Interest Rates and Output in the Long-run

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This draft: September 2004

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 subsamples throughout the second half of the 20th century.

JEL Classification: E3, E4, E5.

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

Acknowledgements: Part of this paper was written while Aksoy was visiting the Research Department of the European Central Bank as research visiting fellow. He would like to express his gratitude to members of the research department, in particular to Frank Smets, for providing stimulating research environment and hospitality. We would like to thank Alan Carruth, Paul De Grauwe, Hans Dewachter, Sylvester Eijffinger, João Faria, Jim Griffin, Marco Lyrio, Robert Miller, Abhinay Muthoo and Bas Werker and participants in seminars at the European Central Bank, at the universities of Leuven, Essex, Tilburg, Nottingham and EEA-Madrid and Ecomod2004 Paris conferences and Kent Money/Macro workshop for their comments and suggestions. Naturally, we assume responsibility for all remaining errors.

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1. Introduction

In this paper we explore long-term relationships between monetary policy indicators that are able to explain U.S. and the U.K business cycle fluctuations and real output.

The research and policy consensus overwhelmingly supports the long-term neutrality of monetary aggregates on key real economic variables, such as GDP and industrial production.[1] Clearly, neutrality of monetary aggregates is only policy relevant if these are indeed used as policy instruments to conduct monetary policy or are useful monetary policy indicators to explain business cycle fluctuations. However, recent research shows that U.S. monetary aggregates are neither policy instruments nor useful monetary indicators.

Currently, in most developed economies short-term nominal interest rates are employed as monetary instruments. There is also 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 20th century, whereas monetary aggregates can be characterized at best as weak indicators for real output.[2] Therefore, we focus on the relevant monetary policy indicator, short-term nominal interest rates. We are not aware of a study that systematically analyses long-term statistical relationship between real output and monetary indicators explicitly focusing on nominal short-term interest rates. Research by Bernanke and Mihov (1998) probably is the only exception to the literature in that it recognizes a causal role for 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.

In this paper, we are 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

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[1] 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 neutrality of monetary aggregates.

[2] See for example Bernanke and Blinder (1992), Friedman and Kuttner (1992, 1996), Estrella and Mishkin (1997), Friedman (1998), Stock and Watson (1999, 2001). See also Aksoy and Piskorski (2004) for evidence of information content in monetary aggregates after accounting for foreign holdings.

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.[3]

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 has difficulties to reject the nonstationarity of most short-term interest rate series, one cannot take this result at face value. Economic intuition suggests that short-term interest rates should be rather stationary.[4]

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 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 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.

In this paper we argue that both statistics and economic theory based evidence largely rejects the existence of long term relationships between relevant policy

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[3] 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).

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

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. One can interpret these findings as evidence of support for the long-term neutrality hypothesis.

The paper is organised 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. Finally, Section 7 concludes.

2. Data

The annual data for the U.K. covers the period 1873-2001.[5] 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.[6]

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.

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

[6] 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.

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. [7] Results are reported in Table 1 and Figure 1.

insert Table 1 and Figure 1 about here

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

[7]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.

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 1 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.

Note that given high level of price stickiness 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.[8]

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).[9] 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.[10]

Insert Tables 2 and 3 about here

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).

[8] 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.

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

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

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.[11]

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 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. In principle one can conclude in favour of monetary non-neutrality.

[11] Results available on request.

Johansen's method of estimating cointegrating vectors is a good starting point for tests of long run relationships. [12] 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.[13]

Insert Table 4 about here

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 no 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.[14] 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. [15]

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[12] 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.

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

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

[15] 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

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 subsamples 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. [16]

Insert Figures 2 and 3 around here

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 2 and 3) 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

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equation can be characterized by an intercept but no trend. All other specifications favour no cointegration between long term interest rates and real output.

[16] 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.

relationship. For the U.S. results show we cannot reject the hypothesis of no cointegration in all rolling subsamples considered.[17]

Fixing starting points: As alternative sub-sample stability evidence we report recursive cointegration results when the starting point is fixed. Second rows in Figures 2 (U.K.) and 3 (U.S.) present the recursive LR-values for the Johansen tests with alternative specifications of the cointegrating equation over the sample periods 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.[18]

In Figure 2 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 3 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 2 (U.K.) and Figure 3 (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 2 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 3 represent the results for U.S. T-Bills data. When the

[17] 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.

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

sample endpoint 2001 held fixed the hypothesis of no cointegration can not be rejected in none of the subsamples considered in the exercise.

Overall, various tests can not 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):

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

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.[19] 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.[20] Also, if the F-statistic for the joint

[19] 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.

[20] 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.

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.[21] This covers all likely combinations of deterministic trends. Nevertheless, given the behaviour 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.

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.[22] 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.[23]

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.[24] 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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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.

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

[22] 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.

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

[24] 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.[25]

Plots of the F-tests are provided in Figures 4, 5 and 6 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.[26]

[25] 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.

7. Conclusions

In this paper we tested for the long-term relationships between monetary policy indicators and real output. We used 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 favour 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 subsamples considered.

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Appendix: Data sources

Variable	Period	Periodicity	Source
		US	
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
		UK	
Real Output	1960-2001	Quarterly	OECD
Treasury Bill 3month	1960-2001	Quarterly	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

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
GB → 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 → GB	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
GB → 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 → GB	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.

Figure 1: Granger-causality p-values: Rolling Regressions (30 years window)

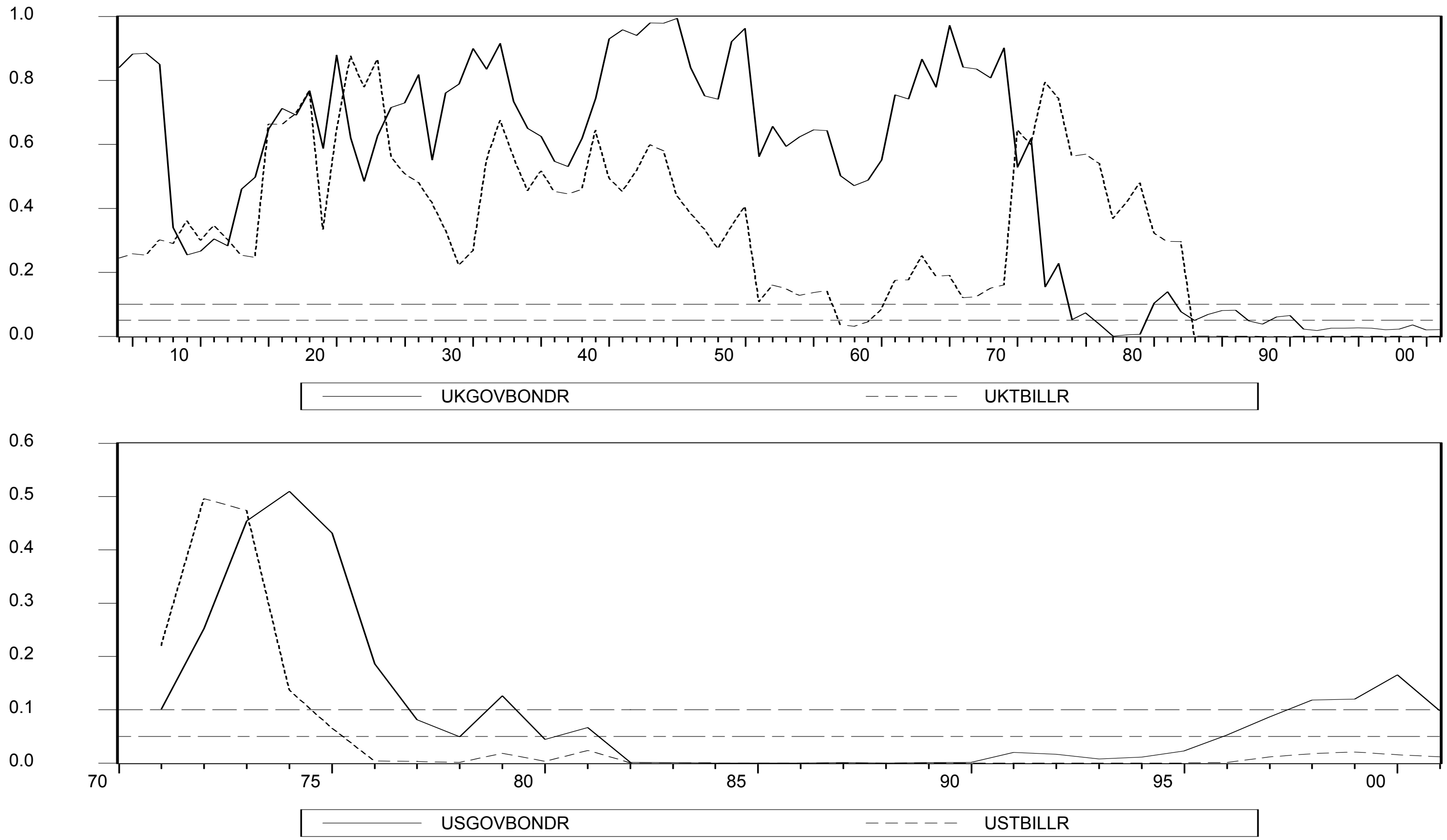


Figure 2: U.K. Cointegration Results: Sub-sample Stability 1948-2001 (likelihood ratio)

Case I | Case II | Case III | Case IV

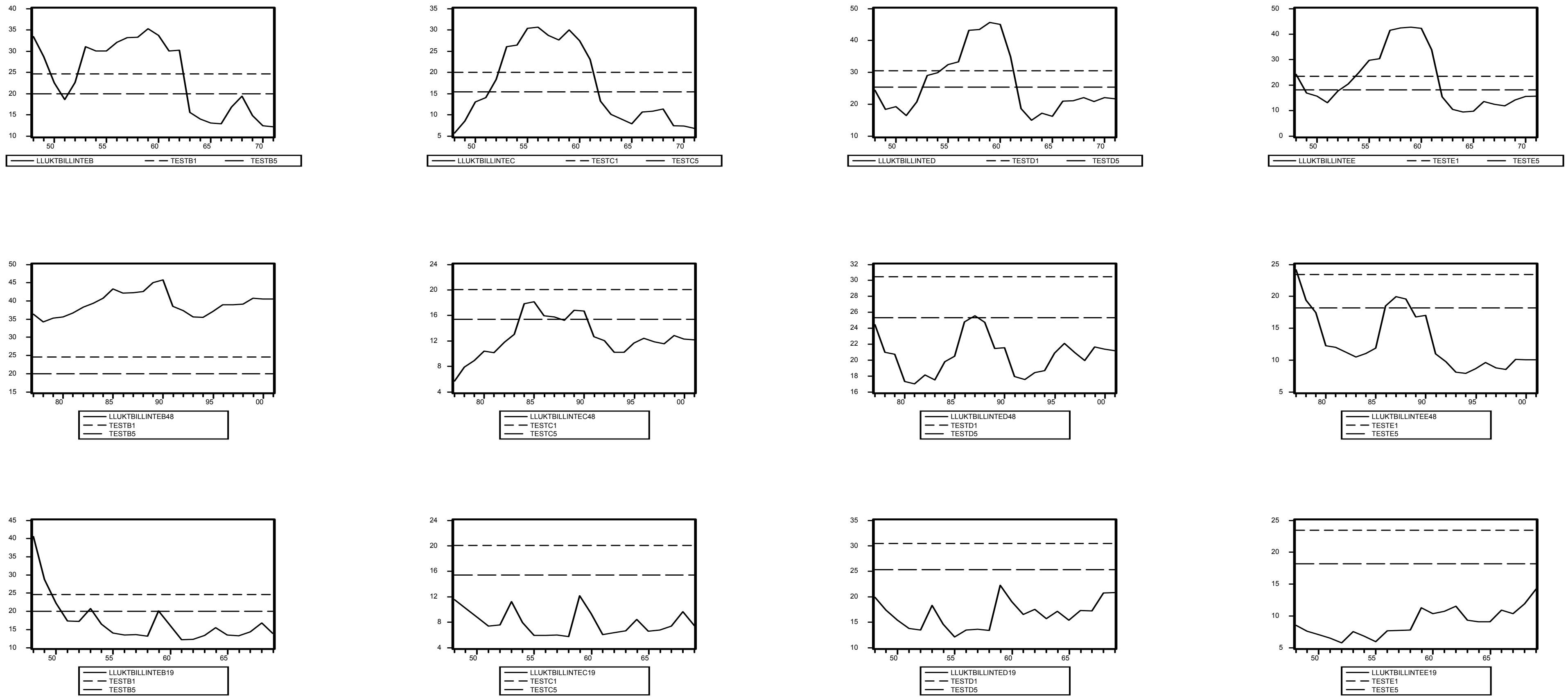


Figure 3: U.S. Cointegration Results: Sub-sample Stability 1947-2001 (likelihood ratio)

Case I | Case II | Case III | Case IV

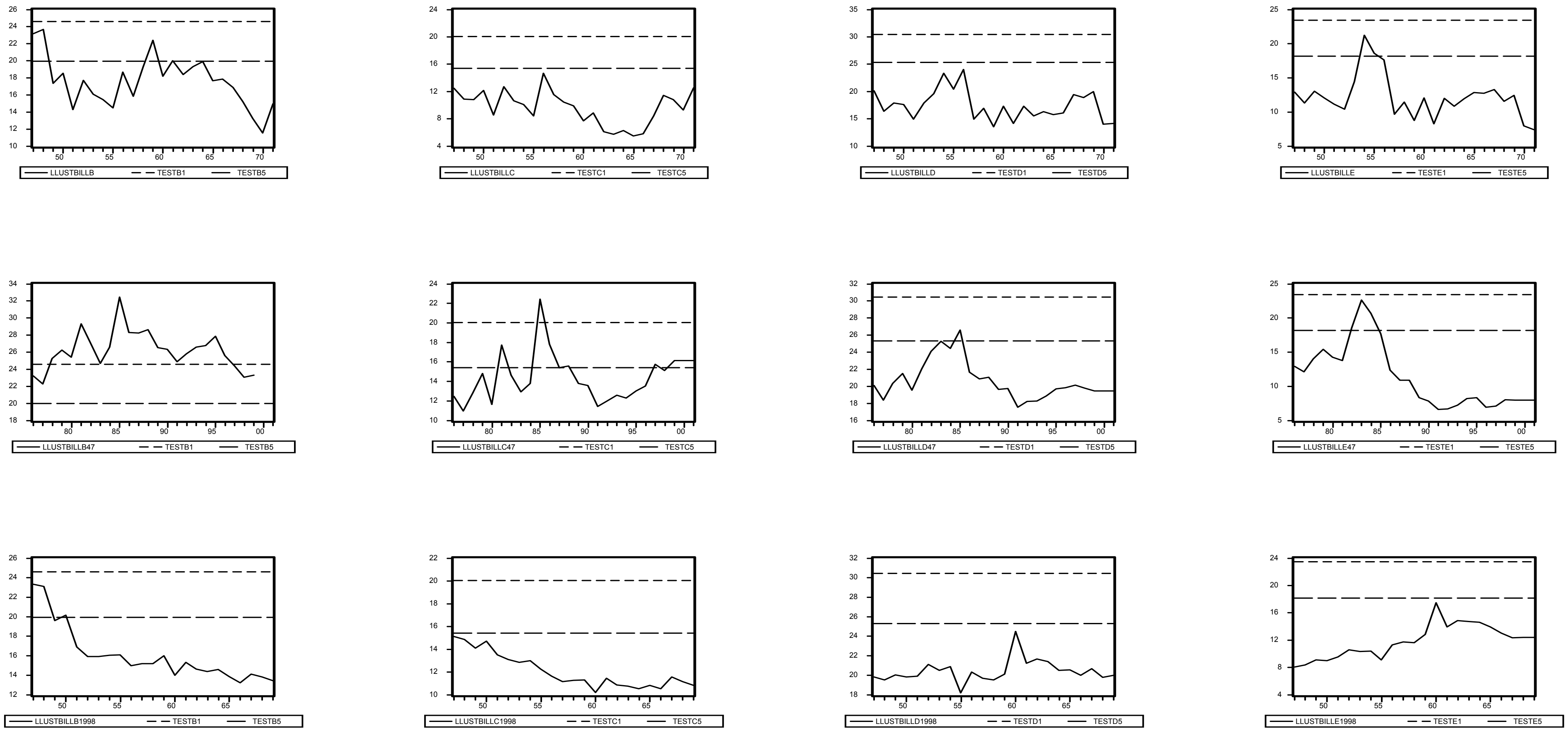
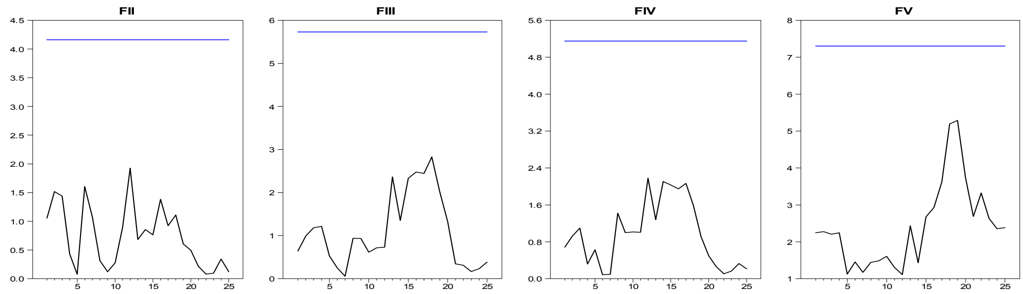
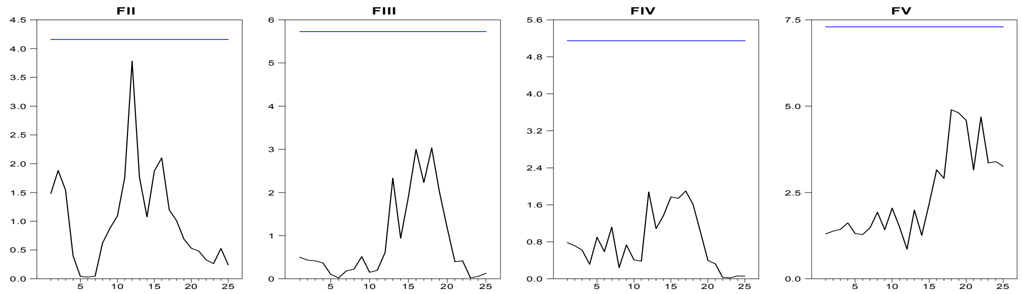


Figure 4: Bounds test results: rolling window estimates

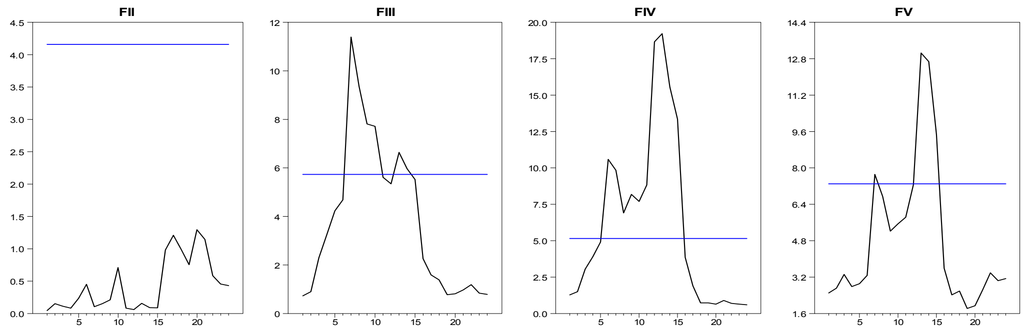
US Treasury Bill Rate



US Government Bond Rate



UK Treasury Bill Rate



UK Government Bond Rate

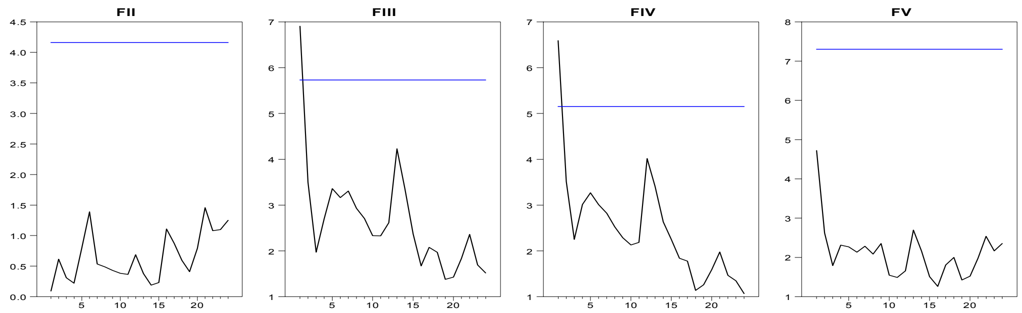
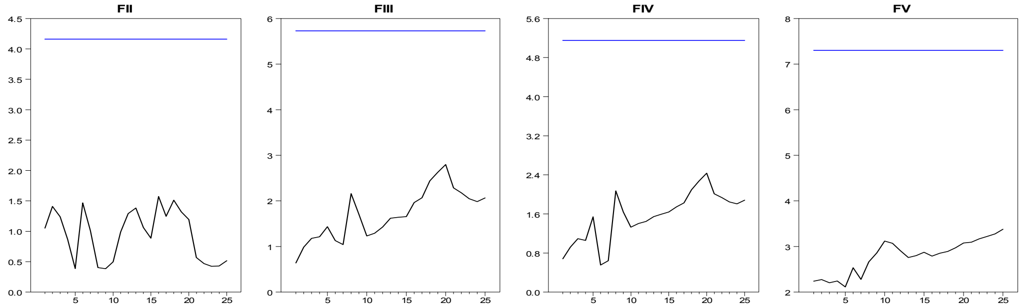
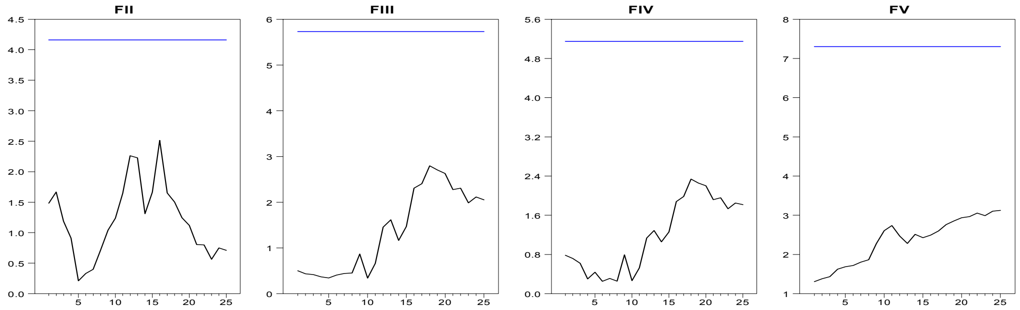


Figure 5: Bounds test results: recursive estimates and fixed initial point

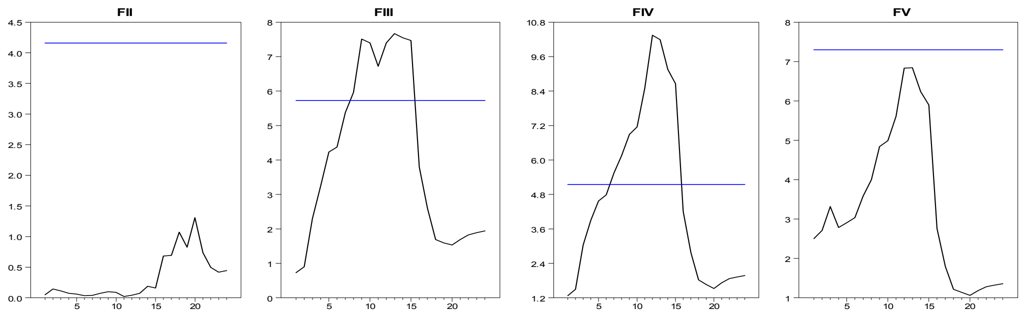
US Treasury Bill Rate



US Government Bond Rate



UK Treasury Bill Rate



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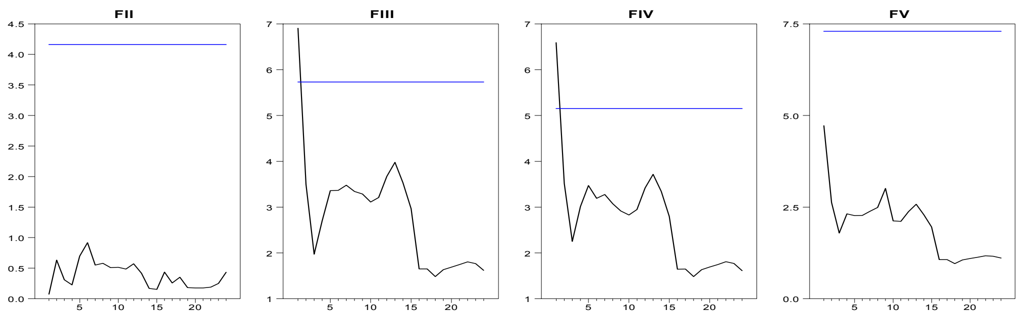
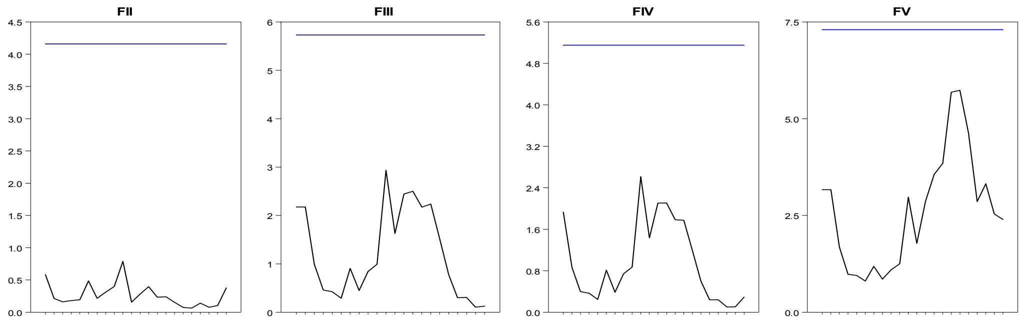
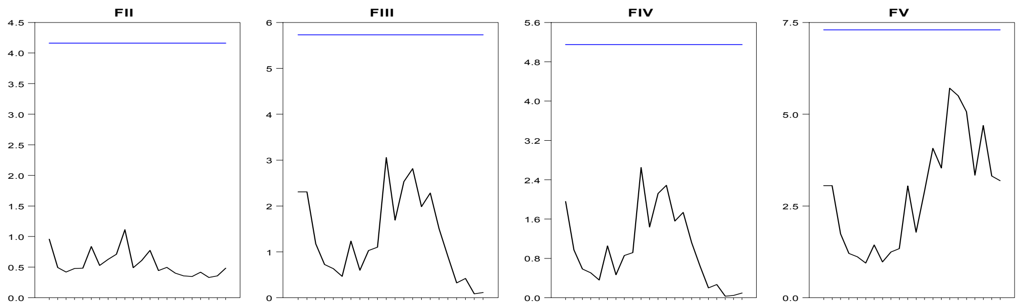


Figure 6: Bounds tests results: recursive estimates and fixed end point

US Treasury Bill Rate



US Government Bond Rate



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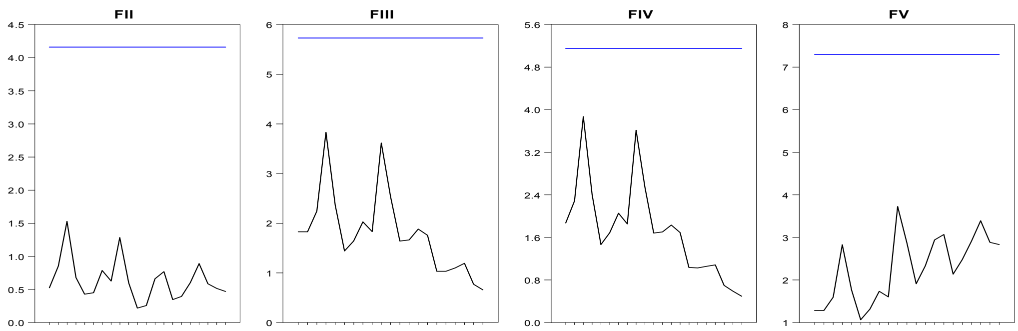

UK Government Bond Rate