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Discussion Paper No. 49

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### Abstract

This paper uses a 'trendy' approach to understand UK inflation dynamics. It focuses on the time series to isolate a low-frequency and slow-moving component of inflation (the trend) from deviations around this trend. We find that this slow-moving trend explains a substantial share of UK inflation dynamics. International prices are significantly correlated with the short-term cyclical movements in inflation around its trend, and the exchange rate is significantly correlated with movements in the slow-moving, persistent trend. Other variables emphasized in standard inflation models — such as slack and inflation expectations — may also play some role, but their significance varies and the magnitude of their effects is substantially smaller than for commodity prices and the exchange rate. These results highlight the sensitivity of UK inflation dynamics to events in the rest of the world. They also provide guidance on when deviations of inflation from target are more likely to be temporary, and when (and how quickly) a monetary policy response is appropriate.

**Key words:** UK, inflation, UCSV, exchange rate, slack, inflation expectations, monetary policy.

**JEL classification:** E31, E5.

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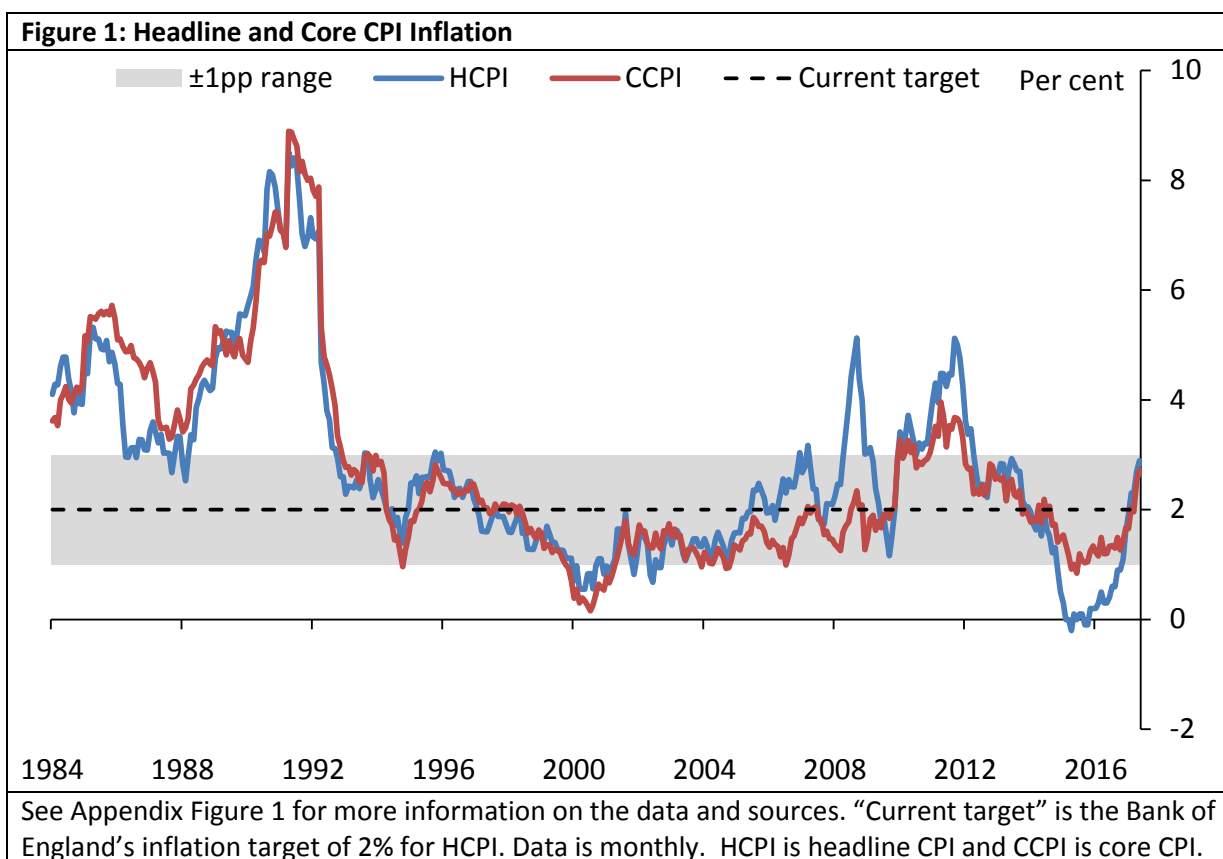
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## I. Introduction

UK inflation has been quite volatile over the past decade. Figure 1 shows that consumer price inflation spiked to 5.2% in September 2008, and then fell to 1.1% the next September, before rising back to 5.2% in September 2011. Inflation fell below zero over the course of 2015, and then rose quickly to 2.9% in May 2017. Moreover, some of these deviations of inflation from the 2% target have lasted for substantial periods of time.<sup>1</sup> For example, inflation was at or above 3% for 28 months from January 2010 through April 2012, and at or below 1% for 24 months from November 2014 through October 2016. In both cases, inflation deviated from today's 2% target by over 1% (as shown in the shaded area of the Figure), and these deviations required the Governor of the Bank of England to write a series of letters to the Chancellor. In its May 2017 *Inflation Report*, the Bank of England forecast that inflation would remain above its 2% target for its entire 3-year forecast horizon.



What is driving these sharp—and often prolonged—movements in inflation away from 2%? Does this volatility primarily reflect temporary price movements around a fairly stable underlying rate of inflation close to 2%? If so, what drives these temporary movements? Or, does this volatility primarily reflect shifts in the low-frequency – or ‘trend’ – component of inflation? If so, what variables can drive these more persistent shifts in inflation? How important are global variables

<sup>1</sup> The 2% CPI inflation target was adopted in January 2004. From June 1997 to December 2003, the target was for RPIX inflation of 2.5%, while from October 1992 to May 1997, the target was for RPIX inflation in a range from 1% to 4%.

versus domestic variables? This paper attempts to answer these questions for the United Kingdom, using a framework that has been successful in understanding inflation dynamics in the US but not carefully applied to the UK. The analysis not only helps improve our understanding of UK inflation dynamics, but also provides important insights for when and how quickly monetary policy should respond to deviations of inflation from target.

An extensive academic literature attempts to understand inflation dynamics. Much of this literature is grounded in a DSGE framework that models a complex set of structural relationships to understand the cyclical variation in inflation. This literature requires a number of assumptions and places substantial weight on the role of inflation expectations and the amount of slack in the economy (incorporating some variant of a Phillips curve). Trend inflation is normally assumed to be constant, pinned down by the policy function of the central bank, and if trend inflation is time-varying, it is normally assumed to be exogenous.

A branch of the literature, inspired by Stock and Watson (2007), takes a very different and less-structured approach. This literature focuses on the time-series dynamics of inflation, primarily for the US, and isolates a low-frequency and slow moving component of inflation (the ‘trend’) from deviations around this trend.<sup>2</sup> This paper builds on this ‘trendy approach’ to analyse inflation dynamics in the UK, most closely following a recent example for the US in Cecchetti, Feroli, Hooper, Kashyap, and Schoenholtz (2017), hereafter referred to as CFHKS (2017). More specifically, after estimating a slow-moving trend rate of inflation for the UK, we attempt to explain this trend and the deviations around it using a wide array of variables and with minimal structure. This approach yields important insights for understanding UK inflation dynamics—insights starkly different than those attained using the more standard DSGE framework.

Before estimating this trend, however, this paper begins by presenting several stylized facts that support this approach to understanding UK inflation dynamics. We show that different measures of UK inflation have a high degree of comovement and are largely explained by a common principal component. Movements in these different measures of inflation (including the common component) also show a high degree of persistence, suggesting an important low-frequency trend component. Changes in inflation, however, are negatively serially correlated. These stylized facts are very similar to those documented for the US in CFHKS (2017), although movements in UK inflation appear to be somewhat less persistent than in the US, especially for core measures. UK core inflation is somewhat more volatile and commoves more tightly with headline inflation than in the US.

After establishing these stylized facts for UK inflation dynamics, we develop an atheoretical, univariate modelling framework to estimate trend inflation. Our approach builds on the work of Stock and Watson (2007), Chan, Koop, and Potter (2013), and CFHKS (2017). To be precise, similar to Stock and Watson (2007) (but differently than Chan, Koop, and Potter, 2013 and the preferred model used in CFHKS, 2017), we allow for stochastic volatility in the innovations to the inflation process; this turns out to be a key feature of the UK data. Similar to Chan, Koop, and Potter (2013) and CFHKS (2017), (but differently than Stock and Watson, 2007), our model allows deviations in trend inflation to follow an autoregressive process. As discussed in Cogley, Primiceri, and Sargent

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<sup>2</sup> See Cecchetti *et al.* (2017) for a detailed summary of this literature, as well as Section III below. We follow Stock and Watson (2015) and use the term “trend” to capture the persistent component of the inflation rate. Cecchetti *et al.* (2017) use the term “local mean” to capture the same concept.

(2010) and Chan, Koop, and Potter (2013), this formulation allows us to separately study the dynamics in the inflation gap from variations in trend inflation.

These estimates of trend inflation and deviations around the trend confirm a high degree of comovement in the primary UK inflation measures since 1984. Over 95% of trend inflation in the five inflation series on which we focus is explained by one principal component. The model's estimates suggest that trend inflation plays a powerful role in explaining inflation measures; for example, about 39% of the variation in headline inflation, and 46% of that for core inflation, is explained by trend inflation. Additional volatility can be explained by temporary, cyclical innovations around this trend. A breakdown of inflation into the trend and a cyclical component confirms that cyclical movements have significantly affected inflation dynamics during certain periods—such as during the period of high inflation in the late-80s/early-1990s and during the commodity price boom of 2007/08. Perhaps most striking, however, are several periods since the mid-1990s when trend inflation has moved sharply and been a key factor driving CPI inflation away from the target.

Next, we investigate which variables influence changes in the cyclical and trend components of inflation using simple regressions. Our tests suggest that, after controlling for the trend, most macroeconomic variables used in the inflation literature add little or no explanatory power to regressions predicting inflation—including changes in slack. In some cases, an increase in inflation expectations has a positive and significant correlation with inflation after controlling for the trend, but the significance of the results is mixed and the magnitudes of the effects are generally small.<sup>3</sup> The one set of variables which is the exception and appears to have a significant impact on inflation after controlling for the trend is changes in international prices. Increases in international prices (whether measured as world export prices in sterling, US\$ Brent oil prices, or an index of commodity prices) are correlated with significant and large increases in both headline and core UK inflation—even after controlling for trend inflation. Therefore, after controlling for the slow-moving trend in UK inflation, domestic factors seem to play little role in explaining UK inflation dynamics, while movements in international prices seem to have a meaningful impact.

But even if domestic variables appear to have little significant impact on UK inflation after controlling for trend inflation—do they impact this trend? Several different analyses of the determinants of trend inflation suggest that certain domestic variables can play a role—although the exchange rate appears to be even more important. More specifically, the results suggest that changes in the sterling exchange rate index have significant and economically meaningful effects on both headline and core CPI trend inflation. For example, a 10% depreciation is correlated with an increase in trend inflation of around 0.4 percentage points for both headline and core CPI. This suggests that movements in sterling can have significant, large, and persistent effects on headline and core inflation. Lower levels of slack are also significantly correlated with higher levels of trend inflation in many specifications, but the magnitude of these effects tends to be much smaller. Inflation expectations may play some role in affecting headline trend inflation—although its significance fluctuates based on the specification and measure of inflation expectations. Other variables appear to play an even smaller role in explaining movements in trend inflation.

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<sup>3</sup> Examples of papers which highlight the role of inflation expectations for the future path of inflation include: Faust and Wright (2013) and Rowe (2016).

These two different sets of analysis—examining what drives UK inflation around its trend and what drives UK trend inflation—both highlight the role of global variables and UK prices relative to the rest of the world in understanding UK inflation dynamics. World export and commodity prices are the only variables consistently significant in explaining movements in UK headline and core inflation around its trend. The sterling exchange rate is the only variable consistently significant and economically meaningful in explaining movements in UK trend core inflation. Other variables emphasized in economic models of inflation—such as the level of slack in the economy and inflation expectations—may also play some role, but their significance varies based on the specification and the magnitude of their estimated effects is much smaller. These results highlight the sensitivity of UK inflation dynamics to events in the rest of the world (albeit the sterling exchange rate is determined by a combination of global and domestic influences).

These results for UK inflation dynamics are also noteworthy in how they compare to a similar analysis for US inflation dynamics in CFHKS (2017). Although there are some differences in methodology,<sup>4</sup> there are a number of noteworthy similarities—and differences—in the results. In both the US and UK, a slow-moving trend has a powerful role in explaining inflation dynamics, and few variables (including those central to most models of inflation) can explain a significant portion of inflation dynamics around this trend or movements in the trend. In the US, trend core inflation is somewhat more stable, and there is less role for international influences (such as the exchange rate) than in the UK. These differences are not surprising. The UK is more of a “small open economy” than the US, and therefore its inflation rate would be expected to be more sensitive to movements in international prices.

These results also have a number of implications for monetary policy. First, inflation dynamics are dominated by a slow-moving trend and many of the variables central to modelling inflation dynamics in the DSGE literature appear to have only a limited ability to influence price movements. Central banks should appreciate the limits of structural models of inflation dynamics that are centred on relationships of prices with inflation expectations and/or slack.

Second, UK inflation dynamics are powerfully affected by variables which are partially or largely outside the control of the United Kingdom—world export prices (or simply oil or commodity prices) and the sterling exchange rate. This suggests that even if the UK economy is fairly solid and stable, with low levels of slack and well-grounded inflation expectations, UK inflation could still continue to be volatile. Moreover, these international influences cannot be dismissed as only having temporary effects on UK inflation dynamics. Movements in sterling can have more persistent effects on headline and core inflation.

Third, and closely related, these results have important implications for whether monetary policy should respond when inflation deviates from the target. Changes in global commodity prices tend to significantly affect UK inflation—but these effects tend to be short-lived. They primarily drive cyclical movements in UK inflation around its slow moving trend, with little effect on this underlying trend—

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<sup>4</sup> There are two differences worth highlighting. First, each paper focuses on the measure of inflation most relevant for monetary policy in the given country, with CFHKS (2017) focusing on core PCE and core CPI inflation for the US, while we focus on CPI and core CPI inflation for the UK. The other important difference is in the model used to estimate trend inflation. As discussed in more detail below, CFHKS (2017) assume that the variances of the terms capturing deviations around the trend and innovations to the trend are constant, while we allow them to vary over time.

especially for core inflation. These effects, in isolation, would generally not merit a monetary policy response. In contrast, movements in sterling have more persistent effects on UK inflation, as they primarily drive movements in the slow-moving trend. This suggests that monetary policy should carefully consider the impact of sterling on inflation, as it could drive inflation away from target for a prolonged period. There may be situations where it is still optimal to “look through” these more persistent effects of sterling on inflation, especially if slack in the economy could partially counteract the impact of sterling’s movements on trend inflation. But given the magnitude of the impact of sterling on UK headline and core inflation, and the persistence of these effects, monetary policy cannot automatically dismiss the effects of sterling on inflation as temporary and may need to respond in order to ensure that inflation returns sustainably to target.

Finally, the results complement other evidence that there is a cost to delaying any monetary policy response to shifts in trend inflation away from target (such as in CFHKS, 2017 and Clarida, Gali and Gertler, 1999), whether these shifts are caused by movements in the exchange rate or other variables. Since shifts in the underlying trend inflation rate are persistent, they will not unwind quickly or automatically (assuming no change in other key variables). Moreover, as other research has found, the longer the deviation in trend inflation from target persists, the more this deviation becomes engrained in underlying inflation dynamics, and the more difficult it will be to unwind in the future. A given undershoot (or overshoot) of trend inflation from target will take a larger overshoot (or undershoot) of headline inflation in the future to return inflation to target sustainably.

The remainder of the paper proceeds as follows. Section II presents stylized facts about UK inflation dynamics and examines key characteristics of the data in order to inform our empirical approach. Section III discusses our estimation strategy in more detail, calculates the trend rate of inflation for different price series, and compares our approach to alternatives. Section IV assesses what variables can explain movements in inflation after controlling for this trend, and then what variables can influence this trend. Section V concludes.

## ***II. UK Inflation Dynamics: The Stylized Facts***

There are a number of different measures of UK price inflation. We focus on five that include those most important for monetary policy and any automatic indexing in the economy, that capture inflation in different segments of the economy, that are comparable to the CFHKS (2017) analysis for the United States, and that have a fairly reliable time-series since 1984. These five measures are: headline consumer price inflation (HCPI); core consumer price inflation (CCPI), which is HCPI excluding food and energy; headline personal consumption expenditures (HPCE)<sup>5</sup>; headline retail price inflation, excluding mortgage interest payments (HRPIX); and the GDP deflator (PGDP).<sup>6</sup> We begin our analysis in 1984 in order to more easily compare our results to those for the US in CFHKS

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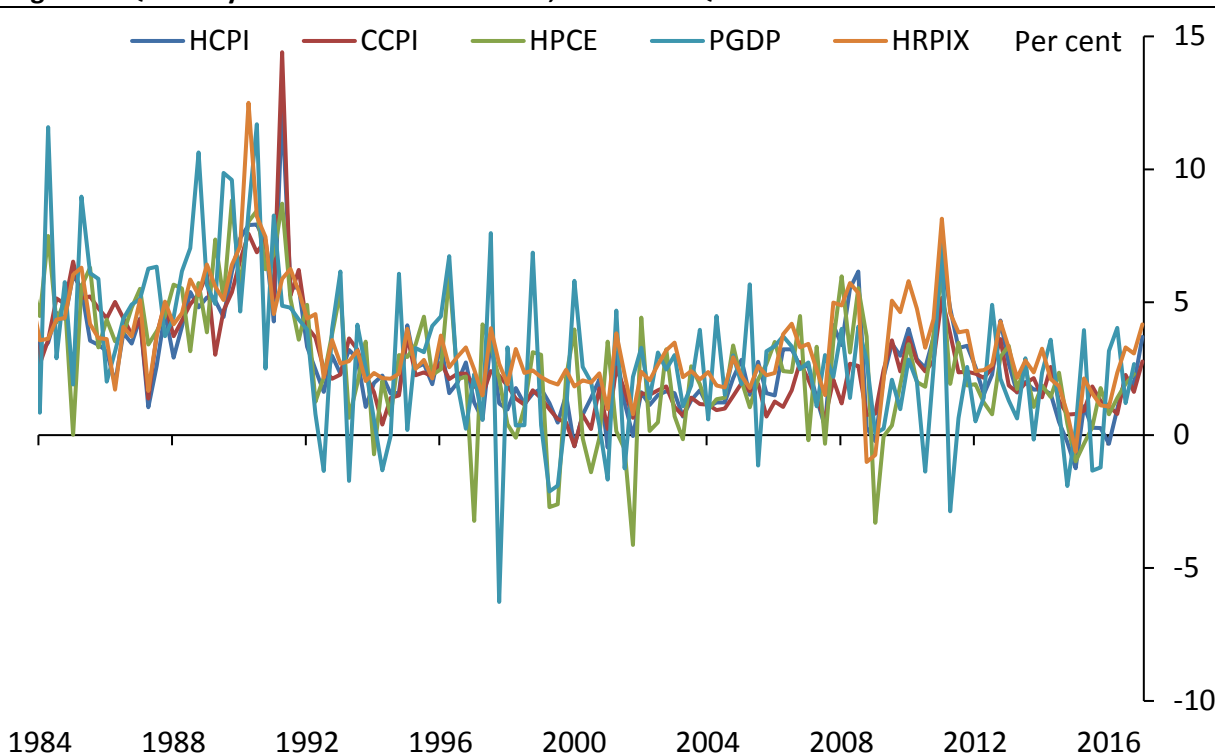
<sup>5</sup> This is also known as the consumption deflator in the UK. We use this terminology to be consistent with CFHKS (2017).

<sup>6</sup> All inflation measures are calculated as the quarter-to-quarter percent change in the level of the price index, seasonally adjusted (using X12), and expressed as an annual rate. See Appendix Figure 1 for more information on the data and sources. Unlike CFHKS (2017), we do not focus on core PCE as a UK version of this series shows several irregular patterns. We also investigated the properties of series for CPI and core CPI excluding the estimated effects of changes in VAT, with no meaningful impact on the key results highlighted in this section.

(2017). A series of the results, however, including the empirical analysis in the next section, will focus on the period starting in 1993, which is soon after the UK left the Exchange Rate Mechanism linking sterling to other European currencies and when the UK officially adopted inflation targeting.

Figure 2 graphs these five measures of quarterly UK inflation from 1984 through 2017Q1. The measures show a high degree of comovement, although the GDP deflator, and at times the PCE index, exhibit substantially more volatility than the other measures. Appendix Figure 2, which reports the correlations between these measures, confirms their high degree of comovement—albeit somewhat less so for the PCE, and especially the GDP deflator. Figure 2 shows that inflation was substantially higher in the latter half of the 1980s (the ‘Lawson boom’) and spiked in 1991 (due partly to an increase in VAT), before settling at a lower average rate since then. Although inflation has generally been lower since the early 1990s, it has clearly not flat-lined around the current target of 2%. Various measures have fallen below 0% and above 5% at different points in time. For example, most inflation measures were notably lower than 2% in late 2014 and throughout 2015—after global commodity prices fell sharply. Most measures were also notably above 2% in 2010 and 2011—after sterling depreciated sharply in the aftermath of the global financial crisis. These types of influences of international prices will be an important theme in the more formal empirical analysis on inflation dynamics in the following sections.

**Figure 2: Quarterly Measures of UK Inflation, 1984-2017Q1**



Sources: ONS and Bank calculations.

All inflation measures are seasonally adjusted and calculated as the quarter-to-quarter percent change in the level of the price index at an annual rate. See Appendix Figure 1 for more information on the data and sources.

To better understand the comovement between these five inflation measures, we perform a principal component analysis. The results are reported in Figure 3. The top of the table shows the fraction of the variance in the five series that can be explained by a common component, and the



bottom shows the factor loadings, i.e. the weight on each series to calculate each common component. The 0.72 for the first component suggests that there is a substantial common component—that 72% of the variance in these five series can be explained by just one shared component. The lower rows show that this first principal component places a roughly similar weight on each of the five inflation series—albeit less so for the GDP deflator. In contrast, the second principal component only explains a small share of the inflation measures and seems to primarily pick up the differences in the GDP deflator, and to a lesser extent the PCE deflator. It is also noteworthy that there is less distinction in the common movement between the headline and core consumer price indices than found for the US in CFHKS (2017).<sup>7</sup>

**Figure 3: Principal Component Analysis of UK Inflation, 1984-2016**

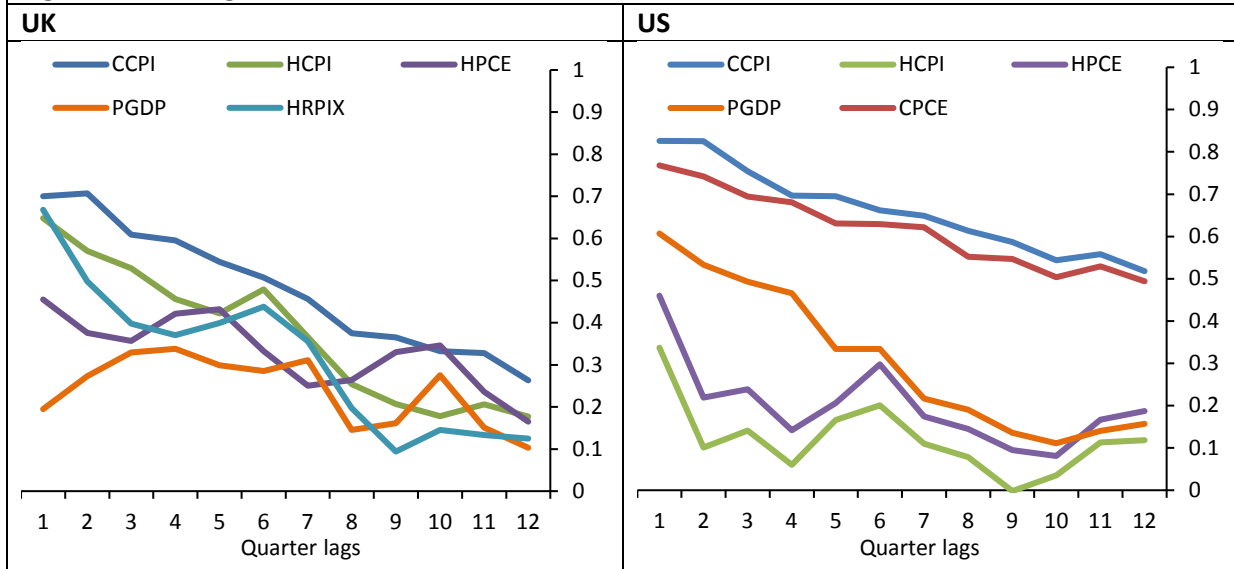
Fraction of variance accounted for					
	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5
Five series	0.72	0.15	0.07	0.05	0.01
Factor loadings					
HCPI	0.49	-0.33	0.08	-0.01	-0.80
CCPI	0.47	-0.33	0.07	0.70	0.42
HPCE	0.43	0.35	-0.83	-0.07	0.04
PGDP	0.36	0.78	0.51	0.10	-0.04
HRPIX	0.47	-0.25	0.22	-0.70	0.42

While this analysis confirms the high degree of comovement between the five inflation measures, it does not provide information on the persistence of movements in these measures. Therefore, we next examine several statistics to better understand the dynamic properties of the various inflation measures.

Figure 4 begins with a correlogram for the same five measures of UK inflation, plus the five measures of US inflation used in CFHKS (2017). These basically capture the autocorrelation in each inflation measure. The high starting points and gradual slopes for most of the lines show that movements in inflation are fairly persistent over time. For example, the left of Figure 4 shows that in the UK the correlation between core CPI inflation today and core CPI inflation one quarter ago is 70%. The correlation falls to only 50% after six quarters. The patterns are fairly similar for the five different UK inflation measures, albeit with less persistence in movements in the GDP deflator (as expected given the volatility in this series in Figure 2). The graph for the US (on the right) also shows high degrees of inflation persistence in the core inflation measures—even higher than in the UK. The main difference for the US, however, is the sharply higher persistence of the core PCE and core CPI measures relative to the other inflation measures. These graphs suggest that movements in inflation are fairly persistent in both countries, albeit somewhat less so in the UK than in the US for core measures, and that there is less difference in persistence between core and headline inflation in the UK than in the US.

<sup>7</sup> CFHKS (2017) find that 74% of the variance in their five inflation measures can be explained by the first principal component—very similar to the UK. They find less distinction with the US GDP and PCE deflators in the second component than in the UK, but more distinction between the headline and core measures.

**Figure 4: Correlogram of Inflation Measures, 1984-2016**



Sources: ONS, Bureau of Economic Analysis, Bureau of Labour Statistics and Bank calculations.  
 Notes: Correlogram shows the correlation coefficient between measures of inflation and their lags. US core CPI (CCPI) and core PCE (CPCE) are measured as CPI and PCE, respectively, each excluding food and energy. See Appendix Figure 1 for more information on the UK data and sources.

As a final test of the dynamic properties of UK inflation, Figure 5 reports the autocorrelations of the changes in each of the five inflation measures over each of the following three quarters. This provides information on whether there is persistence in how inflation changes each quarter (instead of whether there is persistence in the level of inflation each quarter). For each of the five UK inflation measures, the first autocorrelation is negative and significant. Positive surprises in inflation one quarter tend to be followed by negative movements the next (and vice versa). This suggests a role for noisy innovations to inflation around its trend. In contrast, however, the autocorrelations for the second and third lags are rarely significant.<sup>8</sup> This suggests that these innovations in inflation are fairly short-lived.

**Figure 5: Autocorrelations in Changes in UK Inflation Measures, 1984-2016**

	Lag 1		Lag 2		Lag 3	
	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat
DHCPI	-0.39	-4.79	-0.06	-0.63	0.05	0.57
DCCPI	-0.51	-6.78	0.18	2.02	-0.14	-1.61
DHPCE	-0.44	-5.52	-0.05	-0.55	-0.08	-0.90
DPGDP	-0.54	-7.57	0.00	0.06	0.03	0.38
DHRPIX	-0.24	-2.84	-0.11	-1.24	-0.11	-1.24

Notes: "D" denotes change in the given inflation measure. For example, "DHCPI" is the change in HCPI.

<sup>8</sup> The only exception is the second autocorrelation of core CPI, which is positive and just significant at the 5% level.

To summarize, this section shows a number of stylized facts for UK inflation data—facts which will be important in modelling UK inflation dynamics. First, the five UK inflation measures show a high degree of comovement and can largely be explained by a common principal component (albeit less so for the deflators). Second, movements in UK inflation—including in this common component—are quite persistent. Third, changes in UK inflation are negatively serially correlated. Finally, these stylized facts are very similar to those documented for the US in CFHKS (2017), although movements in UK inflation appear to be somewhat less persistent than in the US for core measures. In fact, UK core inflation is somewhat more volatile and commoves more tightly with headline inflation than in the US.

### **III. Modelling and Estimating Trend Inflation**

#### **a. The Model**

This section builds on the stylized facts presented above to develop a framework to estimate UK inflation dynamics. It begins by briefly summarizing key literature related to this paper’s approach, a literature which has been fairly successful but primarily focused on the US. Then the section builds on this literature to model UK inflation as a “trend” (a slow-moving underlying rate of UK inflation) and a “cycle” (short-lived movements around this trend).

An extensive literature has attempted to explain inflation dynamics using micro-founded and detailed theoretical models. These generally include two key components: 1) some type of Phillips curve relationship in which higher unemployment reduces inflation, and 2) some role for inflation expectations to stabilize inflation dynamics.<sup>9</sup> Stock and Watson (2007) was important in breaking from this framework to propose a less theoretical and more parsimonious model of the inflation process. They suggested that inflation could be well characterised by an unobserved component stochastic volatility model (UCSV) and highlighted the role of a slow-moving trend in inflation dynamics. CFHKS (2017) detail the subsequent series of papers building on this approach, including those which focus on the role of inflation expectations, those which attempt to explain the higher levels of inflation after the global financial crisis than predicted using the standard framework, and those which attempt to reconcile the importance of “trend” inflation found in the UCSV approach with the more complicated theoretical models.

CFHKS (2017) builds on this literature. First, they use the UCSV framework to model inflation dynamics in the US (updating an analysis by a subset of the same authors in Cecchetti, Hooper, Kasman, Schoenholtz, and Watson, 2007). Then, focusing solely on measures of core inflation, they further develop their model by allowing deviations in trend inflation (what they call the local mean) to follow an AR(1) process. This draws on the work of Chan, Koop, and Potter (2013). This framework is referred to as the autoregressive-unobserved-components model (or ARUC) and involves an assumption that there is no stochastic volatility in the US inflation series, an assumption which they justify based on characteristics of the US core inflation data (but does not apply as well to the UK). Loosely speaking, our analysis will merge the Stock and Watson (2007) and Chan, Koop, and Potter

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<sup>9</sup> See Fuhrer (2009) for a summary.

(2013) approaches, (i.e., the UCSV and ARUC frameworks). This allows for greater flexibility in the modelling assumptions and appears to better fit the characteristics of the UK inflation data.

Most of this literature focusing on the role of trend inflation and using variants of UCSV models has focused on the United States. There have also been a number of related papers, however, which focus primarily on UK inflation dynamics. For example, Cogley *et al.* (2005) develop a Bayesian VAR (BVAR) for UK inflation data with time-varying coefficients and stochastic volatility. Chan (2017) investigates whether inflation uncertainty affects the level of inflation and concludes that while this appears to have boosted UK and US inflation in the 1970s, this had less impact in more recent decades. Ellis, Mumtaz and Zabczyk (2014) develop a time-varying FAVAR model and demonstrate that UK monetary policy shocks had a bigger impact on inflation, equity prices and the exchange rate during the inflation targeting period. Harrison and Oomen (2010) and Burgess, Fernandez-Corugedo, Groth, Harrison, Monti, Theodoridis and Waldron (2013) develop and estimate DSGE models to understand UK inflation dynamics.

The framework in this paper builds most closely on that developed for the US in Stock and Watson (2007) and Chan, Koop, and Potter (2013), and most recently adapted in CFHKS (2017). More specifically, we assume that each measure of inflation,  $\pi_t$ , can be expressed as:

$$\pi_t - \tau_t = \varphi(\pi_{t-1} - \tau_{t-1}) + \eta_t, \text{ where } \eta_t = \sigma_{\eta t} \zeta_{\eta t} \quad (1)$$

$$\tau_t = \tau_{t-1} + \varepsilon_t, \text{ where } \varepsilon_t = \sigma_{\varepsilon t} \zeta_{\varepsilon t}, \text{ and} \quad (2)$$

$$\zeta_{\eta t}, \zeta_{\varepsilon t} \sim N(0,1). \quad (3)$$

In other words, inflation can be expressed as a combination of a slow moving trend ( $\tau_t$ ), and deviations around this trend ( $\eta_t$ ). The trend follows a unit root process (as suggested by the persistence in the UK inflation data in Figure 4). Inflation deviations around this trend follow an AR(1) process, such that shocks to inflation around its trend have a modest degree of persistence. The innovations ( $\zeta_{\eta t}$  and  $\zeta_{\varepsilon t}$ ) are both assumed to be independent, normally distributed, and serially uncorrelated.

Next, the evolution of the variances of the shocks to the trend and cyclical shocks around that trend are given by:

$$\ln(\sigma_{\eta t}) = \ln(\sigma_{\eta t-1}) + v_{\eta t}, \quad (4)$$

$$\ln(\sigma_{\varepsilon t}) = \ln(\sigma_{\varepsilon t-1}) + v_{\varepsilon t}, \quad (5)$$

$$v_{\eta t} \sim N(0, \gamma_1), \text{ and} \quad (6)$$

$$v_{\varepsilon t} \sim N(0, \gamma_2), \quad (7)$$

with the  $v_{\eta t}$  and  $v_{\varepsilon t}$  both also assumed to be independent, normally distributed and serially uncorrelated. Our framework can therefore be roughly characterized as a combination of the UCSV and ARUC models—so we will refer to our framework as the ARSV model. It captures both the autoregressive process as well as the stochastic volatility observed in the inflation data, while making minimal other assumptions.

## b. Baseline Results

Next, we use this ARSV model to estimate trend inflation ( $\tau_t$ ), the standard deviation of this trend ( $\sigma_{\tau t}$ ), and the standard deviation of the innovations ( $\sigma_{\eta t}$ ) for each of the five measures of UK inflation discussed in Section II from 1984 through 2017Q1.<sup>10</sup> The resulting estimates are shown in Figures 6a, 6b, and 6c, respectively. Figure 6a shows that trend inflation was high for all measures in the 1980s, increased in the late 80s (during the ‘Lawson boom’), but then fell sharply as growth slowed in the early 90s. Trend inflation measures for the CPI (headline and core) and headline PCE have since comoved fairly tightly. A principal component analysis of these five measures of UK trend inflation, reported in Figure 7, confirms the high degree of comovement in all of the inflation measures over the whole period—with 95% of the trends of these five series explained by one principal component.

These estimates of trend inflation shown in Figure 6a, however, also include several noteworthy swings away from the inflation target. Focusing on the CPI and PCE measures, after remaining roughly around 2% after the UK left the ERM and inflation targeting was introduced, all three measures declined during the latter half of the 1990’s to around 1% in 2000. Then the trends steadily increased in the later part of the 2000s to materially above 2% after the global financial crisis, before falling to roughly around 1% in 2014 and 2015. The trends for headline and core CPI and PCE inflation have recently begun to pick up. These graphs suggest that trend inflation can move away from 2% for fairly extended periods.

Estimates of the standard deviations of these trends are shown in Figure 6b. Continuing to focus on the CPI and PCE measures, the standard deviations of the corresponding trends fell very gradually from the late 1980s, a pattern consistent with inflation targeting reducing the volatility in trend inflation. More recently, some measures have picked up a bit – especially the volatility of trend headline CPI inflation. The standard deviations of the innovations (shown in Figure 6c), however, have been substantially more volatile. These deviations increased notably for several inflation measures during the late 2000s and are at higher levels today than during much of the late-1990’s and early-2000’s for headline and core CPI. This suggests that temporary shocks—which may not affect underlying trend inflation—have continued to be important drivers of inflation dynamics. It is noteworthy that although these affect headline inflation somewhat more than core inflation, the differential is modest and much smaller than in the US (where the standard deviation of the innovations is much more muted for core than for headline inflation measures). It is also worth highlighting that the volatility in Figure 6c confirms that a model of UK inflation dynamics should not assume a constant variance in the innovations (unlike in the US, where a constant variance in the innovations to core inflation is more justified, as used in CFKHS, 2017).

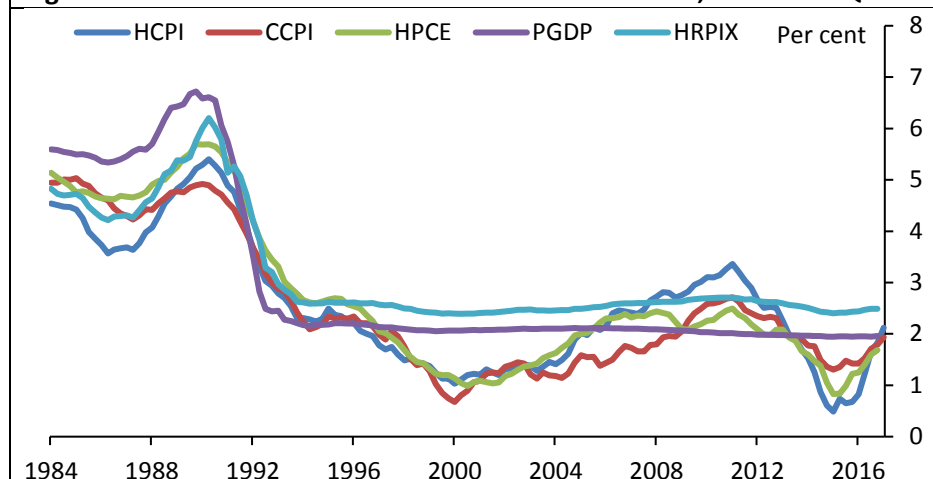
One other noteworthy aspect of these results is the more stable trend estimates for the GDP deflator and headline RPIX measures of inflation (in Figure 6a), which are associated with a substantially lower estimated volatility for the corresponding trends relative to those for the other inflation series (in Figure 6b). In the case of the GDP deflator, this is not surprising given the stylized facts shown in Figure 2; this series appears to be dominated by noise. The relative stability of the estimated trend for HRPIX is more noteworthy, given that the underlying data are closely correlated with headline CPI (with a correlation coefficient of 89% reported in Appendix Figure 2). In the case of HRPIX inflation, the model ascribes the majority of the variation in the data to the “cycle”. These

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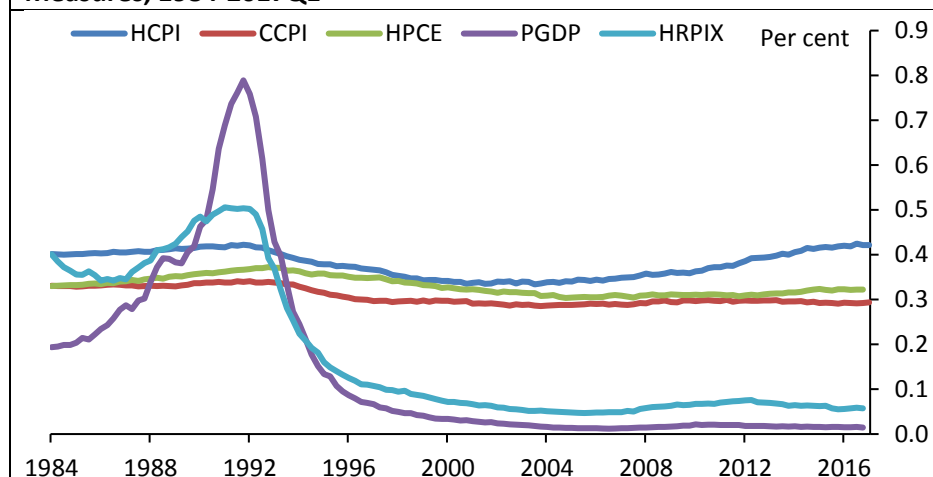
<sup>10</sup> We use a particle filter with 30,000 reps, with the first 29,000 discarded. We use 20 particles.

results show the challenge that can occur in this framework in distinguishing between the trend and the cycle. This identification challenge becomes more difficult when the inflation series is more volatile (such as the GDP deflator), or after a sharp movement in inflation (as in the late 1980s). We will return to this challenge of identifying the persistent changes in inflation from the slower moving trend in a series of robustness tests using alternative models and assumptions.

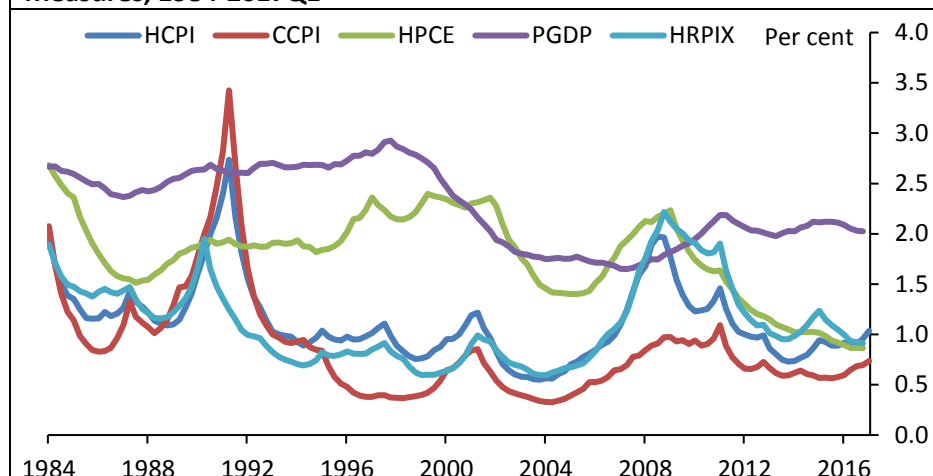
**Figure 6a: Estimates of Trends in UK Inflation Measures, 1984-2017Q1**



**Figure 6b: Estimates of Standard Deviations of Trends in UK Inflation Measures, 1984-2017Q1**



**Figure 6c: Estimates of Standard Deviations of Innovations in UK Inflation Measures, 1984-2017Q1**



**Figure 7: Principal Component Analysis of the Inflation Trends, 1984-2016**

Fraction of variance accounted for					
	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5
Five series	0.95	0.03	0.01	0.00	0.00
Factor loadings					
HCPI	0.44	0.64	0.48	0.25	0.32
CCPI	0.45	0.18	-0.75	0.41	-0.17
HPCE	0.45	0.17	-0.14	-0.86	-0.10
PGDP	0.44	-0.63	-0.01	0.04	0.64
HRPIX	0.45	-0.36	0.43	0.17	-0.67

### c. A Closer Look at Headline and Core CPI Inflation

The empirical analysis in the next section, primarily focuses on explaining headline and core CPI inflation—the two measures which receive the most prominent attention in the UK (including for monetary policy). Therefore, the remainder of this section takes a closer look at the model’s results for headline and core CPI inflation—including the precision of the results, the explanatory power of the model, and how much of inflation dynamics can be described by movements in the “cycle” versus the “trend”.

Figure 8 begins this closer look with the estimates of trend headline and core CPI inflation at a quarterly frequency based on the ARSV model described above. It also shows the 10<sup>th</sup> and 90<sup>th</sup> percentiles of these estimates in dashed lines (basically where we can say the estimated trend is with 80% confidence). The graphs show that the estimated trend of both headline and core inflation dropped from around 5% in the late-1980s to around 2% in the mid-1990’s. Since then, both measures have remained well below their elevated levels at the start of the sample period, but they have also fluctuated notably above and below 2%. This is especially true for the trend of headline inflation, which peaked at 3.4% in 2011 and troughed at 0.5% in 2015. Even though the movements in the estimated trend of core inflation are not quite as large, they are still large and noteworthy—with the estimated trend of core inflation ranging from 0.7% in 2000 to 2.7% in 2011.

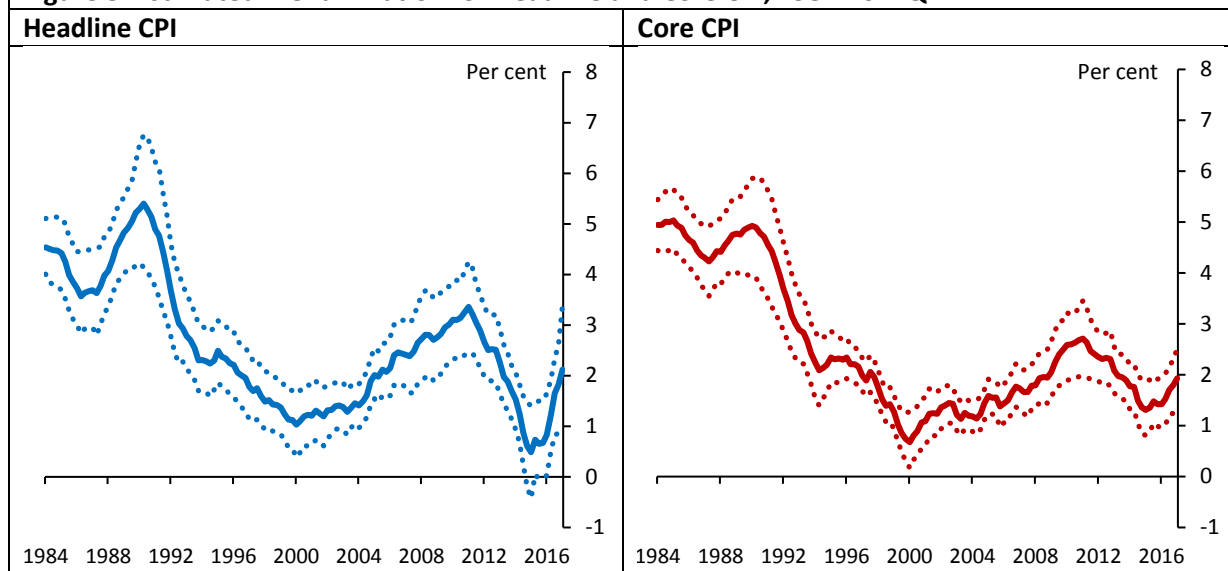
In order to get a sense of the precision of these estimates, we also calculate the average distance from the 10<sup>th</sup> to 90<sup>th</sup> percentiles of these estimates of trend inflation as shown in the dotted lines in Figure 8. Since 1984, the average distance was 1.4pp for headline inflation and 1.1pp for core, highlighting that these estimates are not precise.

Next, to make these results more concrete, Figure 9 reports the main parameter estimates for the ARSV model for the period from 1984 through 2017Q1. The estimates of the AR(1) parameters (in the first row) suggest that the AR(1) parameter is similar for headline and core CPI inflation (at 0.25 and 0.27, respectively).<sup>11</sup> The next two lines confirm that the average variance of changes in the trend and in the innovations is greater for headline than core inflation. This would be expected if headline inflation is subject to greater shocks—both in the trend rate as well as deviations around

<sup>11</sup> These estimates cannot be directly compared to those for the US in CFHKS (2017) due to the different estimation methodologies.

the trend (as could occur from oil price shocks, for example, whose direct effect is removed from calculations of core inflation). Most noteworthy in this table are the relative magnitudes of the average variances for changes in the trend relative to that for the innovations. The magnitudes are substantially greater for the innovations, consistent with our interpretation of the trend as a slow-moving component. As a result, in any given period, news in the trend only accounts for a small percentage of the overall forecast error from the model (13%-17%, as shown in the bottom row), with the vast majority of the forecast error attributable to noisy innovations around the trend.

**Figure 8: Estimated Trend Inflation for Headline and Core CPI, 1984-2017Q1**



The fourth row suggests, however, that the trend still plays a powerful role in explaining overall inflation dynamics. About 39% of the variation in headline inflation, and 46% in core inflation, can be explained simply by the trend. Taken together, these calculations suggest that although in any given period most of the news in inflation relates to noisy innovations around the trend, over longer time horizons a sizeable share of the variation in inflation is explained by movements in the low-frequency trend.

**Figure 9: Full Sample Parameter Estimates for Headline and Core CPI Inflation, 1984-2017Q1**

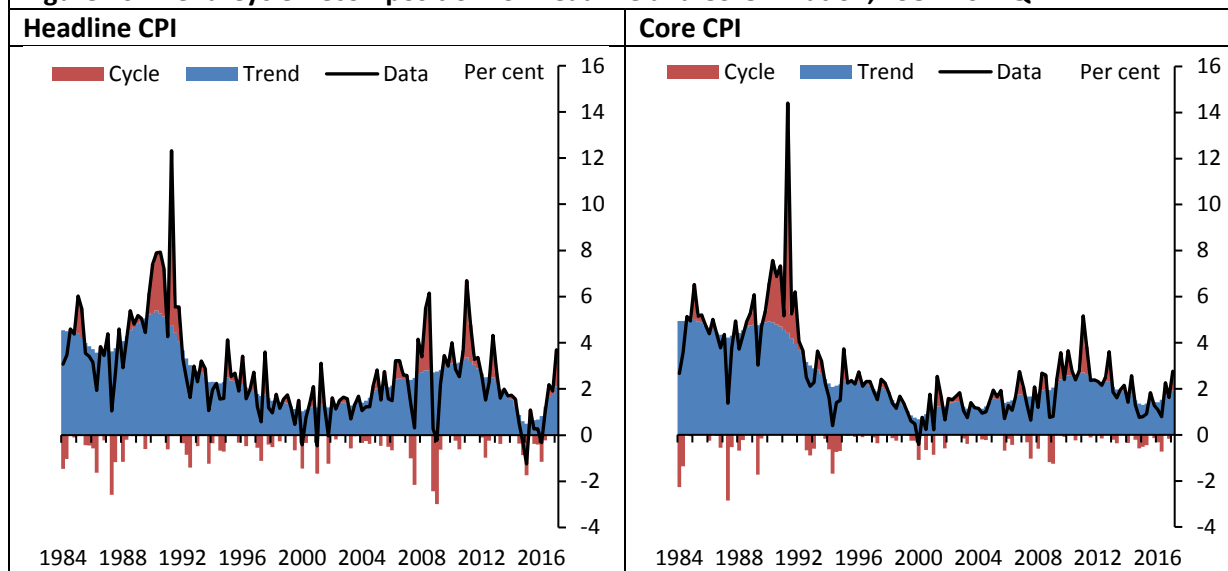
	Headline CPI	Core CPI
AR(1) parameter $\varphi$	0.25	0.27
Average variance of changes in trend <sup>(a)</sup>	0.14	0.09
Average variance of innovations <sup>(b)</sup>	1.41	1.02
% of variation explained by trend <sup>(c)</sup>	0.39	0.46
Average % of forecast error explained by shocks to trend <sup>(d)</sup>	0.13	0.17
Notes: (a) Calculated as: $\frac{1}{T} \sum_{t=1}^T \sigma_{\varepsilon t}^2$ . (b) Calculated as: $\frac{1}{T} \sum_{t=1}^T \sigma_{\eta t}^2$ . (c) Calculated as: $\frac{\sum_{t=1}^T (\tau_t - \bar{\pi}_t)^2}{\sum_{t=1}^T (\pi_t - \bar{\pi}_t)^2}$ . (d) Calculated as: $\frac{1}{T} \sum_{t=1}^T \frac{\sigma_{\varepsilon t}^2}{\sigma_{\varepsilon t}^2 + \sigma_{\eta t}^2}$ .		

Figure 10 provides a useful summary of some of the key results from Figure 9, including how these estimates have changed over time. It graphs headline and core CPI inflation, and then breaks them into the share identified as trend and the share identified as the “cycle”—*i.e.*, deviations from trend.



The graphs shows that more temporary, cyclical movements have played an important role in driving inflation dynamics during certain periods—such as during the period of high inflation in the late 1980s / early 1990s and during the commodity price boom of 2007-08. Perhaps more striking, however, is the importance of the trend in explaining movements in inflation over longer periods of time, including the sharp movements in this trend away from the 2% inflation target since the mid-1990s. These movements away from the inflation target are noteworthy in both headline and core inflation, and raise a number of questions about what could explain these movements.

**Figure 10: Trend-Cycle Decomposition for Headline and Core Inflation, 1984-2017Q1**



#### d. Sensitivity Tests

Before investigating the factors behind these movements in trend inflation and movements around this trend, however, it is important to examine the sensitivity of these baseline estimates to different modelling frameworks. We perform two sets of sensitivity tests: one using different modelling assumptions and the other using different dates/timing for the estimation.

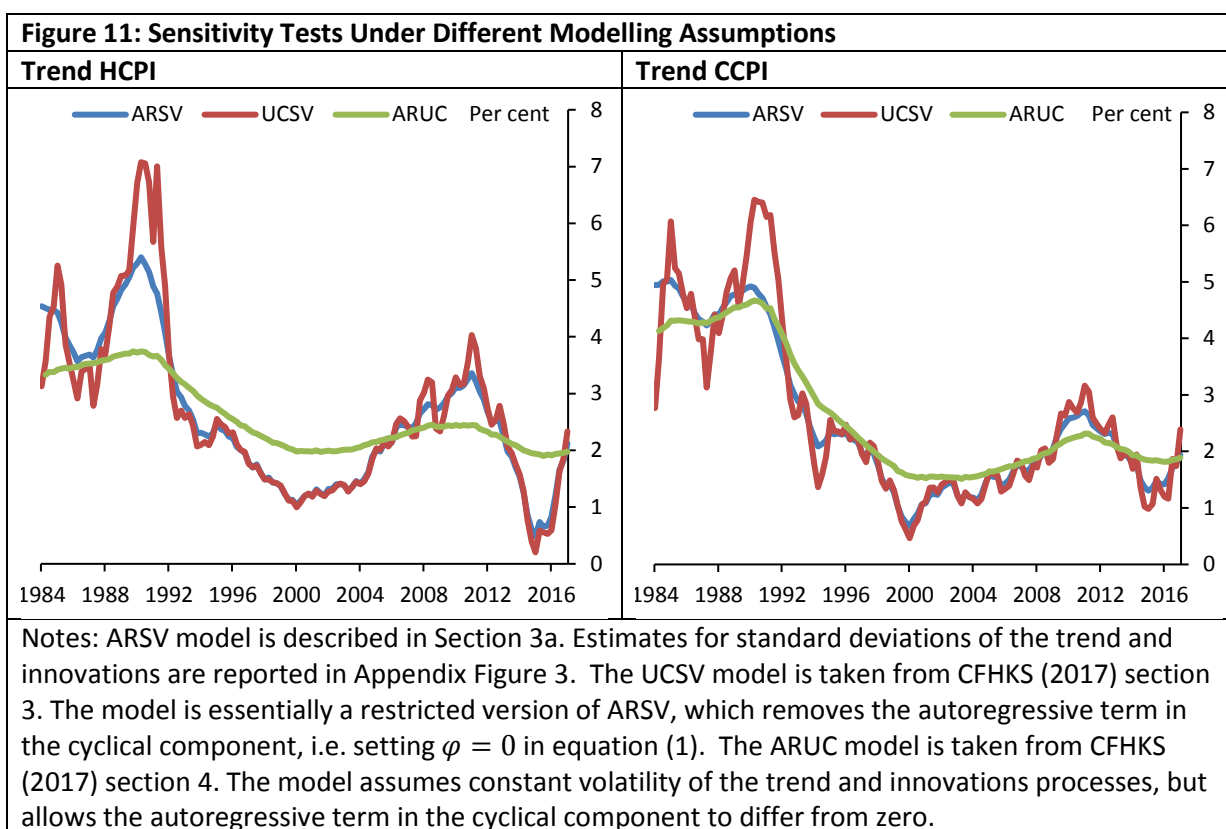
As a first set of sensitivity tests, we use two different models based on assumptions used in past work: a) an unobserved component stochastic volatility model (UCSV), which does not allow for an AR(1) term in cyclical inflation deviations from trend, and b) an autoregressive-unobserved-components model (ARUC), which assumes that the stochastic volatilities remain constant.<sup>12</sup> These two variants correspond to the approaches taken in sections 3 and 4, respectively, of CFHKS (2017). Figure 11 shows the results of these different modelling assumptions for the estimates of trend inflation for UK headline and core CPI inflation. Results for the volatility of the trend and the noise are reported in Appendix Figure 3. As expected, the UCSV model yields more volatile estimates of the trend, since most persistent changes in inflation are incorporated as changes in the trend. In contrast, the ARUC model generates substantially smoother estimates, with most deviations in inflation now interpreted as persistent (albeit not permanent) changes that are not part of the unit

<sup>12</sup> More specifically, the variances  $\sigma_{\eta_t}^2$  and  $\sigma_{\varepsilon_t}^2$  are assumed to be constant.

root. The large size of the estimated AR parameter (around 0.6) in the ARUC model suggests that this is an important component to include.

The estimated volatilities (in Appendix Figure 3) are constant by assumption in the ARUC model, whereas they appear to vary significantly over time in the results from the UCSV model. This time variation suggests that the constant variance assumption—especially for the innovations around the trend—is difficult to justify for the UK data.

Taken together, the significance of the estimated autoregressive coefficient in the ARUC model, combined with the non-constant stochastic volatility observed in the UCSV model, suggest that both models have merit, but are insufficient, on their own, to satisfactorily characterise UK inflation dynamics. As a result, we prefer the ARSV model, which nests the two models in one framework.<sup>13</sup>



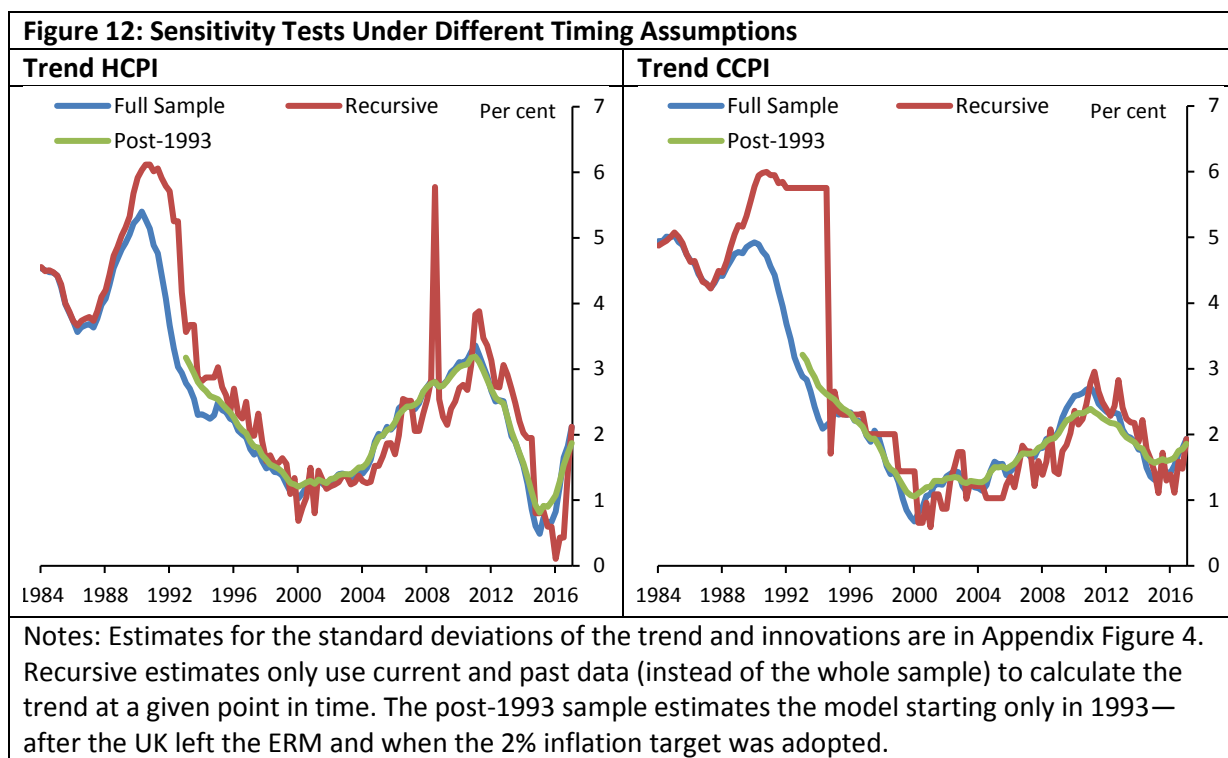
As an additional set of sensitivity tests, we examine the robustness of the estimates to different timing assumptions. More specifically, we estimate the model using recursive estimates—in which only current and past data (instead of the whole sample) are used to calculate the trend at a given point in time.<sup>14</sup> This follows the approach used in papers such as Stock and Watson (2011), and contrasts with the baseline methodology in which estimates for every time period are constructed using information from the entire sample. We also estimate the model starting only in 1993—after the UK left the ERM and when inflation targeting was adopted.

<sup>13</sup> As explained in Sims and Zha (2006), allowing for the variance of the error terms to evolve across time is a necessary component in order to avoid spurious variations in the trend/parameters. This is also supported by the analysis of Osborne and Sensier (2009) and Kontonikas(2004).

<sup>14</sup> This is a one-sided filter.

These estimates are shown in Figure 12, along with our baseline estimates. (Results for the volatility of the trend and in the noise for the post-1993 trend estimates are reported in Appendix Figure 4.) In each case, the model is estimated using the baseline ARSV model discussed above, and the resulting estimates of the trend are very similar to our main estimates. In some cases, the recursive estimates of the trend move with a slight lag to those in the baseline model—which is as expected since the recursive estimates do not know whether any given movement in inflation will be temporary and fade over time, or whether it will be more persistent. The recursive trend estimates are also somewhat more volatile. This is partly a numerical issue arising from the estimation procedure in which each time  $t$  trend median estimate is constructed from a different estimated model implicitly.<sup>15</sup>

An additional point worth noting across the different approaches is the lower stochastic volatility observed in the post-1993 trend estimates (shown in Appendix Figure 4). It appears that the baseline model ‘remembers’ the high inflation of the 1980s. It continues to incorporate this into its estimates of a higher volatility in the trend, even though this period does not significantly impact the trend estimates themselves (increasing our confidence in the regression results below which focus on the shorter period). Put slightly differently, the estimated stochastic volatility is affected by the initial condition, and since this is an extremely persistent process, the effect of the initial condition does not fade very quickly.



<sup>15</sup> The recursive estimation of the model is carried out using parallel computing techniques as the model is estimated at each point in time. For each task/estimation, we set an upper time limit of five hours. If the estimation (number of posterior draws) is not completed after five hours then the task is cancelled and the estimates in time  $t$  are set equal to the estimates in time  $t-1$ . These failures are the reason for behaviour of the CCPI trend estimate between 1992 and 1994.

## e. Model Summary

UK inflation dynamics can be well captured by a simple, unobserved components model that allows for a trend rate of inflation with substantial persistence and allows for cyclical deviations to follow an AR(1) process. Both core and headline inflation appear to follow this similar process. Unlike in the US, the variances of the innovations to core and headline inflation do not appear to be constant over time, and therefore a model of inflation dynamics should allow for this variation. These findings suggest that an ARSV model, which allows for some persistence in the cyclical component of inflation, as well as changes in the variances of the shocks to inflation, is the appropriate modelling framework to capture trend UK inflation and movements around this trend.

### ***IV. Explaining UK Inflation and the Trend***

The previous section showed that a slow-moving trend explains a substantial portion of the variation in UK headline and core CPI inflation. What other variables explain inflation dynamics after controlling for this trend? In other words, what variables can explain the cyclical movements in inflation around the more persistent component? And, potentially even more important in understanding longer term inflation dynamics, what variables can explain movements in this slow-moving trend rate of inflation? This section will attempt to answer each of these questions in turn. It will take an atheoretical approach and run “horse races” at each stage to see which variables help explain UK inflation dynamics. The goal is to “let the data speak” and impose as few assumptions as possible. This approach is straightforward, but subject to the caveat that we may not be able to capture underlying, structural economic relationships that are more complex and not easily tested in simple regressions. As a result, all of the conclusions from this exercise should be interpreted tentatively and seen as a compliment to more complicated models. Also, although we will consider a range of variables throughout these tests, we will pay particular attention to assessing the concepts that are central to most models of inflation dynamics: inflation expectations and slack.

#### **a. What (other than the trend) Explains Inflation Dynamics?**

In order to assess what variables other than the slow-moving trend rate of inflation might help improve our understanding of inflation dynamics, we use OLS to estimate the equation:

$$\pi_t = \alpha + \beta \tilde{\tau}_t + \gamma X_t + e_t, \quad (8)$$

where  $\pi_t$  is headline or core CPI inflation,  $\tilde{\tau}_t$  is the slow-moving trend estimated in the last section and shown in Figure 8, and  $X_t$  is an additional variable that could help explain movements in inflation around this trend. For our baseline analysis, we focus on the period starting in 1993 (after the UK left the ERM and formally adopted an inflation target) through 2016.<sup>16</sup> We focus on 21 variables that can be divided into five broad groups for  $X_t$ . All of these variables could help explain inflation dynamics, have received at least some support in the empirical literature, and are available for our baseline estimation period. These five groups, and the individual measures within each group, are:

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<sup>16</sup> We do not start earlier as previous monetary policy regimes may have generated substantially different inflation dynamics than under inflation targeting. Data are also more limited for many of the variables of interest before 1993.

- Inflation expectations (6 measures): 5-year financial market breakevens (FMB5); 5-year, 5-year financial market breakevens (FMB55)<sup>17</sup>; Barclays' Basix 1-year and 2-year household inflation expectations (BASIX1 and BASIX2); GFK household price expectations over the next 12 months, mean-variance adjusted (GFKE); and NIESR's 1-year ahead CPI inflation forecast (NIESR4Q)<sup>18</sup>.
- Slack (4 measures): BoE measure of the output gap (YGAPBOE); HP filter measure of the output gap (YGAPHP); OBR measure of the output gap (YGAPOBR); and BoE measure of the unemployment gap (UGAPBOE).
- Labour costs (2 measures, all expressed as quarterly annualised growth rates): average weekly earnings (AWE) and unit labour costs (ULC).<sup>19</sup>
- International costs and prices (4 measures): world export prices, quarterly annualised growth rate (DPWX); Brent crude prices, quarterly % change in \$ prices (DBRENT); commodity price index, quarterly % change in \$ prices (DGSCI); and the sterling exchange rate index, in log levels (SERI).
- Domestic financial conditions (5 measures): a principal component of credit spreads (SPREADPCA)<sup>20</sup>; shadow bank rate, which incorporates the effects of unconventional monetary policies (SHADOWBR)<sup>21</sup>; 2-year gilt yields (GILT2); broad money growth (M4EX); and broad credit growth (M4LEX).

Appendix Figure 1 includes additional information on the sources, definitions, and summary statistics for each of these 21 variables. These variables encapsulate a broad range of factors that could influence inflation dynamics, including a number of measures for inflation expectations and slack. Both of these concepts are central to models of inflation dynamics, but also difficult to measure precisely. By including a variety of definitions for each concept, we hope to be able to form a general picture of the role of these measures—despite these measurement challenges.

Figure 13 reports regression results for equation (8). The coefficients on trend inflation ( $\beta$ ), coefficients on each of the 21 “extra”  $X_t$  variables ( $\gamma$ ), and corresponding p values and  $R^2$ 's for each specification are listed by row.<sup>22</sup> Results for headline CPI inflation are on the left, and core CPI inflation on the right. Coefficient estimates for each of the 21 “extra” variables are shaded green if the estimates are significant at the 5% level with the expected sign, and red if significant with the “wrong” sign.

<sup>17</sup> Data for breakevens at shorter maturity are unfortunately not available for all periods.

<sup>18</sup> This variable was also used in Cloyne and Hürtgen (2016) in an analysis of UK monetary policy shocks.

<sup>19</sup> Following the New Keynesian literature, we also experimented with the change in the labour share, but this lacked empirical significance in all of the specifications we estimated.

<sup>20</sup> The underlying credit spreads series are taken from the ‘three centuries of data’ dataset available on the Bank’s website, originally used in Hills *et al.* (2010).

<sup>21</sup> This variable is discussed in more detail in Burgess *et al.* (2013).

<sup>22</sup> Throughout this paper we use estimated error variance-covariance matrices that are robust to heteroscedasticity and serial correlation.

**Figure 13: Explaining Inflation: The Trend and Other Variables**

			HCPI			CCPI		
			Trend	Extra	R <sup>2</sup>	Trend	Extra	R <sup>2</sup>
Inflation expectations	FMB5	coeff	1.39	0.01	0.51	1.43	-0.19	0.61
		p value	0.00	0.96		0.00	0.06	
	FMB55	coeff	1.40	-0.03	0.51	1.61	-0.30	0.61
		p value	0.00	0.83		0.00	0.01	
	BASIX1	coeff	1.06	0.67	0.55	1.26	0.15	0.59
		p value	0.00	0.05		0.00	0.12	
	BASIX2	coeff	1.25	0.33	0.51	1.29	0.09	0.58
		p value	0.00	0.12		0.00	0.36	
	GFKE	coeff	1.29	0.41	0.56	1.31	0.04	0.59
		p value	0.00	0.06		0.00	0.72	
NIESR4Q	coeff	1.39	0.00	0.51	1.34	-0.05	0.59	
	p value	0.00	0.97		0.00	0.38		
Slack	YGAPBOE	coeff	1.58	-0.17	0.53	1.41	-0.04	0.59
		p value	0.00	0.14		0.00	0.53	
	YGAPHP	coeff	1.44	-0.18	0.53	1.30	0.03	0.59
		p value	0.00	0.30		0.00	0.64	
	YGAPOBR	coeff	1.53	-0.10	0.52	1.40	-0.03	0.59
		p value	0.00	0.32		0.00	0.53	
UGAPBOE	coeff	1.56	-0.33	0.53	1.73	-0.38	0.62	
	p value	0.00	0.07		0.00	0.00		
Labour costs	AWE	coeff	1.41	0.03	0.51	1.35	0.02	0.59
		p value	0.00	0.44		0.00	0.44	
	ULC	coeff	1.38	-0.03	0.51	1.32	-0.01	0.59
		p value	0.00	0.14		0.00	0.53	
International costs and prices	DPWX	coeff	1.16	0.15	0.63	1.28	0.06	0.62
		p value	0.00	0.00		0.00	0.01	
	DBRENT	coeff	1.31	0.03	0.59	1.34	0.01	0.61
		p value	0.00	0.00		0.00	0.03	
	DGSCI	coeff	1.32	0.04	0.59	1.37	0.01	0.62
		p value	0.00	0.00		0.00	0.02	
SERI	coeff	1.47	0.01	0.51	1.59	0.02	0.60	
	p value	0.00	0.39		0.00	0.03		
Domestic financial conditions	SPREADPCA	coeff	1.47	-0.14	0.52	1.51	-0.12	0.60
		p value	0.00	0.27		0.00	0.07	
	SHADOWBR	coeff	1.40	0.01	0.51	1.31	-0.01	0.58
		p value	0.00	0.63		0.00	0.56	
	GILT2	coeff	1.39	0.00	0.51	1.32	-0.02	0.59
		p value	0.00	0.89		0.00	0.45	
	M4EX	coeff	1.37	-0.02	0.51	1.30	-0.01	0.59
		p value	0.00	0.55		0.00	0.37	
M4LEX	coeff	1.40	0.00	0.51	1.32	0.00	0.58	
	p value	0.00	0.79		0.00	0.90		

Note: See Appendix Figure 1 for variable definitions.

A first point worth noting from this table relates to the estimates of the coefficients on trend inflation. In every iteration, the coefficient on trend inflation ( $\beta$ ) is significant and positive (as would be expected given the underlying model—so they are not shaded). The  $R^2$ 's are also quite high for these simple equations. While this is not surprising given that the trend is a function of the inflation data, these results confirm that the trend is closely associated with overall headline and core inflation. The size of the beta coefficient also warrants a brief discussion. The average coefficient estimate is 1.4 for both headline inflation and core. That might be surprising at first glance; one



might expect an estimated coefficient near unity given the model specification in equation (1). This can partly be explained, however, by the constant in the regression (not shown), which tends to be significantly negative. When the constant is excluded from the specification, the beta coefficients are close to one. In other words, the model has difficulty distinguishing the impact of the slow-moving trend from that of a constant. This does not affect the analysis below, however, since the main goal of these regressions is to consider the incremental information contained in variables *other than* the trend.

A noteworthy result from the table, especially in contrast to the significance of the  $\beta$  coefficients on the trend variables, is the insignificance of most of the  $\gamma$  coefficients on the additional explanatory variables. This suggests that few variables can improve our understanding of inflation dynamics after controlling for the slow-moving trend. This includes all the measures of slack in regressions for headline CPI, and all but one for core CPI. This is despite the fact that these slack variables have received prominent attention in most models of inflation dynamics and are at the core of most macroeconomic models. This insignificance also applies to measures of inflation expectations, which have also received prominent attention in these models and discussions. No measures of inflation expectations are significant with the expected sign after controlling for trend inflation for either the headline or core regressions.

Another clear result is the small set of variables whose coefficients are consistently significant with the expected sign—different measures of international prices. More specifically, after accounting for estimated trend inflation, growth in sterling world export prices, Brent oil prices (in US\$), and a broader commodity price index (in US\$) are all significantly correlated with higher headline and core CPI inflation. The corresponding coefficients on headline inflation are larger than those for core, as would be expected, but the consistently significant impact on core is also noteworthy. Moreover, the magnitude of the coefficients on these international prices suggests that they are economically meaningful. A one standard deviation increase in world export price inflation (which is equivalent to 3.3pp on a 1Q, annualized basis) correlates to CPI inflation 0.51pp higher (after controlling for the trend). A one-standard deviation increase in US\$ Brent oil prices (which is equivalent to 15%, or around \$7 at current prices) correlates to CPI inflation 0.41pp higher (after controlling for the trend). In the United Kingdom, changes in commodity prices and world export prices appear to significantly affect inflation—even after controlling for a slow moving trend.<sup>23</sup>

A final noteworthy result is how these results compare to those for the US in CFHKS (2017). CFHKS (2017) also find a powerful role for trend inflation in explaining inflation dynamics. The  $R^2$ 's for similar equations for the US, however, were significantly greater, suggesting that trend inflation may be even more important for US inflation dynamics than in the UK.<sup>24</sup> This is not surprising given the stylized fact in the previous section, that movements in UK inflation appear to be somewhat less persistent than in the US for core measures. CFHKS (2017) also found that most of the other explanatory variables in equation (8) were not significant and/or had the wrong sign, except for inflation expectations, for which one of their six measures was significant in explaining core CPI and PCE inflation. They also found a significant role for the exchange rate, but do not test for any impact

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<sup>23</sup> Import price inflation (in sterling terms) is also significant in regressions for headline CPI inflation.

<sup>24</sup> More specifically, the average  $R^2$  for US core CPI inflation is 79%, and for US core PCE inflation is 70%. Our results for the UK are not directly comparable due to differences in the analysis, but we find an  $R^2$  averaging about 53% for headline CPI inflation and about 60% for core CPI inflation.

of world export prices, oil prices, or commodity prices. These may play a more important role in UK inflation dynamics than in the US, however, as the UK is more of a “small open economy.”

We also estimate a number of sensitivity tests for these results. For example, we estimate equation (8) with the preferred measure of trend inflation (based on the ARSV method), but with four lags for each of the 21  $X_t$  variables in order to capture any slower moving impact of the control variables on inflation. Next we estimate an alternate specification for equation (8) which focuses on predicting the pure innovations in inflation (similar to an extension suggested in CFHKS, 2017):

$$\eta_t = \alpha + \beta X_t + e_t, \text{ where } \eta_t = (\pi_t - \tilde{\tau}_t) - \varphi(\pi_{t-1} - \tilde{\tau}_{t-1}). \quad (9)$$

This specification is particularly useful to minimize any concerns related to issues which can arise from the use of the constructed regressor  $\tilde{\tau}_t$ .

We also estimate the base case regression (using the ARSV estimate of the trend and specification in equation 8), but add a dummy variable for the peak of the global financial crisis—in 2008Q4 and 2009Q1 (as also suggested by CFHKS). Finally, we estimate equation (8) using the measure of trend inflation based on the post-1993 sample only (shown in Figure 12) to check that the inclusion of the pre-inflation targeting period in our baseline trend estimates is not driving the results. Many of these robustness tests are included in Appendix Figures 5-7.

The main results from all of these robustness tests confirm the conclusions discussed above. In each case, the coefficients on trend inflation are positive and significant, indicating an important role for the trend in explaining inflation dynamics. In most other cases, the other coefficients are usually insignificant, including measures of slack and inflation expectations. The main exception is the results from estimating equation (9), which yield significant and economically meaningful roles for half of the measures of inflation expectations (those based on household measures) when predicting headline CPI inflation (but not core). The coefficients on international prices indicate a fairly consistent significant correlation with headline inflation. All three measures relating to international prices (world export prices, oil prices, and commodity prices) are also significant in estimates for core inflation in the tests based on equation (9), as well as the tests using post-1993 trend estimates.

The one set of robustness tests which yields somewhat different results is when the dummy for the peak of the crisis is included (with results in Appendix Figure 6). In this case, the signs and significance of many of the variables change. This suggests that the sharp movements in economic variables and prices that occurred around the crisis can significantly affect estimated relationships. For example, international prices are less significant in predicting inflation after controlling for both the trend and a crisis dummy, possibly reflecting the fact that the crisis period (here defined as 2008Q4-2009Q1) coincides with sizeable falls in these international prices and in UK inflation.

During the full sample, however, after controlling for trend inflation, international prices (including oil and other export prices) significantly affect inflation dynamics across a range of specifications. Other variables, except possibly household inflation expectations, appear to play little role.

## **b. What Explains Trend Inflation?**

The powerful role of trend inflation in explaining inflation dynamics suggests that understanding what influences this trend is critically important to understanding overall inflation. This section takes



several different approaches to advance our understanding—beginning by focusing on those variables that have received the most attention in the literature (inflation expectations and slack), and then looking at a broader set of factors.

To begin, following CFHKS (2017) we regress trend inflation (as estimated using ARSV) on changes in inflation expectations and slack:<sup>25</sup>

$$\Delta\tilde{\tau}_t = \alpha + \beta\Delta E[\pi_t] + \gamma\Delta Slack_{t-1} + e_t. \quad (10)$$

The top of Figure 14 shows the results using the 6 different measures of inflation expectations and measuring slack based on the BoE measure of the unemployment gap. Just as found in the earlier estimates of movements in inflation around the trend (Figure 13), changes in measures of slack are usually insignificant—and they often even have the “wrong” sign (with increases in slack correlated with higher inflation). Only four of the twelve coefficients on inflation expectations have positive and significant coefficients. These results suggest that changes in measured slack have little clear relationship with trend inflation, while changes in inflation expectations might play some role. The magnitudes of the coefficients on the inflation expectations variables which are significant, however, suggest that even these estimates would only imply a small impact. For example, a 1pp increase in household inflation expectations, measured by the Barclays Basix 1-year ahead measure, is associated with only a 0.08pp increase in trend inflation. These results are broadly unchanged if we use different measures of slack (as shown in Appendix Figure 8 when slack is measured using the OBR’s measure of the output gap<sup>26</sup>). The most notable difference is if we use the post-1993 trend estimates. In this case (shown in Appendix Figure 9), the measures of slack not only continue to have the “wrong” sign, but are often significant, and just less than half of the coefficients on inflation expectations are positive and significant, albeit continuing to correspond to small magnitudes.

But is it changes in slack that determine the trend rate of inflation? Or could it be the level of slack? Even if slack is decreasing, if it is decreasing from a very high level and still implies a substantial amount of slack in the economy, trend inflation might be expected to fall rather than increase. To test if the level of slack may be more important than changes in slack when explaining trend inflation, we estimate the same series of regressions, but replace the change in slack in equation (10) with the level:

$$\Delta\tilde{\tau}_t = \alpha + \beta\Delta E[\pi_t] + \gamma Slack_{t-1} + e_t. \quad (11)$$

The results are shown in the bottom panel of Figure 14 and are noticeably different. Although the main results for inflation expectations are unchanged (occasionally significant, but small in magnitude), the coefficients on slack are now always negative and significant at the 5% level in regressions explaining trend headline CPI inflation—although never significant for core inflation. This

<sup>25</sup> We follow CFHKS (2017) and estimate the equation in first differences since inflation is assumed to follow a unit root process.

<sup>26</sup> As shown in Appendix Figure 8, the most notable difference when using this output gap measure of slack is that in several formulations the coefficient on slack is significant with a positive sign. We focus on the BoE measure of the unemployment gap, rather than the OBR measure, as the OBR measure aims to capture “the additional output that could be produced once all shocks have worked through the economy”, which is a longer term concept. The BoE measure is more of a current measure of the extent of slack given the current structure of the economy.

suggests that higher levels of slack correlate to lower levels of trend headline inflation. The magnitude of the coefficient estimates, however, indicates that the size of these effects tends to be quite small. More specifically, when the unemployment gap is 1%, trend inflation tends to fall by only around 0.08pp for headline CPI and around 0.03pp for core CPI. The sensitivity tests reported in Appendix Figure 9, based on post-1993 trend estimates yield similar results, but the sensitivity tests reported in Appendix Figure 8, using an output gap measure of slack, continue to find no significant negative relationship between trend inflation and slack—whether measured in levels or differences.<sup>27</sup>

**Figure 14, Explaining Trend Inflation with Inflation Expectations and Slack**

Slack in differences		HCPI			CCPI		
		Slack	$\pi$ -expect	R <sup>2</sup>	Slack	$\pi$ -expect	R <sup>2</sup>
FMB5	coeff	0.02	0.06	0.02	0.10	-0.04	0.03
	p value	0.86	0.23		0.22	0.50	
FMB55	coeff	0.01	0.11	0.04	0.10	0.04	0.03
	p value	0.89	0.04		0.24	0.52	
BASIX1	coeff	0.03	0.08	0.06	0.11	0.04	0.04
	p value	0.76	0.00		0.26	0.12	
BASIX2	coeff	0.02	0.05	0.03	0.10	0.03	0.03
	p value	0.88	0.03		0.26	0.21	
GFKE	coeff	0.09	0.11	0.13	0.13	0.04	0.05
	p value	0.38	0.00		0.16	0.08	
NIESR4Q	coeff	0.02	0.01	0.00	0.10	0.00	0.02
	p value	0.83	0.70		0.22	0.53	

Slack in levels		HCPI			CCPI		
		Slack	$\pi$ -expect	R <sup>2</sup>	Slack	$\pi$ -expect	R <sup>2</sup>
FMB5	coeff	-0.08	0.05	0.16	-0.03	-0.04	0.04
	p value	0.00	0.25		0.21	0.46	
FMB55	coeff	-0.07	0.09	0.17	-0.03	0.03	0.04
	p value	0.01	0.08		0.23	0.58	
BASIX1	coeff	-0.07	0.07	0.19	-0.03	0.03	0.04
	p value	0.00	0.00		0.24	0.15	
BASIX2	coeff	-0.07	0.05	0.17	-0.03	0.03	0.04
	p value	0.00	0.02		0.23	0.15	
GFKE	coeff	-0.08	0.11	0.27	-0.03	0.04	0.05
	p value	0.00	0.00		0.20	0.16	
NIESR4Q	coeff	-0.08	0.00	0.14	-0.03	0.00	0.04
	p value	0.00	0.76		0.22	0.66	

**Note:** See Appendix Figure 1 for variable definitions and sources. Slack is measured using the BOE measure of the unemployment gap (UGAPBOE).

<sup>27</sup> When using output gap measures of slack, the smaller and insignificant coefficients may reflect the fact that these measures have greater variances than the unemployment gap measures.

Next, just as the results in Figure 13 suggested that variables other than inflation expectations and slack could play an important role in explaining movements of inflation around trend, we examine if other variables could explain movements in trend inflation. More specifically, we estimate equation (10), except instead of including changes in inflation expectations or slack, we estimate the impact of changes in the other variables discussed in Section IVa: measures of labour costs, international costs and prices, and domestic financial conditions.<sup>28</sup> Since many of these variables would be expected to only affect trend inflation with a lag, we also include 4 lags or 8 lags (in quarters) of each of the 10 explanatory variables:

$$\Delta \tilde{\tau}_t = \alpha + \beta \sum_{j=0}^L \Delta X_{t-j} + e_t, \quad (12)$$

where  $L$  is the number of lags of each variable (either 4 or 8). The results from including each of these additional explanatory variables, one at a time, are shown in the top of Figure 15. Each column lists the sum of the  $\beta$ 's for the coefficient estimates for each of the additional variables, as well as the corresponding p-values (from an F test of their joint significance). For comparison with the earlier results, we also include estimates (at the bottom) when slack is included—first measured in changes and then in levels (and each also with the same number of lags as done for the other  $X_t$ ). For robustness, we repeat these estimates with a dummy variable for the peak of the global financial crisis (reported in Appendix Figure 10), and also using the post-1993 trend estimates (reported in Appendix Figure 11). This discussion focuses on the results that are robust to these various specifications.

The initial key result that jumps out from the table, once again, is that most of the variables that could affect trend inflation appear to play only a minimal role—if any. For example, changes in labour costs mostly have no significant correlation with trend inflation (although unit labour costs occasionally have a significant positive coefficient) and the same is true for the variables measuring domestic financial conditions.<sup>29</sup> Changes in slack appear to have no significant negative relationship, and often have the “wrong” sign. The level of slack often has a significant relationship with trend inflation with the expected negative sign—and in some specifications (including the results in Figure 15), the relationship can be significant for core inflation, as well as headline. The significance of this result varies, however, and once again the estimates imply that the magnitude of any impact from slack is fairly small. The coefficient on the shadow Bank Rate is always negative, suggesting that tighter monetary policy corresponds to lower trend inflation, but the coefficients are usually insignificant. The coefficients on the various measures of world export prices—such as the world export price index, US\$ Brent crude prices, or a commodity price index—are always positive (as one might expect) and sometimes significant, more often for predicting headline inflation.

<sup>28</sup> Differencing the explanatory variables means, for example, that the regressors relating to labour costs are measured as the *change* in labour cost growth.

<sup>29</sup> One notable exception is that changes in credit spreads often correlate positively with changes in trend inflation. This might point to the role of financial frictions in driving inflation. As shown below, however this variable tends to be insignificant when simultaneously controlling for other variables.

Figure 15: Explaining Trend Inflation with Lagged Variables

			HCPI				CCPI				
			4 lags		8 lags		4 lags		8 lags		
			coeff	R <sup>2</sup>	coeff	R <sup>2</sup>	coeff	R <sup>2</sup>	coeff	R <sup>2</sup>	
Labour costs	AWE	sum(coeffs)	0.03	0.02	0.05	0.03	0.00	0.00	-0.04	0.02	
		p value	0.20		0.52		0.92		0.60		
	ULC	sum(coeffs)	0.02	0.06	0.06	0.10	0.04	0.16	0.06	0.17	
		p value	0.24		0.27		0.02		0.08		
International costs and prices	DPWX	sum(coeffs)	0.03	0.10	0.06	0.12	0.00	0.02	0.01	0.03	
		p value	0.03		0.10		0.72		0.60		
	DBRENT	sum(coeffs)	0.01	0.14	0.01	0.17	0.00	0.05	0.00	0.08	
		p value	0.07		0.08		0.78		0.84		
	DGSCI	sum(coeffs)	0.01	0.14	0.02	0.16	0.00	0.06	0.01	0.08	
		p value	0.03		0.03		0.96		0.58		
	SERI	sum(coeffs)	-0.03	0.12	-0.04	0.15	-0.02	0.12	-0.04	0.20	
		p value	0.03		0.00		0.00		0.00		
Domestic financial conditions	SPREADPCA	sum(coeffs)	0.06	0.01	0.22	0.08	0.11	0.05	0.29	0.17	
		p value	0.37		0.05		0.06		0.00		
	SHADOWBR	sum(coeffs)	-0.02	0.01	-0.03	0.01	-0.06	0.02	-0.10	0.06	
		p value	0.70		0.73		0.27		0.10		
	GILT2	sum(coeffs)	-0.02	0.03	-0.09	0.05	0.00	0.02	-0.01	0.07	
		p value	0.82		0.66		0.94		0.95		
	M4EX	sum(coeffs)	0.02	0.04	-0.01	0.09	0.02	0.05	-0.01	0.14	
		p value	0.40		0.86		0.36		0.77		
	M4LEX	sum(coeffs)	0.01	0.02	-0.01	0.04	-0.01	0.06	-0.03	0.09	
		p value	0.82		0.72		0.54		0.21		
Slack (levels)	YGAPBOE	sum(coeffs)	-0.03	0.06	-0.04	0.18	-0.01	0.04	-0.01	0.14	
		p value	0.10		0.00		0.71		0.20		
	YGAPHP	sum(coeffs)	-0.02	0.01	-0.06	0.11	-0.01	0.07	-0.04	0.14	
		p value	0.43		0.01		0.56		0.02		
	YGAPOBR	sum(coeffs)	-0.02	0.10	-0.03	0.18	0.00	0.10	-0.01	0.19	
		p value	0.09		0.00		0.90		0.29		
	UGAPBOE	sum(coeffs)	-0.08	0.14	-0.10	0.21	-0.03	0.06	-0.04	0.13	
		p value	0.00		0.00		0.25		0.05		
	Slack (differences)	YGAPBOE	sum(coeffs)	0.04	0.02	0.16	0.07	0.09	0.07	0.17	0.12
			p value	0.50		0.14		0.08		0.00	
YGAPHP		sum(coeffs)	0.04	0.01	0.16	0.05	0.08	0.06	0.15	0.10	
		p value	0.37		0.08		0.06		0.02		
YGAPOBR		sum(coeffs)	0.06	0.04	0.15	0.07	0.09	0.10	0.21	0.21	
		p value	0.18		0.04		0.01		0.00		
UGAPBOE		sum(coeffs)	0.06	0.01	0.26	0.04	0.17	0.04	0.43	0.12	
		p value	0.71		0.43		0.23		0.02		

Most noteworthy, however, is the one (and only) variable that consistently yields a coefficient estimate that is significant for both headline and core inflation and for the shorter and longer lag structures: the sterling exchange rate index. A sterling depreciation is significantly correlated with both higher subsequent headline and core inflation. Moreover, the magnitude of this effect is estimated to be material. A 10% depreciation in the sterling ERI correlates to an eventual increase in trend inflation of 0.36pp for the headline CPI and 0.43pp for the core CPI.<sup>30</sup> To put this in context, the sterling ERI depreciated by about twice that in the year to October 2016 in the run-up and aftermath of the June 2016 vote for the UK to leave the European Union. This roughly 20% depreciation would imply an eventual increase in trend headline CPI inflation of 0.73pp and in trend core CPI inflation of 0.86pp. These are large effects. They imply that movements in sterling can correspond to large and meaningful movements in the slow moving and persistent trend in headline and core inflation rates. The significance of the impact of movements in sterling on trend headline and core inflation is robust to each of the sensitivity tests we have tried—including to different estimation techniques for trend inflation, different lag specifications, and the inclusion of a crisis dummy.

These large, and fairly persistent, effects of sterling’s movements on UK inflation agree with other analyses of the impact of changes in the exchange rate on the UK economy. For example, it is well understood that the UK is an example of the textbook “small open economy” and affected by exchange rate movements through many channels.<sup>31</sup> It is also well understood that changes in the sterling exchange rate index take some time to fully “pass-through” into UK consumer prices. For example, the Bank of England estimates that annual inflation is normally affected by changes in sterling over at least four years.<sup>32</sup> These slow-moving effects of the exchange rate on UK prices may be captured as persistent movements in our estimates of trend inflation, and be a factor behind the significant coefficient estimates for the exchange rate in Figure 15.

One potential concern with the results reported in Figures 14 and 15 is that many of the explanatory variables included in the individual regressions are correlated. For example, in some specifications the coefficient on world export prices is positive and significant in predicting trend headline inflation. But is this capturing the relationship of trend inflation with world export prices measured in foreign currency—or with changes in the sterling exchange rate index (which is significant in all the regressions)? Similarly, could some variables that appear to have an insignificant relationship with trend inflation have a significant impact after controlling for simultaneous movements in other variables?

To test for this, we estimate a number of versions of equation (12), except now we include combinations of the different explanatory variables ( $\Delta X_{t-j}$ ) instead of including them one at a time. We reduce the number of lags to 4 in order to preserve degrees of freedom,<sup>33</sup> but the results are robust to including more lags (as shown in Appendix Figure 12). Figure 16 shows a sample of the results, focusing on including variables that are significant in at least some of the previous iterations and that represent the five different sets of variables (as listed in Appendix Figure 1). The top panel measures slack in changes, while the bottom panel measures slack in levels.

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<sup>30</sup> Using the results with 8 lags of the regressor.

<sup>31</sup> For example, see Forbes (2014).

<sup>32</sup> See the Bank of England’s *Inflation Report*, February 2017 and Forbes, Hjortsoe and Nenova (2015).

<sup>33</sup> The exception is slack and inflation expectations, which only include contemporaneous regressors.

Figure 16: Explaining Trend Inflation with Different Combinations of Variables

Slack in differences		HCPI					CCPI				
		(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
<b>BASIX1</b>	coeff	0.09	0.07	0.08	0.10	0.09	0.03	0.05	0.04	0.05	0.04
	p value	0.00	0.03	0.00	0.00	0.05	0.11	0.15	0.11	0.09	0.39
<b>UGAPBOE</b>	coeff	-0.01	0.01	0.05	0.11	0.02	-0.15	-0.18	-0.19	0.00	-0.23
	p value	0.92	0.92	0.70	0.33	0.89	0.05	0.03	0.04	0.98	0.00
<b>SERI</b>	coeff	-0.03	-0.03	-0.03		-0.03	-0.03	-0.04	-0.03		-0.04
	p value	0.01	0.02	0.02		0.05	0.00	0.00	0.00		0.01
<b>DGSCI</b>	coeff		0.01			0.00		-0.01			-0.01
	p value		0.17			0.64		0.21			0.26
<b>SPREADPCA</b>	coeff			-0.08		0.13			0.06		0.11
	p value			0.48		0.73			0.46		0.61
<b>SHADOWBR</b>	coeff				-0.03	0.10				-0.07	0.00
	p value				0.50	0.38				0.20	0.98
<b>ULC</b>	coeff					0.01					0.03
	p value					0.56					0.06
<b>M4LEX</b>	coeff					-0.01					-0.02
	p value					0.77					0.46
<b>R<sup>2</sup></b>		<b>0.17</b>	<b>0.28</b>	<b>0.19</b>	<b>0.08</b>	<b>0.43</b>	<b>0.17</b>	<b>0.25</b>	<b>0.20</b>	<b>0.05</b>	<b>0.50</b>

Slack in levels		HCPI					CCPI				
		(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
<b>BASIX1</b>	coeff	0.08	0.06	0.07	0.07	0.07	0.04	0.05	0.04	0.04	0.03
	p value	0.00	0.11	0.01	0.01	0.06	0.07	0.16	0.12	0.14	0.44
<b>UGAPBOE</b>	coeff	-0.08	-0.08	-0.08	-0.09	-0.10	-0.03	-0.03	-0.03	-0.03	-0.04
	p value	0.00	0.00	0.00	0.00	0.00	0.14	0.26	0.18	0.24	0.06
<b>SERI</b>	coeff	-0.04	-0.04	-0.04		-0.04	-0.03	-0.03	-0.03		-0.03
	p value	0.00	0.00	0.00		0.00	0.00	0.00	0.01		0.02
<b>DGSCI</b>	coeff		0.01			0.00		0.00			-0.01
	p value		0.24			0.92		0.41			0.29
<b>SPREADPCA</b>	coeff			-0.09		0.18			-0.01		0.05
	p value			0.28		0.35			0.90		0.78
<b>SHADOWBR</b>	coeff				-0.12	0.06				-0.09	-0.02
	p value				0.03	0.50				0.11	0.80
<b>ULC</b>	coeff					0.01					0.03
	p value					0.48					0.04
<b>M4LEX</b>	coeff					-0.01					-0.02
	p value					0.83					0.50
<b>R<sup>2</sup></b>		<b>0.31</b>	<b>0.42</b>	<b>0.33</b>	<b>0.22</b>	<b>0.61</b>	<b>0.17</b>	<b>0.23</b>	<b>0.19</b>	<b>0.07</b>	<b>0.50</b>

The results in Figure 16 suggest, once again, that the one variable which is consistently significant in explaining trend headline and core inflation is the sterling exchange rate. This is also true for the series of sensitivity tests (a subset of which are reported in Appendix Figures 12-14). In almost every specification, sterling depreciations are significantly correlated with increases in trend core inflation and trend headline inflation, with similar large magnitudes to those reported in the bivariate

regressions in Figure 15.<sup>34</sup> Movements in the sterling exchange rate appear to be an important influence on the slow-moving and persistent trend rate of UK inflation.

Another key set of results are the coefficients on the two variables which receive prominent attention in models of inflation dynamics: inflation expectations and slack. The coefficients on inflation expectations continue to be positive in each specification, but are often not significant in models predicting trend headline inflation, and are rarely significant for trend core inflation. Moreover, the coefficients often become insignificant if there is a simultaneous control for changes in commodity prices (which are correlated with inflation expectations). Changes in slack appear to have little significant correlation with changes in trend headline inflation, although they are often significant in regressions of core inflation. By contrast, the level of slack is significantly correlated with changes in trend headline inflation, but usually not significant for core. The magnitudes of the estimated effects corresponding to the level or changes in slack continue to be small, however, as found in the analysis with fewer control variables (in Figure 15).

The coefficient estimates on the other variables are generally insignificant, and some even have an unexpected sign, with the signs and significance fluctuating across specifications. One additional noteworthy point is the coefficient estimates for the shadow Bank Rate (a measure of monetary policy that incorporates unconventional policy). This coefficient is often negative and sometimes significant when changes in sterling are not simultaneously controlled for (as in column 4 in Figure 16 and Appendix Figure 14), but insignificant and often positive when a control for sterling is included (as in the other columns). This suggests that a channel by which monetary policy affects trend inflation may be through the impact of monetary policy on the exchange rate.

Finally, it is worth noting how these results compare to those for the US in CFHKS (2017). The variables and estimation techniques for trend inflation are different across the two studies—so we do not want to make too much of these comparisons. Nonetheless, the similarities and differences in the general results are worth noting. For the US, CFHKS (2017) also found some role for changes in the unemployment gap in explaining movements in trend inflation, and very mixed evidence for a role of inflation expectations. CFHKS (2017) found a more prominent role for domestic financial conditions (as measured by a broad financial conditions index and changes in nonfinancial debt) than for the UK. CFHKS (2017) also found some evidence that movements in the exchange rate index affected core inflation—although the role of the exchange rate does not appear to be as consistently significant and is much smaller in magnitude than in the UK.<sup>35</sup> This is not surprising, however, given the more important role of trade and the global economy to the “small” open economy of the United Kingdom.

## **V. Conclusions**

UK inflation dynamics can be well characterized using a “trendy” approach—an approach which focuses on the time series and does not rely on the strict structural assumptions in standard DSGE

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<sup>34</sup> This remains true when controlling for (changes in) sterling import price inflation, which is insignificant.

<sup>35</sup> Drawing direct comparisons is difficult due to the different specifications, but with this caveat, the coefficient on the exchange rate index for regressions predicting core CPI trend inflation is about 5 times bigger for the UK than the comparable estimate for the US.

models. Instead, UK inflation can be separated empirically into two components: a slow-moving trend and short-term movements around this trend. This slow-moving trend plays an important role in driving UK inflation dynamics, explaining about 39% of the variation in headline inflation and 46% in core inflation since 1984.

The results in this paper suggest that global variables—primarily international prices (commodity prices or world export prices) and the exchange rate (which also has a domestic component)—are critical determinants of these inflation dynamics. Across a range of specifications, international prices are important determinants of the short-term cyclical movements in UK inflation around its trend, and the sterling exchange rate is an important determinant of movements in the more persistent trend in inflation. These relationships are not only significant, but economically meaningful and robust to a range of specifications. As a result, UK inflation is likely to continue to be affected by external shocks, and therefore continue to be volatile and hard to predict. UK policymakers may only have a limited ability to reduce this volatility in the face of external influences.

In contrast, UK domestic variables that are at the core of the popular DSGE models of inflation dynamics, such as slack and inflation expectations, seem to play a less significant role. Although some measures of inflation expectations and the level of slack in the economy are correlated with movements in trend headline inflation and movements around this trend, the significance of these relationships tends to fluctuate across specifications. These standard measures of slack and inflation expectations are also rarely significant in explaining the dynamics of core inflation. Moreover, even in the specifications when slack and inflation expectations are significant, the magnitudes of their estimated relationships with UK inflation tend to be smaller than those for international prices and the exchange rate.

These results have a number of implications for monetary policy. They support other analysis that the Phillips curve has been fairly flat in the UK in recent decades. They also suggest that the standard DSGE models that are at the core of central bank forecasts and analysis should be used cautiously. These models are useful for some purposes, but may place undue weight on hard-to-measure variables such as slack and inflation expectations in explaining inflation dynamics.

These results also provide guidance on when monetary policy should react to price volatility and any movements in inflation away from target. If movements in inflation primarily reflect movements in the cyclical innovations around UK trend inflation (such as those driven by global commodity prices), then the effects on inflation should be temporary and, in isolation, the appropriate monetary policy response would be to “look through” and not respond. This is even true if inflation deviates from 2% for an extended period, but that deviation primarily reflects shocks corresponding to deviations of inflation around its trend and no movement in the trend. In this case, the duration or magnitude of the inflation overshoot or undershoot is less of a concern. Inflation will return to its trend, which should not be affected.

In contrast, variables which affect the slow-moving trend are more likely to generate a persistent effect on UK inflation and therefore more likely to merit a monetary policy response. Of the variables which affect this slow-moving trend, the exchange rate appears to be the most important. There may be times where any such effects of sterling on inflation are partially balanced (or aggravated) by other variables—such as the level of slack in the economy or changes in inflation



expectations. This would complicate the appropriate monetary policy response and require an evaluation of the relative magnitudes of the effects in order to ensure trend inflation returns sustainably to target. The estimates in this paper, however, suggest that since the effect of exchange rate movements on trend inflation is larger than that of other variables (including slack and inflation expectations), a material movement in these other variables would be required to fully balance the impact of a moderate exchange movement on trend inflation. Policymakers also need to consider a number of other factors, however, such as unnecessary volatility in output, when setting the appropriate path for monetary policy.<sup>36</sup>

The framework central to this paper also suggests that the magnitude and timing of deviations of inflation from the 2% target can be important when assessing the magnitude and timing of monetary policy responses. Other work has found that the longer this trend rate of inflation moves away from target, the more difficult it will be to return to target.<sup>37</sup> Similarly, CFHKS (2017) argue that if the trend rate of inflation moves above (below) 2%, and assuming no other variables are affecting trend inflation in a meaningful way, then headline inflation would need to undershoot (or overshoot) 2% in order to return the trend to 2%. This framework suggests that the longer a given deviation of trend inflation from target persists, or the larger the gap, the longer (or larger) the corresponding overshoot or undershoot in the opposite direction will be required.

The analysis in this paper should be interpreted with a number of caveats. The main results focus on a period since the early 1990s. Although UK inflation has been somewhat volatile since then, and inflation has deviated from its target for sustained periods, this is still a period of fairly low and stable inflation when compared to the longer historic time series for the UK (or the experience of other countries). Therefore, the results in this analysis—such as the limited role for inflation expectations—may not hold in other countries or time periods when inflation expectations are less well anchored. Similarly, the predominant role found for global commodity prices and the exchange rate in explaining UK inflation dynamics may not apply to other economies that are more closed to trade and financial flows, or that are larger and more likely to affect global prices through their own actions (such as the United States). Lastly, our atheoretical approach may not be able to capture complex structural economic relationships that are not easily tested in simple regressions, or broader concerns that may factor into monetary policy decisions.

Nonetheless, the results also suggest that analysing inflation dynamics by focusing on a more persistent component and cyclical movements around that component is not just “trendy”. It can provide important insights for the United Kingdom. Applying this approach to other countries could also yield important insights for those countries’ inflation dynamics, as well as for the appropriate response of monetary policy when inflation moves away from target.

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<sup>36</sup> For a detailed discussion of how to evaluate these types of tradeoffs, see Carney (2017).

<sup>37</sup> This point is made using a different framework in papers such as Clarida, Galí and Gertler (1999), which highlights the role of inflation persistence in determining optimal monetary policy.

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## Appendix Figure 1: Data Definitions and Sources

All data are quarterly and from 1993-2016 unless noted.

Category	Code	Name	Source	Mean	Standard deviation
Inflation	HCPI	Headline CPI inflation	ONS	1.97	1.39
	CCPI	HCPI excluding food, non-alcoholic beverages and energy	ONS	1.80	0.92
	HPCE	Consumption deflator	ONS	1.80	1.99
	PGDP	GDP deflator	ONS	1.97	2.38
	HRPIX	RPI excluding mortgage interest	ONS	2.73	1.35
Inflation expectations	FMB5	Breakevens 5-year	BoE	3.23	0.79
	FMB55	Breakevens 5-year, 5-year	BoE	3.35	0.73
	BASIX1	Household $\pi$ e 1-year	Barclays	2.89	0.58
	BASIX2	Household $\pi$ e 2-year	Barclays	3.30	0.56
	GFKE	Household price expectations	Gfk	-0.36	0.79
	NIESR4Q	Professionals $\pi$ e 1-year	NIESR	2.48	0.72
Slack	YGAPBOE	Output gap (BoE)	BoE	1.08	1.41
	YGAPHP	Output gap (HP filter)	ONS	0.02	1.12
	YGAPOBR	Output gap (OBR)	OBR	0.31	1.80
	UGAPBOE	Unemployment gap (BoE)	BoE	0.70	0.70
Labour costs	AWE	Average Weekly Earnings growth, 1Q(a)	ONS	3.21	3.19
	ULC	Unit labour cost growth, 1Q(a)	ONS	2.20	3.70
International costs and prices	DPWX	World export price growth, 1Q(a)	ONS	0.92	3.30
	DBRENT	\$ Brent crude growth, 1Q	ICIS-LOR	0.99	15.10
	DGSCI	\$ Commodity price index growth, 1Q	S&P	0.73	10.63
	SERI	Sterling ERI level (natural log)	BoE	4.51	0.10
Domestic financial conditions	SPREADPCA	Credit spreads principal component <sup>38</sup>	BoE	1.94	1.18
	SHADOWBR	Shadow Bank Rate	BoE	3.23	3.13
	M4EX	Broad money (M4ex) growth, 1Q(a)	BoE	4.24	2.41
	M4LEX	Broad credit (M4Lex) growth, 1Q(a)	BoE	6.35	3.60

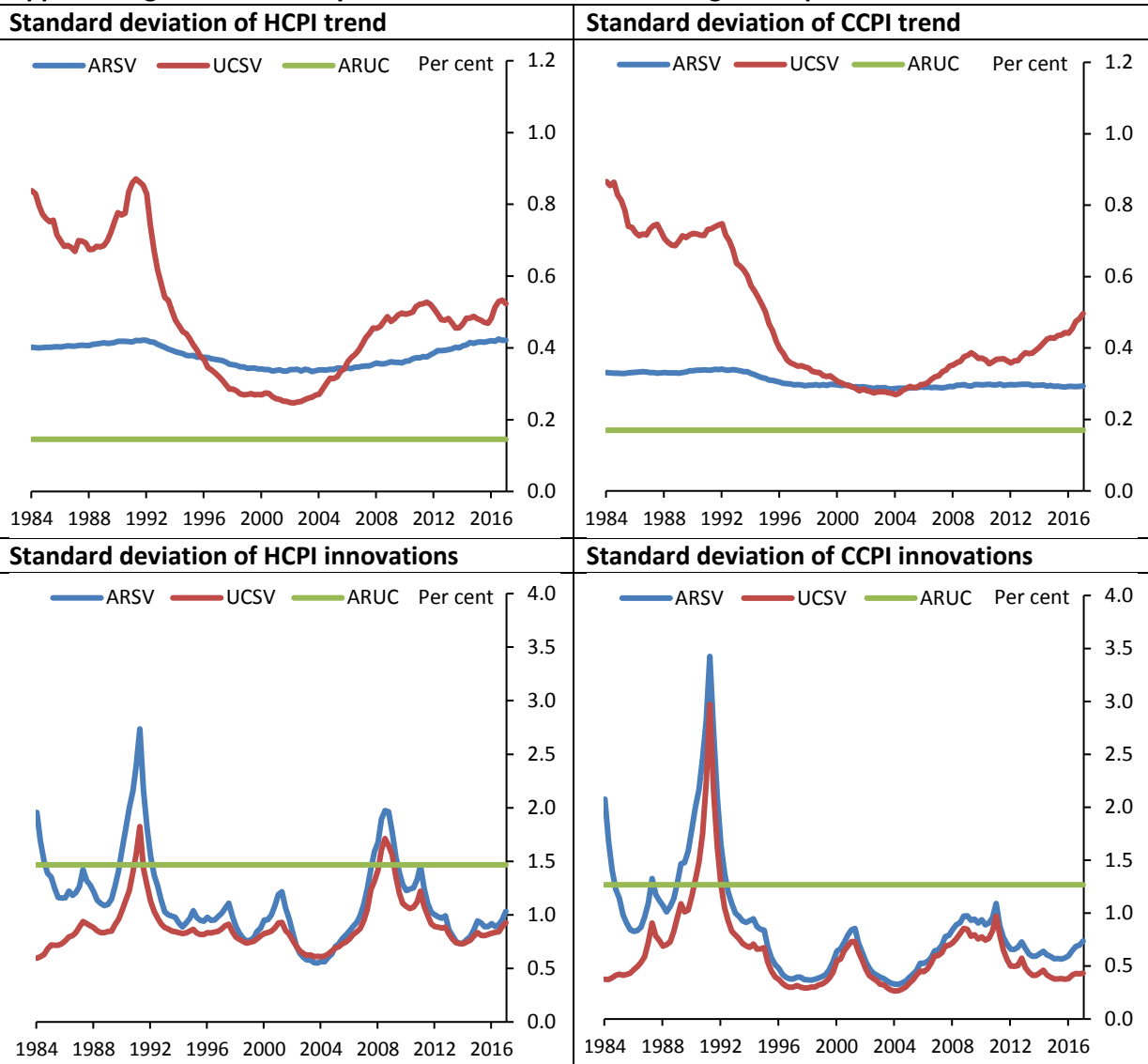
<sup>38</sup> The underlying data is taken from the 'three centuries of data' dataset available on the Bank of England's website, originally used in Hills *et al.* (2010)

**Appendix Figure 2: Correlation of Quarterly Inflation Measures, 1984-2016Q4**

	HCPI	CCPI	HPCE	PGDP	HRPIX
HCPI	1.00	0.89	0.66	0.47	0.89
CCPI	0.89	1.00	0.61	0.45	0.75
HPCE	0.66	0.61	1.00	0.61	0.62
PGDP	0.47	0.45	0.61	1.00	0.49
HRPIX	0.89	0.75	0.62	0.49	1.00

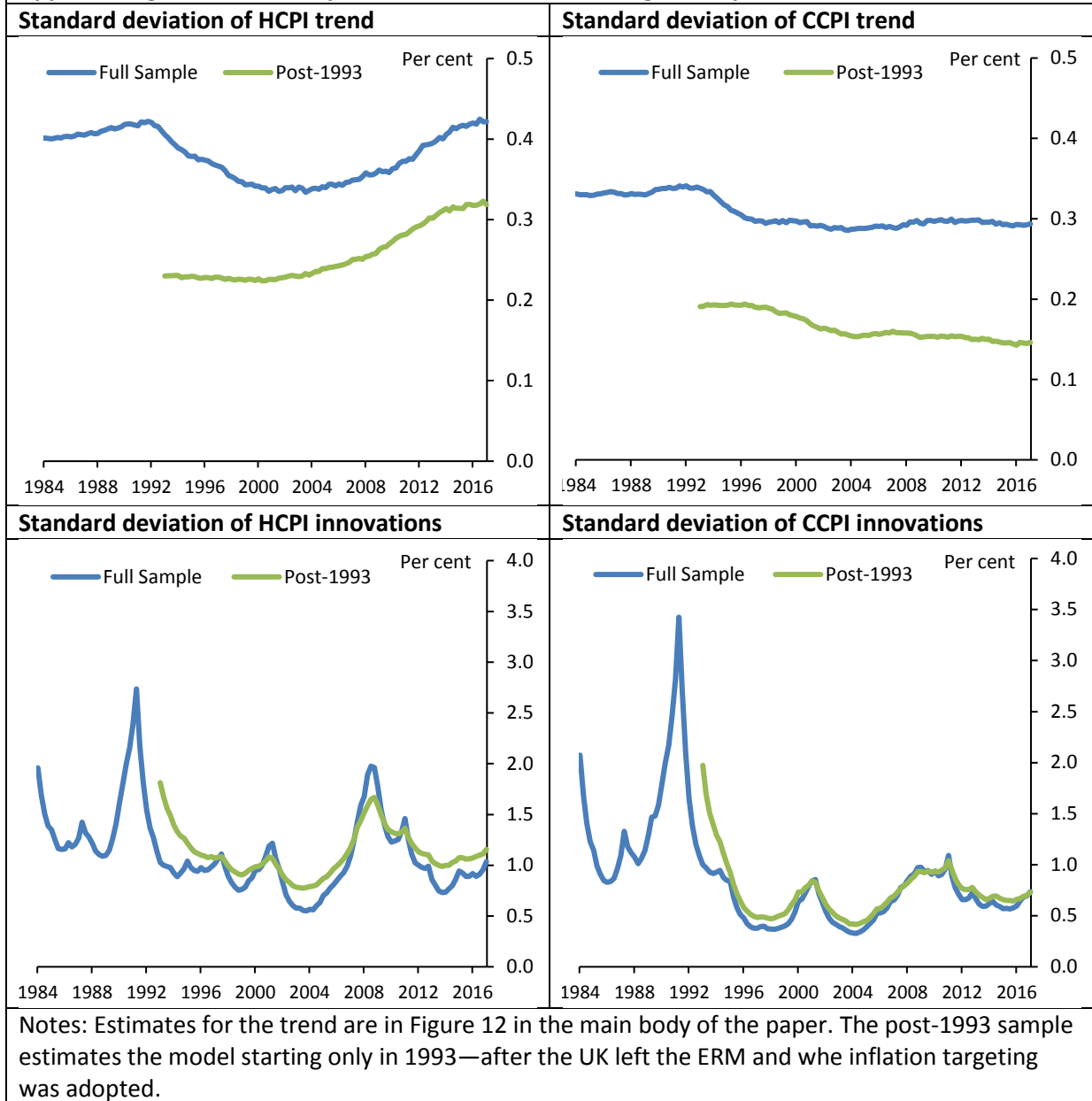
Note: See Appendix Figure 1 for data definitions and sources.

**Appendix Figure 3: Sensitivity Tests Under Different Modelling Assumptions**



Notes: ARSV model is described in Section 3a. See Figure 11 for corresponding estimates of trend HCPI and CCPI under these three modelling assumptions. The UCSV model is taken from CFHKS (2017). The model is essentially a restricted version of ARSV, which removes the autoregressive term in the cyclical component, i.e. setting  $\varphi = 0$  in equation (1). The ARUC model is taken from CFHKS (2017). The model assumes constant volatility of the trend and innovations processes, but allows the autoregressive term in the cyclical component to differ from zero.

**Appendix Figure 4: Sensitivity Tests Under Different Timing Assumptions**



## Appendix Figure 5: Explaining Inflation: The Trend and Other Variables – alternative specification

Specification:  $\eta_t = \alpha + \beta X_t + e_t$ , where  $\eta_t = (\pi_t - \tilde{\tau}_t) - \varphi(\pi_{t-1} - \tilde{\tau}_{t-1})$

			HCPI		CCPI	
			Beta	R <sup>2</sup>	Beta	R <sup>2</sup>
Inflation expectations	FMB5	coeff	0.07	0.00	-0.05	0.00
		p value	0.44		0.57	
	FMB55	coeff	0.13	0.01	0.02	0.00
		p value	0.18		0.82	
	BASIX1	coeff	0.54	0.10	0.19	0.03
		p value	0.02		0.07	
	BASIX2	coeff	0.39	0.05	0.17	0.02
		p value	0.04		0.11	
	GFKE	coeff	0.40	0.10	0.10	0.02
		p value	0.04		0.36	
NIESR4Q	coeff	-0.01	0.00	-0.03	0.00	
	p value	0.89		0.61		
Slack	YGAPBOE	coeff	-0.01	0.00	0.05	0.01
		p value	0.89		0.20	
	YGAPHP	coeff	-0.11	0.01	0.07	0.01
		p value	0.45		0.26	
	YGAPOBR	coeff	0.01	0.00	0.04	0.02
		p value	0.85		0.16	
	UGAPBOE	coeff	-0.02	0.00	0.04	0.00
		p value	0.84		0.62	
Labour costs	AWE	coeff	0.02	0.01	0.01	0.00
		p value	0.54		0.68	
	ULC	coeff	-0.03	0.01	-0.01	0.00
		p value	0.10		0.47	
International costs and prices	DPWX	coeff	0.16	0.26	0.06	0.10
		p value	0.00		0.01	
	DBRENT	coeff	0.03	0.24	0.01	0.07
		p value	0.00		0.04	
	DGSCI	coeff	0.05	0.23	0.02	0.07
		p value	0.00		0.02	
SERI	coeff	0.00	0.00	0.00	0.00	
	p value	0.01		0.00		
Domestic financial conditions	SPREADPCA	coeff	-0.04	0.00	0.02	0.00
		p value	0.65		0.74	
	SHADOWBR	coeff	0.00	0.00	-0.02	0.01
		p value	0.99		0.33	
	GILT2	coeff	0.01	0.00	-0.01	0.00
		p value	0.87		0.56	
	M4EX	coeff	-0.03	0.01	-0.02	0.02
		p value	0.32		0.24	
	M4LEX	coeff	-0.02	0.01	-0.02	0.02
		p value	0.35		0.10	

**Appendix Figure 6:  
Explaining Inflation: The Trend and Other Variables – with crisis dummy**

Specification:  $\pi_t = \alpha + \beta\tilde{\tau}_t + \gamma X_t + \delta D_t + e_t$ , where  $D_t = 1$  in 2008Q4-2009Q1 and 0 otherwise

			HCPI			CCPI			
			Trend	Extra	R <sup>2</sup>	Trend	Extra	R <sup>2</sup>	
<b>Inflation expectations</b>	FMB5	coeff	1.51	-0.07	0.61	1.48	-0.23	0.66	
		p value	0.00	0.41		0.00	0.02		
	FMB55	coeff	1.53	-0.08	0.61	1.65	-0.32	0.66	
		p value	0.00	0.41		0.00	0.01		
	BASIX1	coeff	1.22	0.54	0.64	1.29	0.13	0.63	
		p value	0.00	0.06		0.00	0.16		
	BASIX2	coeff	1.41	0.17	0.61	1.33	0.05	0.63	
		p value	0.00	0.32		0.00	0.60		
	GFKE	coeff	1.42	0.26	0.63	1.37	-0.04	0.63	
		p value	0.00	0.09		0.00	0.74		
	NIESR4Q	coeff	1.49	-0.07	0.61	1.37	-0.09	0.63	
		p value	0.00	0.45		0.00	0.16		
<b>Slack</b>	YGAPBOE	coeff	1.61	-0.11	0.62	1.33	0.01	0.63	
		p value	0.00	0.22		0.00	0.85		
	YGAPHP	coeff	1.51	-0.09	0.62	1.29	0.08	0.63	
		p value	0.00	0.51		0.00	0.07		
	YGAPOBR	coeff	1.57	-0.06	0.62	1.33	0.01	0.63	
		p value	0.00	0.46		0.00	0.78		
	UGAPBOE	coeff	1.66	-0.31	0.63	1.70	-0.34	0.65	
		p value	0.00	0.08		0.00	0.01		
	<b>Labour costs</b>	AWE	coeff	1.48	-0.02	0.61	1.34	-0.01	0.63
			p value	0.00	0.37		0.00	0.73	
ULC		coeff	1.49	-0.02	0.61	1.34	0.00	0.63	
		p value	0.00	0.35		0.00	0.76		
<b>International costs and prices</b>	DPWX	coeff	1.29	0.11	0.65	1.31	0.04	0.64	
		p value	0.00	0.01		0.00	0.17		
	DBRENT	coeff	1.42	0.02	0.63	1.35	0.00	0.63	
		p value	0.00	0.03		0.00	0.22		
	DGSCI	coeff	1.45	0.02	0.63	1.39	0.01	0.64	
		p value	0.00	0.12		0.00	0.34		
	SERI	coeff	1.53	0.01	0.61	1.53	0.01	0.63	
		p value	0.00	0.58		0.00	0.05		
<b>Domestic financial conditions</b>	SPREADPCA	coeff	1.53	-0.06	0.61	1.45	-0.07	0.63	
		p value	0.00	0.51		0.00	0.21		
	SHADOWBR	coeff	1.50	0.01	0.61	1.33	-0.01	0.63	
		p value	0.00	0.73		0.00	0.49		
	GILT2	coeff	1.49	-0.01	0.61	1.34	-0.03	0.63	
		p value	0.00	0.74		0.00	0.35		
	M4EX	coeff	1.47	-0.02	0.61	1.32	-0.02	0.63	
		p value	0.00	0.51		0.00	0.31		
	M4LEX	coeff	1.50	0.00	0.61	1.33	0.00	0.63	
		p value	0.00	0.88		0.00	0.72		



## Appendix Figure 7:

### Explaining Inflation: The Trend and Other Variables – post-1993 trend estimates

Specification:  $\pi_t = \alpha + \beta\tilde{\tau}_t + \gamma X_t + e_t$ , where  $\tilde{\tau}_t$  is estimated from 1993Q1-2017Q1.

			HCPI			CCPI		
			Trend	Extra	R <sup>2</sup>	Trend	Extra	R <sup>2</sup>
Inflation expectations	FMB5	coeff	1.40	-0.12	0.44	1.55	-0.41	0.47
		p value	0.00	0.40		0.00	0.00	
	FMB55	coeff	1.44	-0.14	0.44	1.69	-0.44	0.43
		p value	0.00	0.35		0.00	0.01	
	BASIX1	coeff	0.96	0.77	0.50	1.03	0.29	0.42
		p value	0.00	0.02		0.00	0.02	
	BASIX2	coeff	1.18	0.37	0.44	1.07	0.19	0.40
		p value	0.00	0.08		0.00	0.12	
	GFKE	coeff	1.24	0.38	0.48	1.15	0.01	0.39
		p value	0.00	0.11		0.00	0.94	
NIESR4Q	coeff	1.36	-0.08	0.44	1.24	-0.14	0.40	
	p value	0.00	0.53		0.00	0.12		
Slack	YGAPBOE	coeff	1.54	-0.15	0.45	0.91	0.14	0.41
		p value	0.00	0.23		0.00	0.13	
	YGAPHP	coeff	1.41	-0.17	0.45	1.09	0.11	0.40
		p value	0.00	0.33		0.00	0.19	
	YGAPOBR	coeff	1.47	-0.08	0.44	0.88	0.11	0.41
		p value	0.00	0.45		0.00	0.14	
UGAPBOE	coeff	1.63	-0.43	0.47	1.23	-0.07	0.39	
	p value	0.00	0.05		0.00	0.70		
Labour costs	AWE	coeff	1.37	0.03	0.44	1.16	0.00	0.39
		p value	0.00	0.52		0.00	0.91	
	ULC	coeff	1.35	-0.02	0.44	1.14	-0.02	0.39
		p value	0.00	0.24		0.00	0.40	
International costs and prices	DPWX	coeff	1.12	0.17	0.58	1.11	0.07	0.44
		p value	0.00	0.00		0.00	0.02	
	DBRENT	coeff	1.29	0.03	0.54	1.18	0.01	0.42
		p value	0.00	0.00		0.00	0.05	
	DGSCI	coeff	1.31	0.04	0.54	1.25	0.02	0.44
		p value	0.00	0.00		0.00	0.01	
	SERI	coeff	1.44	0.01	0.44	1.04	-0.01	0.39
		p value	0.00	0.46		0.00	0.52	
Domestic financial conditions	SPREADPCA	coeff	1.48	-0.17	0.45	1.14	0.01	0.39
		p value	0.00	0.21		0.00	0.91	
	SHADOWBR	coeff	1.35	0.00	0.44	1.12	-0.05	0.41
		p value	0.00	0.97		0.00	0.12	
	GILT2	coeff	1.36	-0.02	0.44	1.19	-0.06	0.41
		p value	0.00	0.60		0.00	0.11	
	M4EX	coeff	1.33	-0.02	0.44	1.11	-0.03	0.40
		p value	0.00	0.59		0.00	0.22	
	M4LEX	coeff	1.36	0.00	0.44	0.98	-0.03	0.41
		p value	0.00	0.88		0.00	0.05	

## Appendix Figure 8:

### Explaining Trend Inflation with Inflation Expectations and Slack – alternative slack measure

Specification:  $\Delta\tilde{\pi}_t = \alpha + \beta\Delta E[\pi_t] + \gamma\Delta Slack_{t-1} + e_t$ , where Slack = YGAPOBR and  $\tilde{\pi}_t$  is estimated from 1993Q1-2017Q1

Slack in differences		HCPI			CCPI		
		Slack	$\pi$ -expect	R <sup>2</sup>	Slack	$\pi$ -expect	R <sup>2</sup>
FMB5	coeff	0.04	0.05	0.04	0.06	-0.04	0.08
	p value	0.06	0.29		0.00	0.41	
FMB55	coeff	0.03	0.10	0.05	0.06	0.02	0.07
	p value	0.07	0.07		0.00	0.69	
BASIX1	coeff	0.05	0.09	0.09	0.06	0.04	0.09
	p value	0.02	0.00		0.00	0.05	
BASIX2	coeff	0.04	0.05	0.06	0.06	0.03	0.08
	p value	0.04	0.03		0.00	0.15	
GFKE	coeff	0.06	0.12	0.18	0.07	0.05	0.11
	p value	0.00	0.00		0.00	0.05	
NIESR4Q	coeff	0.04	0.01	0.02	0.06	0.00	0.07
	p value	0.05	0.67		0.00	0.56	

Specification:  $\Delta\tilde{\pi}_t = \alpha + \beta\Delta E[\pi_t] + \gamma Slack_{t-1} + e_t$ , where Slack = YGAPOBR and  $\tilde{\pi}_t$  is estimated from 1993Q1-2017Q1

Slack in levels		HCPI			CCPI		
		Slack	$\pi$ -expect	R <sup>2</sup>	Slack	$\pi$ -expect	R <sup>2</sup>
FMB5	coeff	-0.02	0.06	0.07	0.00	-0.04	0.01
	p value	0.08	0.18		0.93	0.51	
FMB55	coeff	-0.02	0.11	0.10	0.00	0.04	0.01
	p value	0.07	0.02		0.88	0.49	
BASIX1	coeff	-0.02	0.08	0.11	0.00	0.04	0.01
	p value	0.10	0.00		0.94	0.14	
BASIX2	coeff	-0.02	0.05	0.09	0.00	0.03	0.01
	p value	0.10	0.02		0.91	0.16	
GFKE	coeff	-0.02	0.11	0.18	0.00	0.03	0.02
	p value	0.06	0.00		0.89	0.18	
NIESR4Q	coeff	-0.02	0.01	0.06	0.00	0.00	0.00
	p value	0.10	0.69		0.90	0.64	

**Appendix Figure 9:**

**Explaining Trend Inflation with Inflation Expectations and Slack – post-1993 trend estimates**

Specification:  $\Delta\tilde{\tau}_t = \alpha + \beta\Delta E[\pi_t] + \gamma\Delta Slack_{t-1} + e_t$ , where Slack = UGAPBOE

Slack in differences		HCPI			CCPI		
		Slack	$\pi$ -expect	R <sup>2</sup>	Slack	$\pi$ -expect	R <sup>2</sup>
FMB5	coeff	0.04	0.04	0.02	0.10	0.00	0.07
	p value	0.54	0.21		0.02	0.93	
FMB55	coeff	0.04	0.09	0.06	0.10	0.04	0.10
	p value	0.56	0.03		0.02	0.11	
BASIX1	coeff	0.05	0.06	0.06	0.10	0.03	0.10
	p value	0.47	0.00		0.03	0.02	
BASIX2	coeff	0.04	0.03	0.02	0.10	0.01	0.08
	p value	0.54	0.09		0.02	0.18	
GFKE	coeff	0.09	0.08	0.14	0.12	0.03	0.12
	p value	0.18	0.00		0.01	0.01	
NIESR4Q	coeff	0.05	0.01	0.01	0.10	0.00	0.07
	p value	0.50	0.37		0.02	0.64	

Specification:  $\Delta\tilde{\tau}_t = \alpha + \beta\Delta E[\pi_t] + \gamma Slack_{t-1} + e_t$ , where Slack = UGAPBOE

Slack in levels		HCPI			CCPI		
		Slack	$\pi$ -expect	R <sup>2</sup>	Slack	$\pi$ -expect	R <sup>2</sup>
FMB5	coeff	-0.07	0.04	0.27	-0.03	0.00	0.09
	p value	0.00	0.23		0.08	0.95	
FMB55	coeff	-0.07	0.07	0.29	-0.03	0.04	0.11
	p value	0.00	0.07		0.10	0.14	
BASIX1	coeff	-0.07	0.05	0.30	-0.03	0.02	0.10
	p value	0.00	0.00		0.09	0.14	
BASIX2	coeff	-0.07	0.03	0.28	-0.03	0.01	0.10
	p value	0.00	0.06		0.09	0.13	
GFKE	coeff	-0.07	0.07	0.38	-0.03	0.02	0.12
	p value	0.00	0.00		0.07	0.12	
NIESR4Q	coeff	-0.07	0.01	0.26	-0.03	0.00	0.09
	p value	0.00	0.38		0.08	0.90	

**Appendix Figure 10:**

**Explaining Trend Inflation with Lagged Variables – with crisis dummy**

Specification:  $\Delta\tilde{\tau}_t = \alpha + \beta \sum_{j=0}^8 \Delta X_{t-j} + \delta D_t + e_{t'}$ , where  $D_t = 1$  in 2008Q4-2009Q1 and 0 otherwise

			HCPI		CCPI	
			coeff	R <sup>2</sup>	coeff	R <sup>2</sup>
<b>Labour costs</b>	AWE	sum(coeffs)	0.07	0.04	-0.02	0.03
		p value	0.42	0.00	0.82	
	ULC	sum(coeffs)	0.06	0.10	0.06	0.17
		p value	0.27	0.00	0.08	
<b>International costs and prices</b>	DPWX	sum(coeffs)	0.08	0.16	0.03	0.06
		p value	0.03	0.00	0.22	
	DBRENT	sum(coeffs)	0.02	0.20	0.00	0.10
		p value	0.07	0.00	0.66	
	DGSCI	sum(coeffs)	0.03	0.21	0.01	0.11
		p value	0.01	0.00	0.31	
	SERI	sum(coeffs)	-0.05	0.19	-0.05	0.21
		p value	0.00	0.00	0.00	
<b>Domestic financial conditions</b>	SPREADPCA	sum(coeffs)	0.30	0.10	0.36	0.19
		p value	0.03	0.00	0.00	
	SHADOWBR	sum(coeffs)	-0.05	0.02	-0.10	0.06
		p value	0.54	0.00	0.12	
	GILT2	sum(coeffs)	-0.10	0.05	0.01	0.08
		p value	0.65	0.00	0.97	
	M4EX	sum(coeffs)	0.00	0.09	0.00	0.16
		p value	0.89	0.00	0.94	
M4LEX	sum(coeffs)	-0.01	0.04	-0.03	0.09	
	p value	0.72	0.00	0.27		
<b>Slack (levels)</b>	YGAPBOE	sum(coeffs)	-0.04	0.18	-0.01	0.14
		p value	0.00	0.00	0.21	
	YGAPHP	sum(coeffs)	-0.06	0.13	-0.04	0.16
		p value	0.01	0.00	0.02	
	YGAPOBR	sum(coeffs)	-0.03	0.19	-0.01	0.20
		p value	0.01	0.00	0.33	
	UGAPBOE	sum(coeffs)	-0.10	0.22	-0.04	0.13
		p value	0.00	0.00	0.05	
<b>Slack (differences)</b>	YGAPBOE	sum(coeffs)	0.18	0.07	0.18	0.12
		p value	0.15	0.00	0.01	
	YGAPHP	sum(coeffs)	0.19	0.06	0.19	0.12
		p value	0.10	0.00	0.03	
	YGAPOBR	sum(coeffs)	0.19	0.09	0.23	0.22
		p value	0.01	0.00	0.00	
	UGAPBOE	sum(coeffs)	0.32	0.05	0.44	0.12
		p value	0.37	0.00	0.04	

**Appendix Figure 11:**

**Explaining Trend Inflation with Lagged Variables – post-1993 trend estimates**

Specification:  $\Delta\tilde{\tau}_t = \alpha + \beta \sum_{j=0}^8 \Delta X_{t-j} + e_t$ , where  $\tilde{\tau}_t$  is estimated from 1993Q1-2017Q1

			HCPI		CCPI	
			coeff	R <sup>2</sup>	coeff	R <sup>2</sup>
<b>Labour costs</b>	AWE	sum(coeffs)	0.03	0.02	-0.03	0.04
		p value	0.54		0.20	
	ULC	sum(coeffs)	0.03	0.04	0.01	0.07
		p value	0.23		0.44	
<b>International costs and prices</b>	DPWX	sum(coeffs)	0.04	0.12	0.02	0.04
		p value	0.04		0.23	
	DBRENT	sum(coeffs)	0.01	0.14	0.00	0.05
		p value	0.07		0.67	
	DGSCI	sum(coeffs)	0.02	0.13	0.00	0.05
		p value	0.06		0.48	
	SERI	sum(coeffs)	-0.03	0.15	-0.03	0.29
		p value	0.00		0.00	
<b>Domestic financial conditions</b>	SPREADPCA	sum(coeffs)	0.17	0.08	0.19	0.21
		p value	0.03		0.00	
	SHADOWBR	sum(coeffs)	-0.02	0.02	-0.07	0.08
		p value	0.70		0.03	
	GILT2	sum(coeffs)	-0.04	0.02	0.01	0.03
		p value	0.64		0.79	
	M4EX	sum(coeffs)	-0.01	0.07	-0.02	0.12
		p value	0.53		0.18	
	M4LEX	sum(coeffs)	-0.02	0.03	-0.03	0.09
		p value	0.34		0.03	
<b>Slack (levels)</b>	YGAPBOE	sum(coeffs)	-0.04	0.29	-0.01	0.20
		p value	0.00		0.09	
	YGAPHP	sum(coeffs)	-0.05	0.16	-0.02	0.14
		p value	0.00		0.02	
	YGAPOBR	sum(coeffs)	-0.03	0.29	-0.01	0.27
		p value	0.00		0.05	
	UGAPBOE	sum(coeffs)	-0.09	0.35	-0.03	0.29
		p value	0.00		0.00	
<b>Slack (differences)</b>	YGAPBOE	sum(coeffs)	0.16	0.10	0.14	0.18
		p value	0.02		0.00	
	YGAPHP	sum(coeffs)	0.11	0.05	0.08	0.09
		p value	0.07		0.03	
	YGAPOBR	sum(coeffs)	0.12	0.09	0.14	0.28
		p value	0.01		0.00	
	UGAPBOE	sum(coeffs)	0.25	0.04	0.37	0.23
		p value	0.11		0.00	

**Appendix Figure 12: Explaining Trend Inflation with Different Combinations of Variables –8 lags**

Specification:  $\Delta\tilde{\tau}_t = \alpha + \beta \sum_{j=0}^8 \Delta X_{t-j} + e_t$

Slack in levels		HCPI					CCPI				
		(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
<b>BASIX1</b>	coeff	0.05	0.04	0.04	0.07	0.15	0.01	0.03	0.02	0.05	0.09
	p value	0.03	0.31	0.12	0.03	0.06	0.75	0.41	0.60	0.17	0.20
<b>UGAPBOE</b>	coeff	-0.11	-0.11	-0.12	-0.11	-0.11	-0.06	-0.06	-0.07	-0.04	-0.06
	p value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.05
<b>SERI</b>	coeff	-0.06	-0.07	-0.04		-0.06	-0.06	-0.06	-0.04		-0.06
	p value	0.00	0.00	0.01		0.00	0.00	0.00	0.01		0.01
<b>DGSCI</b>	coeff		0.01			0.00		-0.01			-0.01
	p value		0.40			0.95		0.40			0.59
<b>SPREADPCA</b>	coeff			0.20		0.46			0.19		0.20
	p value			0.11		0.21			0.07		0.53
<b>SHADOWBR</b>	coeff				-0.23	0.16				-0.17	0.13
	p value				0.01	0.43				0.02	0.57
<b>ULC</b>	coeff					0.05					0.07
	p value					0.37					0.15
<b>M4LEX</b>	coeff					0.02					-0.02
	p value					0.78					0.74
<b>R<sup>2</sup></b>		<b>0.41</b>	<b>0.53</b>	<b>0.47</b>	<b>0.29</b>	<b>0.84</b>	<b>0.29</b>	<b>0.43</b>	<b>0.40</b>	<b>0.13</b>	<b>0.79</b>

**Appendix Figure 13: Explaining Trend Inflation with Different Combinations of Variables – with crisis dummy**

Specification:  $\Delta\tilde{\tau}_t = \alpha + \beta \sum_{j=0}^4 \Delta X_{t-j} + \delta D_t + e_t$ , where  $D_t=1$  in 2008Q4-2009Q1 and 0 otherwise

Slack in levels		HCPI					CCPI				
		(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
<b>BASIX1</b>	coeff	0.07	0.06	0.07	0.08	0.07	0.04	0.05	0.04	0.05	0.03
	p value	0.02	0.08	0.04	0.01	0.08	0.15	0.14	0.16	0.13	0.47
<b>UGAPBOE</b>	coeff	-0.08	-0.08	-0.08	-0.09	-0.10	-0.03	-0.03	-0.03	-0.03	-0.04
	p value	0.00	0.00	0.00	0.00	0.00	0.15	0.26	0.18	0.23	0.06
<b>SERI</b>	coeff	-0.04	-0.03	-0.04		-0.04	-0.03	-0.03	-0.03		-0.04
	p value	0.00	0.00	0.00		0.00	0.00	0.00	0.01		0.02
<b>DGSCI</b>	coeff		0.01			0.00		0.00			-0.01
	p value		0.27			0.70		0.53			0.21
<b>SPREADPCA</b>	coeff			-0.09		0.19			-0.01		0.05
	p value			0.30		0.34			0.91		0.75
<b>SHADOWBR</b>	coeff				-0.11	0.05				-0.07	-0.03
	p value				0.08	0.56				0.25	0.73
<b>ULC</b>	coeff					0.01					0.03
	p value					0.46					0.04
<b>M4LEX</b>	coeff					-0.01					-0.02
	p value					0.83					0.49
<b>R<sup>2</sup></b>		<b>0.32</b>	<b>0.42</b>	<b>0.33</b>	<b>0.22</b>	<b>0.61</b>	<b>0.17</b>	<b>0.23</b>	<b>0.19</b>	<b>0.07</b>	<b>0.50</b>

**Appendix Figure 14: Explaining Trend Inflation with Different Combinations of Variables – post-1993 trend estimates**

Specification:  $\Delta\tilde{\tau}_t = \alpha + \beta \sum_{j=0}^4 \Delta X_{t-j} + e_t$  where  $\tilde{\tau}_t$  is estimated from 1993Q1-2017Q1

Slack in levels		HCPI					CCPI				
		(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
<b>BASIX1</b>	coeff	0.05	0.04	0.05	0.05	0.03	0.03	0.03	0.03	0.03	0.02
	p value	0.00	0.07	0.00	0.01	0.29	0.00	0.02	0.00	0.01	0.20
<b>UGAPBOE</b>	coeff	-0.08	-0.08	-0.08	-0.08	-0.09	-0.02	-0.02	-0.02	-0.03	-0.04
	p value	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.03	0.03	0.00
<b>SERI</b>	coeff	-0.03	-0.03	-0.03		-0.03	-0.02	-0.02	-0.02		-0.02
	p value	0.00	0.00	0.00		0.01	0.00	0.00	0.02		0.07
<b>DGSCI</b>	coeff		0.00			0.00		0.00			0.00
	p value		0.26			0.85		0.29			0.11
<b>SPREADPCA</b>	coeff			0.00		0.21			0.03		0.13
	p value			0.95		0.12			0.55		0.19
<b>SHADOWBR</b>	coeff				-0.12	0.04				-0.08	0.01
	p value				0.01	0.59				0.01	0.91
<b>ULC</b>	coeff					0.00					0.01
	p value					0.71					0.46
<b>M4LEX</b>	coeff					-0.01					-0.01
	p value					0.76					0.57
<i>R</i> <sup>2</sup>		0.32	0.42	0.33	0.22	0.61	0.17	0.23	0.19	0.07	0.50