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In 2005 all ECB publications will feature a motif taken from the €50 banknote.

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Abstract

In this paper we argue that both statistics and economic theory-based evidence largely indicate the absence of long run relationships between the real output and the most relevant monetary indicator for the U.K. and the U.S, short term interest rates. These findings are not only a full sample result, but also valid in most of the sub-samples throughout the second half of the 20th century and are robust to the inclusion of possible omitted real variables.

JEL classification: E3, E4, E5.

Keywords: information value, long term relationship, cointegration, bounds tests.

Non-technical summary

In this paper, we focus on the relevant monetary policy business cycle indicator, short-term nominal interest rates, and their long-run relations with output. There are at least two reasons to study the matter. First, nominal short term rates are explicit, controllable, operating targets and more importantly useful indicator variables to explain business cycle fluctuations. We investigate implied long term equilibrium relationships between the operating target/indicator variable and real output. Second, given high degree of inflation inertia, nominal rates tend to track very closely ex-ante or ex-post real short term interest rates. In Woodford's (2003, p.34) words "…once one recognizes that many prices (and wages) are fairly sticky over short time intervals the arbitrariness of the path of nominal prices implies that the path of real activity and the associated path of equilibrium real interest rates are equally arbitrary. It is equally possible, from a logical standpoint, to imagine allowing the central bank to determine, by arbitrary fiat, the path of aggregate real activity, or the path of real interest rates." This clearly poses some challenging theoretical as well as empirical questions. If we believe that real interest rates proxy the price of capital, an exogenous change in the policy variable, nominal rates, should also have long lasting implications in the real output path via standard aggregate demand channels. Think for example sensitivity of consumption, housing demand or manufacturing investment decisions to short term rates. Alternatively, by adjusting the nominal interest rate, the policymaker may simply be accommodating changes in the structural conditions in the economy taking into account the term structure of inflation expectations. In that case, even under inflation inertia, equilibrium long term real rates may be disconnected from short term real rates formulated in markets' short and long term inflation expectations. In that case we do not expect to see a long term relationship between nominal and real short term interest rates and real output. Otherwise, we do.

We are explicitly interested on the *information content* of policy indicators in explaining long term equilibrium real output. Therefore, issues raised by earlier work related to structural models and Lucas critique is not of direct relevance.

Our results show that both statistics and economic theory based evidence largely rejects the existence of long term relationships between the relevant policy indicators and real output. The absence of long run relationships between short-term interest rates and real output is not only a full sample result, but also valid in most of the subsamples in the post Second World War period and are robust to the inclusion of possible omitted real variables. One can also interpret these findings as evidence of some support for the long-term monetary policy neutrality hypothesis.

1. Introduction

Relationship between monetary policy and real output and inflation has always been the core focus of monetary policy research. First of all, policymakers, financial analysts and researchers are interested to know how effective monetary policy to stabilize business cycle fluctuations is. There is by now a huge volume of theoretical and empirical literature in this area of research.[1] Secondly, the very same people would like to know how monetary policy decisions to stabilize business cycle fluctuations affect *long term* equilibrium real output, inflation and other fundamentals. In this paper we are interested in investigating empirically the second question. We analyze long-term relationships between monetary policy indicators that are able to explain U.S. and the U.K business cycle fluctuations and real output. In other words, we will make use of statistical information that comes from business cycle research to analyze long term equilibrium relationships between monetary policy indicators and real output.

In order to stabilize business cycle fluctuations most central banks employ operating targets in the form of short term interest rates or monetary aggregates. Since the seminal work of Poole (1970) it is well known that, in a frictionless certainty equivalent economy, money supply and interest rate policies to stabilize business cycle fluctuations would be identical. In this view money demand volatility is the sole criteria to judge on the operating target. Furthermore, even if monetary aggregates or short term interest rates are not used as operating targets these can be used as indicator variables if these contain useful information to explain business cycle fluctuations.

However, in an economic environment with large uncertainties and real and nominal rigidities this instrument equivalence tends to disappear. More worryingly, recent empirical research provides statistical evidence that after around 1982 the relationship between the changes in the U.S. monetary aggregates and macroeconomic fundamentals collapsed and therefore the information content of monetary aggregates simply vanished. To date, monetary aggregates can be characterized at best as weak indicators for real output whereas there is substantial evidence that short term interest rates are useful monetary indicator variables in explaining real output in the U.K. and U.S. in all subsamples available from the second half of the 20th century.[2] Currently, in most developed economies short-term nominal interest rates are employed as operating targets with the aim to stabilize business cycle fluctuations. Accordingly business cycle research has shifted its focus from monetary aggregates to nominal interest rates in analyzing monetary policy effectiveness.

[1] See e.g. detailed survey in Walsh (2003).

[2] See for example Bernanke and Blinder (1992), Friedman and Kuttner (1992, 1996), Estrella and Mishkin (1997), Friedman (1998), Stock and Watson (1999, 2001). In the literature several explanations are provided to understand as to why U.S. money demand became very unstable. Among others, these are innovations related to mortgage activity, (Board of Governors of Federal Reserve System, 2003) foreign holdings of U.S. Dollars (Aksoy and Piskorski (2003), the spread of sweep accounts (Anderson and Rasche (2001), and increased use of plastic cards. See also Duca and VanHoose (2004) for an excellent survey on the recent empirical developments on money demand.

On the other hand, long term monetary neutrality is the key building block of mainstream business cycle research. Business cycle analysis relies on the assumption that monetary innovations can not have long term implications on the equilibrium level of real output in the long run. To date, empirical consensus is in favor of the long-term neutrality of *monetary aggregates* on key real economic variables, such as GDP and industrial production.[3]

In this paper, we focus on the relevant monetary policy business cycle indicator, short-term nominal interest rates, and their long-run relations with output. There are at least two reasons to study the matter. First, nominal short term rates are explicit, controllable, operating targets and more importantly useful indicator variables to explain business cycle fluctuations as argued above. We investigate implied long term equilibrium relationships between the operating target/indicator variable and real output. Second, given high degree of inflation inertia, nominal rates tend to track very closely ex-ante or ex-post real short term interest rates. In Woodford's (2003, p.34) words "…once one recognizes that many prices (and wages) are fairly sticky over short time intervals the arbitrariness of the path of nominal prices implies that the path of real activity and the associated path of equilibrium real interest rates are equally arbitrary. It is equally possible, from a logical standpoint, to imagine allowing the central bank to determine, by arbitrary fiat, the path of aggregate real activity, or the path of real interest rates." This clearly poses some challenging theoretical as well as empirical questions. If we believe that real interest rates proxy the price of capital, an exogenous change in the policy variable, nominal rates, should also have long lasting implications in the real output path via standard aggregate demand channels. Think for example sensitivity of consumption, housing demand or manufacturing investment decisions to short term rates. Alternatively, by adjusting the nominal interest rate, the policymaker may simply be accommodating changes in the structural conditions in the economy taking into account the term structure of inflation expectations. In that case, even under inflation inertia, equilibrium long term real rates may be disconnected from short term real rates formulated in markets' short and long term inflation expectations. In that case we do not expect to see a long term relationship between nominal and real short term interest rates and real output. Otherwise, we do. In any case it is important to know the implied long term equilibrium relations between the changes in the policy rate or monetary indicator variables that can explain business cycle fluctuations and the fundamentals.[4] In this paper, we are interested in the issue in an empirical sense.

We are not aware of a study that systematically analyses long-term statistical relationships between real output and monetary indicators explicitly focusing on nominal short-term interest rates. Research by Bernanke and Mihov (1998) probably

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[3] See among others Bae and Ratti (2000), Bernanke and Mihov (1998), Boschen and Mills (1995), Boschen and Otrok (1994), Bullard (1999), Fisher and Seater (1993), Geweke (1986), King and Watson (1997), Serletis and Koustas (1998), Weber (1994) for testing neutrality of monetary aggregates in a structural framework. Note that in most of the empirical literature, hypothesis of superneutrality of monetary aggregates in general can be rejected. It is also worth to note that in most of this empirical research an analysis of long-term monetary neutrality is interpreted to be monetary aggregates neutrality instead of the more general concept of monetary policy neutrality.

[4] Throughout the paper, we also conduct tests based on U.S. ex-ante real interest rates. Our results confirm close co-movement of these two rates, being therefore statistically indistinguishable.

is the only exception to the literature in that it recognizes a causal role for nominal interest rates in the provision of liquidity into the economy and its implications in the long run. In their structural model, they find little evidence for rejecting either the liquidity effect or long term monetary neutrality.

We are explicitly interested on the *information content* of policy indicators in explaining long term equilibrium real output. The information value approach for business cycle analysis as introduced by Sims (1972, 1980) allows us to address the issue on whether there is some reliable long run relationship between real output and potential instruments, such as interest rates. It is important to stress that the information value approach, as a first test of statistical connection between certain variables, is immune to questions of causality, exogeneity or controllability of potential instruments. In other words, as long as long-term swings in the policy indicator contain information about long term movements in income beyond what is already contained in movements in income itself, monetary policy can potentially exploit this regardless of whether the information it contains reflects true causation, reverse causation based on anticipations, or mutual causation by some independent but unobserved influence. Therefore, issues raised by earlier work related to structural models and Lucas critique is not of direct relevance.[5]

However, since an assessment of the long term relationships very much depends on the stationarity properties of the variables, we will carefully address the order of integration of variables. Although standard univariate analysis cannot reject the nonstationarity of most short-term real or nominal interest rate series, one cannot take this result at face value. Economic intuition suggests that short-term nominal interest rates should be rather stationary.[6]

In order to address this uncomfortable statistical feature of short term interest rates we proceed in two steps. In the first step, we take simple *statistical evidence* seriously. We test the univariate and bivariate properties of the short-term nominal interest rates and real output. We provide a series of cointegration tests based on univariate *statistical* properties of short term interest rates. Cointegration tests based on Johansen's maximum likelihood procedure impose minimal auxiliary assumptions to account for long term relationships. However, here we interpret our results with caution due to tensions between economic theory and the univariate statistical features of short term nominal interest rates. In the second step, we take the critique from *economic theory* seriously and implement the Pesaran et al. (2001) bounds tests. These bounds tests for long run level relationships do not require non-stationarity of short-term interest rates and, therefore, are economic theory consistent.

Once we establish whether or not there is long-run information content about output in the interest rate series, we address the issue of whether these findings are the result of the omission of important variables that explain the long-run evolution of output. If we believe that long-run real output is determined by a set of real variables including technology, energy prices, factor inputs, etc., then the omission of these

[5] For the rational expectations critique, see for example Sargent (1971), Sargent and Wallace (1975), Lucas (1995) and King and Watson (1997). See also Lin (2003) for a recent survey of the issue. For a discussion of the information variable approach see for example Friedman and Kuttner (1992).

[6] For recent evidence on the debate of interest rate stationarity see, for instance, Wu and Zhang (1996) and Wu and Chen (2001).

variables could lead us to finding no common trend between output and interest rates just because these real variables are needed to complete the long-run stationary combination.

Our results show that both statistics and economic theory based evidence largely rejects the existence of long term relationships between the relevant policy indicators and real output. The absence of long run relationships between short-term interest rates and real output is not only a full sample result, but also valid in most of the subsamples in the post Second World War period and are robust to the inclusion of possible omitted real variables. One can interpret these findings as evidence of support for the long-term policy neutrality hypothesis.

The paper is organized as follows. In Section 2, we present the data. Section 3 discusses the choice of monetary indicator. Section 4 presents univariate time series properties of the variables before conducting long-term tests. In Section 5 we conduct long-term tests based on statistical evidence. We present cointegration results with a particular emphasis on sub-sample stability. In Section 6 we implement economic theory consistent bounds tests with particular emphasis on sub-sample stability. Section 7 addresses the omitted variables problem. Section 8 concludes.

2. Data

The annual data for the U.K. covers the period 1873-2001.[7] We will study real output represented by real GNP. This data was obtained from the study of Hendry (2001) [http://www.nuff.ox.ac.uk/users/hendry/]. This study stops in 1991 and hence, from this year onwards we update the data using OECD's Main Economic Indicators and IMF's International Financial Statistics database (IFS). We use the Treasury Bill rate as the short term interest rate measure and 10-years Government Bond yield as long term interest rate as reported by Hendry (2001).

In the case of the U.S. data on output and the Treasury Bill Rate is obtained from the U.S. Federal Reserve. Treasury Bill Rates have missing observations during the end of the 1930s and beginning of WWII, so we could only start in 1941. We also use two long-term interest rates such as the 10-year Government Bond Rate and Moody's AAA Yield Index starting from 1929.[8]

As a cross check of our annual data results we also carried out our tests using quarterly data from 1960:1 to 2001:2. In this case we used as short term rates the Treasury Bill rate for both UK and US and also the Federal Funds Rate for the US. This quarterly data comes from IFS, OECD and the statistics provided by the U.S. Federal Reserve Board (FRB). We report the quarterly data results whenever they yielded substantially different results from the annual data.

Figure 1 plots the annual data on the Treasury Bill rate and the log of GDP for the US and UK. The main feature that arises from both plots is the large and sustained increase in interest rates that reach a peak in the 1980-1982 period of dis-inflationary policies. In the case of the UK this pattern appears as more accentuated as we can

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[7] Detailed data descriptions and source references are tabulated in the Appendix.

[8] The behaviour of the AAA Yield Index was very close to the one of the 10-year Bond and hence we do not report these results here.

observe practically constant interest rates in the 1873-1929 period. In contrast, output shows the typical upwards trend with few and isolated changes over time.

3. Interest Rates as Monetary Policy Indicators

A long run analysis of policy indicators that are not informative about short term business cycle fluctuations is not useful for our purposes. Before proceeding to the long run analysis we need the sample period that delivers significant and stable information content of short term interest rates to explain business cycle fluctuations in the U.K. and the U.S.

In order to determine the relevant sample size we proceed as follows. We first specify an autoregressive specification for real output changes *a la* Sims (1972) that is given by:

$$\Delta y_t = \alpha + \sum_{k=1}^{m} \beta_k \Delta y_{t-k} + \sum_{k=1}^{n} \delta_k \Delta i_{t-k} + v_t \qquad (1)$$

where Δy and Δi are the growth rates of real output (annual log differences of real GNP) and the change in the short term interest rate (annual log differences of the T-Bill). We then run full sample as well as recursive Granger Causality tests for the policy indicator, short-term interest rates. [9] Results are reported in Table 1 and Figure 2.

Our preferred annual data sample for the U.K is 1948-2001 and for the U.S. 1947-2001. For the U.K. there are several earlier episodes in which short-term interest rates contain useful information to explain business cycle fluctuations. However, in periods with major events such as First World War and Great Depression the information content of short-term interest rates vanishes making periods before 1948 redundant for the long-term analysis. In the case of U.S., short-term interest rates do not exhibit stable and significant information content before 1947 therefore we drop these data points from our sample relevant for the long-term analysis.

In Table 1 we present full sample χ-Square (and p-values) for the corresponding interest rate measures. Irrespective of the maturity all interest rate measures are significant for the full sample we choose. In Figure 2 we also present p-values of rolling regressions (with a 30 years window). Here we note that in most of the sub-samples U.K. and U.S. T-Bill rate contain significant information content in explaining real output fluctuations.

[9] We select lags based on AIC and SIC. Our preferred specification for the U.S. contains four lags for short-term interest rates and our preferred specification for the U.K. contains one lag for the short-term interest rates. To capture autoregressive dynamics for real output both U.K. and U.S. real output equations contain four lags. In recursive estimates minimum sample size is 30 years. The White test for heteroskedasticity rejected the non-constancy of the residual variance for almost all-financial variables in specification (1). Therefore, the White heteroskedasticity-consistent standard errors are used to derive the corresponding χ-square statistics of the Granger causality tests. Moreover, the relative performance of short term interest rates in terms of the heteroskedasticity consistent Granger causality statistics is very similar to those based on the statistics computed with unadjusted OLS residuals. Finally, we note that the Ljung-Box Q-statistics do not reject the null hypothesis that there is no autocorrelation in the residuals of the equations (1).

Note that given high level of inflation persistence in the U.S. and the U.K., nominal interest rates very well track real interest rates and therefore stand as a reasonable proxy for even ex-ante real interest rates.[10]

4. Univariate Time Series Properties

We carried out four standard unit-root tests on the data. These were an ADF test of the null of non-stationarity; the KPSS variance ratio test of the null of stationarity; the Modified Phillips-Perron test with GLS de-trending (M_{α}^{GLS}) of Ng and Perron (2001) for the null of a unit root; and Elliott et al's (1997) most powerful DF-GLS test for the null of a unit root. The lag augmentation was chosen using the Ng and Perron (2001) Modified Information Criteria (MIC).[11] This method reduces very substantially size distortions. The tests were carried out using a constant term and a constant and a deterministic trend. The results are reported in Tables 2 and 3. They reveal that most of the variables are non-stationary. We can reject the stationarity hypothesis for all the variables involved except for the US Treasury Bill rate when using quarterly data.[12]

The behaviour of the series may have also been characterised by the existence of structural breaks that will affect the power of the previous unit root tests. We hence tested for structural change in the series using the Bai and Perron (1998) technique and found that most interest rates show one structural change around 1981-82 for both countries. When applying unit root tests considering these breaks we found non-stationarity when we model the break as a trend break with both segments joined at the break time point, but not when using other specifications.[13]

5. Long Term Relationship Tests: Taking Statistics Seriously

As mentioned earlier, possibly non-stationary interest rates are an uncomfortable result from a theoretical viewpoint, as interest rates have to be stationary for a dynamic general equilibrium to exist. Our results may also reveal the well-known power problems of unit-root tests and/or problems arising from structural breaks. This is a non-trivial problem as cointegration tests such as the Johansen's VAR method rely on the strong assumption that all endogenous variables to the system are strictly I(1). In order to deal with this problem we will proceed to analyze long-run relations between interest rates and output by using two approaches. In the first, we will assume that both variables are I(1) and apply traditional cointegration

[10] We also repeat the same exercise with the use of U.S. ex- ante real interest rates instead of nominal interest rates. In constructing the ex-ante real interest rates based on inflation expectations, we relied on Federal Reserve Bank of Philadelphia's survey of professional forecasters (for the period of 1970-2001). Our results indicate that the information role of real interest rates is very much in line with the short term nominal interest rates in the U.K. and the U.S.

[11] The results using other information methods such as AIC or a general to specific method (GTS) did not change the conclusions about unit-roots.

[12] For longer term maturities the evidence strongly supports non-stationarity.

[13] Results are available on request.

tests. That is, we rely on the statistical evidence on stationarity. In the second, we will use a bounds tests procedure that is independent of the stationarity results and allows us to be both theoretically and statistically consistent.

5.1. Cointegration

Long term neutrality tests based on vector autoregressions may be misleading if first order stationary variables (output and monetary indicators) are also cointegrated. If these are cointegrated a finite vector autoregressive process for log differences will be absent. If monetary shocks are exogenous and permanent one can in principle conclude in favor of monetary non-neutrality.

Therefore, Johansen's method of estimating cointegrating vectors is a good starting point for tests of long run relationships.[14] It needs minimal auxiliary assumptions to make tests workable. If real output and nominal interest rates are cointegrated, this method will yield a super consistent estimator. Note however that explicit long term neutrality cointegration tests require the existence of permanent monetary indicator shocks. Variations in the monetary indicator should partly reflect exogenous changes in the monetary authority's policymaking rather than fully adjusting to changing macroeconomic environments. Here we do not make any assumptions about the nature of the shocks but rather focus on the long term relationship between the short term interest rates and real output. In other words, we are interested in the long term information content of short term interest rates in explaining the long term equilibrium output.[15]

We consider four cases about the deterministic trends present in the relation between output and the interest rate. Case I corresponds to no deterministic trend in the data, and an intercept but no trend in the cointegrating equation. Case II corresponds to a linear trend in the data and an intercept but not a trend in the cointegrating equation. Case III corresponds to a linear trend in the data and both an intercept and a trend in the cointegrating equation and finally Case IV corresponds to a quadratic trend in the data, and both an intercept and a trend in the cointegrating equation.[16] Case I would imply that the first differenced variables share the same mean which, on inspection of Figure 1, is very unlikely as output appears to be heavily trended. Case IV would imply that the first difference of the variables have a deterministic trend. This is again unlikely and very evident in the case of the interest rate that shows no accelerating or decelerating growth over time (see Figure 1 for both countries). A priori, hence, the most likely cases to describe accurately any deterministic trend in the data are cases II and III.

[14] Gonzalo (1994) compares ordinary least squares, nonlinear least squares, maximum likelihood in an error correction model, principal components and canonical correlations performance in estimating cointegrating vectors. Based on Monte Carlo simulations, he finds that the estimation of a fully specified error correction model by maximum likelihood as suggested by Johansen procedure performs better even when the errors are non-normal distributed or when the dynamics are unknown.

[15] For an attempt to explicitly identify exogenous monetary shocks within the cointegration framework see Lin (2003).

[16] Note that these four cases correspond to four cases that will be presented with Pesaran et al. (2001) bounds test procedure in Section 6.

With exception of Case I, full sample cointegration tests reported in Table 4 cannot reject, in general, the hypothesis of no cointegration for the short term interest rate measures for alternative specifications on the cointegrating equation. [17]

5.2 Stability of Cointegration Relationships

To analyze the long run stability of the output and interest rate relationships we conduct several exercises based on recursive LR-values.

Recursive LR-values. First, we graphically explore the stability of LR-values for at least *thirty years* long time intervals within which we expect that any monetary impact would disappear. For this purpose we present a series of LR-values of Johansen tests obtained from recursive estimations for real output and interest rates. Three types of recursive estimations are considered. In the first exercise, we implement a rolling sub-samples analysis where we allow for 30 years window in the recursive estimations. In the second exercise, the beginning of the entire sample period (1948 for the UK variables, 1947 for the US variables) remains unchanged. In the third and final exercise endpoint of the entire sample period 2001 is held fixed. [18]

Rolling sub-sample LR-values (30 years window): We first present rolling sample cointegration evidence. Here we display the LR-values of the cointegration tests obtained from the rolling regressions with 30 years windows when both the beginning and the endpoint of the estimation sample change. (First row in Figures 3 and 4) For the U.K. (U.S.) the first LR-value corresponds to the 1948-1977 (1949-1978) estimation period and the last one to 1972-2001 estimation period.

In the case of the U.K. there are several episodes for which the hypothesis of no cointegration can be rejected under alternative cointegrating equations. Particularly, periods corresponding to the loss of independent monetary policy during the participation in the ERM seem to be connected to a violation of no-cointegration relationship. For the U.S. results show we cannot reject the hypothesis of no cointegration in all rolling sub-samples considered.[19]

Fixing starting points: As alternative sub-sample stability evidence we report recursive cointegration results when the starting point is fixed. Second rows in Figures 3 (U.K.) and 4 (U.S.) present the recursive LR-values for the Johansen tests with alternative specifications of the cointegrating equation over the sample periods

[17] It is well known that since it is very difficult to distinguish an I(d,d>.5) from an I(1) variable, Johansen LR tests often tend to find spurious cointegration relation even if there is none. Therefore, in our case a Johansen LR test of finding no cointegration should be interpreted as a rather conservative result. Note that we have also tested for long run interest rates. Only in the case of U.S. there is some evidence of cointegration between the long term interest rates and real output if the cointegrating equation can be characterized by an intercept but no trend. All other specifications favor no cointegration between long term interest rates and real output.

[18] For the sake of comparison we also run cointegration tests for whole available sample period irrespective of whether the short term interest rates are useful policy indictors or not. In that case, in the first exercise (2001) is held fixed, while in the second one the beginning of the entire sample period (1873 for the UK variables, 1941 for the US variables) remains unchanged. Results are available upon request.

[19] We have repeated the same exercise for U.K. and U.S. medium to long term interest rates (Moody's AAA Corporate Bonds, and 10 years Bond yield for the U.S. and 10 years Bond yield for the U.K.) Results do not change substantially. Results for medium to long term interest rates are available upon request from authors.

starting at 1948 in the UK and 1947 in the U.S. The first LR-value plotted in the figures displays the test statistics for the sample period 1948-1977, and the subsequent LR-values refer to the expanded samples 1948-1978, 1948-1979, and so on, with the last value corresponding to the entire sample period 1948-2001. The two dashed lines correspond to the 5% and 1% significance level.[20]

In Figure 3 second row we show that when the sample staring point 1948 held fixed the hypothesis of no-cointegration can in general not be rejected for U.K. short term interest rate (T Bill) and real output However, Test I indicates high instability in the corresponding LR-values and the null hypothesis is rejected. Similarly for the U.S., with exception of Test I the hypothesis of no cointegration can not be rejected in general in nearly all subsamples. (Figure 4 second row) Some exceptions arise for the early 1980's when the U.S. monetary policymaking has changed drastically.

Fixing endpoints: Third rows in Figure 3 (U.K.) and Figure 4 (U.S.) display recursive LR-values for the Johansen tests with alternative specifications of the cointegrating equation over the sample periods ending in 2001. The first LR-value plotted in each graph of the figures gives the Johansen LR statistics for the U.K. sample period 1948-2001 (1947-2001 in the U.S.), and the subsequent LR-values refer to the reduced samples 1949-2001, 1950-2001, and so on with the last value corresponding to the sample period 1972-2001.

In Figure 3 we show that when the sample endpoint 2001 held fixed the hypothesis of no-cointegration can not in general be rejected for U.K. short term interest rate (T-Bill) and real output under alternative specifications in the cointegration equation. Figure 4 represent the results for U.S. T-Bills data. When the sample endpoint 2001 held fixed, no sub-samples reject the hypothesis of no cointegration.

Overall, various tests cannot reject the hypothesis of no cointegration in most sub-samples considered.

6. Bounds Tests: Taking Economic Theory Seriously

Power problems of unit-root tests and theory-based arguments cast doubts about the assumption made earlier that both output and the interest rate are I(1) variables. Pesaran et al (2001) develop a technique to test for the existence of a long-run relationship between two variables irrespective of whether they are I(1) or I(0). This methodology becomes most useful in our empirical tests where variables with different orders of integration may be involved. Their approach is based on the estimation of an unconstrained dynamic error correction representation for the variables involved and testing whether or not the lagged levels of the variables are significant. In other words, Pesaran et al's (2001) test consists of the estimation of the following conditional error correction model (ECM):

$$\Delta y_t = \alpha_0 + \beta_1 y_{t-1} + \beta_2 i_{t-1} + \sum_{k=1}^{m} \varphi_k \Delta y_{t-k} + \sum_{k=1}^{m} \theta_k \Delta i_{t-k} + \omega \Delta i_t + u_t \qquad (2)$$

[20] In the recursive regressions, the minimum sample period equals 30 years.

In order to test for the existence of a long run relationship Pesaran et al (2001) consider two alternatives. First, an F-statistic test of joint significance of the lagged levels of the variables involved.[21] Second, following Banerjee et al (1998), a t-ratio test for the significance of the lagged level of the dependent variable (y_{t-1}). Pesaran et al provide two sets of critical values assuming that both regressors are I(1) and that both are I(0). These two sets provide a band covering all possible combinations of the regressors into I(0), I(1) or mutually cointegrated.[22] Also, if the F-statistic for the joint null of zero coefficients on y_{t-1} and i_{t-1} shows to be insignificant, then we cannot reject the null hypothesis that the variable i_t is not a *long run forcing variable*. By interchanging y_t and i_t as dependent and independent variables in regression (2) we can assess whether y_t is or not a forcing variable. We consider four cases about the deterministic trends present in the relation between output and the interest rate. In the first one, Case II in Pesaran et al (2001), we consider a constant in the long-run relation and no trends. In the second, Case III, the constant appears unconstrained in the ECM. Case IV includes a constant and a trend in the long-run relation and an unconstrained constant in the ECM. In Case V we include both a constant and a trend unconstrained in the ECM.[23] This covers all relevant combinations of deterministic trends. Nevertheless, given the behavior of the variables involved, we consider Cases III and IV as the most likely representations. This is because interest rates do not show the trend present in the output level and because the first difference of output and the interest rate do not show a trended divergence as discussed in the previous section.

Table 5 reports the results of the tests together with the 5% critical bounds. If the statistic is below the 5% upper bound we cannot reject the null of no long-run relationship between the variables.[24] We report the tests both assuming that the interest rate is the forcing variable (our testable hypothesis) and that output is the forcing variable. The lag order was chosen using the SBC on the ECM model (2). We report both the F-tests and the t-tests for each of the cases. The results reveal a very clear picture. In all the tests we can reject the existence of a long-run relationship between output and the interest rate. This was also the case when using the quarterly data.[25]

In order to test whether these results are stable and robust to the choice of the sample we carried out three stability testing procedures equivalent to those used for the cointegration analysis. First, we used rolling sub-sample with a moving window of 30 years and recursively applied the bounds test.[26] Secondly, we fixed the initial 30 years and recursively added one observation to the sample. Finally, we fixed the end point, that is, we start with the whole sample and then subtract one observation at a

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[21] In case that the ECM contains a deterministic trend, the F-test also includes the null of the coefficient on the trend being equal to zero.

[22] We refer to Pesaran et al (2001) for a detailed description of the testing procedure. Note that the critical values provided contain an upper and lower bound outside which inference is conclusive. However, if the F- or t-statistics fall within these bounds, we cannot reach any conclusion unless the cointegration rank of the forcing variable i_t is known a priori.

[23] Only in Cases III and V can we report t-tests as well as F-tests.

[24] Note that, in order to be on the conservative side, we will reject long-run relations even if the statistic lies within the critical bounds.

[25] The results using all the available sample period also show no long-run relationships.

[26] The results are invariant if we use a 30 years or a 20 years window in both annual and quarterly data.

time with the final recursion being the last 30 years of data. The three different methods will obviously yield different patterns and give a complete overview of the stability of the results.[27]

Plots of the F-tests are provided in Figures 5, 6 and 7 together with the upper 5% bound. If the plot is above the bound there would be evidence of a long-run relation for that recursion. Focusing on the US Treasury Bill and tests FIII and FIV we can see that, despite some variation, the tests are always below the 5% bound with a tendency to decrease in the final years of the sample, and especially after the "Volcker disinflation" period. This is a very similar pattern to that found in the cointegration analysis. For the US, hence, absence of long term relationship between real output and monetary policy indicator is unequivocally the hypothesis supported. For the UK our results also show a higher instability and some isolated periods of long term relationship. This set of results, however, support absence of long term relationship much more strongly than the cointegration tests, as most recursions yield statistics below the critical band. When looking at the annual data recursive tests for the UK using the Treasury bill rate we can observe that the test substantially surpasses the upper bound in some periods which are common to those found when using cointegration tests. This period coincides with the inclusion of the years between 1988 and 1992 and is also reflected, to a lesser extent, in the quarterly data estimates. This is the period when the pound sterling first shadowed the DM and then entered the ERM and the subsequent speculative attack that took the pound out of the ERM in September 1992. The loss of monetary policy generated by these events may have had some long-run impact on output. However, this appears as an isolated event not supported by all three methods and should be taken with some degree of caution. For the rest of the observations for the UK the bounds test is below the critical band.[28]

7. Are There Omitted Variables?

Our evidence so far shows that there is no long-run information content of interest rates for output. In other words, interest and output do not appear to share a common trend that allows establishing a long-run role of the monetary policy instrument. However, it could be argued that these results are subject to omitted variables bias. Assume that long-run real output is determined by an N-1 set of real shocks z_t stemming from technology, labor supply, energy prices, etc, plus the interest rate. Then there should be a linear combination $\beta\{y_t \quad i_t \quad z_t\}'$, with β a 1×N+1 vector of coefficients, which yields stationary errors. However, if the elements z_t are omitted from the relation, we would find that there is no common trend just because these real variables are needed to complete the long-run stationary combination.

[27] We also carried out formal tests for parameter stability on the unrestricted error correction model. We applied Hansen's (1992) stability test and found no evidence of individual parameter or joint instability. Instability was higher for the UK, although always below the critical values. For the US there was some evidence of variance instability. Applying the Bai and Perron (1998 and 2003) methods for testing for multiple structural changes we found no evidence of a single structural change in the regression when we set the maximum number of breaks to 1, 2 and 3.

[28] When using the full sample available for both the UK and US the results are also similar but also show outliers during the II World War (especially for the UK). Results are available upon request.

Hence, we will now analyze whether the results from the previous sections are robust to the inclusion of variables that share common trends with real output.

The way we proceed is as follows. We first test whether a set of potentially important real variables influencing the long-run evolution of output share common trends. If some of these variables share common trends we can reduce the vector to a sub-set of variables z_t^s that share common trends with the rest but not between them (see Boschen and Mills, 1995). Hence, the long-run impact matrix of this vector z_t^s will have rank 0 (*rank* = 0). We then test if these variables are cointegrated with real output, i.e. if the rank of $\{y_t\ z_t^s\}$ is 1. If so, we can conclude that these variables have long-run information content about output. We then introduce the interest rate in the vector and test for the rank of $\{y_t\ z_t^s\ \ i_t\}$. If we find that the rank of the long run impact matrix of this vector is still 1, we can then conclude that the interest rate does not enter the common trend of output with the rest of real variables. If the rank was found to be 2, we would then conclude that interest rates do have a long-run relation with output and our previous results are just a consequence of omitting relevant variables. Note that, given that we have previously found that the rank of the long run matrix of $\{y_t\ i_t\}$ is 0, this rules out that finding a cointegration rank of 2 in $\{y_t\ z_t\ \ i_t\}$is the consequence of cointegration between i_t and z_t. This is because if we find *rank* = 2 and we have that the relations $\{y_t\ z_t\}$ and $\{z_t\ i_t\}$ have *rank* = 1, then this automatically entails a cointegration relation between y_t and i_t. In case we found no long-run relation between y_t and z_t and by adding i_t find *rank* = 1, then we can again conclude against no long-run information content and our previous results would be a consequence of omitted variables.[29]

Due to data availability issues we could only use annual data starting in 1949 for the US and the UK and ending in 1999 for the UK. The set of variables z_t included real oil prices (OIL), world income minus US/UK income (WI), a measure of multifactor productivity (MFP), total labor force (LF), real government expenditure (GE) and real total tax revenue (TAX).[30] These variables would be able to capture shocks stemming from energy prices, external shocks, productivity, demographic change and fiscal policy as in Boschen and Mills (1995). The results from the cointegration tests between these variables in vector z_t showed that for the US the vector of real variables can be reduced to OIL and MFP and for the UK to OIL and LF.[31] For the US, OIL and MFP do not appear to have a common trend when we estimate the model with a trend in the data but not in the cointegration equation, but seem to have one when introducing a trend in the cointegration vector. For the UK, OIL and LF do not have common trends in any specification. We then test for cointegration relations between output and these two z_t^s variables. Table 6 reports the results of the LR test of no-cointegration. Given the behavior of the data involved and for reasons of space we report only Case II and III for deterministic trends. The results show that, for both countries, the real variables share a common trend with output both together and separately (with the exception of MFP in Case II for the US). When

[29] During this exercise we will work assuming that interest rates are I(1). This is because, to our knowledge, there is no system equivalent to the bounds test procedure used in section 5.
[30] The source of the variables is described the Appendix The productivity measure for the UK was not directly available and was estimated as labor productivity not explained by capital deepening as in Hendry (2001).
[31] We do not report these tests here to save space, but results are available on request.

we introduce the Treasury Bill rate in the VAR, results reject the existence of more than one cointegrating vector. This lends support to the hypothesis that interest rates and output do not share common trends. That is, the results presented in the previous sections are not driven by the possible bias arising from the exclusion of relevant variables explaining long-run output.

8. Conclusions

In this paper we test for the long-term relationships between monetary policy indicators and real output. We use short term nominal interest rates as the relevant monetary indicator that contains significant and stable information about the U.K. and U.S. business cycle fluctuations in the post-II World War period.

Our various tests favor the absence of long term relationships between real output and nominal interest rates. There is neither significant nor stable long term relationship between short term interest rates and real output in the U.K. and the U.S. in most of the sub-samples considered. These results are robust to the inclusion of a set of real side variables that have common trends with output.

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Appendix: Data sources

Variable	Period	Periodicity	Source
US data			
Real Output	1960-2001	Quarterly	OECD MEI
Treasury Bill (3-month)	1960-2001	Quarterly	IMF-IFS
Federal Funds Rate	1960-2001	Quarterly	FRB
Treasury Bill 3 month	1941-2001	Annual	FRB
Moody's AAA	1929-2001	Annual	http://www.globalfindata.com/
10-years Gov Bond Rate	1929-2001	Annual	http://www.globalfindata.com/
Real Output	1929-2001	Annual	FRB
Real Oil Prices	1949-2001	Annual	IMF-IFS
World Income	1949-2001	Annual	IMF-IFS
Multi-factor productivity	1949-2001	Annual	Bureau of Economic Analysis
Labor force	1949-2001	Annual	Bureau of Economic Analysis
Real Government expenditure	1949-2001	Annual	IMF-IFS
Real tax revenue	1949-2001	Annual	IMF-IFS
UK data			
Real Output	1960-2001	Quarterly	OECD
Treasury Bill 3month	1960-2001	Quarterly	IMF-IFS
10-GovBond	1960-2001	Quarterly	OECD
Treasury Bill	1873-2001	Annual	Hendry (2001) updated with IFS
10-year Gov Bond Rate	1873-2001	Annual	Hendry (2001) updated with OECD
Real Output	1873-2001	Annual	Hendry (2001) updated with OECD
Real Oil Prices	1949-2001	Annual	IMF-IFS
World Income	1949-2001	Annual	IMF-IFS
Productivity measure	1949-1999	Annual	Hendry (2001) updated with OECD and own estimates
Labor force	1947-1999	Annual	Hendry (2001) updated with OECD
Real Government expenditure	1947-2001	Annual	IMF-IFS
Real tax revenue	1947-2001	Annual	IMF-IFS

Table 1: Granger Causality χ-Square Statistics (OLS Estimates, White Heteroskedasticity Consistent Standard Errors)

	χ-Square (p-values)
U.K. Real Output Equation (1948-2001)	
T-Bill	2.844 (0.091)
Gov Bond	6.669 (0.0098)
U.S. Real Output Equation (1947-2001)	
T-Bill	14.713 (0.0053)
Gov Bond	13.288 (0.0099)

Table 2. Unit root tests on output

		ADF		KPSS		M_{α}^{GLS}		ERS DFGLS	
	Lag	Const	Trend	Const	Trend	Const	Trend	Const	Trend
US									
1960:1-2001:2	4	-1.002	-3.335	2.825	0.282	1.500	-10.02	-1.752	-2.267
1947A-2001A	0	-0.925	-2.359	1.289	0.200	1.779	-6.734	3.224	-1.983
UK									
1960:1-2001:2	0	-0.482	-2.221	4.154	0.250	1.650	-7.506	2.421	-1.987
1947A-2000A	0	-0.698	-2270	3.645	0.230	1.924	-6.009	3.332	-1.928

NOTES: Bold indicates rejection of the null of a unit root for ADF, DFGLS and M_{α}^{GLS} and acceptance of the null of stationarity for the KPSS test at the 5% level.

Table 3. Unit root tests on interest rates

		ADF		KPSS		M_{α}^{GLS}		ERS DFGLS	
	Lag	Const	Trend	Const	Trend	Const	Trend	Const	Trend
US									
Quarterly Data (1960:1-2001:2)									
T-Bill	5	-3.205*	-3.084	0.521	0.442	-16.77*	-26.16*	-2.563*	-2.921*
FedFunds	2	-2.263	-2.159	5.525	0.913	-6.545	-8.708	-1.819	-2.158
Annual Data (1947-2001)									
T-Bill	0	-2.339	-2.233	4.678	0.689	-5.106	-8.821	-1.742	-2.205
Gov Bond	0	-1.839	-1.553	5.744	0.750	-2.891	-5.486	-1.308	-1.605
UK									
Quarterly Data (1960:1-2001:2)									
T-Bill	1	-2.710	-2.624	0.630	0.495	-7.504	-12.55	-1.939	-2.407
Annual Data (1948-2001)									
T-Bill	0	-2.174	-1.945	2.538	0.356	-3.150	-6.194	-1.384	-1.887
Gov Bond	0	-1.578	-0.630	6.225	0.992	-1.380	-1.528	-0.968	-0.679

NOTES: Ibid Table 1

Table 4: Johansen Cointegration Tests Likelihood Ratio Statistics (Full sample)

	Case I	Case II	Case III	Case IV
		U.K. (1948-2001)		
T Bill	40.57614*	12.28785	21.35119	10.04771
10 years Bond	32.83165*	7.828417	24.40714	19.09715*
		U.S. (1947-2001)		
T Bill	23.32090*	15.15664	19.45023	7.996870
Gov Bond	26.72015*	15.07568	21.91855	6.941328
		Critical Values		
5%	19.96	15.41	25.32	18.17
1%	24.60	20.04	30.45	23.46

Case I: no deterministic trend in the data, and an intercept but no trend in the cointegrating equation.
Case II: linear trend in the data and an intercept but not no trend in the cointegrating equation
Case III: linear trend in the data and both an intercept and a trend in the cointegrating equation
Case IV: quadratic trend in the data, and both an intercept and a trend in the cointegrating equation.

Table 5. Bounds Test analysis of long-run relationships.

	Lag	F-II	F-III	F-IV	F-V	t-III	t-V
			US (1947-2001)				
T Bill → Y	2	0.788	2.241	2.006	3.554	-1.032	-2.462
Gov Bond → Y	2	1.076	2.375	2.075	3.378	-1.302	-2.331
Y → T Bill	2	2.012	0.639	0.595	0.019	-1.116	0.002
Y → Gov Bond	2	1.556	0.796	0.924	0.203	-0.760	-0.001
			UK (1948-2001)				
T Bill → Y	3	0.565	1.859	1.871	1.313	0.228	-0.503
Gov Bond → Y	3	0.274	1.725	1.722	1.167	0.017	-0.353
Y → T Bill	3	1.768	0.995	1.381	0.000	0.818	0.000
Y → Gov Bond	3	1.503	1.069	1.538	0.008	0.244	-0.008
				5% Critical Bounds			
		3.62	4.94	4.68	6.56	-2.83	-3.41
		4.16	5.73	5.15	7.30	-3.22	-3.69

NOTES:
1) The table produces tests for the existence of long-run relationships between real output and short term interest rates. It has F-tests and t-tests. There are 4 cases of deterministic components considered (corresponding to PSS's (2002) cases):

- Case II: restricted intercepts and no trends.
- Case III: unrestricted intercepts and no trends (t-test also reported).
- Case IV: unrestricted intercepts and restricted trends.
- Case V: unrestricted intercepts and unrestricted trends (t-test also reported).

2) Bold numbers indicate that we cannot reject the null of no long-run relation at the 5% level. To be on the conservative side, we use the upper bound of the 5% critical value.

3) Abbreviations are as follows: T-Bill for Treasury Bill Rate; GB for Government Bond Rate; Y for real output.

Table 6. LR cointegration tests. Omitted variables.

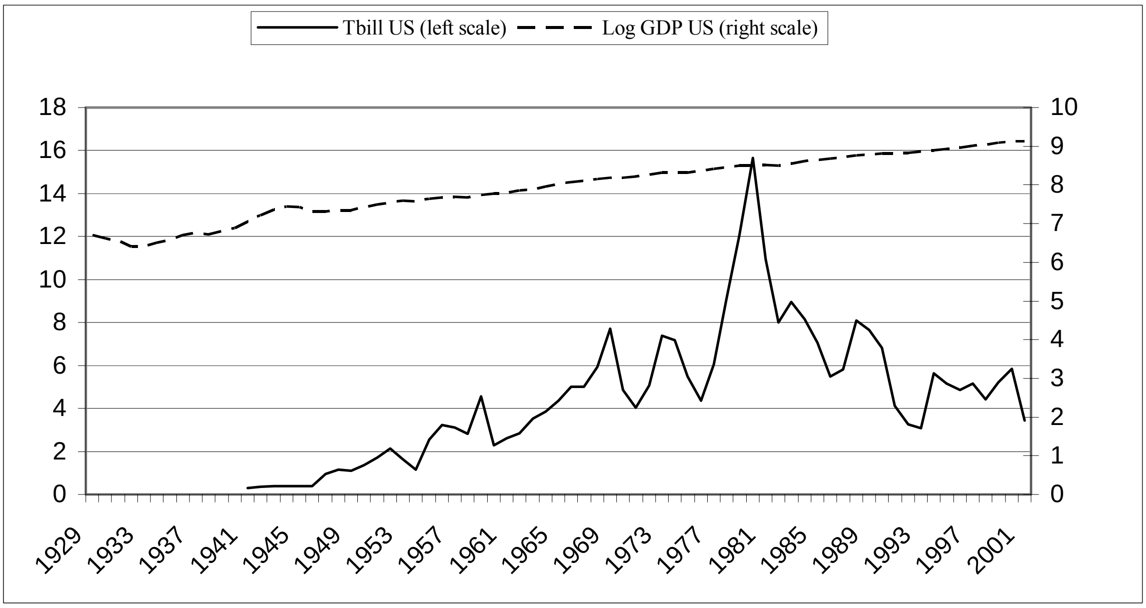
	Case II			Case III		
	r ≤ 2	r ≤ 1	r = 0	r ≤ 2	r ≤ 1	r = 0
	US (1949-2001)					
	Real variables and output					
Y, OIL, MFP	-	8.58	27.80*	-	9.63	38.25**
Y, OIL	-	-	23.20**	-	-	33.40**
Y, MFP	-	-	17.20	-	-	34.75**
	Real variables, output and interest rates					
Y, OIL, MFP, TBill	9.64	15.54	36.61**	9.75	15.71	45.22**
Y, OIL, TBill	-	6.65	26.70*	-	6.67	35.56**
Y, MFP, TBill	-	14.52	31.43**	-	14.80	38.78**
	UK (1949-1999)					
	Real variables and output					
Y, OIL, LF	-	12.82	24.48*	-	12.97	31.50**
Y, OIL	-	-	17.75*	-	-	26.48**
Y, LF	-	-	19.27*	-	-	27.48**
	Real variables, output and interest rates					
Y, OIL, LF, TBill	11.92	16.01	30.82*	11.38	16.92	43.47**
Y, OIL, TBill	-	13.65	24.51*	-	15.60	38.04**
Y, LF, TBill	-	11.87	21.05	-	11.43	33.68**

Case II: linear trend in the data and an intercept but not no trend in the cointegrating equation

Case III: linear trend in the data and both an intercept and a trend in the cointegrating equation

For reasons of space, if the VAR contains N variables, we do not report the r ≤ N-2 test if the r ≤ N-3 test already rejects the null.

Figure 1. Treasury Bill Rates and log GDP



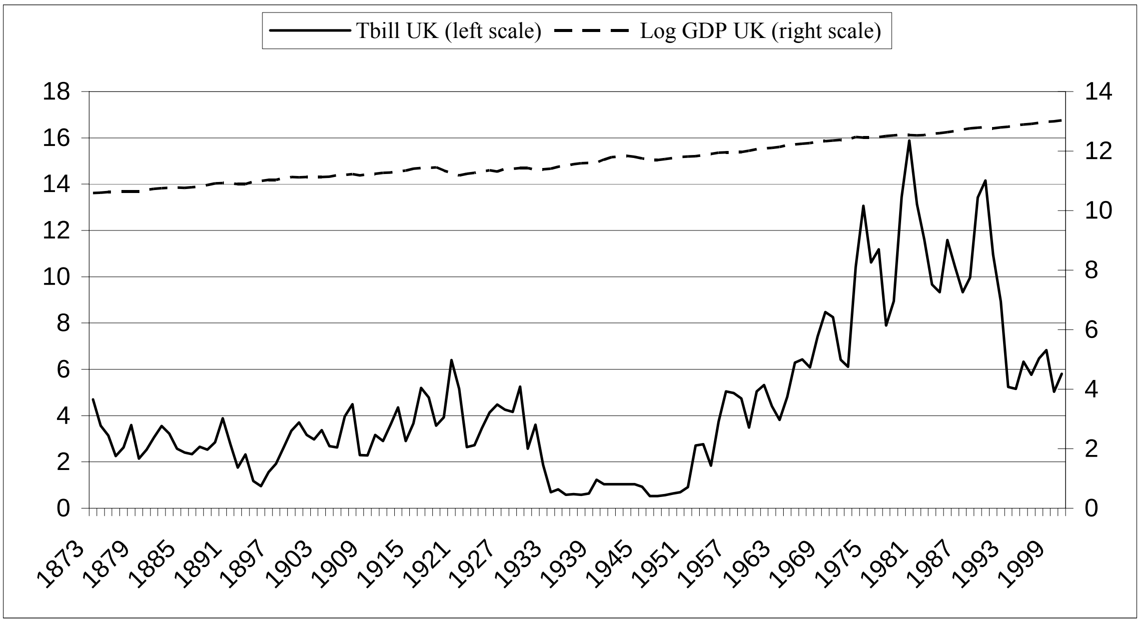


Figure 2: Granger-causality p-values: Rolling Regressions (30 years window)

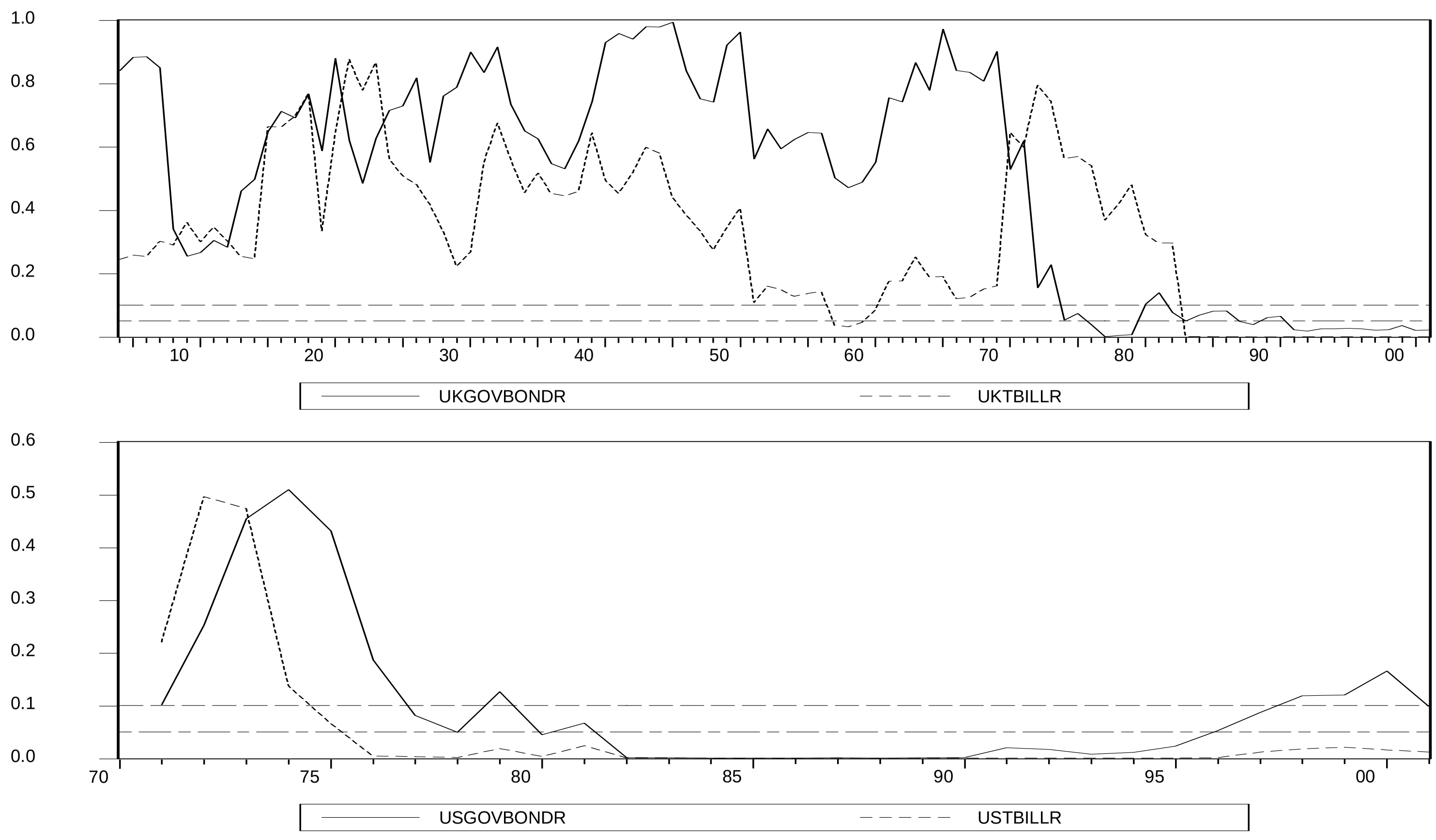


Figure 3: U.K. Cointegration Results: Sub-sample Stability 1948-2001 (likelihood ratio)

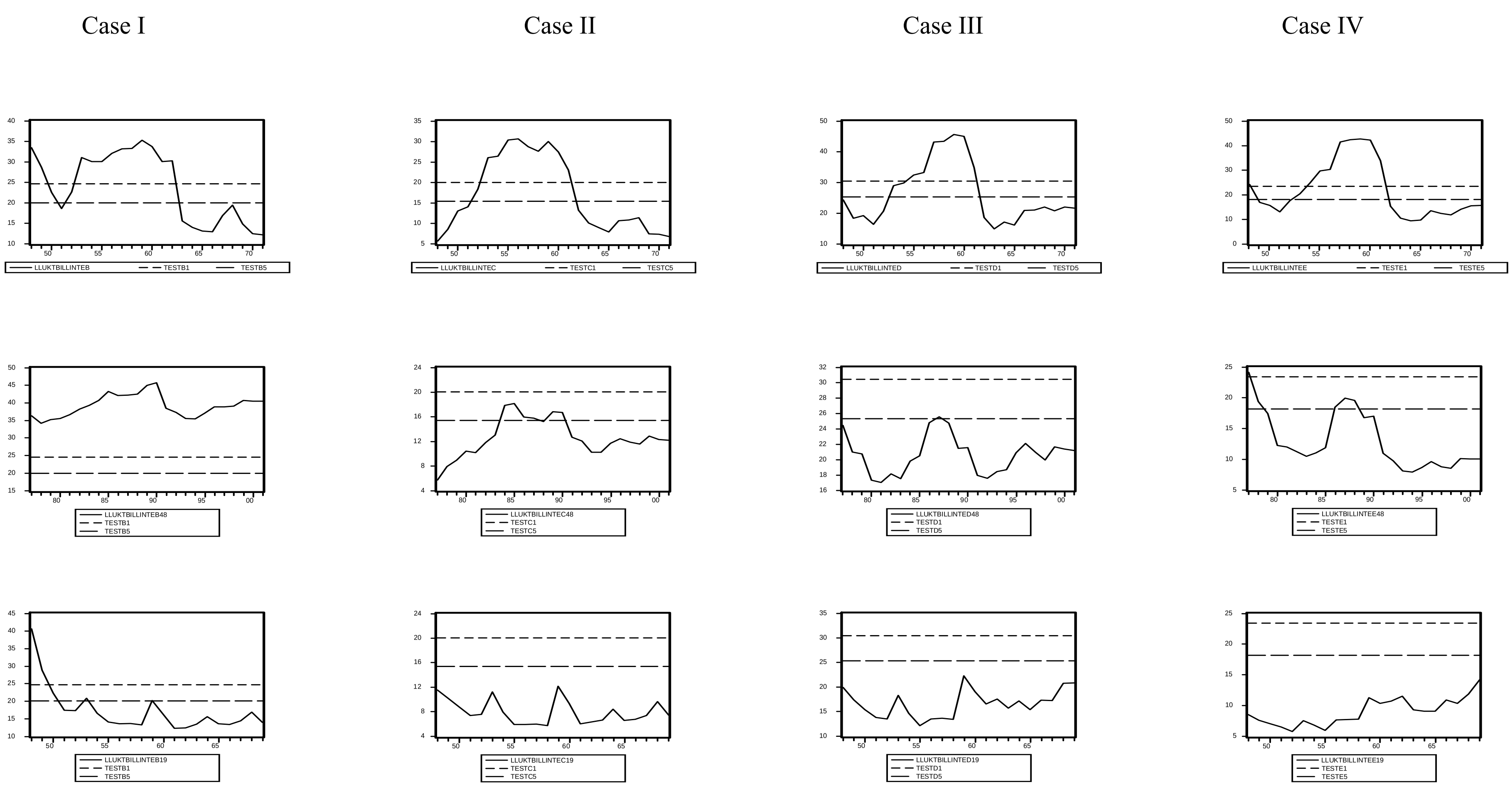


Figure 4: U.S. Cointegration Results: Sub-sample Stability 1947-2001 (likelihood ratio)

Case I | Case II | Case III | Case IV

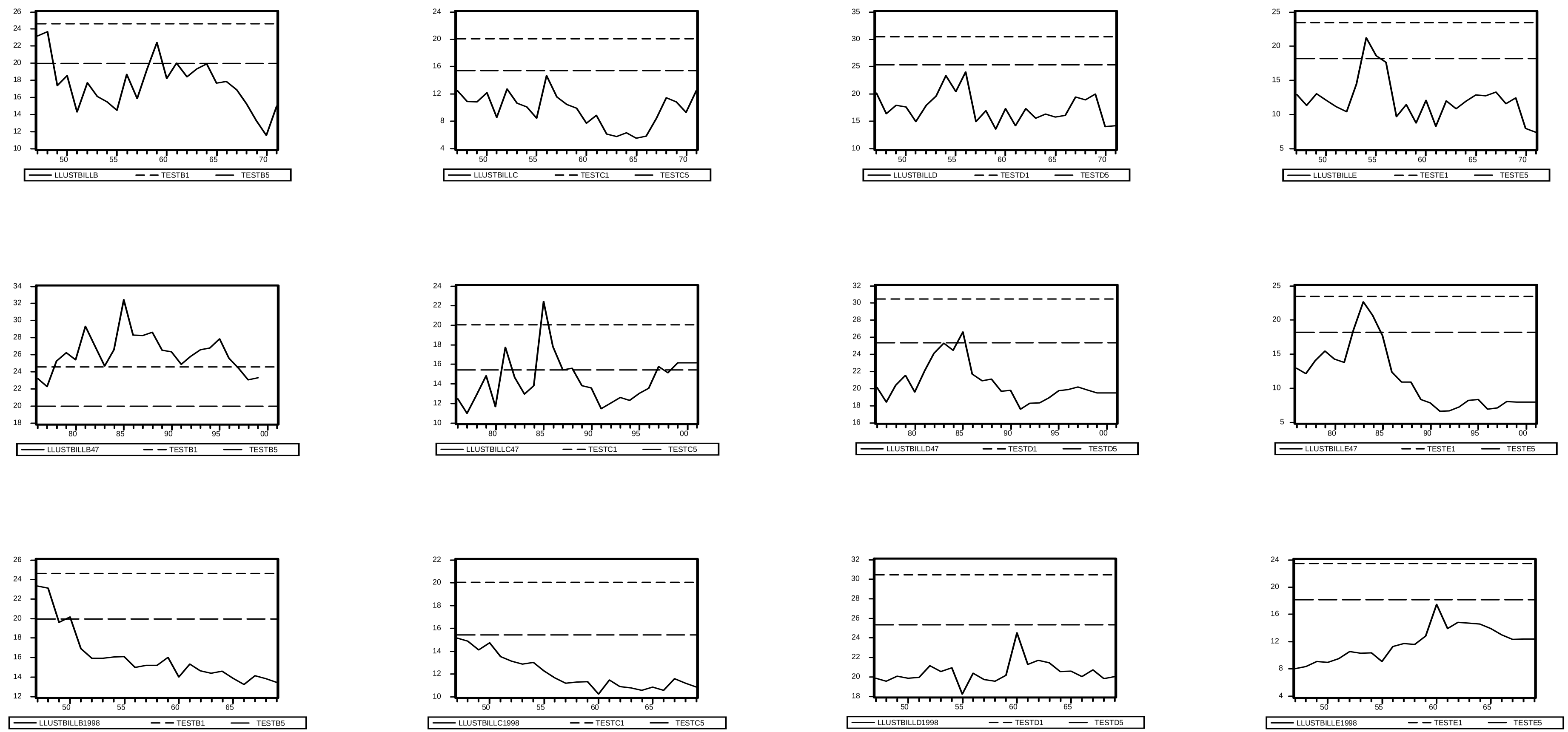


Figure 5: Bounds test results: rolling window estimates

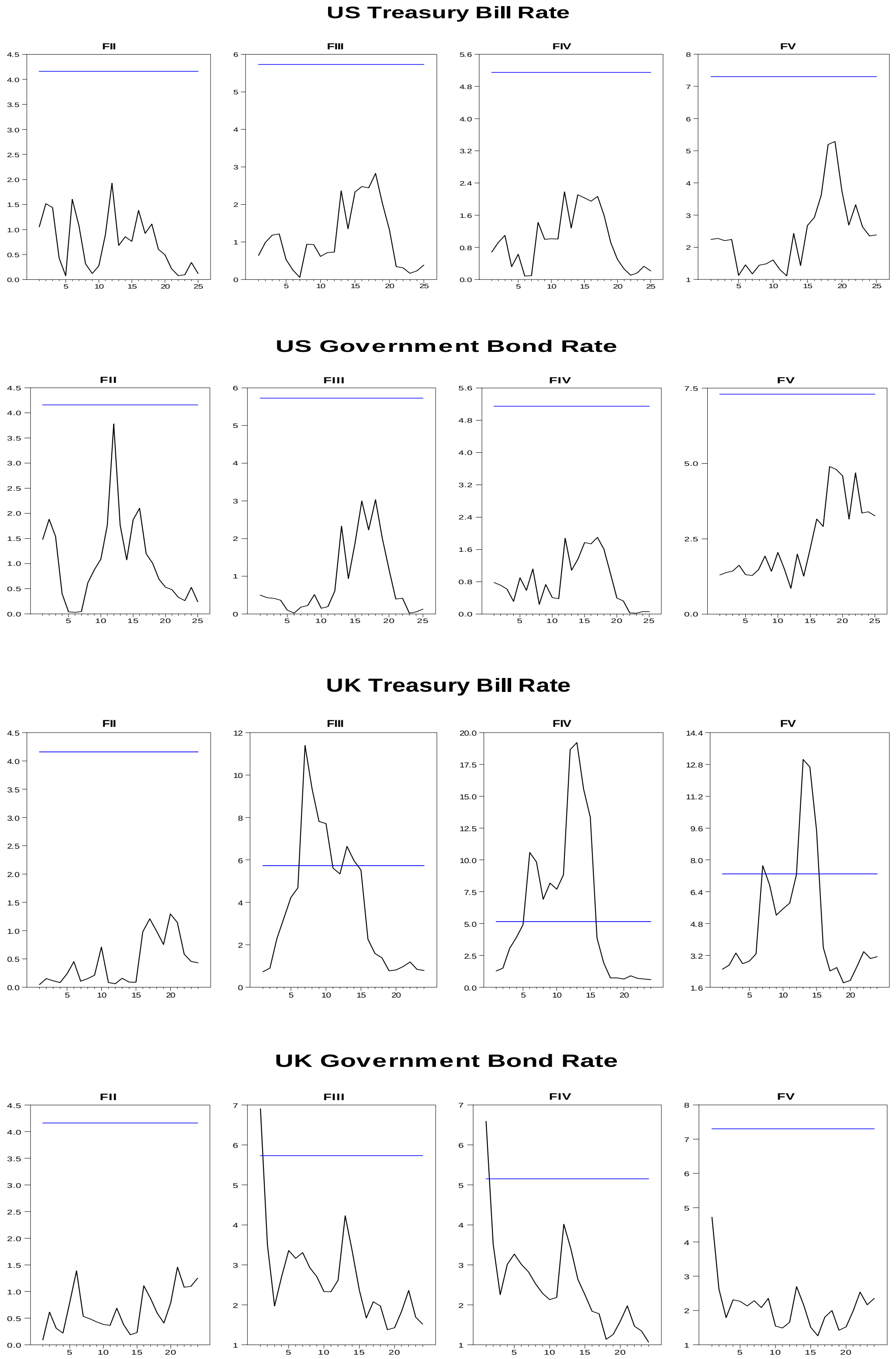


Figure 6: Bounds test results: recursive estimates and fixed initial point

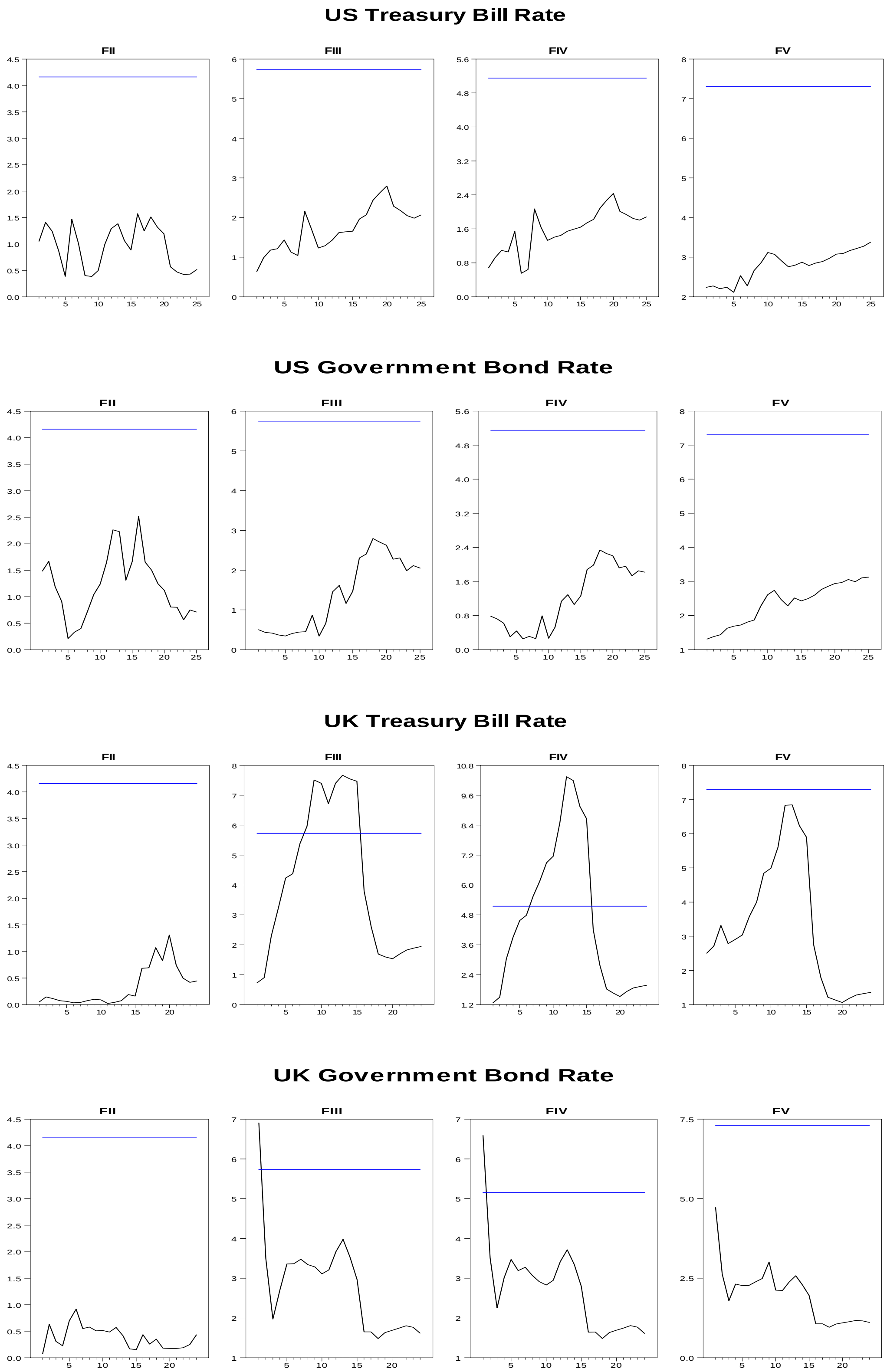
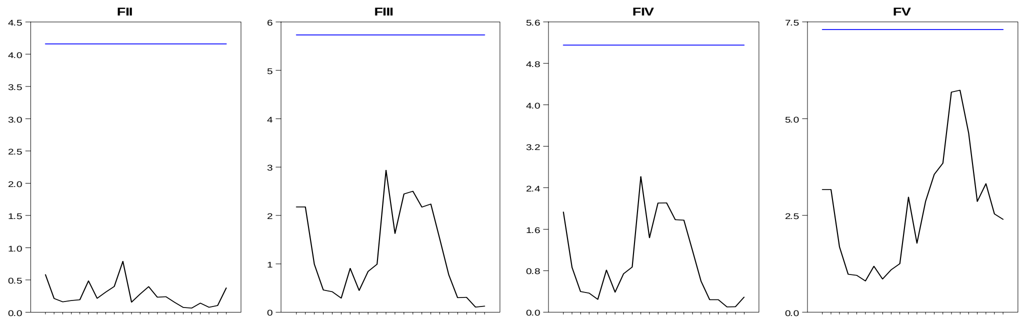
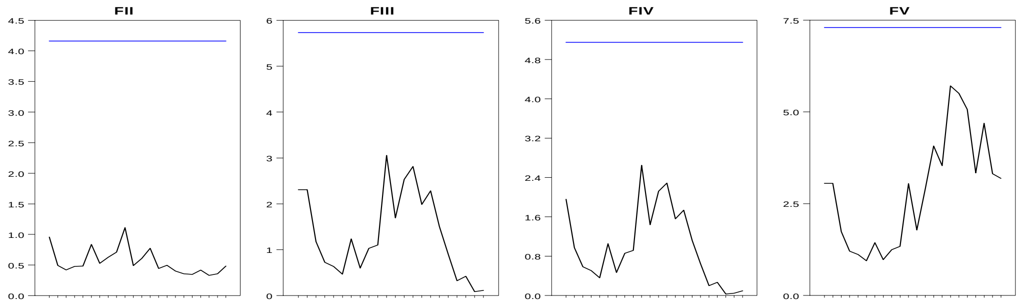


Figure 7: Bounds tests results: recursive estimates and fixed end point

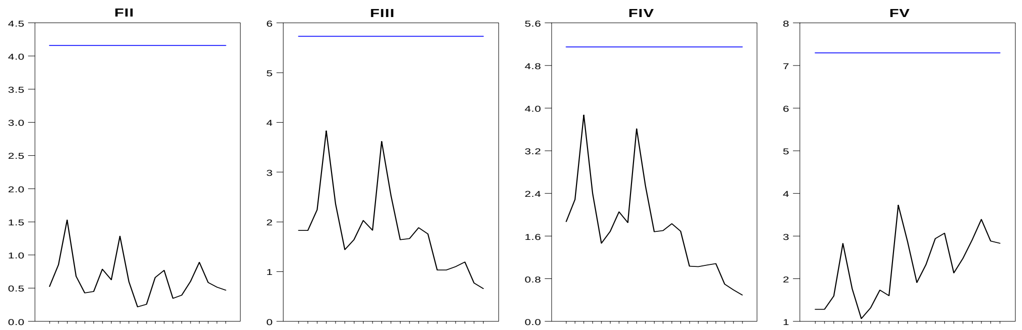
US Treasury Bill Rate



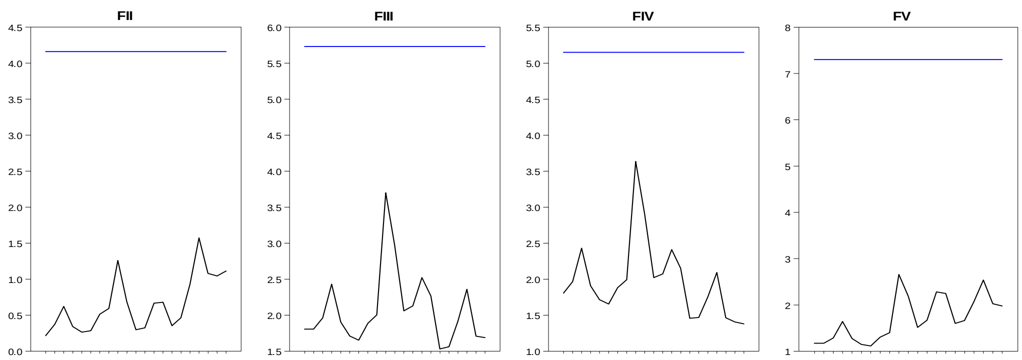
US Government Bond Rate



UK Treasury Bill Rate



UK Government Bond Rate



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