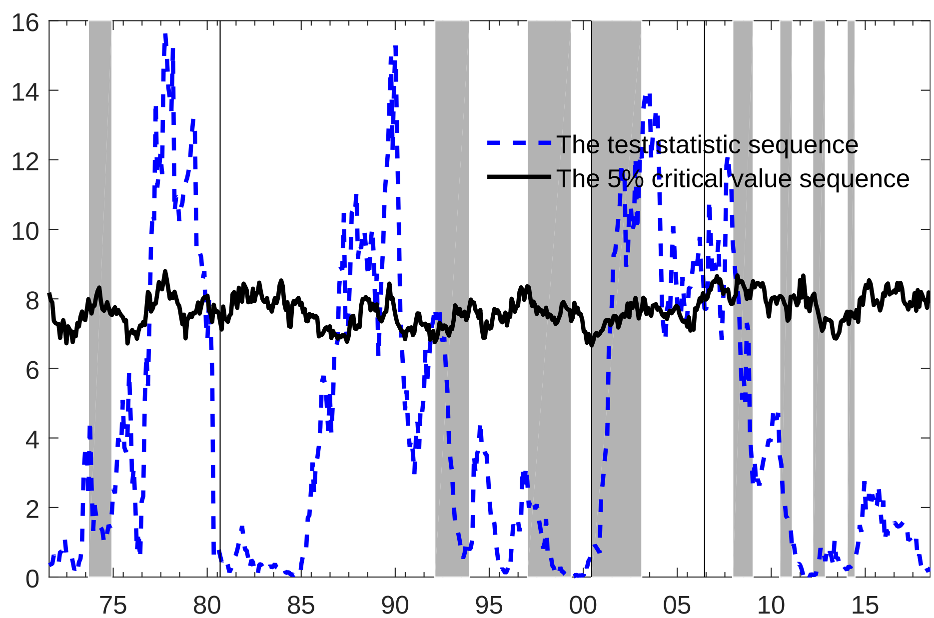

Figure 17. Japan Spread to Growth in IP

Table A1—Monetary Regimes

Date	US	UK	Germany	Japan
1899				
1900				
1946	Bretton Woods	Bretton Woods	Bretton Woods	Bretton Woods
1971	Great Inflation			
1972		Interim	Interim	Great Inflation
1982	Volcker Stabilization			
1983				Deflationary era
1990			Reunification	
1992		Inflation Targetting		
1999			EMU	

Source: Benati, 2008, Bordo and Siklos 2015