Investigating Multiple Changes in Persistence in International Yields

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ABSTRACT

Although better information about the dynamics of the yields on financial assets is decisive for both borrowers and lenders alike, it is not uncommon for researchers to employ standard unit-root tests to determine the extent of the persistence and, based on such results, treat the entire series as either stationary or non-stationary. In this paper, using weekly data of yields in four international markets — Canada, the UK, the US and the euro area — from March 1997 to October 2013, and employing an approach which allows us to identify regime switches between periods of I(0) versus I(1) behaviour, we provide empirical evidence for the realistic possibility that yields may, in fact, have changing persistence over time. Our results identify and compare, for each market and several maturities, the time variation properties in the dynamics of the yield curves. Some economic implications of our results are discussed.

1. INTRODUCTION

THE DETRIMENTAL EFFECTS of the recent sovereign debt crisis which has afflicted several hitherto stable major economies, particularly across Europe, has placed the spotlight on various aspects of sovereign debt instruments. Notably, on this issue there has been a surge in the number of studies on contagion (see Gorea and Radev 2014); the impacts of high debt levels on economic activity (see Proaño *et al.* 2014); and measurement and pricing of sovereign debt (see Dias *et al.* 2014). Intuitively, however, a clear understanding of the dynamics of the yields is crucial when considering issues related to sovereign debt.

Studies on the inter-market/cross-country dynamics of yields should be relevant to investment decision-making and portfolio adjustment, particularly as it has the potential to enhance risk reduction via diversification. This study aims to contribute to this area of research by focusing on if, and how, the dynamics of the term-structure compare across some international markets, which are available to the international investor. We posit that the economic and financial implications of such an investigation underscore its importance as a policy issue.

Given the different statistical and economic implications of classifying a series as stationary I(0) or non-stationary I(1), it is now commonplace in empirical research to test for the presence of unit-roots in time series data. In particular, such a distinction is important, and contributes to our understanding of the behaviour (and potential effects) of shocks on economic and financial variables. Whilst the impact of shocks will be transitory for stationary (I(0)) series, i.e. stationary time series display mean-reverting behaviour, a random shock may have persistent effects for non-stationary (I(1)) series, i.e. a non-stationary variable will exhibit persistent behaviour following the shock. To this end, standard unit-root tests are often employed in the attempt to determine stationarity of time series data. There is emerging evidence however, suggesting that such blanket and knife-edge classifications of entire series as being either I(0) or I(1) may in fact be misleading, as it may not be fully representative of the series' behaviour (see among others Bataa *et al.* 2013, and Halunga et al. 2009). Against this background, some studies have determined that it is possible for certain economic and financial time series to display changes in persistence, varying between difference-stationary I(1), and trend-stationary I(0) regimes (see Taylor 2005; Harvey *et al.* 2006; Leybourne *et al.* 2007). Further, some empirical evidence of such behavioural shifts can be found in the literature (see Pesaran et al. 2006, for US Treasury bills; Sollis 2006 and Sanso-Navarro 2009, for the S&P composite dividend yield; Noriega and Ramos-Francia 2009, for US inflation rates; and Leone and Medeiros 2014, for the NASDAQ composite index and dividend yield). Interestingly however, in applied work the assumption of uniform stationarity or non-stationarity is still not uncommon and is often based on the standard augmented Dickey-Fuller (ADF) tests. We note here that such pre-modelling analyses are necessary to determine the characteristics of the data. However, given that they only provide a somewhat static summary of the series' behaviour over a given timespan, some information may be lost on possible changes in behaviour over time. In fact, testing for changing persistence, arguably an important pre-cursor to modelling time series, is rather uncommon despite the high potential for misleading implications.

In this study, the primary objective is to examine changes in the persistence of yields. Such a pre-modelling exercise would prove informative to any subsequent modelling of the term structure, which falls outside the scope of this paper, and be beneficial in analyses which are likely to assist policy decision-making.

Specifically, the aim here is to investigate the behaviour of government bonds yields, which should be informative for investors and speculators alike.

This line of enquiry is motivated not only by the relevance of the huge increases in sovereign debt in recent years, but also by the importance of potential asymmetric behaviour in the dynamics of the various yields, and the implications for risk reduction via diversification. In particular, we aim to identify the similarities between the structural properties in weekly yield curve data for four internationally recognised financial areas, namely Canada, the euro area, the UK and the US, employing a test proposed by Leybourne *et al.* (2007, hereafter LKT), which determines changes in the order of integration of a time series. The iterative property of the LKT approach allows us to identify all the I(0) and I(1) periods in each series over the sample period, which then allows clear comparison of the break dates and properties across the yields. Our analyses allow, with empirical backing, discussion of the potential for diversifiable risk reduction for investors allocating across these markets and informs the important question of which international markets are most likely to exhibit similar behaviour. Furthermore, within each of the four market areas we investigate, employing the dynamic correlation methods proposed by Yetman (2011), the extent of comovement between the various maturities. In particular, this exercise sheds light on how the short end and long end maturities comove, if at all.

The remainder of this paper is organised as follows: Section II presents the motivation for this study, Section III provides a description of the data and econometric techniques, Section IV presents the main results and Section V concludes.

2. Motivation

There are two main motivations for this study. First, it is now common knowledge that in recent years, particularly the years preceding the most recent global financial crisis of 2007/8, that government debt levels increased dramatically. To illustrate, Table 1 presents a summary of the public debt levels for some international markets for 2014. The source of these funds, i.e. lenders (investors), obviously would be concerned about the potential for losses in their investments. Intuitively, the increased debt levels suggest an increase in either the number of investors or an increase in the amount invested per capita. In either case, the huge amounts suggest that the detrimental effects of any losses, should they occur, will be high and the more informed investors are about the behaviour of the different maturities of government bonds available to them — domestically and internationally — the more effectively they can allocate their wealth. Further, it is worth noting that while bond yields and their prices are a matter of concern mainly for investors' decisions about buying or selling bonds, for investors who decide to hold until maturity interim fluctuations in price and yield might affect the current value of their portfolio, but should not, all things being equal, have an effect on the cash flow or the total investment return of these bonds.

Table 1: Total Public Debt as of May 2014

	USA	*UK*	*Canada*
Public Debt	$13,677,681,967,213	$2,529,857,377,049	$1,633,997,814,208
Public Debt/GDP (%)	83.4	96.8	85.9

Source: Data compiled by Economic Intelligence Unit [See http://www.economist.com/content/global_debt_clock]

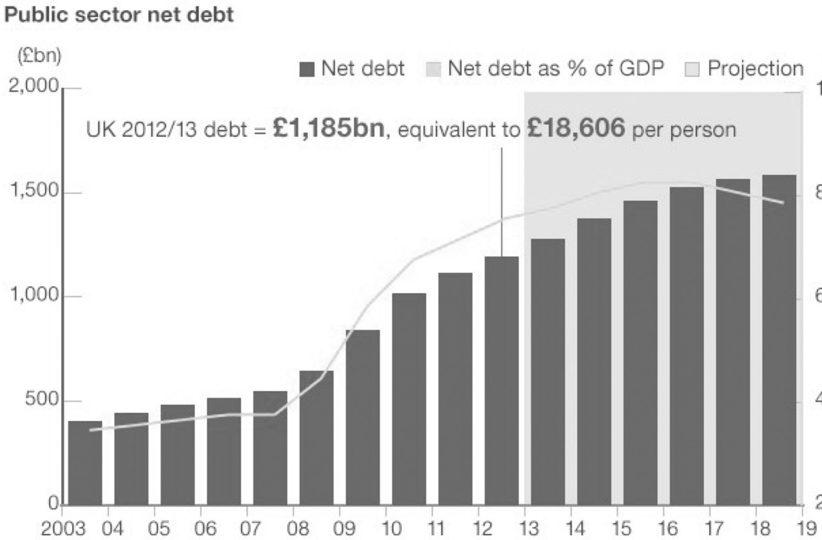
For the UK, Figures 1a - 1c below illustrate recent levels of Public Sector Net Debt, Deficit/Surplus and Net Borrowing. A noticeable feature is that they show significant increases in government debt, particularly in recent years.

Furthermore, Figure 2 points to a general downward trend in yields in the pre-2007 period across all maturities and markets. However, there also appears to be greater variability amongst the markets at the short end of the yield curve i.e. 3- and 12-month. In the post-2007 period, some extreme behaviour is clear. In particular, dramatic falls coinciding with the onset of the crisis are seen, with historically low yields being observed and remaining low through this post-crisis period in the UK, US and Canadian markets, which are typically considered to be safe havens. This is coupled with diverging and relatively higher yields in the euro area, a potential driver being the sovereign debt issues plaguing some countries in this region. We suggest that this goes someway to underscore the relevance of analysing the similarities and differences across these international markets.

It is apparent that these observed extreme changes in the yield behaviour i.e. in the time series properties of the yields, are in direct response to the global financial crisis. Coleman and Sirichand (2014) highlight the similar monetary policy responses by the central banks of these regions to this global financial shock, which is expected to result in a higher degree of comovement amongst these international yields.

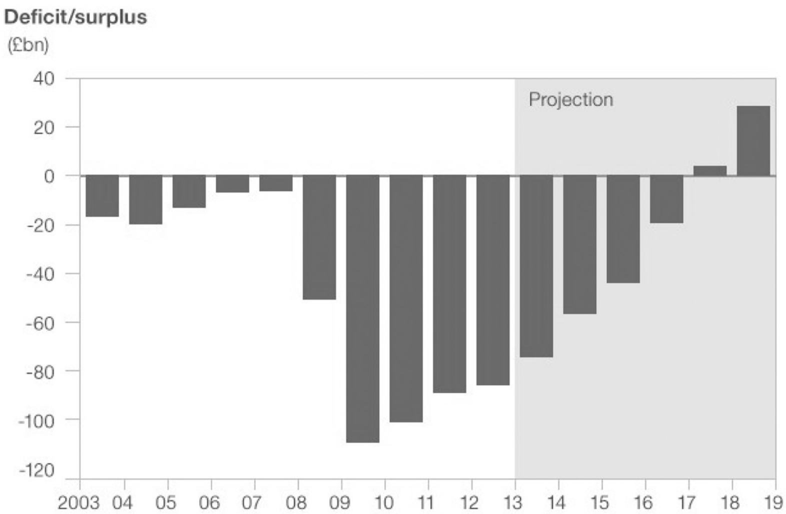
The second motivation, from the investor's perspective, is the potential information that can be extracted for the purposes of diversification and portfolio rebalancing, so as to reduce exposure to risk. For the risk-averse international investor, theories supporting diversification suggest that portfolios composed of assets that respond similarly to a shock will increase investors' exposure to unsystematic risk, whereas portfolios comprising a mix of assets that do not respond similarly to shocks should mitigate some of this risk. Since the seminal work by Markowitz (1952) and Tobin (1958) on the gains from holding a well-diversified portfolio of assets (to reduce overall portfolio variance), there has been ample evidence positing that the degree to which diversification can reduce risk depends upon the correlations among asset returns. In short, unsystematic risk can be mitigated through diversification when returns are not perfectly correlated. There is no shortage of studies highlighting the benefits of international diversification to the investor, whereby gains to the investor come about from foreign assets having a lower correlation with domestic assets. This includes the early works of Grubel (1968) and

Figure 1a: UK Public Sector Net Debt (2003 - 2013 actual; 2013 - 2019 projected)



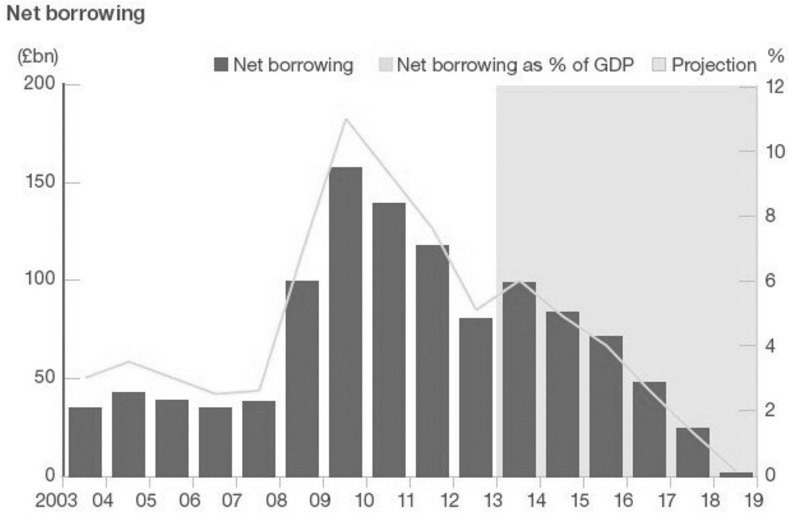
All figures for financial years, eg April 2012-March 2013
Source: ONS/OBR

Figure 1b: UK Deficit/Surplus amount (2003 - 2013 actual; 2013 - 2019 projected)



All figures for financial years, eg April 2012-March 2013
Source: ONS/OBR

Figure 1c: UK Net Borrowing (2003 - 2013 actual; 2013 - 2019 projected)



All figures for financial years, eg April 2012-March 2013
Source: ONS/OBR

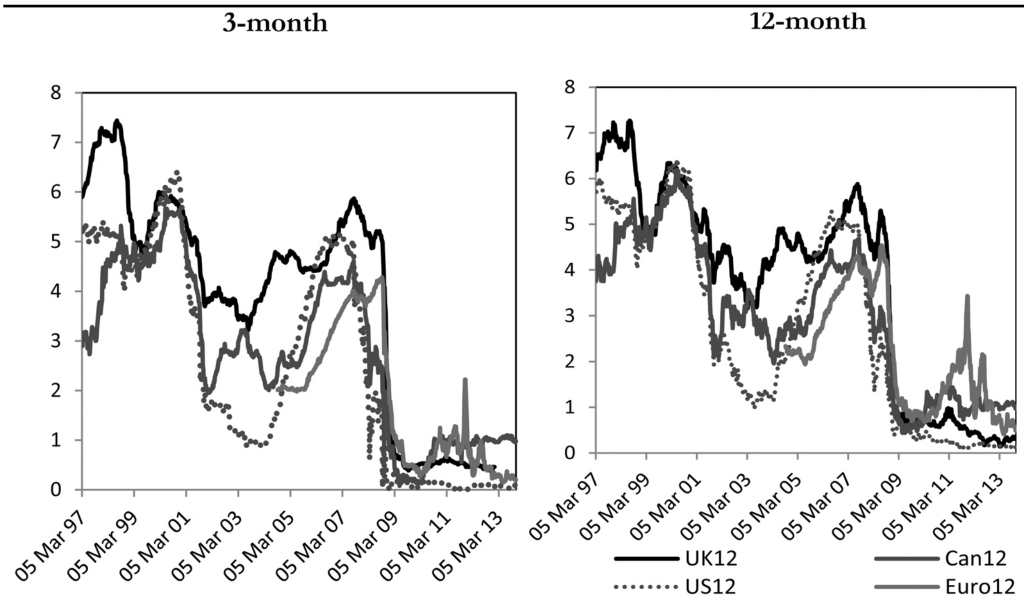
Levy and Sarnat (1970) on welfare and capital gains, through to recent studies by Coeurdacier and Guibaud (2011) on bilateral cross-border equity holdings. Following the recent global financial crisis of 2007/8, several studies have attempted to examine how investors rebalance their portfolios during times of uncertainty. Notably, the focus of these studies has been on the relation between equities and bonds and has highlighted investors' desire for safe havens, such as bonds and gold (see for example Ciner *et al.* 2013 and references cited therein). However, it is also worth noting the interesting perspective hypothesised by Raffestin (2014), that although portfolio diversification makes investors individually safer, it also creates connections between them through common asset holdings, which creates endogenous covariances between assets and investors, and thereby enhances systemic risk by propagating shocks more swiftly through the system. Further, whilst the benefits of international diversification are well documented, several recent studies argue that greater financial market integration and increasing correlations between international assets has the effect of eroding such benefits, see You and Daigler (2010), Wibaut and Wilford (2009, cited in Kemper, Lee and Simkins (2012)). However, De Santis and Gerard (2009) also find that EMU has enhanced financial market integration, and granted euro area investors greater access to euro area markets; suggesting that there are still substantial gains from diversifying internationally.

With the significant liberalisation of financial markets, the avenues for diversification have widened, providing investors with greater investment opportunities. Changes in the time series properties of yields would alter the risk and return characteristics of these assets, and potentially affect investors' holding of that asset. Further, such changes may also impact on the correlations between national yields of differing maturities and international yields, which would have implications for optimal portfolio allocation. With this in mind, identifying changes in the times series properties of the yields and determining the extent of any changes would inform investors and assist them to make optimal allocations, whereby they may reallocate their wealth among debt-securities and other assets. In order to contribute to the literature on portfolio selection involving international bond markets, this study examines the similarities or differences in the observed breaks in each of these markets and thereby allows comment on the potential, if any, that may accrue from international diversification.

3. Data

Our analysis employs weekly yield curve data for four internationally recognised financial areas, namely Canada, the euro area, the UK and the US.[2] We consider four points on these government liability curves, i.e. maturities of 3-, 12-, 60- and 120-months (hereafter *y*3, *y*12, *y*60 and *y*120), spanning 05/03/1997 to 30/10/2013 for Canada, the UK and US; and 08/09/2004 to 30/10/2013 for the euro area (due to data availability).[3] This analysis could easily be extended to consider more points along the yield curve, however we focus on two points at the short and two points at the long end of the yield curve, which is in line with our objective to compare the changes in persistence at the short end with the long of the maturity spectrum.

Figure 2: Yields March 1997 to October 2013



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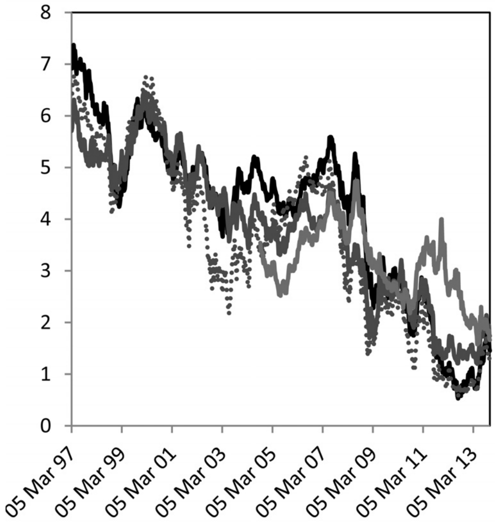
60-month | **120-month**



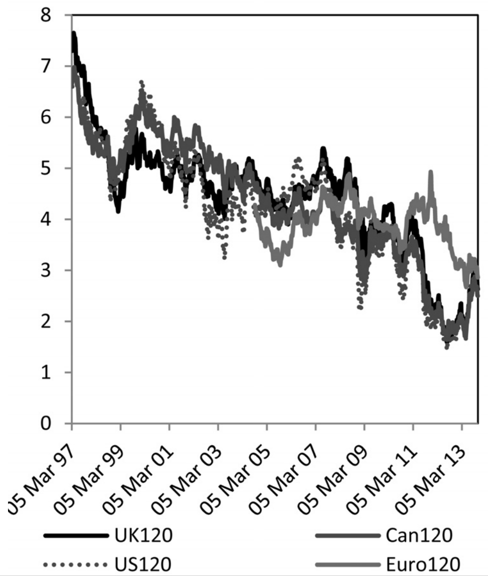


Table 2a: Summary Statistics of Yields

Series		*Mean*	*Std. Dev*	*Maximum*	*Minimum*	*Obs.*
3-month	UK	3.88	2.17	7.44	0.39	827
	Can	2.77	1.58	5.67	0.08	870
	US	2.51	2.15	6.41	0.00	870
	euro area	1.77	1.33	4.28	0.15	478
12-month	UK	3.70	2.21	7.27	0.14	870
	Can	3.00	1.59	6.19	0.44	870
	US	2.74	2.13	6.42	0.09	870
	euro area	2.13	1.22	4.54	0.41	478
60-month	UK	4.10	1.65	7.37	0.53	870
	Can	3.83	1.40	6.47	1.20	870
	US	3.61	1.70	6.79	0.56	870
	euro area	3.12	0.69	4.74	1.58	478
120-month	UK	4.40	1.14	7.65	1.59	870
	Can	4.33	1.24	6.98	1.64	870
	US	4.22	1.28	6.91	1.43	870
	euro area	3.87	0.45	4.93	2.67	478

Figure 2 provides a graphical representation of the data and Table 2a provides summary statistics. A general comovement between the regions for each of the n-month rates (n = 3, 12, 60 and 120) can be observed, with an overall decline across all rates over the sample. Moreover, the yield curves also appear to exhibit tighter comovement at the long end than at the short.

The correlations, presented in Table 2b, corroborate this, with UK, US and Canadian yields being more strongly correlated at both the short and long end, than each of those countries with the euro area. Further, the correlation is markedly weaker between the UK, US, Canada and the euro area at the longer end.

Table 2b: Correlations

	3-month	*12-month*	*60-month*	*120-month*
UK-Can	0.88	0.91	0.94	0.91
UK-US	0.86	0.90	0.94	0.92
UK-euro area	0.92	0.87	0.73	0.49
Can-US	0.92	0.94	0.95	0.94
Can-euro area	0.86	0.85	0.65	0.37
US-euro area	0.77	0.76	0.61	0.31

Notes: Descriptive statistics are presented for weekly observations of the 3-, 12-, 60- and 120-month yields over 05/03/1997 to 30/10/2013 for the UK, Canada and the US (870 observations), and over 08/09/2004 to 30/10/2013 for the euro area (478 observations). UK 3-month has a slightly shorter sample, ending 02/01/2013 (827 observations). The Pearson's Correlation Coefficient is computed for each pairwise combination.

In empirical studies, it has now become standard practice to include in the pre-modelling stages unit root tests aimed at ascertaining stationarity or otherwise of the data. In this study, we follow this trend by assessing the stationarity properties of the data by employing the widely used augmented Dickey-Fuller (ADF) unit root tests. Further, aiming to establish robustness of the main investigation to be carried out in this work, as a preliminary measure we also investigate the possibility that the results are not being driven by outliers. As such, we also analyse the Kalman-smoothed data in a similar fashion. The results obtained indicate clearly that the stationarity properties of both the raw and Kalman-smoothed data are, in each case, qualitatively the same.[4] The results confirm that for each series, the null of non-stationarity cannot be rejected. A more robust analysis of the data is necessary to allow us to comment explicitly on the cross-market dynamics and to make any credible assertions regarding the merits of diversifying across these markets.

4. Empirical methods

Our empirical analyses proceed as follows. Aiming to compare the dynamics of the financial assets across the four international markets, we test for and date changes in the order of integration of each of the financial assets, i.e. between different trend-stationary and difference-stationary regimes. We apply a test proposed by Leybourne *et al.* (2007, LKT) which determines changes in the order of integration of a time series. By allowing consistent estimation of the change dates LKT is robust to the presence of (multiple) level breaks and therefore, has advantages over similar tests proposed by Harvey *et al.* (2006) and Leybourne and Taylor (2006), both of which are inconsistent against processes which display multiple changes in persistence. In brief, the data generation process consists of the following time-varying AR(p):

$$y_t = d_t + u_t \tag{1}$$

where in our case y_t is the yield and $d_t = z'_t\,\beta$, the deterministic component. The LKT approach allows for two alternatives:

(i) z_t = 1 and $\beta = \beta_0$, the (possibly non-constant) level of the variable, and
(ii) $z_t = [1,t]$ and $\beta = [\beta_0, \beta_1]'$, and ε_t is a martingale difference sequence.

In Eq. (1), u_t is taken to be a time-varying AR(p) process, which can be rewrit ten as $u_t = \rho_i u_{t-1} + \sum_{j=1}^{k_i} \vartheta_{ij} \Delta u_{t-j} + \varepsilon_t$, t = 1,2, ... ,T, where $k_i = p_i$-1, i=1,..., m+1, and m is the number of changes in persistence. Thus, Eq. (1) permits the estimation of separate ρ_i (the dominant AR root) and ϑ_{ij} (the lag coefficients) to differ across the m+1 regimes, i.e. the AR coefficients and orders are regime dependent. There are two hypotheses: the null, H_0: $y_t \sim I(1)$ throughout, that is $\rho_i = 1 \forall t$, versus the alternative, H_1: y_t undergoes one or more regime shifts between $I(1)$ and $I(0)$ behaviour. Therefore, under the alternative, ρ_i may undergo $m \geq 1$ unknown persistence changes, giving rise to m+1 segments with change point fractions given by $\tau_1 < \tau_2 < ... < \tau_{m-1} < \tau_m$. LKT's procedure partitions the time series, y_t, (t=1,...,T) into its separate $I(0)$ and $I(1)$ regimes, and consistently estimates the associated change point fractions. LKT define the fraction $\tau \in (\lambda,1)$ for a given λ in (0,1), and base their test H_0 vs. H_1 on the local GLS de-trended ADF unit root statistic (see Elliot *et al.* 1996), that uses the sample observations between λT and τT, called DFG(λ,τ), obtained as the standard t-statistic associated with $\hat{\rho}_i$ in the fitted regression:

$$\Delta y_t^d = \hat{\rho}_i y_{t-1}^d + \sum_{j=1}^{k_i} \hat{b}_{i,j} \Delta y_{t-j}^d + \hat{\varepsilon}_i, \qquad t=\lambda T;\ \lambda T + 1;...;\ tT \tag{2}$$

where $y_t^d = y_t - z_t' y_t^d = y_t - z_t'\hat{\beta}$, with $\hat{\beta}$ the OLS estimate of β (obtained from regressing $y_{\lambda T}$ on $z_{\lambda T}$ where $y_{\lambda T} \equiv (y_{\lambda T}, y_{\lambda T+1} - \hat{\alpha} y_{\lambda T,...,} y_{\lambda T} - \hat{\alpha} y_{\tau T-1})'$ and

$z_{\lambda T} \equiv (z_{\lambda T}, z_{\lambda T+1} - \hat{\alpha} z_{\lambda T,...,} y_{\lambda T} - \hat{\alpha} z_{\tau T-1,}$ with $\hat{\alpha} = 1 + \overline{c} / T$, and $\overline{c} = -10$.

In our analyses, we set $\lambda = 1/T$ and explore the subsamples. Following LKT, we set $\tau = 0.20$, and employ the modified Akaike Information Criterion (MAIC) for determining the value of k_i, as suggested by Ng and Perron (2001) using a maximum lag order of 12.

The test statistic proposed by LKT is based on doubly-recursive sequences of DF type unit root statistics:

$$M = \inf_{\lambda \in (0,1)} \inf_{\tau \in (\lambda,1)} DF(\lambda, \tau) \tag{3}$$

The corresponding estimators $(\hat{\lambda}, \hat{\tau}) \equiv \arg\inf_{\lambda \in (0,1)} \inf_{\tau \in (\lambda,1)} DF(\lambda, \tau)$ give the start and end points, i.e. the interval $[\hat{\lambda}, \hat{\tau}]$ of the first $I(0)$ regime over the whole sample. Any further $I(0)$ regimes are then detected sequentially by applying the M statistic to each of the resulting subintervals $[0, \hat{\lambda}]$ and $[\hat{\tau}, 1]$. We continue in this fashion for all temporal dimensions exceeding 20 observations, which is the minimum for which LKT (p. 13) report finite sample critical values until, for each period considered the 'most prominent' $I(0)$ regime, together with their start and end points, have been identified. We note that the period between the end point of one $I(0)$ regime and the start point of the next $I(0)$ regime must represent an $I(1)$ regime.

Furthermore, with the aim of analysing whether bond yields' regime switches are country and/or maturity specific, we conduct a dynamic correlation exercise. An analysis of the extent and direction of comovement between the yields within each market, would provide key insights into any similarities that may exist between the behaviour of the yields for different maturities. For its simplicity and insightful information content we adopt the approach proposed by Yetman (2011). Although the Pearson Correlation Coefficient is often employed and is a popular measure to analyse comovement a major limitation, particularly with high frequency data, is the narrowness of the time-specific information it provides. Further, it does not provide the user with the dynamic correlation, which may be more informative. Hence, our use here of the dynamic approach, which proposes an improvement based on a *z*-score. In brief, as applied to our dataset, the comovement at time *t* between an n- and m-month yield (denoted *yn* and *ym*) is estimated as the product of their respective *z*-scores:

$$\rho_t^{nm} = \frac{(yn_t - \overline{yn})}{\sqrt{\frac{1}{T-1}\sum_{t=1}^{T}(yn_t - \overline{yn})^2}} \cdot \frac{(ym_t - \overline{ym})}{\sqrt{\frac{1}{T-1}\sum_{t=1}^{T}(ym_t - \overline{ym})^2}} = z_{nt} z_{mt} \tag{4}$$

where a positive value for ρ_t^{nm} implies that the yields move in the same direction (either both increase or both decrease), whereas a negative value implies movement in opposite directions. Further, the size of the coefficient reflects the magnitude of change. The dynamic correlations we obtain and present in graphical format, Figure 4, allow us to comment on the potential for identifying similarities and/or differences across the maturities within a given market.

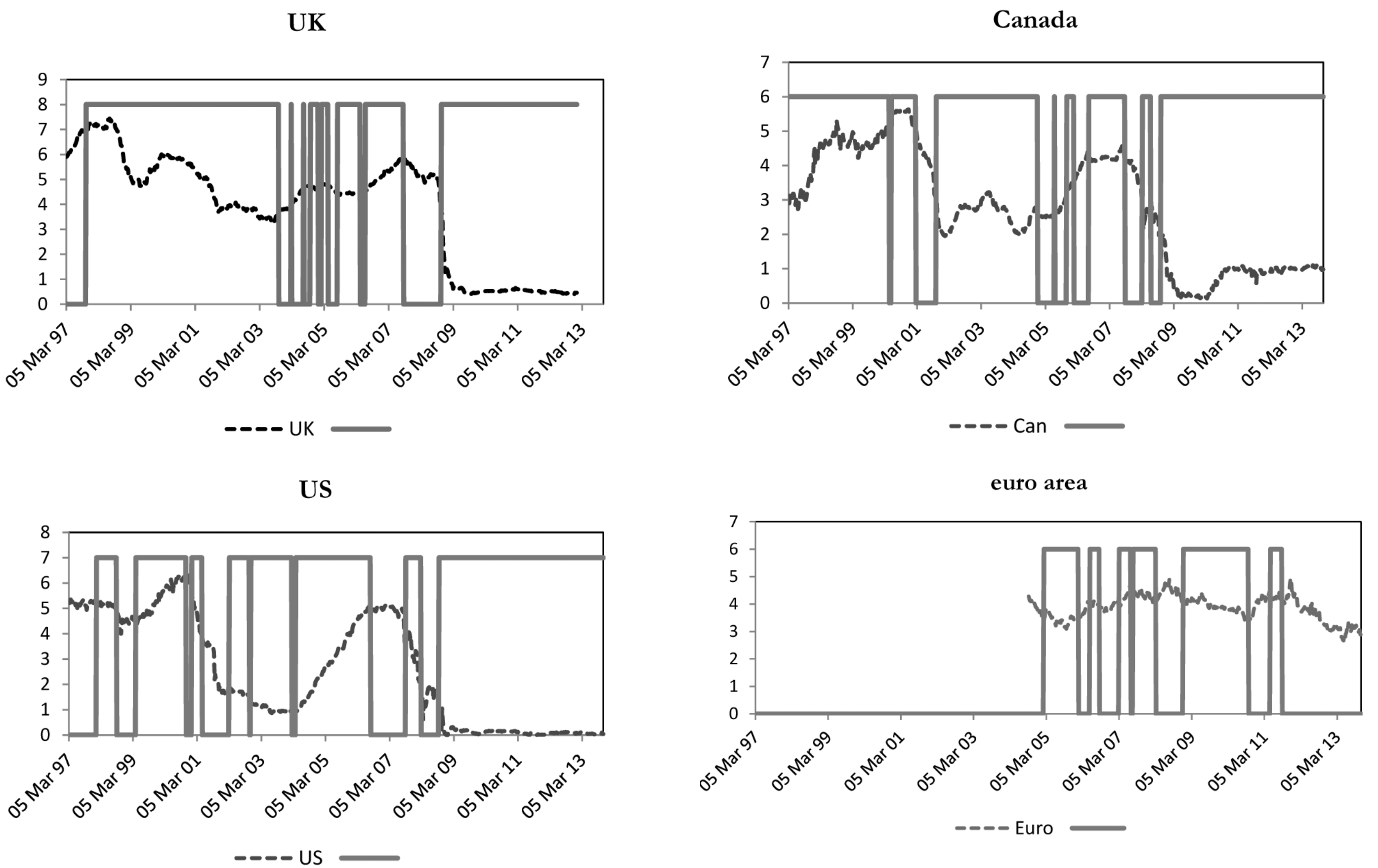
5. Results and discussion

Given that a visual inspection of the data (shown in Figure 2) suggests a general long-term reduction in yields, which is not inconsistent with a downward linear trend, we employ the *M*-test with a constant and trend, $z_t = (1, t)'$ in our application of the LKT test to the data. For each maturity and each of the four areas, we are able to determine and identify, recursively, all the *I*(0) periods over the entire sample, Appendix A reports in detail the specific break dates and Figures 3a - 3d illustrate the periods identified as *I*(0).

For each of the maturities, we highlight some of the salient issues. First, at the shorter end, specifically for the 3- and 6-month yields, our analyses uncover many dates when the data are consistent with regime switching between *I*(0) and *I*(1) over the period. We note that prior to the recent global financial crisis (GFC) of 2007/8, the break dates we uncover are fairly similar across the four markets (Canada, the UK, US and euro area), both in number and timing. However, in the period following 2007/8, we find the yields for Canada, the UK and US conform to an *I*(0) process and have similar break dates. But the dynamics of the yields for the euro area behave differently and can be described as *I*(1) processes. We note that this global shock was a market-wide shock that had an impact on all the four areas considered, where this type of systematic risk cannot be eliminated through portfolio diversification. However, it is also worth noting that different assets were affected in different ways, such that those investors with a well-diversified portfolio would have been affected to a lesser extent. Second, for the longer end, 60- and 120-month, there appear to be fewer clear-cut similarities across the market areas — both pre-2007/8 and post-2007/8. This suggests that there are potential gains, so far as risk reduction is concerned, to be made if investors diversify internationally at these longer maturities. Nonetheless, some similarities between Canada and the US are noticeable, whereas (particularly for the 120-month instruments) there appears to be some similarity between the dynamics observed for the UK and the euro area markets. Interestingly for the euro area, irrespective of the maturity of these assets, our results indicate *I*(1) behaviour in the post 2007/8 period, suggesting persistence. In addition we note that, for the 120-month instruments across all four market areas, the dynamics in the post-2007/8 era are characterised by persistence. Specifically, for the risk-averse investor, gains from diversification across three of these markets i.e. the UK, US and Canada, would be lower given the similarities we have highlighted in the behaviour of these yields i.e. break dates and order of integration; more so at the longer end compared to the short end.

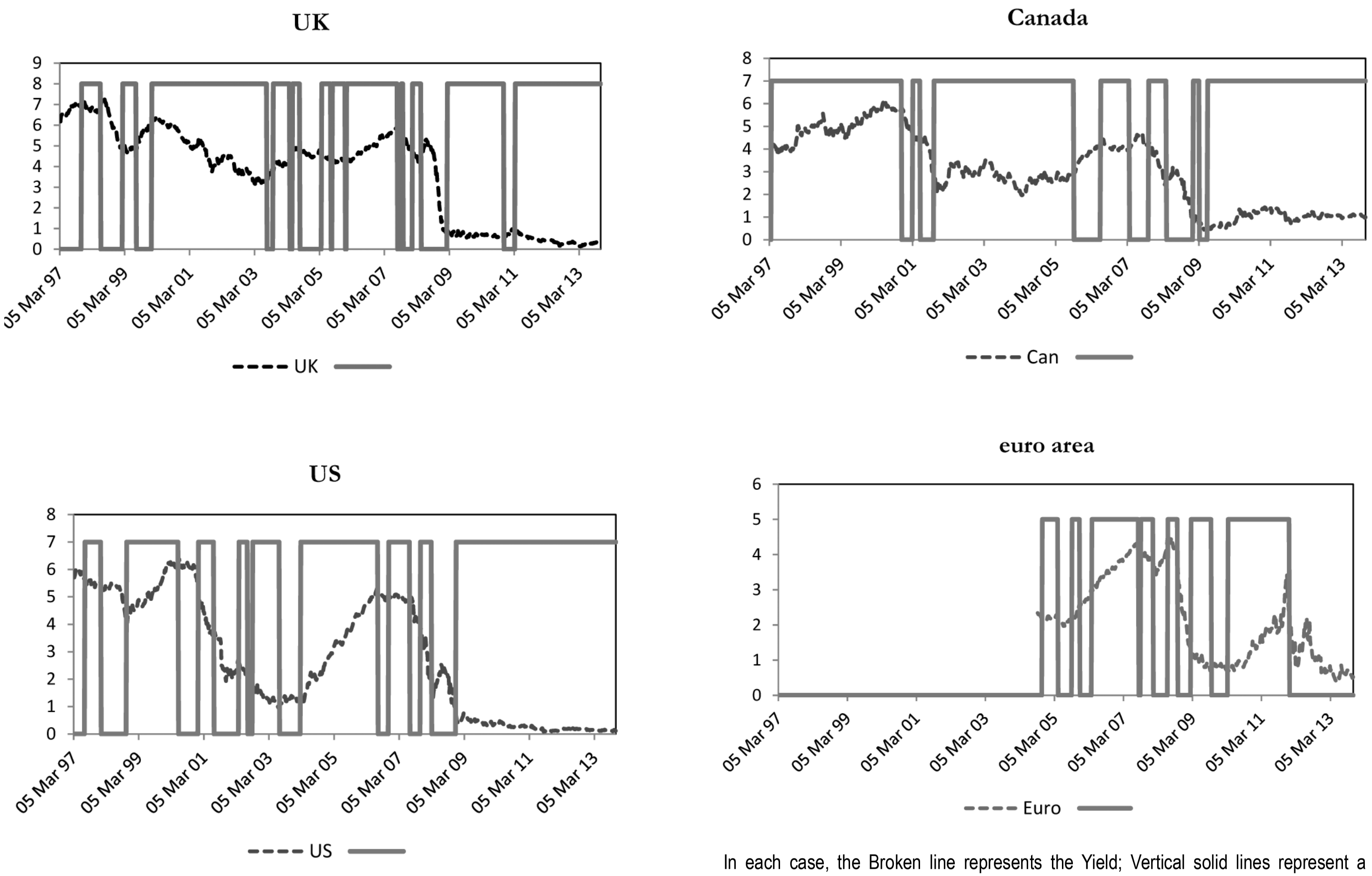
Our analyses of the dynamic correlation between the yields across the four maturities (see Figure 4) for each of the individual markets, suggest that there is significant positive comovement between the maturities within the UK, US and Canadian markets. The positive values of ρ_t^{nm} imply movement in

Figure 3a: I(0) and I(1) periods based on LKT Test for 3-month Yields



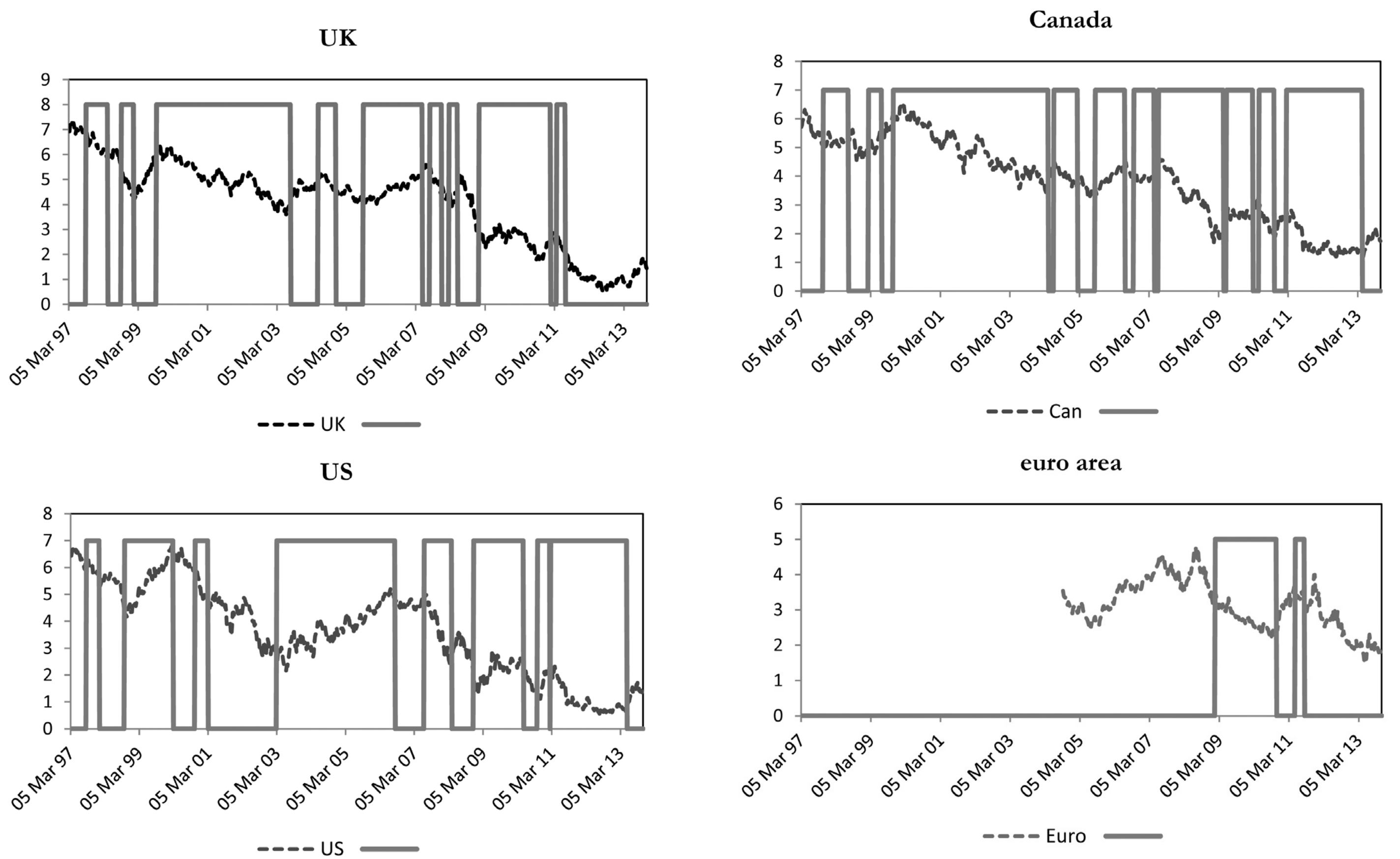
In each case, the Broken line represents the Yield; Vertical solid lines represent a regime switch. *I*(1) periods represented by 0 on y-axis.

Figure 3b: I(0) and I(1) periods based on LKT Test for 12-month Yields



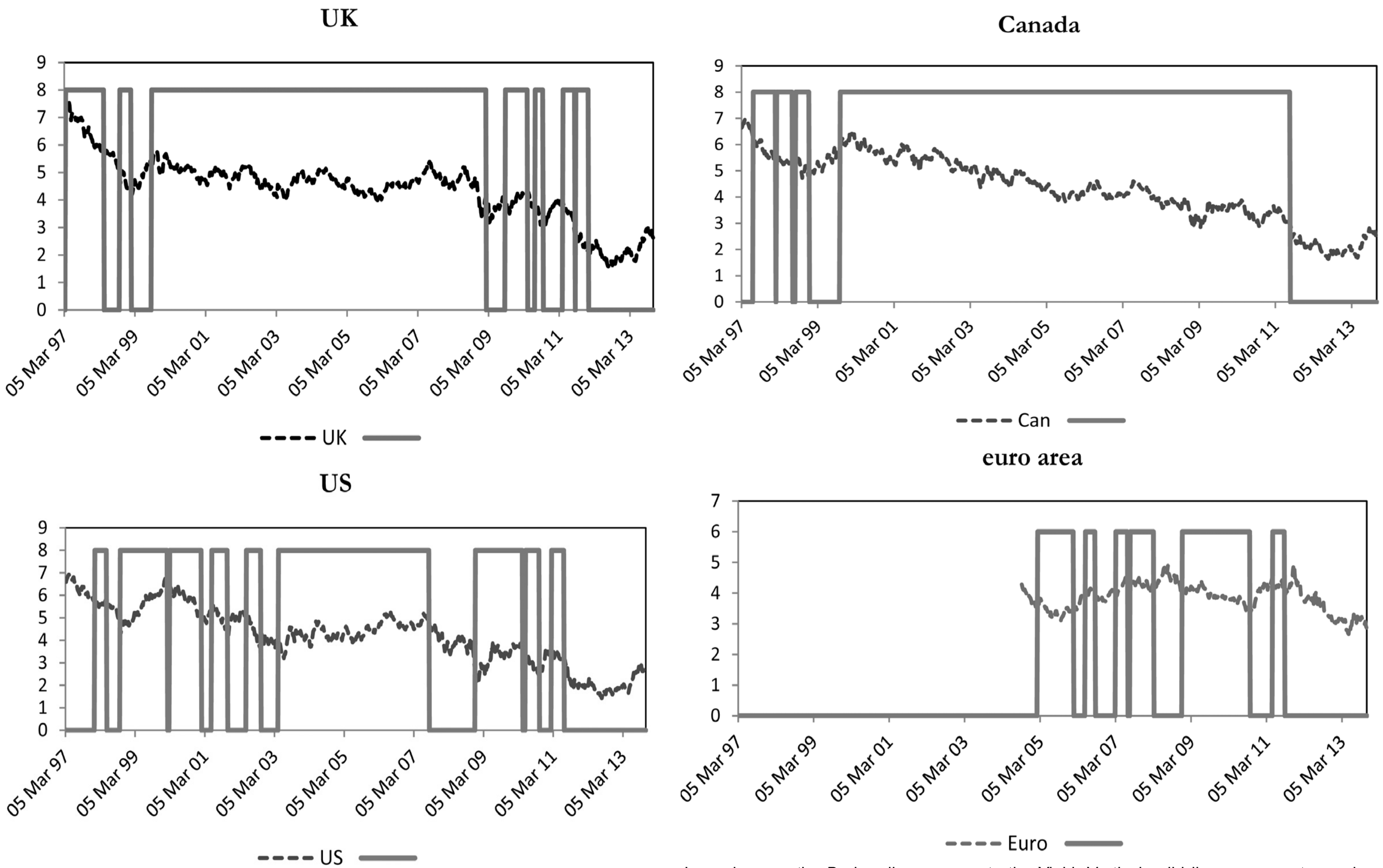
In each case, the Broken line represents the Yield; Vertical solid lines represent a regime switch. *I*(1) periods represented by 0 on y-axis.

Figure 3c: $I(0)$ and $I(1)$ periods based on LKT Test for 60-month Yields



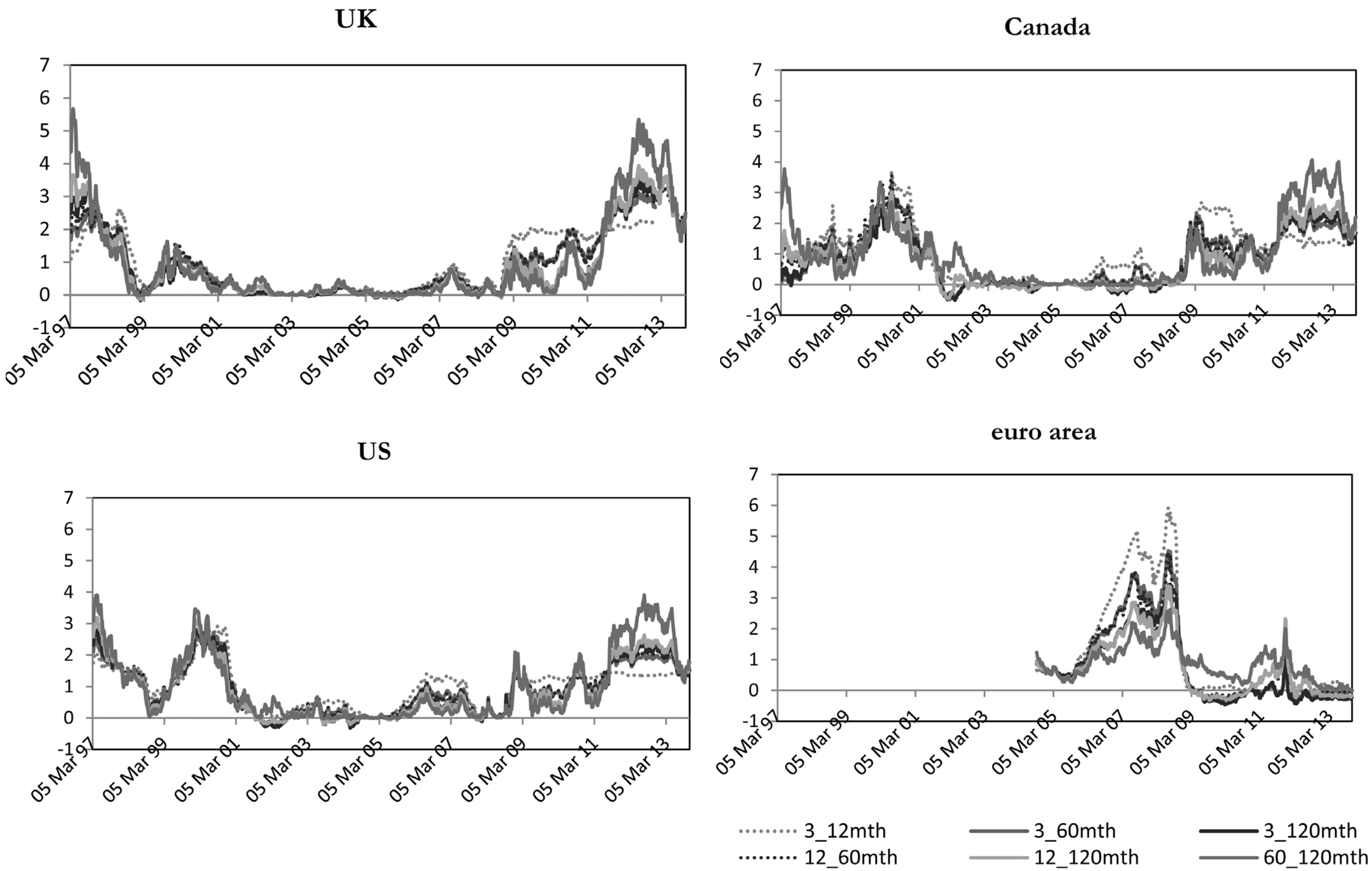
In each case, the Broken line represents the Yield; Vertical solid lines represent a regime switch. $I(1)$ periods represented by 0 on y-axis.

Figure 3d: I(0) and I(1) periods based on LKT Test for 120-month Yields



In each case, the Broken line represents the Yield; Vertical solid lines represent a regime switch. *I*(1) periods represented by 0 on y-axis.

Figure 4: Dynamic Correlations between (country-specific) Yields



the same direction. However there is relatively low and sometimes negative comovement within the euro area, particularly following the global financial crisis, between the short (3- and 12-month) and the long (120-month) maturities, highlighting differences in the behaviour at these extremes.

Much as it is tempting empirically to make a direct link between comovement and the observed regime switches, we find in the initial part of our investigation there are several reasons not to do so, a key reason being that similar $I(0)/I(1)$ behaviour does not necessarily imply positive or negative comovement, in that it is not necessarily the case that if a pair of yields are either both $I(0)$ or $I(1)$, this will result in high, positive, dynamic comovement; whether a series is stationary or not does not provide us with the direction in which the series is moving. However, it is also conceivable that if they do share the same time series properties then they do comove, given that they are assets that belong to the same asset class, differing only in their maturity. It is worth pointing out that the yields for the UK, US and Canada i.e. yields belonging to each country, are likely to carry the same default risk. However, for the euro area default risks are likely to differ quite substantially among member states. Against this background, the relatively positive comovement observed for the maturities within the UK, US and Canada is not surprising, especially given the link between yields of differing maturities, e.g. as postulated by the expectations hypothesis.

6. Summary and conclusions

In view of the reported increasing levels of public debt and the implications of these increases for sovereign credibility and fiscal policies, studies such as this, which aim to shed some light on the dynamics of the yields on these sovereign debt instruments, are both important and topical. Further, the added information these studies provide to investors cannot be underestimated, particularly because of the direct financial implications the dynamics of yields and returns on these investments have on investor decisions and portfolio composition.

This paper assesses the dynamic properties of yields across four international market areas — Canada, the UK, US and euro area. Employing the LKT approach of identifying regime switches between $I(0)$ and $I(1)$ states, we are able to make comparisons within and across these markets. Our results answer the following questions: how (dis)similar are the regime switches across these international markets? Are there any noticeable differences which suggest that there are potential gains from diversifying across these markets? We find that at the shorter end, i.e. 3- and 6-months, the regime switches for Canada, the UK and the US show significant similarities, thereby suggesting limited gains from diversification across these markets. However, the regime switches in the euro area appear to be significantly different in terms of the timing. Overall, the results show some noticeable similarities in the dynamics between Canadian, UK and US yield curves. We find ample evidence of significant overlaps in the dates and periods when the LKT approach detects *I*(0) behaviour for these three markets, corroborating the findings of studies which posit comovement in international markets. However, there is much less evidence of overlapping *I*(0) behaviour in the dynamics of the yields between the euro area and the other markets.

Against this background, and in line with the diversification literature, the risk-averse investor stands to reduce their exposure by diversifying across any of these markets. However, it is worth noting that the sovereign debt issues plaguing many euro member states has seen many investors seeking safe havens in the form of, for instance, UK and US government debt. So even though there are potential gains from diversifying across all the markets considered, financial and economic conditions may make for some markets being considerably more attractive than others. Further, our examination of comovement between different maturities within the individual markets shows positive comovement between yields of different maturities within the UK, US and Canadian markets, even following the recent financial crisis. However, we find that the comovement between yields of different maturities within the euro area market is relatively low and at times negative; particularly following the crisis. Again, the gains from diversification would be lower for an investor seeking to invest across different maturities within the UK, US and Canadian markets. The potential gains in the euro area market would be higher, given the low levels of comovement across the maturities in that market (post-2007/8). However, the earlier caution against ignoring any other stability related issues which have recently plagued many euro area states remains.

In conclusion, the analyses we have conducted provide empirical evidence for regime switches in yields, and therefore we posit that empirical studies that assume a uniform order of integration may lead to misleading inferences. Moreover, for the risk-averse international investor there is evidence to suggest that there are differences in the dynamics across these international markets, which provides scope for decreasing investors' exposure to diversifiable risk. The UK, US and Canadian markets show several similarities in behaviour, whereas the euro area differs in time series behaviour. Further, there is evidence of comovement among yields of different maturities within each of the same three markets, but a distinctly lower level of comovement across same for the euro area.

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APPENDIX

A: ADF Tests [Lag Length: (Based on Modified AIC, maxlag=20)]

Series		*On the raw data*		*On the Kalman-smoothed data*		
		t-stat	*Prob*	*Lag length (MAIC)*	*t-stat*	*Prob*
3-month	UK3	-1.22	0.67	16	-1.22	0.67
	Can3	-1.45	0.56	14	-1.45	0.56
	US3	-1.34	0.61	13	-1.34	0.61
	euro area	-0.82	0.81	3	-0.82	0.81
12-month	UK12	-1.17	0.69	6	-1.17	0.69
	Can12	-1.11	0.71	8	-1.11	0.71
	US12	-1.26	0.65	6	-1.26	0.65
	euro area	-1.31	0.63	8	-1.31	0.63
60-month	UK60	-1.26	0.65	2	-1.26	0.65
	Can60	-1.09	0.72	0	-1.09	0.72
	US60	-1.38	0.60	0	-1.38	0.60
	euro area	-0.87	0.80	1	-0.87	0.80
120-month	UK120	-2.16	0.22	0	-2.16	0.22
	Can120	-1.48	0.54	0	-1.48	0.54
	US120	-1.79	0.39	0	-1.79	0.39
	euro area	-1.56	0.50	1	-1.56	0.50
Test critical values:		1% level	-3.4377			
		5% level	-2.8646			
		10% level	-2.5684			

B. Detected breakdates (Estimates obtained by the Leybourne *et al.* 2007 approach)

Table B1: 3-month (*y*3) yield (with trend)

Series	*Sample*	*Sample size*	*k*	*M*	*I*(0) *start*	*I*(0) *end*
UK3	03/05/1997-01/02/2013	827	3	-1.433	10/22/2008	01/02/2013
	03/05/1997-10/15/2008	607	4	-2.040	10/15/1997	10/01/2003
	10/08/2003-10/15/2008	263	0	-3.182	06/14/2006	08/15/2007
	10/08/2003-06/07/2006	141	4	-3.708	08/03/2005	04/12/2006
	10/08/2003-07/27/2005	95	4	-3.518	02/25/2004	07/14/2004
	07/21/2004-07/27/2005	54	2	-6.212	09/29/2004	12/22/2004
	12/29/2004-07/27/2005	31	4	-10.243	02/02/2005	04/13/2005
	10/22/2008-01/02/2013	220	3	-3.471	08/26/2009	04/28/2010
	05/05/2010-01/02/2013	140	3	-4.463	03/16/2011	01/02/2013

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Can3	03/05/1997-10/30/2013	870	2	2.682	10/08/2008	10/30/2013
	03/05/1997-10/01/2008	605	1	-2.560	12/24/1997	04/19/2000
	04/26/2000-10/01/2008	441	4	-2.324	10/10/2001	08/18/2004
	04/26/2000-10/03/2001	76	3	-4.752	05/17/2000	10/04/2000
	10/11/2000-10/03/2001	52	4	-10.471	10/11/2000	02/14/2001
	08/25/2004-10/01/2008	215	2	-3.772	07/12/2006	08/22/2007
	08/29/2007-10/01/2008	58	2	-4.734	03/12/2008	06/11/2008
	08/25/2004-07/05/2006	98	1	-3.697	12/01/2004	06/15/2005
	06/22/2005-07/05/2006	55	4	-10.872	11/02/2005	01/18/2006
US3	03/05/1997-10/30/2013	870	4	-4.095	09/17/2008	10/30/2013
	03/05/1997-09/10/2008	602	1	-3.158	03/31/2004	07/26/2006
	03/05/1997-03/24/2004	369	0	-3.900	04/07/1999	10/25/2000
	03/05/1997-03/31/1999	109	0	-5.232	01/14/1998	08/26/1998
	11/01/2000-03/24/2004	178	4	-3.531	06/04/2003	02/11/2004
	11/01/2000-05/28/2003	135	1	-4.693	11/06/2002	05/28/2003
	11/01/2000-10/30/2002	105	2	-4.283	03/06/2002	10/16/2002
	11/01/2000-02/27/2002	70	4	-4.671	01/03/2001	04/25/2001
	08/02/2006-09/10/2008	111	3	-4.276	09/05/2007	02/20/2008
Euro3	09/08/2004-10/30/2013	382	2	-4.162	11/18/2009	12/21/2011
	09/08/2004-11/11/2009	271	3	-4.357	08/15/2007	04/15/2009
	09/08/2004-08/08/2007	153	4	-4.006	09/27/2006	05/02/2007
	09/08/2004-09/20/2006	107	0	-4.533	04/27/2005	09/28/2005
	10/05/2005-09/20/2006	51	4	-9.423	02/08/2006	04/26/2006

Table B2: 3-month ($y12$) yield (with trend)

Series	*Sample*	*Sample size*	*k*	*M*	*I*(0) *start*	*I*(0) *end*
UK12	03/05/1997-10/30/2013	870	0	-2.677	01/05/2000	07/16/2003
	03/05/1997-12/29/1999	148	4	-4.313	11/05/1997	06/03/1998
	10/15/2008-10/30/2013	178	3	-4.423	02/10/1999	07/07/1999
	07/23/2003-10/30/2013	537	1	-4.962	02/11/2009	11/03/2010
	07/23/2003-02/04/2009	290	0	-3.995	01/04/2006	07/25/2007
	08/11/2010-10/30/2013	224	4	-2.933	10/01/2003	03/31/2004
	04/07/2004-12/28/2008	91	1	-3.284	07/27/2005	12/14/2005
	04/07/2004-07/20/2005	68	3	-3.711	03/30/2005	07/06/2005
	04/07/2004-03/23/2005	51	4	-8.062	05/05/2004	07/21/2004
	08/01/2007-02/04/2009	80	4	-5.411	09/12/2007	12/26/2007
	01/02/2008-02/04/2009	58	0	-4.338	01/16/2008	04/16/2008
	11/10/2010-10/30/2013	156	3	-6.764	03/16/2011	10/30/2013

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Can12	03/05/1997-10/30/2013	870	2	-3.363	03/26/1997	11/08/2000
	11/15/2000-10/30/2013	677	4	-2.786	10/10/2001	08/31/2005
	11/15/2000-10/03/2001	47	4	-11.478	03/07/2001	05/16/2001
	09/07/2005-10/30/2013	426	1	-3.121	06/03/2009	10/30/2013
	09/07/2005-05/27/2009	195	4	-3.678	06/07/2006	03/21/2007
	03/28/2007-05/27/2009	114	2	-4.200	10/10/2007	04/02/2008
	04/09/2008-05/27/2009	60	4	-5.569	01/07/2009	03/04/2009
US12	03/05/1997-10/30/2013	870	2	-3.261	12/03/2008	10/30/2013
	03/05/1997-11/26/2008	613	2	-3.427	02/25/2004	07/05/2006
	03/05/1997-02/18/2004	364	2	-2.703	10/21/1998	05/17/2000
	03/05/1997-10/14/1998	85	0	-3.736	07/09/1997	12/31/1997
	05/24/2000-02/18/2004	196	1	-4.998	09/04/2002	06/25/2003
	05/24/2000-08/28/2002	119	0	-3.821	01/03/2001	06/20/2001
	06/27/2001-08/28/2002	62	4	-5.927	04/03/2002	07/03/2002
	07/12/2006-11/26/2008	125	4	-3.529	11/08/2006	06/27/2007
	07/04/2007-11/26/2008	74	3	-4.593	10/31/2007	02/27/2008
Euro12	09/08/2004-10/30/2013	478	2	-4.157	03/17/2010	12/21/2011
	09/08/2004-03/10/2010	288	1	-3.616	04/05/2006	08/08/2007
	09/08/2004-03/29/2006	82	1	-4.506	10/27/2004	04/06/2005
	04/13/2005-03/29/2006	51	4	-5.246	09/07/2005	11/23/2005
	08/15/2007-03/10/2010	135	3	-5.216	02/18/2009	09/16/2009
	08/15/2007-02/11/2009	79	4	-4.075	09/05/2007	01/09/2008
	16/01/2008-02/11/2009	57	0	-3.780	06/18/2008	09/24/2008

Table B3: 60-month (*y*3) yield (with trend)

Series	*Sample*	*Sample size*	*k*	*M*	*I*(0) *start*	*I*(0) *end*
UK60	03/05/1997-10/30/2013	870	0	-3.086	09/15/1999	07/23/2003
	03/05/1997-09/08/1999	132	4	-4.032	09/03/1997	04/15/1998
	04/22/1998-09/08/1999	73	4	-6.310	09/09/1998	01/13/1999
	07/30/2003-10/30/2013	536	0	-2.918	08/31/2005	05/09/2007
	07/30/2003-08/24/2005	109	1	-4.359	05/12/2004	11/10/2004
	05/16/2007-10/30/2013	338	0	-3.045	12/31/2008	01/19/2011
	05/16/2007-12/24/2008	85	4	-5.335	08/01/2007	11/28/2007
	12/05/2007-12/24/2008	56	4	-10.808	02/20/2008	05/14/2008
	01/26/2011-10/30/2013	145	4	-55.474	03/30/2011	10/30/2013

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Can60	03/05/1997-10/30/2013	870	1	-4.007	10/27/1999	04/07/2004
	03/05/1997-10/20/1999	138	3	-4.737	10/22/1997	07/08/1998
	07/15/1998-10/20/1999	67	4	-4.863	02/10/1999	06/23/1999
	04/14/2004-10/30/2013	403	0	-2.692	06/13/2007	04/22/2009
	04/14/2004-06/06/2007	165	1	-4.461	06/09/2004	02/09/2005
	02/16/2005-06/06/2007	121	4	-4.373	09/27/2006	04/25/2007
	02/16/2005-09/20/2006	84	3	-3.972	08/17/2005	06/21/2006
	04/22/2009-10/30/2013	236	3	-4.777	05/27/2009	02/24/2010
	03/03/2010-10/30/2013	162	1	-4.237	05/05/2010	10/06/2010
	10/13/2010-10/30/2013	160	4	-4.541	02/16/2011	04/17/2013
US60	03/05/1997-10/30/2013	870	3	-4.366	03/05/2003	08/09/2006
	03/05/1997-02/26/2003	313	0	-3.396	09/30/1998	02/23/2000
	03/05/1997-09/23/1998	82	3	-4.575	08/20/1997	12/31/1997
	03/01/2000-10/11/2000	33	4	-5.141	10/18/2000	02/28/2001
	08/16/2006-12/28/2011	281	2	-2.839	11/26/2008	05/05/2010
	08/16/2006-11/19/2008	119	0	-3.899	06/20/2007	04/02/2008
	05/12/2010-10/30/2013	282	4	-4.257	10/06/2010	02/09/2011
	02/16/2011-10/30/2013	142	4	-677.704	02/23/2011	05/08/2013
Euro60	09/08/2004-10/30/2013	478	2	-4.685	01/21/2009	10/20/2010
	10/27/2010-10/30/2013	158	4	-11.091	05/11/2011	08/10/2011
	09/08/2004-01/14/2009	228	3	-3.280	07/06/2005	06/28/2006
	07/05/2006-01/14/2009	133	0	-4.465	06/25/2008	01/14/2009

Table B3: 60-month (*y*3) yield (with trend)

Series	*Sample*	*Sample size*	*k*	*M*	*I*(0) *start*	*I*(0) *end*
UK120	03/05/1997-10/30/2013	870	3	-3.923	08/25/1999	02/04/2009
	03/05/1997-08/18/1999	129	4	-4.751	03/19/1997	04/15/1998
	04/22/1998-08/18/1999	70	4	-6.592	09/30/1998	01/20/1999
	02/11/2009-10/30/2013	247	2	-3.583	08/26/2009	04/07/2010
	04/14/2010-10/30/2013	186	4	-4.039	08/24/2011	12/28/2011
	04/14/2010-08/17/2011	71	4	-4.328	04/13/2011	08/10/2011
	04/14/2010-04/06/2011	52	4	-15.661	06/30/2010	09/15/2010
Can120	03/05/1997-10/30/2013	870	0	-4.640	10/06/1999	7/20/2011
	03/05/1997-09/29/1999	135	3	-4.506	06/25/1997	01/21/1998
	01/28/1998-09/29/1999	88	4	-5.654	02/04/1998	07/01/1998
	07/08/1998-09/29/1999	65	3	-5.519	08/05/1998	12/09/1998

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US120	03/05/1997-10/30/2013	870	4	-4.413	04/16/2003	08/08/2007
	03/05/1997-04/09/2003	319	0	-3.266	09/30/1998	02/02/2000
	03/05/1997-09/23/1998	82	1	-5.735	01/07/1998	05/06/1998
	02/09/2000-04/09/2003	166	3	-3.738	03/01/2000	01/24/2001
	01/31/2001-04/09/2003	115	0	-3.583	05/16/2001	10/24/2001
	10/31/2001-04/09/2003	76	0	-4.944	05/15/2002	10/09/2002
	08/15/2007-12/28/2011	229	2	-3.012	12/10/2008	04/14/2010
	04/21/2010-10/30/2013	185	4	-4.237	05/19/2010	10/06/2010
	10/13/2010-10/30/2013	160	4	-3.849	02/16/2011	06/22/2011
Euro120	09/08/2004-10/30/2013	478	2	-3.871	12/10/2008	12/10/2008
	09/29/2010-10/30/2013	162	4	-6.311	05/04/2011	05/04/2011
	09/08/2004-01/21/2009	229	3	-3.439	02/09/2005	01/18/2006
	01/25/2006-01/21/2009	157	4	-5.269	07/25/2007	03/05/2008
	01/25/2006-07/18/2007	78	1	-3.375	03/07/2007	06/27/2007
	01/25/2006-02/28/2007	58	4	-4.002	05/17/2006	08/16/2006

Endnotes

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2. We use official central bank yield curve data for each country, from the following sources: Bank of Canada: www.bankofcanada.ca/rates/interest-rates/bond-yield-curves/; the Bank of England: http://www.bankofengland.co.uk/statistics/Pages/yieldcurve/archive.aspx; the European Central Bank: www.ecb.int/stats/money/yc/html/index.en.html; and the US Treasury: www.treasury.gov/resource-center/data-chart-center/interest-rates/Pages/TextView.aspx?data=yieldAll. Specifically, we employ Wednesday observations of nominal government spot rates, where these yields are continuously compounded.

3. The euro area yields are those for central government bonds for all member states- Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Lativa, Luxembourg, Malta, Netherlands, Portugal, Slovenia, Slovakia and Spain.

4. Appendix A reports the results of ADF tests for both the raw and Kalman-smoothed data for the various yields in our sample. The result of this preliminary check reduces the need for the use of alternative approaches e.g. the Kalman Filter or extended Kalman Filter approaches (see for examples including Krishnan and Sen, 1995) to test the persistence results we obtain. We thank an anonymous referee for this suggestion.

References

Bataa E, Osborn D R, Sensier M and van Dijk D (2013) 'Structural Breaks in the International Dynamics of inflation', *The Review of Economics and Statistics*, 95(2), 646-659.

Ciner C, Gurdgiev C and Lucey B M (2013) 'Hedges and Safe Havens: An Examination of Stocks, Gold, Oil and Exchange Rates', *International Review of Financial Analysis*, 29, 202-211.

Coeurdacier N and Guibaud S (2011) 'International portfolio diversification is better than you think', *Journal of International Money and Finance*, 30, 289–308.

Coleman S and Sirichand K (2014) 'International Yield Curve Comovements: Impact of the Recent Financial Crisis', Loughborough University Department of Economics, Discussion Paper Series 2014_07.

De Santis R A and Gerard B (2009) 'International portfolio reallocation: Diversification benefits and European monetary union', *European Economic Review*, 53(8), 1010-1027.

Dias D A, Richmond C and Wright M L J (2014) 'The Stock of External Sovereign Debt: Can We Take the Data at 'Face Value?', *Journal of International Economics*, Available online 16 June 2014. DOI: http://dx.doi.org/10.1016/j.jinteco.2014.05.001.

Elliot G, Rothenberg T J and Stock J H (1996) 'Efficient tests for an autoregressive unit root,' *Econometrica*, 64, 813-836.

Gorea D and Radev D (2014) 'The euro area sovereign debt crisis: can contagion spread from the periphery to the core?', *International Review of Economics and Finance*, 30, 78-100.

Grubel H G (1968) 'Internationally diversified portfolios: Welfare gains and capital flows', *The American Economic Review*, 58, 1299–1314.

Halunga A G, Osborn D R and Sensier M (2009) 'Changes in the order of integration of US and UK inflation', *Economics Letters*, 102, 30-32.

Harvey D I, Leybourne S J and Taylor A M R (2006) 'Modified tests for a change in persistence', *Journal of Econometrics*, 134, 441-469.

Kemper K, Lee A and Simkins B J (2012) 'Diversification revisited', *Research in International Business and Finance*, Volume 26, 2, 304-316.

Krishnan R and Sen K (1995) 'Measuring persistence in industrial output: The Indian case', *Journal of Development Economics,* 48, 25-41.

Leone V and Medeiros O R (Forthcoming 2014) 'Signalling the Dotcom Bubble: A Multiple Changes in Persistence Approach', *Quarterly Review of Economics and Finance*, DOI: http://dx.doi.org/10.1016/j.qref.2014.08.006.

Levy H and Sarnat M (1970) 'International Diversification of Investment Portfolios', *American Economic Review,* 60(4), 668-675.

Leybourne S J and Taylor A M R (2006) 'Persistence change tests and shifting stable autoregressions', *Economics Letters*, 91, 44-49.

Leybourne S, Kim T and Taylor A M R (2007) 'Detecting multiple changes in persistence', *Studies in Nonlinear Dynamics and Econometrics*, 11(3), 1-32.

MacKinnon J G (1996) 'Numerical distribution functions for unit root and cointegration tests,' *Journal of Applied Econometrics*, 11, 601–618.

Markowitz H (1952) 'Portfolio Selection', *Journal of Finance,* 7, 77-91.

Ng S and Perron P (2001) 'Lag Length Selection and the Construction of Unit Root Tests with Good Size and Power', *Econometrica*, 69, 1519-1554.

Noriega A E and Ramos-Francia M (2009) 'The dynamics of US inflation', *Economics Letters*, 105, 168-172.

Pesaran M H, Pettenuzzo D and Timmermann A (2006) 'Forecasting time series subject to multiple structural breaks', *Review of Economic Studies*, 73(4), 1057-1084.

Proaño C R, Schoder C and Semmler W (2014) 'Financial stress, sovereign debt and economic activity in industrialized countries: Evidence from dynamic threshold regressions', *Journal of International Money and Finance*, 45, 17-37.

Raffestin L (2014) 'Diversification and systemic risk', *Journal of Banking and Finance*, 46, 85–106

Sanso-Navarro M (2009) 'Multiple persistence changes in the S&P Composite dividend-price ratio', Departamento de Análisis Económico, Facultad de Ciencias Económicas y Empresariales, Universidad de Zaragoza, Working paper.

Sollis R (2006) 'Testing for bubbles: an application of tests for a change in persistence', *Applied Financial Economics,* 16, 491-498.

Taylor A M R (2005) 'Fluctuation tests for a change in persistence', *Oxford Bulletin of Economics and Statistics*, 67, 207-230.

Tobin J (1958) 'Liquidity preference as behavior towards risk', *Review of Economic Studies*, 25, 65-86.

Wibaut S and Wilford S (2009) 'Holding equity and debt of the same firms can prove suboptimal', *Journal of Applied Finance*, 19(1/2), 19-27.

Yetman J (2011) 'Exporting recessions: International links and the business cycle,' *Economics Letters*, 110, 12–14.

You L and Daigler K (2010) 'Is international diversification really beneficial?', *Journal of Banking and Finance*, 34, 163-173.