# Core Inflation - Why the Fed got it Wrong

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*- Why the Federal Reserve Got it Wrong*

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**Abstract**

This paper introduces a new estimate of core inflation. Core inflation is a real time estimate of monetary inflation. Most existing core inflation estimate do not account for persistent relative price changes and are therefore likely to be poor estimates of the underlying monetary inflation rate. The proposed core inflation estimate estimates core inflation by first estimating the inflation signal in all price series from the price index with a wavelet based signal estimation algorithm. In the second step the weighted inflation average is calculated by using the expenditure weights from the price index as weights. Relative price changes are thus accounted for under the assumption that the household must apply to its long run budget restriction. The proposed estimate of core inflation is estimated using data from the United States and the United Kingdom. It is evaluated by comparing it to existing estimates of core inflation. The empirical analysis show that the proposed estimate has a smaller forecasting error of future inflation than the other estimates and that it rapidly responds to increases in monetary inflation.

**JEL Classification:** E31, E52

**Keywords:** Core Inflation; Signal Estimation, wavelets

# 1 Introduction

Price stability is one of the Federal Reserve's three main objectives (see Humphrey Hawkins Full Employment and Balanced Growth Act of 1978, Public law 95-523). A standard measure of inflation that the Federal Reserve uses is the percentage increase in the Private

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Consumption Expenditure price index (PCE). However, not all fluctuations in the PCE inflation rate (headline inflation) are caused by monetary policy, since other non-monetary shocks such as fiscal policy, seasonal effects, and changes in the exchange rate create fluctuations in the headline inflation rate. The Federal Reserve therefore also monitors core inflation, PCE excluding food and energy prices (XFE). The difference between core inflation and headline inflation is that core inflation is a real time estimate of monetary policy induced inflation (monetary inflation), while headline inflation also includes non-monetary fluctuations. Non-monetary inflation is transitory however, and headline inflation therefore equals monetary inflation over the long run (see for example Issing 2003). Core inflation is thus merely a short run intermediate inflation indicator, and not the long run targeted variable, which is monetary inflation. Any price index that systematically excludes certain prices (for example the XFE) cannot account for persistent relative price changes, and is therefore likely to be a poor estimator of monetary inflation. This paper therefore introduces a new estimate of core inflation that accounts for relative price changes when estimating monetary inflation.

Anticipated and unanticipated inflation both impose a cost on the economy, these costs include reallocation of resources and increased financial transaction costs (Rick and Steindel 2005). One of the central bank's core objectives is therefore to limit the cost of inflation by maintaining price stability. The cost of inflation is economy wide and affects all sectors of the economy. Fischer (1920) therefore argues that prices of "everything purchased and purchasable, including real estate, securities, labor and other services rendered by corporations" should be included in the central bank's price index. Since it is difficult to observe all prices in an economy, central banks often use a consumer price index, even if it only includes a sub-set of all prices. Arguments for using a consumer price index include that these prices are relatively easy to observe and that it contains prices from a large and important sector of the economy.

Headline inflation measures the average increase in consumer prices. Many different variables affect the inflation rate, but most of these only have a transitory effect. Inflation is caused by the central bank's monetary policy in the long run (see Friedman 1963 and Issing 2003), and other factors such as seasonal effects and fiscal policy therefore only create short run fluctuations in the inflation rate. Headline inflation thus equals monetary inflation in the long run, but not necessarily in the short run. As a consequence of this, headline inflation is not the optimal short run estimate of inflation for a central bank, which is mainly interested in monetary inflation. Core inflation is a real-time estimate of monetary inflation, and is thus a better short run inflation measure for a central banker. However, it is, furthermore, only an intermediate indicator and not the targeted inflation variable. To be useful as and intermediate measure, it must be possible to estimate core inflation in real time, where there is only limited amount data available.

Estimating core inflation can be thought of as a signal extraction problem; available price data includes information about both monetary inflation (signal) and non-monetary inflation (noise). The Federal Reserve's definition of core inflation, PCE excluding food and energy prices, was introduced during the latter part of the sixties and early seventies following large supply shocks (see Gordon 1975). Headline inflation became a poor estimate of monetary inflation, because these supply shocks were not caused by the Federal Reserve's monetary policy. The supply shocks mainly affected the food and energy sectors, which therefore led the Federal Reserve to remove food and energy prices from the price index in order improve the signal-to-noise ratio (for more information see Clark 2001, Wynne 1999, Rick and Steindel 2005).

The Federal Reserve's systematic exclusion of food and energy prices from the price index triggered a new theoretical literature on core inflation, which mainly developed during the eighties and nineties. Eckstein (1981), for example, was one of the first to use the terminology core inflation, which he defined as the trend cost of inputs to production. Headline inflation equals monetary inflation when the economy is at its equilibrium, and core inflation is therefore estimated in a large macroeconomic model which estimates the equilibrium level of output.

Quah and Vahey (1995) define core inflation as expected inflation, and estimate core inflation in an advanced model by assuming that anticipated inflation has no effect on real output. Bryan and Pike (1991), and Bryan and Cecchetti (1994) approach core inflation from a different angle; they view it as persistent medium to long term inflation. According to them, headline inflation is a poor estimate of monetary inflation since the cross sectional distribution of the transitory shocks is skewed. Bryan and Pike therefore suggest using the median price increase as an estimate of core inflation. Bryan and Cecchetti claim that the skewness of the cross sectional distribution is explained by the way firms set their prices. Firms face menu costs and only change their prices if the optimal price deviates from the asking price by a large enough amount; prices are therefore not updated at every period and this causes the skewness. They propose a Trimmed Mean estimate to solve this problem; prices with relatively large and small changes at a given point in time are excluded from the price index so that the tails of the cross sectional distribution of the price changes are removed. The estimate of inflation is then formed by weighting the remaining prices together using renormalized expenditure weights. If enough of the tails are removed, this will be an unbiased estimate of monetary inflation.

Diewert (1995) views the estimation of core inflation as a pure signal-to-noise problem. He assumes that the data generating process for each price contains only two components; the monetary inflation signal and an idiosyncratic shock component. Because he assumes that the idiosyncratic shocks have mean zero, the original expenditure weights can be replaced by new weights based on the strength of the monetary inflation signal. Diewert's proposed estimate, the Neo-Edgeworthian index, replaces the expenditure weights with weights that are based on the variance of each item of the price index in relation to the average variance in all prices. Items that are more volatile than others are assumed to have a low signal-to-noise ratio and are given a lower weight and vice versa.

Eckstein's and Quah and Vahey's estimate of core inflation is obtained from an economic model that includes more economic variables than price data. Such models are difficult to estimate in real time because there is only a limited amount of data available, and this available data is likely to be revised over time. The XFE, Trimmed Mean and the Neo-Edgeworthian estimates do not require other economic variables than the price series to be estimated, and these are therefore easier to estimate in real time. However none of them account for persistent relative price changes. Productivity growth and other factors has reduced the relative consumer prices of many goods during the last decades compared to the average price level, while many services have become relatively more expensive to the consumer (see for example Hunt 2007). Although monetary policy can affect the overall price level in the long run, individual prices are also affected by conditions in local markets, for example, productivity growth, changes in quality or changes in consumer preferences. Households adjust their spending to these relative prices changes so that an increase in the relative price of one good either leads to a reduction in the relative price of another item or a change in the household's consumption basket. These adjustments by the household, in response to the relative price changes, are necessary to ensure that the household's budget restriction is met[1]. The relative price changes therefore cancel out when the (weighted) average consumer price level (or inflation rate) is calculated. The XFE, Trimmed Mean and the Neo-Edgeworthian index replace the original expenditure weights with new weights

[1] It is also possible to imagine that relative price changes are a function of changes in the household's consumption basket. Irrespective of which, the relative price changes cancel out in the overall price index due to the households budget restriction.

without any correction for relative price changes, and are therefore poor estimates of monetary inflation.

Another method of estimating core inflation is to smooth headline inflation, and such estimates have been proposed by Cogley (2002) and Cotter and Dowd (2006). Cogley uses a band pass filter to smooth inflation while Cotter and Dowd apply a wavelet transform. This approach towards estimating core inflation is appealing because it removes transitory movements from headline inflation, while relative prices are accounted for due to the fact that the original expenditure weights are used when the overall price level is estimated. This estimation is also relatively easy to perform, but smoothing a time series in real time is problematic, because we can only smooth using a backwards looking filter. A sudden discrete change in the mean, for example, will not be detected until many observations later. In other words, a backwards looking filter is not appropriate for core inflation since this is a real time estimate of monetary inflation. It does not provide the early warnings of changes in monetary inflation that the policy maker is interested in.

This paper introduces a new estimate of core inflation – the De-noised Core Inflation (DCI) estimate. We assume that all prices consist of three parts; monetary inflation, medium to long term (persistent) relative price changes, and an idiosyncratic shock component with expected value zero. Core inflation is estimated by first applying a signal estimation algorithm to the data (see Donoho and Johnstone 1994 and Jansen and Bultheel 1999). These algorithms remove the non-monetary shocks under the assumption that the idiosyncratic shocks are independent and normally distributed for each item of the price index. The average inflation rate (weighted average) is calculated using the de-noised inflation rates. The persistent relative price changes will cancel out when we calculate the average inflation rate since we are using expenditures from the price index as weights. The average inflation rate therefore represents an estimate of monetary inflation.

The DCI is estimated from PCE data for the United States during the period 1967Q1 to 2007Q4 and from data for the United Kingdom from 1972Q1 to 2006Q3. The DCI is then compared to other core inflation estimates (XFE, the Median, the Neo-Edgeworthian index and the Cogley filter) using three criteria; (i) similarity of mean with headline inflation (ii) forecasting ability of future headline inflation, following the discussion in Wynne (1999) and Rick and Steindel (2005) and (iii) how the estimates behave at the beginning and the end of the Great Inflation period. Arguably, there has been two periods of large changes in the monetary inflation rate during the last forty years; at the beginning of the seventies and at the beginning of the eighties. Monetary inflation increased at the beginning of the period and did not decline until a decade later, and this period has therefore been called the Great Inflation. By comparing the core inflation estimates to the general movements in headline inflation (which captures the overall movements in monetary inflation) during this period of time, we can evaluate whether they are quick to capture the large changes in the true monetary inflation rate or if they are slow to respond.

## 2. Core Inflation

Let $\pi_{it}$ represent the percentage change of the price of good $i$=1,…,$I$ of some price index at time $t$=1,..,$T$, and assume that this can be decomposed into three components; monetary inflation ($\pi_t$), a medium to long run relative price change component ($r_{it}$), and a short run idiosyncratic shock component ($x_{it}$). Monetary inflation is caused by the central bank's monetary policy, relative price changes reflect conditions in local markets that endure for some time, and the idiosyncratic shock component is a random variable that captures temporary and unanticipated disturbances. Business cycle fluctuations, fiscal policy changes, seasonal effects, and other non-monetary variables that may cause inflation are included in the shock component. The shocks are assumed independent and to have expected value zero and variance $\sigma_i^2$. The data generating process for the price change of each item of the price index can therefore be written as

$$\pi_{it} = \pi_t + r_{it} + x_{it} \tag{1}$$

The relative price component[2], which captures differences between markets, is persistent over time; this means that it reflects medium to long term changes in the real economy, and not short run disturbances. These shocks belong to the shock component $x_{it}$. The causes of the relative price component include changes in consumer preferences and varying productivity growth between different sectors of the economy. Households have time to observe the relative price changes since these are persistent over time, and they can thus adjust their consumption basket so as not to break their long run budget restriction.[3] This implies that

$$\sum_{j=1}^{I} b_{it} r_{it} = 0, \tag{2}$$

[2] Relative compared to the overall price level.

[3] This assumption implies that the relative price changes do not affect the overall price level (for a further discussion see for example, Friedman 1974 or Vining and Elwertowski 1976). It also implies that anticipated inflation have no effect on the real economy see Quay and Vahey (1995).

where $b_{it}$ is the expenditure weight for item $i$ at time $t$. It should be noted that

$$\sum_{j=1}^{I} r_{it} \neq 0 \,. \tag{3}$$

The relative price changes do not necessarily sum to zero if the household simultaneously changes the quantities it consumes of the various goods. Equation (3) only holds if the consumption basket remains constant over time. Furthermore, it is important to note that (2) does not equal to zero if some items are removed from the price index.

Headline inflation, $\pi_t^H$ , is the weighted average of all price changes

$$\pi_t^{\mathrm{H}} = \sum_{i=1}^{I} b_{it}(\pi_t + r_{it} + x_{it}) = \pi_t + \sum_{i=1}^{I} b_{it} x_{it} \;. \tag{4}$$

Headline inflation equals monetary inflation over the long run, because the shocks have expected value zero. Note however that the shocks do not necessarily sum to zero at every point in time. Headline inflation is therefore a noisy short run estimate of monetary inflation.

Monetary inflation is the only inflation rate the central bank can directly influence. The central banker is therefore always interested in knowing the rate of monetary inflation, but it is impossible to directly observe in the short run. Monetary inflation is only directly observable over the long run, when the effect of the non-monetary shocks has disappeared. The central banker therefore has to estimate monetary inflation in the short run by separating the monetary inflation signal from the non-monetary shocks, and this real time estimate of monetary inflation is called the core inflation rate.

### *2.1 Estimating Core Inflation*

It is theoretically appealing to estimate core inflation in the frequency domain. Monetary policy operates over the medium to long run and the relative price changes also persist over several time periods, these two components thus make up the low frequency component of headline inflation. The idiosyncratic shocks are transitory, and hence form the high frequency component of headline inflation. Core inflation can thus, in theory, be estimated by removing all the high frequency fluctuations from headline inflation; the remaining low frequency component forms an estimate of monetary inflation. Such estimation techniques have been proposed by, for example, Clark 2001, Cogley 2002 and Cotter and Dowd 2006.

Methods of decomposing the data into low and high frequency components suffer from two problems. The first problem is a real time estimation problem. Consider, for example, a sudden and discrete change in the mean of a time series. Such a change is in fact a change in the low frequency component, but it will be first observed in the data as a high frequency disturbance. It is not until more observations are available that it will become clear that a change in the mean has occurred and that it was not just a transitory disturbance. The change in the low frequency component will therefore not be detected until several time periods later, which may be too late for the policy maker who is interested in changes of monetary inflation when they actually occur. Common methods of smoothing, such as Hodrick-Prescott filters, Fourier transforms, moving averages, and Cogley filters are thus not appropriate methods for estimating monetary inflation in real time.

The second problem is a problem of definition. To be able to smooth inflation one must determine which frequencies represent monetary inflation and which frequencies represent the shocks. In reality, however, some frequencies are likely to contain information about both monetary inflation and non-monetary shocks. If this is the case, then headline inflation is either smoothed too much by removing too many high frequencies, or too little by removing too few high frequencies.

Donoho and Johnstone (1994) proposed a signal estimation method, where all high frequency fluctuations are not automatically removed from the time series, and which is therefore not a smoothing procedure per se. This signal estimation method, assumes that a time series is mixture of both noise and signal at every given point in time, and at every given frequency. The signal is estimated in the frequency domain, and the signal estimation algorithm is applied to all frequency bands, high as well as low (except the zero frequency). No assumptions that certain frequencies are pure noise or pure signal are imposed on the model. This signal estimation algorithm is therefore a better method of separating monetary inflation from non-monetary noise, than one that removes certain frequency bands from the time series in an ad hoc manner. More information about how the signal is estimates can be found in Section 3.

### *2.2 The De-Noised Core Inflation Estimate*

We propose a new estimate of core inflation, the De-noised Core Inflation (DCI) estimate. The DCI is estimated in two steps; first all the inflation series of the price index are de-noised individually using the signal estimation algorithm introduced by Donoho and Johnstone (1994). By de-noising each inflation rate individually instead of de-noising headline inflation directly, we allow the variance of the idiosyncratic shocks to be different for different items of the price index. The non-monetary shocks are removed when the signal is estimated, and the de-noised inflation rates represent a combination of monetary inflation and persistent relative price changes. The second step in the estimation procedure is to calculate the weighted inflation average using the expenditure weights from the original price index. The weighted average of all relative price changes sum to zero since no item is removed from the price index (equation 2), and the weighted inflation average thus represents an estimate of monetary inflation.

*2.3 Evaluating Core Inflation Estimates*

There is no commonly agreed upon method of estimating core inflation, and the question of which estimate is the best is usually treated as an empirical problem. We use three criteria to evaluate the DCI estimate we propose; (i) similarity to the headline inflation mean, (ii) forecasting ability, and (iii) the Great Inflation. The first two criteria are also used by Rich and Steindel (2005) and Wynne (1999). Headline inflation equals monetary inflation in the long run, which implies that we can use the mean of headline inflation to test if a core inflation estimate consistently overestimates or underestimates monetary inflation. Furthermore, since headline inflation only temporarily deviates from monetary inflation, an accurate core inflation estimate should be able to forecast future headline inflation.

The third criterion is added to the analysis because there have been two periods of major changes in monetary inflation since the sixties; the beginning of the Great Inflation during the late sixties and early seventies, and the end of the Great Inflation during the early/mid eighties. Orphanides (2003), Nelson (2004) and Romer (2005) attribute the Great Inflation to misguided beliefs among central bankers. They argue that central bankers misjudged both the natural rate of unemployment and the causes of the Great Inflation. Because of these mistakes, central bankers often pursued an expansionary policy and did not adopt disinflation policies when they should have. This critique was also voiced by Friedman (1968), who criticized the Federal Reserve's frequent policy changes during mid-sixties. The observed pattern during the seventies for the United Kingdom is the same as for the United States. Nelson and Nikolov (2002) argue that the Great Inflation was caused by a similar error in belief about monetary policy; monetary policy was not seen as responsible for the inflation, which led to the wrong policy implications. An accurate core inflation estimate would have detected the increase in monetary inflation at an early stage and would thus have indicated the need of a more restrictive monetary policy. This would have eliminated the increase in the policy-induced inflation rate, and the Great Inflation could have been avoided. We therefore use the Great Inflation to evaluate how quickly the core inflation estimates respond to large changes in monetary inflation. Do they indicate the necessity of a tighter monetary policy at the right time? Could the Great Inflation have been avoided if the any of the core inflation estimates had been used by the policy makers?

## 3. Signal Estimation

Donoho and Johnstone (1994) proposed an algorithm that estimates a time series' in the wavelet domain[4]. Assume that the data generating process for a series $x$ can be decomposed into two components; signal and noise. In this case the signal contains both the persistent relative price changes and the monetary inflation component, while the noise consists of the transitory (non-monetary shock) component. The signal can be either deterministic, $D$, or random, $C$. The shocks, $\varepsilon$, are assumed to be independent and normally distributed with mean zero. The data generating process for $x$ can thus be written as either (5), deterministic signal, or (6), random signal.

$$x = D + \varepsilon\,, \tag{5}$$

$$x = C + \varepsilon\,, \tag{6}$$

where $D$, $C$ and $\varepsilon$ are not are readily observable, and must be estimated using the algorithms presented below.[5]

### *3.1 Deterministic Signal*

Let $w$ denote the transform coefficients from an orthonormal transformation to the frequency domain of the time series $x$

$$w = \mathcal{W}x\,, \tag{7}$$

where $\mathcal{W}$ is the transform matrix. These transform coefficients represents the time series at different frequencies in the frequency domain instead of at different periods in time in the time domain. A transform of equation (5) yields the transform coefficients

$$w = \mathcal{W}x = \mathcal{W}D + \mathcal{W}\varepsilon = d + e\,, \tag{8}$$

where $d$ denotes the deterministic signal and $e$ the idiosyncratic shocks represented in the frequency domain.

[4] The difference between the wavelet domain and the frequency domain is that the wavelet domain contains both frequency and time resolution, while the frequency domain has only frequency resolution. All wavelet analysis is carried out in the wavelet domain, we call this the frequency domain for the sake of simplicity in this paper..

[5] The following presentation follows Percival and Walden 2006 chapter 10.

The objective signal extraction algorithms is to estimate the signal $D$, which is achieved by altering the transform coefficients so that "unimportant" features of the time series are either removed or reduced in size. The de-noising algorithms therefore maintain the important major features of a time series, but remove relatively "small" fluctuations by minimizing the following loss function

$$\gamma_m = \left\| X - \hat{D} \right\|^2 + m\delta^2 , \tag{9}$$

where $\hat{D} = \mathcal{W}^T J$ is an estimate of the signal[6], $\delta$ is a threshold which will be described later and $m$ is the number of transform coefficients that have been used to estimate $\hat{D}$. $J$ is the vector of transform coefficients that have been altered according to one of the algorithms that are presented below. We minimize (9) by making the difference between the original time series and the estimated signal as small as possible, while at the same time letting the penalty $m\delta^2$ ensure that "unimportant" features of the time series are excluded.

Donoho and Johnstone (1994) show minimizing (9) will asymptotically remove independently and normally distributed noise if $\delta$[7] is defined as

$$\delta = \sqrt{2\sigma_\varepsilon^2 \times \log(m)} , \tag{10}$$

where $\sigma_\varepsilon^2$ denotes the variance of the shocks. To estimate this variance Percival and Walden (2006) proposed using the transform coefficients that represent some of the highest frequencies; these high frequency components are thus assumed to represent the noise. The variance is estimated using a median absolute deviation estimator (MAD);

$$\hat{\sigma}_{mad} = \frac{median\{w_f\}}{0.6745} , \tag{11}$$

where $w_f$ is a vector containing the transform coefficients that represents the noise. The constant 0.6745 rescales the estimate for normally distributed white noise (Percival and Walden, 2006). To estimate the variance of the idiosyncratic component it is necessary to specify some frequency bands as representing noise, and a sensitivity analysis is thus advisable.

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[6] $\mathcal{W}^T$ is the inverse transform matrix.

[7] This threshold is called the Universal Threshold; other thresholds include the Local Threshold (see for example Kezheng *et. al.* 2002).

It can be shown that minimizing (9) is equivalent to setting all transform-coefficients that are smaller than the threshold, $\delta$, to zero. The remaining coefficients can either be kept as they are, which is called *hard* thresholding, (12), or tapered in some way to create an additional smoothing of the series. Tapering can be either be done through *soft* thresholding (13) or through *mid* thresholding (16).

Hard thresholding is defined as

$$J_l^{ht} = \begin{cases} 0, & \text{if } |w_l| \le \delta \\ w_l & \text{otherwise} \end{cases}, \tag{12}$$

where $J_l^{ht}$ are transform coefficient that have been changed according to the Hard threshold algorithm, and $l$=1,…,$L$-$1$. The vector $J^{ht}$ that is used to estimate the signal ($\hat{D}^{ht} = \mathcal{W}^T J^{ht}$) contains $L$ number of coefficients, the last transform coefficient, $J_L$, in the vector represents the zero frequency component, which is kept without any change by the signal estimation algorithms.

Soft thresholding removes coefficients with an absolute value smaller than the threshold and reduces the value of the other coefficients by subtracting the threshold. This causes an additional smoothing of the time series.

$$J_l^{st} = sign\{\tilde{w}_l\}(|\tilde{w}_l| - \delta)_+, \tag{13}$$

where $J_l^{st}$ are the soft transform coefficients,

$$sign\{\tilde{w}_l\} = \begin{cases} +1 & \text{if } w_l > 0 \\ 0 & \text{if } w_l = 0 \\ -1 & \text{if } w_l < 0 \end{cases}, \tag{14}$$

and

$$(|\tilde{w}_l| - \delta)_+ = \begin{cases} |w_l| - \delta & \text{if } |w_l| - \delta \ge 0 \\ 0 & \text{if } |w_l| - \delta < 0 \end{cases}. \tag{15}$$

Mid thresholding is a combination of the soft and the hard thresholding algorithms. As before, coefficients which do not exceed the threshold level are replaced by zeros. Some “medium” coefficients, i.e. those that have a size of between the threshold and twice the threshold, are tapered in the same way as in soft thresholding by subtracting the threshold level. Coefficients which are greater than twice the threshold are left unchanged. Mid thresholding can be written as

$$J_l^{mt} = sign\{\tilde{w}_l\}(|\tilde{w}_l| - \delta)_{++}, \quad (16)$$

where $sign\{\tilde{w}_l\}$ is defined as in (14), $J_l^{mt}$ are the mid-threshold transform coefficients, and

$$(|\tilde{w}_l| - \delta)_{++} = \begin{cases} |w_l| & \text{if } |w_1| \geq 2\delta \\ (|w_l| - \delta) & \text{if } 0 < |w_1| < 2\delta \\ 0 & \text{otherwise} \end{cases}. \quad (17)$$

The estimated soft-threshold signal is $\hat{D}^{st} = \mathcal{W}^T J^{st}$, and the estimated mid-threshold signal is $\hat{D}^{mt} = \mathcal{W}^T J^{mt}$, where as before the zero frequency transform coefficient $J_L=w_L$.

*3.2 Random Signal*

If the signal is a random variable, then the data generating process is given by (6). In the frequency domain it is represented by

$$w = R + e, \quad (18)$$

where $R$ is assumed to follow a sparse signal model

$$R_l \sim (1 - I_l)N(0, \sigma_G^2) \text{ where } \mathbf{P}[\mathrm{I}_l = 1] = p \text{ and } \mathbf{P}[\mathrm{I}_l = 0] = 1 - p, \quad (19)$$

$l$=1,…,$L$-1, and $p$ represents the probability that the signal is zero. When $p$ is close to zero the signal is assumed to be zero most of the time, while when $p$ is close to one it is assumed to be different from zero most of the time. We also assume that the noise is normally distributed

$$e_l \sim N(0, \sigma_e^2). \quad (20)$$

This de-noising algorithm does not remove coefficients, as in the case of the deterministic model, but rescales them based on a shrinkage rule determined by the signal-to-noise ratios. The shrinkage rule is given by

$$J_l^{shr} = \frac{b}{1+c} w_l, \quad (21)$$

and where

$$b = \frac{\sigma_G^2}{\sigma_G^2 + \sigma_e^2} \text{ and } c = \frac{p\sqrt{\sigma_G^2 + \sigma_e^2}}{(1-p)\sigma_e^2} \times \exp(-w_l^2 b / (2\sigma_e^2)), \quad (22)$$

where

$$\hat{\sigma}_G^2 = \frac{\hat{\sigma}_w^2 - \hat{\sigma}_e^2}{1-p}, \quad (23)$$

and

$$\hat{\sigma}_w^2 = \frac{1}{L-1}\sum_{l=0}^{L-1} w_l^2 \tag{24}$$

An estimate of $\sigma_e^2$ can be obtained, as before, from the MAD estimator (11). The exact choice of $p$ is subjective and different values should be applied to check for robustness. The signal is estimated by defining the vector $J^{rv}$ which contains the transform coefficients $J_l^{shr}$, and the transform coefficient that represents the zero frequency component. The signal is estimated as before as $\hat{R} = w^T J^{rv}$.

## 4. Empirical Analysis

Core inflation is estimated for the United States from 1967Q1 to 2007Q4 and for the United Kingdom from 1972Q1 to 2006Q3. We use PCE data instead of CPI data for two reasons. First, consistent PCE price series are available for a much longer time span; from the late fifties and early sixties for the PCE compared to the late nineties for the CPI. Second, the Federal Reserve began using the PCE instead of the CPI in 2000, and the PCE is thus the price index it applies in its monetary policy analysis (see Federal Reserve 2000). We collected the data from the Bureau of Economic Analysis web page[8] for the United States and from National Statistics web page[9] for the United Kingdom. The PCE price data were divided into 15 sub groups for the United States and into 12 subgroups for the United Kingdom; descriptive statistics and figures of the data are available in Tables 1 and 2, and Figures 1- More detailed price data could be obtained for the United Kingdom (more subgroups), but there was no so such data available for the United States. The analysis of the United Kingdom was therefore based on the same level of detail for reasons of comparability.

Inflation was calculated as the quarterly increase in the logged price of the respective items of the PCE;

$$\pi_{it} = \ln(PCE_{it}) - \ln(PCE_{it-1})\,. \tag{25}$$

A discrete wavelet transform is used to transform the data to the frequency domain. There are various other transforms which could have been used instead, for example, the Fourier transform. We use the wavelet transform[10] since it combines both time and frequency

[8] www.bea.gov

[9] www.statistics.gov.uk

[10] We use the Haar-wavelet to avoid boundary problems.

resolution, and can thus account for outliers and structural breaks within a transformed sample. This is an important property of the transform, because such events could otherwise distort the signal estimation algorithms.

To estimate the variance of the idiosyncratic shocks we follow Percival and Walden (2006), and assume that the spectrum of the time series can be decomposed into two parts. The first part, the high frequency fluctuations, is assumed to represent the noise, and the second part represents a combination of shocks and the inflation signal (monetary inflation and persistent relative price changes). The variance of the shocks is therefore estimated using the high frequency component. There is no predefined method for empirically determining which part of a time series' spectrum belongs to the high frequencies or to the low frequencies, and different alternatives must therefore be tested. We tried three different methods; the first assumes that fluctuations with a periodicity of 1-2 quarters are caused by the noise, and that the rest of the time series is a combination of noise and the inflation signal. The second method increases the periodicity of the noise to 4 quarters, whilst the third method increases it further to 8 quarters. There were only minor differences in the results, however, and we therefore only present results using the first method.

The discrete wavelet transform can only be applied to a sample of exactly $2^J$ observations, where $J$ is an integer. A sliding window technique was therefore applied to allow us to meet this restriction. The sliding window technique applies the wavelet transform successively to overlapping segments of the available data. For example, in this study the window was set to 32 observations[11], which means that an estimate of core inflation at time $t$ was obtained by applying the DWT and the signal estimation algorithms to observations $t$-$31$,…,$t$. The DWT and the de-noising algorithms were thus only applied to this sub-set of the data. To estimate core inflation at time $t$+1 the window was moved forward one observation and the wavelet transform was applied to observations $t$-30,…,$t$+1. In addition to making sure that the wavelet transform can be applied to all the data, the sliding window technique also allows the spectrum of the price series to evolve over time. The width of the window was set to 32 observations since the average business cycle lasts approximately 8 years.

For the random signal model, the probability that an observation is a pure noise (no signal) must be specified. We present the result for three choices of $p$; 0.97, 0.98, 0.99. These

[11] Also 64 and 128 observations were also tested but the results were very similar.

were chosen after also experimenting with *p*=0.5, 0.75 and 0.95, but since values below 0.97 resulted in almost no de-noising, we have not included these results in this paper[12].

*4.1 Results of the Empirical Analysis*

Estimates of the DCI[13] are plotted in Figure 5 for the United States and Figure 7 for the United Kingdom. Panel A of the figures show the deterministic estimates and Panel B the random estimates. XFE and the Median are plotted in Figure 6 (Panel A) for the United States and Figure 8 (Panel A) for the United Kingdom. Panel B of these figures show the Neo-Edgworthian index and the Cogley filter. Descriptive statistics of the series are found in Tables 3 and 4 for the United States and Tables 5 and 6 for the United Kingdom. The first table for each country shows the entire sample and the second table covers the period after 1988Q4 (the second half of the United States sample).

The mean of the various core inflation estimates are close to the headline inflation mean, with only small differences, see Tables 3-6. XFE has a smaller mean than headline inflation for both the United States and the United Kingdom irrespective of sample periods; the differences varies between -0.011 (United Kingdom 1972Q1-2006Q3) and -0.054 (United Kingdom 1989Q1-2006Q3), and is in general larger in the second sample than in the whole sample. The Neo-Edgeworthian, the Median and the Cogley filter also have smaller means than headline inflation. The bias is especially large for the Cogley filter in the second sub-sample for the United Kingdom; -0.179.

The mean of the DCI estimates are higher than the mean of headline inflation, the differences are between 0.007 (Hard United States 1989Q1-2007Q4) and 0.052 (Soft United Kingdom 1989Q1-2007Q4) for the deterministic signal, and 0.003 (RW-0.97 United States 1989Q1-2007Q4) and 0.161 (RW-0.99 United Kingdom 1989Q1-2006Q3) for the random variable. The random signal generally performs less well than the deterministic estimates for the United Kingdom, but performs as well for the United States.

All core inflation estimates have a lower variance than headline inflation, except for the XFE, which is more volatile than headline inflation in the second half of the sample for the

[12] Because these estimates of core inflation are close to headline inflation the results of the forecasting analysis below are close to the results of the random walk.

[13] When we refer to the DCI we in general mean all of the DCI estimates (Hard-DCI, Mid-DCI, Soft-DCI, and the Random DCIs). If there are substantial differences between the different DCI methods we will specify which DCI estimate we are referring to in the text.

United Kingdom. The reduction in variation varies from between 10%-50%, where the Cogley filter and the DCI reduce the variation more than the other estimates do.

Core inflation estimates should have the same long run mean as headline inflation according to the first evaluation criteria, since the headline inflation mean equals the mean of monetary inflation. All the core inflation estimates in this paper have means close to the headline inflation mean, but the DCI seems to overestimate monetary inflation slightly, while the other core inflation estimates tend to underestimate it.

### *4.1.1 Forecasts of Headline Inflation*

Forecasts of headline inflation are based on (26).

$$\pi_{t+h}^{forecast} - \pi_t^H = \alpha_h + \beta_h(\pi_t^H - \pi_t^{core}) \quad (26)$$

where $h$=1,…,16 represents the forecasting horizon. This is the same forecasting model that is used in Rich and Steindel (2005), Clark (2001) and Hogan, and Johnson and Lafléche (2001), among others. The forecasts are real time forecasts, which means that a forecast of headline inflation for $t+h$ is obtained by first estimating the parameters in (26) using data up to and including period $t$ before obtaining the forecast for $t+h$. A forecast of headline inflation for period $t+h+1$ is obtained by re-estimating the inflation model using all observations up to the period $t+1$ before obtaining the forecast for the period $t+h+1$. This technique enables us to use all the information that would have been available to the forecaster at the time, without using future information.

Root Mean Squared Errors (RMSE) are calculated for all forecasts. These are normalized using the RMSE for XFE, i.e. the RMSE for each forecast horizon from the various forecast models have been divided by the RMSE from XFE. We present this ratio instead of the actual RMSEs, because it makes the comparison between the core inflation estimates easier, and we use XFE in the denominator since this is the estimate that is used by the Federal Reserve. The ratios are presented in Tables 7-10; the tables present the results for both the full sample and for the two sub-samples; 1967Q1-1988Q4 and 1989Q1-2007Q4 for the United States and 1972Q1-1988Q4 and 1989Q1-2006Q3 for the United Kingdom.

The DCI outperform the XFE with few exceptions; the average improvement is between 10% and 30% depending on the country and the time period, and it performs better in the second sub-sample than in the first. The DCI also performs better than the other core inflation estimates, especially the deterministic DCI. The only exception is for the full sample for the United States, where the Neo-Edgeworthian index is the best core estimate for forecast horizons from 9 to 16 quarters. In the second sub-sample, however, the Hard DCI has a smaller RMSE for these forecast horizons as well.

Hard DCI has the smallest forecast error for the full sample for the United Kingdom, while the Soft DCI has the smallest forecasting error for the second sup-sample. The differences between the Hard DCI and the Soft DCI are small though. The Cogley filter reduces the forecast error by about 25% compared to the XFE, which is almost as much as for the deterministic DCIs. The Cogley filter has a relatively high forecast error in the second-sub sample for the United States, where both the DCI and the XFE have smaller forecast errors.

We also compare the forecasting performance of the core inflation estimates to a random walk. All estimates perform better than the random walk in the second sub-sample, for the United States and, in particular for the United Kingdom. For the United Kingdom, all core inflation estimates have a forecasting error that is 25% to 50% smaller than a random walk. For the United States the random walk outperforms all core inflation estimates in two of the 16 forecast horizons for the full sample.

*4.1.2 The United States during the Great Inflation*

In this section we evaluate the core inflation estimates during the Great Inflation, to determine whether they are quick to respond to changes in monetary inflation (for more information about the Great Inflation, see for example, Orphanides 2003, Nelson 2004 and Romer 2005). All core inflation estimates indicate an increase in monetary inflation for the United States during the late sixties, from around 1.5% in early 1967 to between 2% and 6.2%, depending on the estimate, at the end of 1969. In 1970 the core estimates begin to deviate from each other however, and the disinflation policy in 1969/70 seems to be successful if we look at the XFE, Neo-Edgeworthian index and the Median, which all decline by close to 50% between 1970 and 1971. The deterministic and random DCI, however, remain more or less at their 1970 level, and indicate a monetary inflation rate of approximately 3.8%. The Cogley filter also remains at its 1970 level; 3.5%.

All core inflation estimates respond similarly to the oil price shock in 1973 by increasing from their pre-shock level although, as expected, at a slower pace than headline inflation. The next period of deviation between the core estimates is in the mid-seventies when the XFE, the Median, the Neo-Edgeworthian index and the Cogley filter all decline, following their peaks in 197 This decline continues until 1977, when they reach their lowest level during the latter part of the seventies, less than 6%. The deterministic and random DCI, however, show only a small decline. The expansionary policy in 1977/78 causes an increase in all core rates to approximately 8% in 1979 before the second oil price shock.

It is interesting to note that the core inflation estimates deviate substantially on two occasions during the seventies, first following the 1969/70 disinflation period, and then again in 1975-1977. The XFE, Neo-Edgeworthian index and the Median closely follow headline inflation, and when this declines during the recessions they also decline. The DCI, on the other hand, never declines, and remains high throughout the seventies. According to this estimate, the disinflation policies were not successful, and the decline in headline inflation may be attributed to the 1970 and 1974/75 recessions, and not to a decline in monetary inflation. Tables 11 and 12 show the correlation between the output gap (estimated as the cyclical component from a HP-filter[14]) and the transitory inflation rate (the difference between headline inflation and core inflation). These tables show that the correlation coefficient between the output gap and the DCI transitory inflation rate is higher than the correlation coefficient between the output gap and any of the other transitory inflation estimates; much of the transitory DCI inflation may thus be explained by the output gap. The DCI can therefore be interpreted as more accurate capturing monetary inflation than the other core inflation estimates, and that the decline we observe in the other estimates during the seventies may be attributed to the recessions and not to an actual decline in monetary inflation. The disinflation periods were thus too brief to cause a persistent decline in the inflation rate; a finding which is line with Friedman's (1968) critique of the Federal Reserve.

### *4.1.3 The United States Following the Great Inflation*

Headline inflation declined following the disinflation policies in the early eighties. XFE, the Neo-Edgeworthian index and the Median follow headline inflation and decrease quickly during the 1982 recession, while the DCI is slower to decline. However, headline inflation increases again after 1984, and the difference compared to the DCI disappears. Considering the strong correlation between transitory DCI inflation and the output gap, the rapid decline of headline inflation in the early eighties may be attributed to the recession, and not to an actual decline of monetary inflation.

All core inflation estimates follow the same pattern from 1986 and onwards, and show an increase in monetary inflation until 1990, before they decline to between 1.5% and 2% in the mid-nineties, an inflation level that is approximately maintained until 2003. A new period of

[14] The HP-filter is estimated in Eviews 5.1 using the default settings ($\lambda$=100)

deviation between the core inflation estimates begins in 2003, when the deterministic DCI shows a steady increase in monetary inflation, while the other estimates remain at between 2% to 2.5%. The deterministic DCI shows a monetary inflation rate that is rapidly approaching 3.5% by the end of 2007.

*4.1.4 The United Kingdom*

All core inflation estimates show the same tendencies between 1972 and 1976; monetary inflation is rapidly increasing from approximately 5% to close to 20% in 1975, before it declines to about 13% by the end for 1976. Headline inflation continues to decline in 1977 due to a more restrictive policy after the loan agreements with the IMF (for more information see, for example, National Archives 2005). The XFE, the Median and the Neo-Edgeworthian index decline at the same rate as headline inflation, the DCI, on the other hand, attribute the 1977 decline in headline inflation to a negative output gap. Tables 13 and 14 contain the correlations between the output gap and transitory inflation from the various core inflation estimates for the United Kingdom. As for the Untied States there is a higher correlation between transitory DCI inflation and the output gap than between the other transitory inflation estimates and the output gap. The 1977 decline is thus likely to have been caused by the recession and not by a decline in monetary inflation, and headline inflation does return to the DCI rate during 1978 when the contractionary policy was reversed.

The disinflation policies in 1982 have an effect on headline inflation, which declines rapidly. According to the DCI, this decline is due to the recession, and the decline in monetary inflation is slow; the other core inflation estimates decline at the same rate as headline inflation. The output gap for the United Kingdom is negative from 1980 until 1987, except for a brief period around 1984. After 1987 the output gap becomes positive, and the difference between headline inflation and DCI inflation becomes smaller. The difference between headline inflation and DCI inflation can thus be attributed to the negative output gap, a fact which is supported by the correlation tables.

Headline inflation increases at the end of the eighties due to both the booming economy, and an increase in monetary inflation, according to all core inflation estimates. The early/mid-nineties recession causes a decrease in headline inflation, and the core inflation estimates also decline although at a less rapid pace than headline inflation. Monetary inflation stabilizes around 1.5% to 2% at the end of the nineties, a level which is approximately maintained until the end of the sample in 2006 according to all core inflation estimates.

*4.1.5 Summary of the Great Inflation Period*

The core inflation estimates often show the same tendencies, although there are a few important periods where they deviate from each other. The correlation tables indicate that the DCI (in particular the deterministic DCI but also to some extent the random DCI) are better at estimating monetary inflation for two reasons. First, any deviation between headline inflation and DCI is temporary, and the differences gradually disappear after a year or two. Second, the difference between headline inflation and DCI is to a large extent explained by the output gap, more than for any other core inflation estimate. While the XFE, the Median and the Neo-Edgeworthian index rapidly decline during recessions, the DCI is slower to decline. The DCI still captures the quick rise of monetary inflation at the beginning of the Great Inflation period, however, for both the United States and the United Kingdom.

## 5. Conclusions

We introduce a new measure of core inflation, the De-noised Core Inflation estimate. A general increase in the price level is the result of the central bank's monetary policy over the long run, but non-monetary shocks can cause temporary fluctuations in the headline inflation rate in the short run. Headline inflation is therefore a noisy short run estimate of monetary inflation.

Core inflation is a real time estimate of monetary inflation. The Federal Reserve estimates core inflation by excluding energy and food prices from the PCE price index, even though, any price index that excludes certain goods is a poor estimate of monetary inflation, since it is affected by persistent relative price changes. These relative price changes cancel out in the overall price index, due to the household's long run budget restriction, but not when some items are excluded from the price index.

We estimate core inflation by applying a signal estimation algorithm to the inflation rates of the individual items of the price index to remove the non-monetary shocks. Once these shocks have been removed we can calculate the weighted inflation average by weighting all items using the same expenditure weights as in the price index. The relative price changes now cancel out, and the calculated average is an estimate of monetary inflation.

The DCI is estimated for the United States 1967Q1 to 2007Q4 and for the United Kingdom 1972Q1 to 2006Q4 using PCE data. Alternative core inflation estimates, such as the PCE excluding food and energy prices, the Median, the Neo-Edgeworthian index and a Cogley filter, are estimated for the sake of comparison. The empirical analysis shows that all core inflation measures have a similar mean compared to headline inflation, with only minor differences, and that the deterministic DCIs are generally better at forecasting headline inflation.

The empirical analysis also shows that the various core inflation estimates usually indicate the same changes of direction of monetary inflation, but there are few important exceptions. The DCI do not indicate any reduction in monetary inflation during the seventies for either the United States or the United Kingdom, while the other estimates decline during the brief disinflation periods. It is not until the early eighties that monetary inflation begins to decline according to the DCI. Transitory DCI inflation (headline inflation minus the DCI estimate) is also more correlated with the output gap than transitory inflation estimated using any of the other core inflation estimates. This implies that the other core inflation estimates may contain a business cycle component, and thus do not isolated the monetary inflation rate.

The result of our analysis is therefore that the DCI is a better estimate of monetary inflation, and that the policy mistakes of the sixties and seventies could have been avoided if the DCI had been used by the makers of monetary policy in the United States and the United Kingdom. Since PCE excluding food and energy prices is almost the worst core inflation estimate we have considered in this study according to our three evaluation criteria, it may be a good idea if the Federal Reserve changes its core inflation estimate.

In conclusion, it is interesting to note that monetary inflation in the United States has been increasing steadily since 2003, following a stable period since the mid nineties, and that monetary inflation at the end of 2007 is about 3.5% according to the DCI estimates.

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**Table 1: Average Expenditure Weights - United States**

| Price Series | Average Expenditure Weight |
|---|---|
| Motor vehicles and parts | 0.0578 |
| Furniture and household equipment | 0.0497 |
| Other durables | 0.0220 |
| Food | 0.1850 |
| Clothing and shoes | 0.0603 |
| Gasoline and oil | 0.0322 |
| Fuel oil and coal | 0.0059 |
| Other non-durables | 0.0781 |
| Housing | 0.1491 |
| Electricity and gas | 0.0262 |
| Other household operation | 0.0343 |
| Transportation | 0.0376 |
| Medical Care | 0.1164 |
| Recreation | 0.0297 |
| Other services | 0.1158 |

**Table 2: Average Expenditure Weights - United Kingdom**

| Price Series | Average Expenditure Weight |
|---|---|
| Food and drink | 0.1540 |
| Alcohol and tobacco | 0.0558 |
| Clothing and footwear | 0.0751 |
| Housing | 0.1689 |
| Household goods and services | 0.0660 |
| Health | 0.0122 |
| Transport | 0.1401 |
| Communication | 0.0175 |
| Recreation and culture | 0.1006 |
| Education | 0.0096 |
| Restaurants and hotels | 0.1096 |
| Miscellaneous | 0.0906 |

**Table 3: Descriptive Statistics - United States 1967Q1-2007Q4**

| Inflation Estimate | Mean | Standard Deviation |
|---|---|---|
| Headline Inflation | 1.004 | 0.627 |
| Hard | 1.032 | 0.576 |
| Mid | 1.033 | 0.565 |
| Soft | 1.026 | 0.539 |
| RW-0.97 | 1.025 | 0.554 |
| RW-0.98 | 1.024 | 0.552 |
| RW-0.99 | 1.022 | 0.548 |
| Neo-Edgeworthian | 0.922 | 0.465 |
| Median | 0.903 | 0.552 |
| Cogley | 0.922 | 0.440 |
| XFE | 0.970 | 0.542 |

**Table 4: Descriptive Statistics - United States 1989Q1-2007Q4**

| Inflation Estimate | Mean | Standard Deviation |
|---|---|---|
| Headline Inflation | 0.609 | 0.309 |
| Hard | 0.616 | 0.177 |
| Mid | 0.621 | 0.189 |
| Soft | 0.631 | 0.196 |
| RW-0.97 | 0.612 | 0.165 |
| RW-0.98 | 0.613 | 0.166 |
| RW-0.99 | 0.614 | 0.170 |
| Neo-Edgeworthian | 0.583 | 0.178 |
| Median | 0.530 | 0.275 |
| Cogley | 0.544 | 0.168 |
| XFE | 0.567 | 0.236 |

**Table 5: Descriptive Statistics - United Kingdom 1972Q1-2006Q3**

| Inflation Estimate | Mean | Standard Deviation |
|---|---|---|
| Headline Inflation | 1.573 | 1.381 |
| Hard | 1.648 | 1.164 |
| Mid | 1.655 | 1.148 |
| Soft | 1.655 | 1.123 |
| RW-0.97 | 1.674 | 1.082 |
| RW-0.98 | 1.675 | 1.076 |
| RW-0.99 | 1.675 | 1.062 |
| Neo-Edgeworthian | 1.540 | 1.342 |
| Median | 1.556 | 1.334 |
| Cogley | 1.394 | 0.934 |
| XFE | 1.562 | 1.369 |

**Table 6: Descriptive Statistics - United Kingdom 1989Q1-2006Q3**

| Inflation Estimate | Mean | Standard Deviation |
|---|---|---|
| Headline Inflation | 0.550 | 0.314 |
| Hard | 0.590 | 0.209 |
| Mid | 0.596 | 0.207 |
| Soft | 0.602 | 0.195 |
| RW-0.97 | 0.695 | 0.265 |
| RW-0.98 | 0.700 | 0.269 |
| RW-0.99 | 0.711 | 0.276 |
| Neo-Edgeworthian | 0.502 | 0.261 |
| Median | 0.571 | 0.286 |
| Cogley | 0.525 | 0.154 |
| XFE | 0.496 | 0.372 |

**Table 7: Forecast Performance - United States 1967Q1-2007Q4**

| *h* | Hard | Mid | Soft | RW-0.97 | RW-0.98 | RW-0.99 | Neo-Edgeworthian | Median | Cogley | Random Walk |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **0.964**[1] | 0.977 | 0.976 | 0.963 | 0.965 | 0.968 | 0.985 | 0.996 | 1.009 | 0.970 |
| 2 | **0.956** | 0.972 | 0.979 | **0.956** | 0.959 | 0.963 | 0.994 | 1.011 | 1.005 | 0.986 |
| 3 | 0.939 | 0.937 | 0.949 | 0.926 | **0.925** | 0.926 | 1.032 | 0.965 | 0.912 | 0.978 |
| 4 | 0.860 | 0.851 | 0.847 | 0.841 | 0.840 | 0.839 | 0.990 | 0.901 | **0.835** | 0.871 |
| 5 | 0.855 | 0.854 | **0.845** | 0.851 | 0.850 | 0.849 | 1.033 | 0.876 | 0.881 | 0.884 |
| 6 | 0.982 | 0.983 | 0.963 | 0.961 | 0.959 | 0.958 | 1.069 | 0.957 | 0.973 | **0.949** |
| 7 | 1.068 | 1.073 | 1.032 | 1.036 | 1.034 | 1.033 | 1.044 | 0.996 | 1.038 | **0.981** |
| 8 | 1.109 | 1.121 | 1.079 | 1.080 | 1.079 | 1.079 | 1.037 | 1.070 | 1.088 | 1.004 |
| 9 | 1.086 | 1.091 | 1.042 | 1.043 | 1.039 | 1.036 | **0.883** | 0.993 | 1.043 | 0.938 |
| 10 | 1.047 | 1.055 | 1.017 | 1.001 | 0.998 | 0.997 | **0.835** | 0.962 | 0.984 | 0.928 |
| 11 | 0.990 | 1.003 | 0.963 | 0.958 | 0.955 | 0.954 | **0.786** | 0.923 | 0.962 | 0.894 |
| 12 | 0.931 | 0.946 | 0.912 | 0.897 | 0.894 | 0.892 | **0.777** | 0.894 | 0.902 | 0.841 |
| 13 | 1.084 | 1.111 | 1.097 | 1.067 | 1.064 | 1.063 | **0.840** | 0.980 | 1.065 | 1.060 |
| 14 | 1.105 | 1.124 | 1.120 | 1.089 | 1.089 | 1.090 | **0.859** | 1.003 | 1.107 | 1.084 |
| 15 | 0.972 | 0.994 | 1.002 | 0.972 | 0.974 | 0.977 | **0.860** | 0.988 | 1.010 | 1.014 |
| 16 | 0.913 | 0.952 | 0.973 | 0.926 | 0.930 | 0.937 | **0.907** | 0.982 | 0.924 | 0.976 |

**Note**

1. The table show the ratio $\frac{RMSE^{core}}{RMSE^{XFE}}$

**Table 8: Forecast Performance - United States 1989Q1-2007Q4**

| $h$ | Hard | Mid | Soft | RW-0.97 | RW-0.98 | RW-0.99 | Neo-Edgeworthian | Median | Cogley | Random Walk |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **0.949**[1] | 0.950 | 0.968 | 0.953 | 0.956 | 0.963 | 1.010 | 1.153 | 1.215 | 0.991 |
| 2 | **0.845** | 0.904 | 0.918 | 0.929 | 0.939 | 0.954 | 0.986 | 1.118 | 1.243 | 0.953 |
| 3 | 1.005 | 0.983 | **0.967** | 0.999 | 0.999 | 0.997 | 0.970 | 1.060 | 1.094 | 0.978 |
| 4 | 0.961 | **0.932** | 0.942 | 0.957 | 0.955 | 0.954 | 0.991 | 1.195 | 1.196 | 0.978 |
| 5 | **0.955** | 0.984 | 1.011 | 1.005 | 1.010 | 1.019 | 0.987 | 1.207 | 1.225 | 1.077 |
| 6 | **0.907** | 0.938 | 0.953 | 0.954 | 0.956 | 0.961 | 0.948 | 1.089 | 1.115 | 0.975 |
| 7 | **0.887** | 0.916 | 0.925 | 0.937 | 0.939 | 0.945 | 0.950 | 1.079 | 1.054 | 0.949 |
| 8 | 0.936 | 0.927 | 0.938 | 0.945 | 0.951 | 0.958 | **0.904** | 1.140 | 1.141 | 0.975 |
| 9 | **0.911** | 0.948 | 0.955 | 0.969 | 0.970 | 0.974 | 0.939 | 1.162 | 1.122 | 1.003 |
| 10 | **0.871** | 0.904 | 0.925 | 0.910 | 0.914 | 0.924 | 0.879 | 1.074 | 1.102 | 0.929 |
| 11 | **0.835** | 0.898 | 0.923 | 0.884 | 0.894 | 0.913 | 0.879 | 1.114 | 1.129 | 0.935 |
| 12 | **0.955** | 0.968 | 0.971 | 1.000 | 1.002 | 1.003 | 1.001 | 1.187 | 1.075 | 1.125 |
| 13 | **0.892** | 0.912 | 0.926 | 0.913 | 0.916 | 0.923 | 0.955 | 1.054 | 1.057 | 1.032 |
| 14 | **0.920** | 0.937 | 0.927 | 0.946 | 0.948 | 0.949 | 0.880 | 1.074 | 1.019 | 1.037 |
| 15 | 0.985 | 0.984 | 0.992 | 0.982 | 0.982 | 0.981 | **0.826** | 1.119 | 1.116 | 0.985 |
| 16 | **0.898** | 0.948 | 0.969 | 0.926 | 0.931 | 0.942 | 0.908 | 1.160 | 1.081 | 1.009 |

**Note**

1. The table show the ratio $\frac{RMSE^{core}}{RMSE^{XFE}}$

**Table 9: Forecast Performance - United Kingdom 1972Q1-2006Q3**

| *h* | Hard | Mid | Soft | RW-0.97 | RW-0.98 | RW-0.99 | Neo-Edgeworthian | Median | Cogley | Random Walk |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.902[1] | 0.905 | **0.899** | 0.917 | 0.918 | 0.920 | 0.977 | 0.979 | 0.976 | 1.707 |
| 2 | **0.865** | 0.870 | 0.869 | 0.903 | 0.903 | 0.902 | 0.979 | 0.975 | 0.948 | 1.560 |
| 3 | **0.868** | 0.870 | 0.869 | 0.910 | 0.910 | 0.910 | 0.995 | 0.981 | 0.953 | 1.587 |
| 4 | **0.893** | 0.891 | 0.889 | 0.942 | 0.941 | 0.941 | 0.983 | 0.986 | 0.967 | 1.651 |
| 5 | 0.862 | **0.857** | 0.860 | 0.925 | 0.924 | 0.923 | 1.000 | 1.005 | 0.947 | 1.664 |
| 6 | **0.852** | **0.852** | 0.853 | 0.927 | 0.925 | 0.922 | 0.938 | 0.943 | 0.882 | 1.717 |
| 7 | **0.847** | 0.855 | 0.858 | 0.927 | 0.927 | 0.926 | 1.005 | 0.985 | 0.869 | 1.748 |
| 8 | 0.908 | **0.906** | 0.910 | 0.984 | 0.982 | 0.979 | 0.999 | 1.007 | 0.916 | 1.743 |
| 9 | **0.913** | 0.922 | 0.928 | 0.995 | 0.994 | 0.991 | 1.013 | 1.019 | 0.922 | 1.758 |
| 10 | **0.889** | 0.892 | 0.897 | 0.969 | 0.968 | 0.964 | 1.009 | 0.994 | 0.987 | 1.676 |
| 11 | **0.895** | 0.910 | 0.914 | 0.970 | 0.969 | 0.968 | 1.017 | 1.004 | 0.905 | 1.647 |
| 12 | 0.910 | 0.922 | 0.928 | 0.996 | 0.994 | 0.993 | 1.016 | 1.016 | **0.904** | 1.777 |
| 13 | **0.930** | 0.955 | 0.960 | 1.029 | 1.028 | 1.026 | 1.030 | 1.023 | 0.999 | 1.801 |
| 14 | **0.901** | 0.914 | 0.918 | 0.995 | 0.992 | 0.987 | 1.024 | 1.020 | 0.943 | 1.784 |
| 15 | **0.925** | 0.936 | 0.937 | 1.007 | 1.003 | 0.996 | 1.035 | 1.021 | 0.951 | 1.711 |
| 16 | **0.903** | 0.916 | 0.919 | 0.986 | 0.985 | 0.982 | 1.047 | 1.041 | 0.968 | 1.702 |

**Note**

1. The table show the ratio $\frac{RMSE^{core}}{RMSE^{XFE}}$

**Table 10: Forecast Performance - United Kingdom 1989Q1-2006Q3**

| *h* | Hard | Mid | Soft | RW-0.97 | RW-0.98 | RW-0.99 | Neo-Edgeworthian | Median | Cogley | Random Walk |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.914[1] | 0.844 | 0.773 | 0.915 | 0.911 | 0.902 | 0.875 | 0.860 | **0.681** | 1.765 |
| 2 | 0.901 | 0.847 | **0.758** | 0.892 | 0.885 | 0.871 | 0.978 | 1.063 | 0.807 | 1.736 |
| 3 | 0.727 | 0.643 | **0.632** | 0.761 | 0.759 | 0.753 | 0.819 | 0.865 | 0.750 | 1.761 |
| 4 | 0.863 | 0.811 | **0.754** | 0.879 | 0.877 | 0.872 | 0.941 | 0.920 | 0.762 | 1.811 |
| 5 | 0.777 | 0.758 | **0.746** | 0.859 | 0.861 | 0.862 | 0.863 | 1.029 | 0.776 | 1.803 |
| 6 | 0.985 | 0.894 | **0.816** | 0.992 | 0.988 | 0.980 | 1.096 | 1.074 | 0.886 | 1.944 |
| 7 | 0.831 | 0.754 | **0.682** | 0.858 | 0.856 | 0.851 | 0.926 | 0.922 | 0.713 | 1.829 |
| 8 | 0.775 | 0.734 | **0.634** | 0.802 | 0.799 | 0.793 | 0.944 | 0.892 | 0.644 | 1.549 |
| 9 | 0.615 | 0.540 | **0.529** | 0.710 | 0.713 | 0.717 | 0.711 | 0.891 | 0.646 | 1.601 |
| 10 | 0.976 | 0.896 | 0.823 | 1.018 | 1.018 | 1.020 | 1.064 | 1.109 | **0.717** | 1.927 |
| 11 | 0.842 | 0.765 | **0.685** | 0.856 | 0.855 | 0.856 | 0.901 | 1.187 | 0.728 | 1.779 |
| 12 | 0.749 | 0.697 | **0.591** | 0.808 | 0.808 | 0.811 | 0.824 | 0.871 | 0.652 | 1.602 |
| 13 | 0.782 | 0.753 | **0.734** | 0.966 | 0.971 | 0.981 | 0.844 | 0.943 | 0.769 | 1.321 |
| 14 | 0.897 | 0.811 | **0.709** | 0.966 | 0.967 | 0.975 | 1.068 | 1.125 | 0.741 | 1.955 |
| 15 | 0.682 | 0.605 | **0.536** | 0.738 | 0.740 | 0.745 | 0.780 | 1.059 | 0.743 | 1.883 |
| 16 | 0.887 | 0.800 | **0.709** | 0.975 | 0.977 | 0.984 | 0.856 | 0.949 | 0.713 | 1.738 |

**Note**

1. The table show the ratio $\frac{RMSE^{core}}{RMSE^{XFE}}$

**Table 11: Correlations between Transitory Inflation and the Output Gap
United States 1967Q1-2007Q4**

| Core Inflation Estimate (*t*) | Output gap (*t*) | Output gap (*t*-4) |
|---|---|---|
| Hard | 0.563 | 0.489 |
| Mid | 0.505 | 0.605 |
| Soft | 0.423 | 0.649 |
| RW-0.97 | 0.413 | 0.500 |
| RW-0.98 | 0.404 | 0.512 |
| RW-0.99 | 0.383 | 0.527 |
| Neo-Edgeworthian | 0.313 | 0.457 |
| Median | 0.378 | 0.499 |
| Cogley | 0.297 | 0.592 |
| XFE | 0.428 | 0.504 |

**Table 12: Correlations between Transitory Inflation and the Output Gap**
**United States 1989Q1-2007Q4**

| Core Inflation Estimate (*t*) | Output gap (*t*) | Output gap (*t*-4) |
|---|---|---|
| Hard | 0.411 | 0.406 |
| Mid | 0.414 | 0.398 |
| Soft | 0.467 | 0.414 |
| RW-0.97 | 0.297 | 0.354 |
| RW-0.98 | 0.292 | 0.357 |
| RW-0.99 | 0.285 | 0.363 |
| Neo-Edgeworthian | 0.063 | -0.203 |
| Median | 0.142 | -0.069 |
| Cogley | 0.447 | 0.341 |
| XFE | 0.368 | 0.193 |

**Table 13: Correlation between Transitory Inflation and the Output Gap United Kingdom 1972Q1-2007Q4**

| Core Inflation Estimate (*t*) | Output gap (*t*) | Output gap (*t*-4) |
|---|---|---|
| Hard | 0.111 | 0.603 |
| Mid | 0.087 | 0.583 |
| Soft | 0.072 | 0.574 |
| RW-0.97 | 0.124 | 0.529 |
| RW-0.98 | 0.119 | 0.525 |
| RW-0.99 | 0.108 | 0.516 |
| Neo-Edgeworthian | 0.053 | 0.163 |
| Median | -0.002 | -0.013 |
| Cogley | 0.099 | 0.560 |
| XFE | -0.039 | 0.124 |

**Table 14: Correlation between Transitory Inflation and the Output Gap United Kingdom 1989Q1-2007Q4**

| Core Inflation Estimate (*t*) | Output gap (*t*) | Output gap (*t*-4) |
|---|---|---|
| Hard | 0.374 | 0.807 |
| Mid | 0.387 | 0.848 |
| Soft | 0.386 | 0.862 |
| RW-0.97 | 0.132 | 0.705 |
| RW-0.98 | 0.132 | 0.709 |
| RW-0.99 | 0.131 | 0.718 |
| Neo-Edgeworthian | 0.178 | 0.242 |
| Median | -0.262 | 0.004 |
| Cogley | 0.314 | 0.824 |
| XFE | 0.542 | 0.375 |

**Figure 1: PCE Inflation – United States 1959Q2-2007Q4**

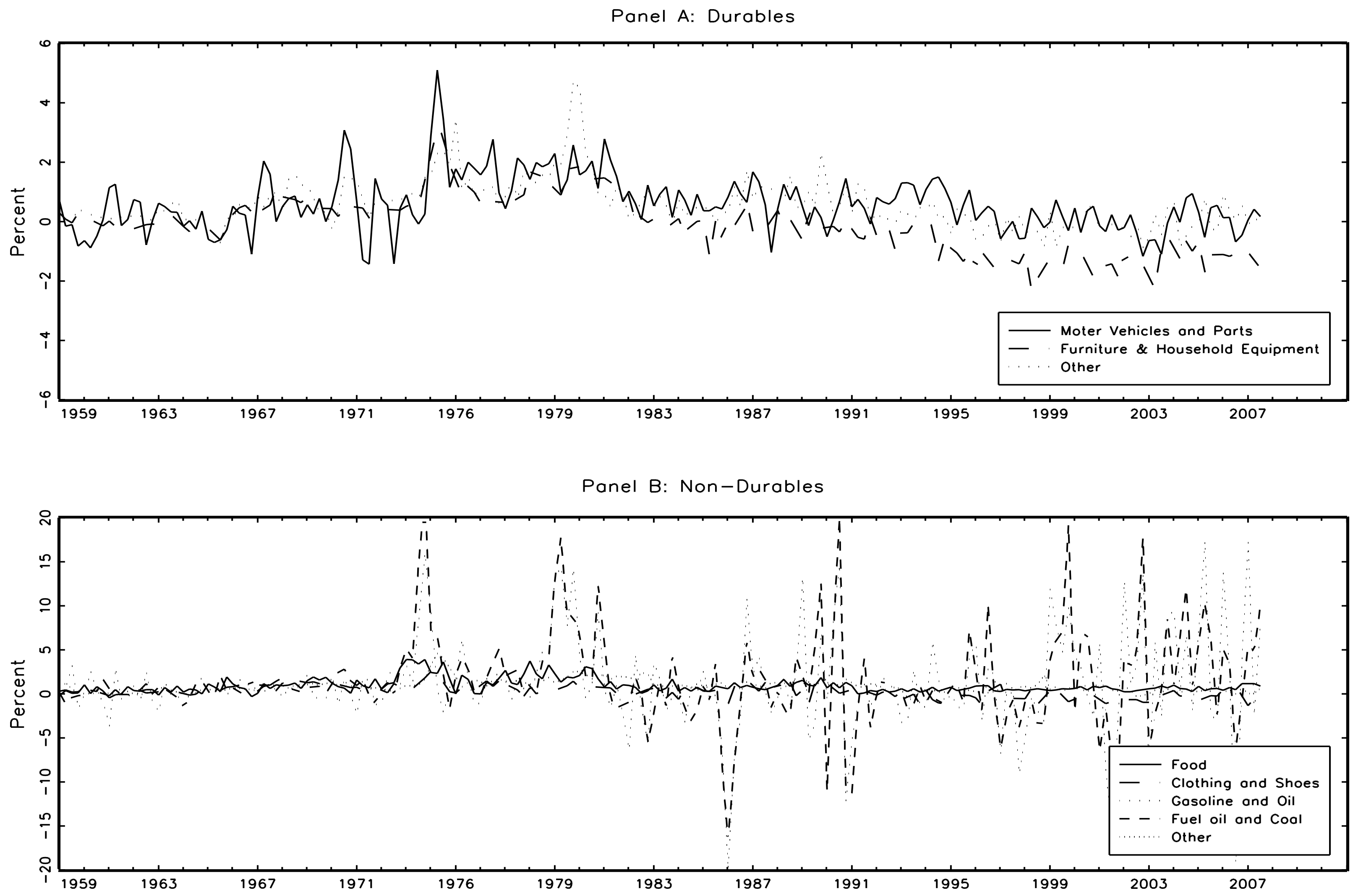
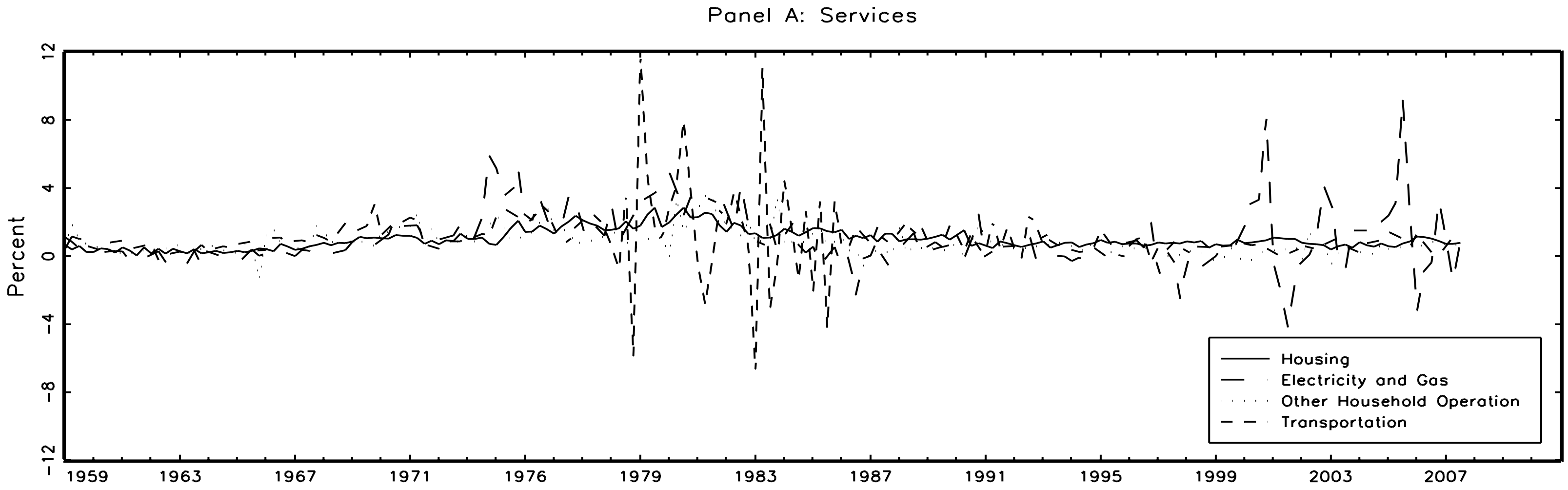


**Figure 2: PCE Inflation – United States 1959Q2-2007Q4 continued**



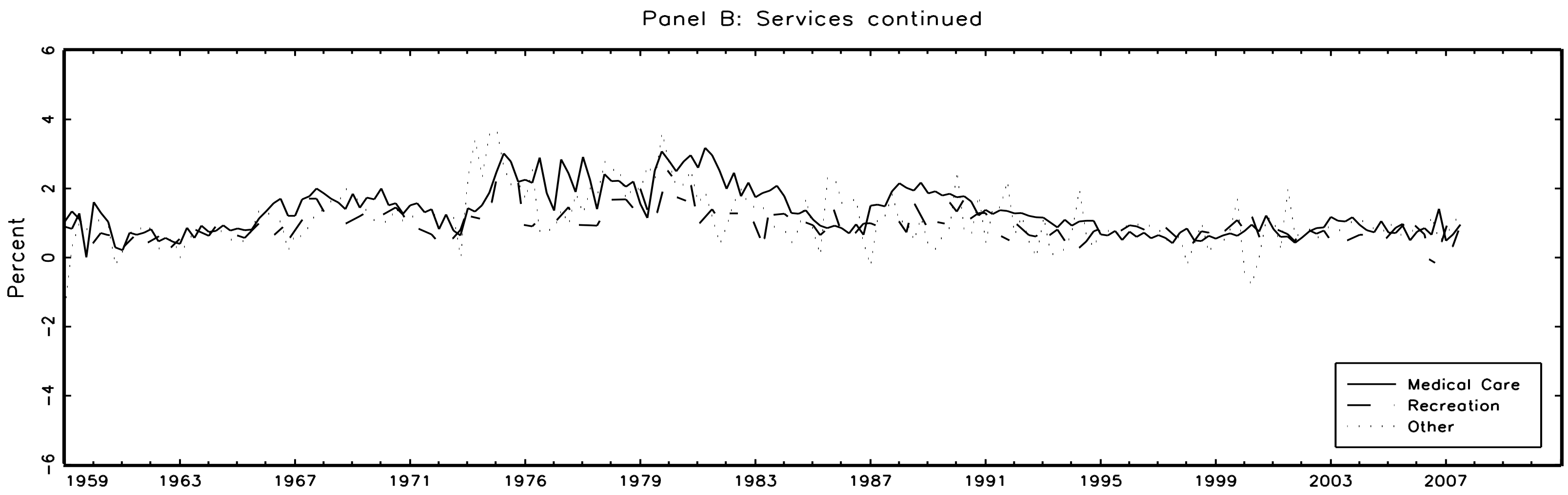



**Figure 3: PCE Inflation – United Kingdom 1964Q2-2006Q3**

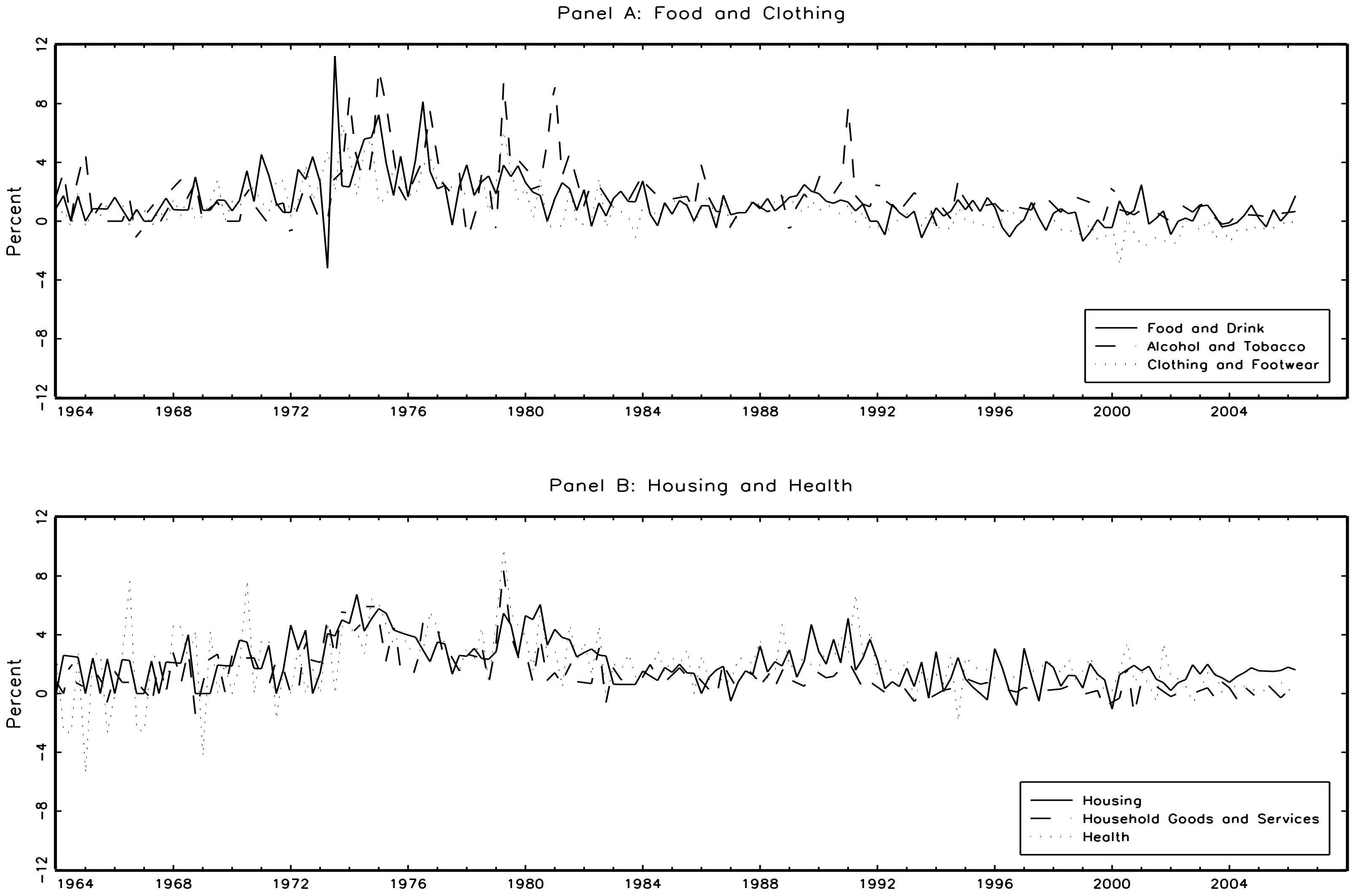
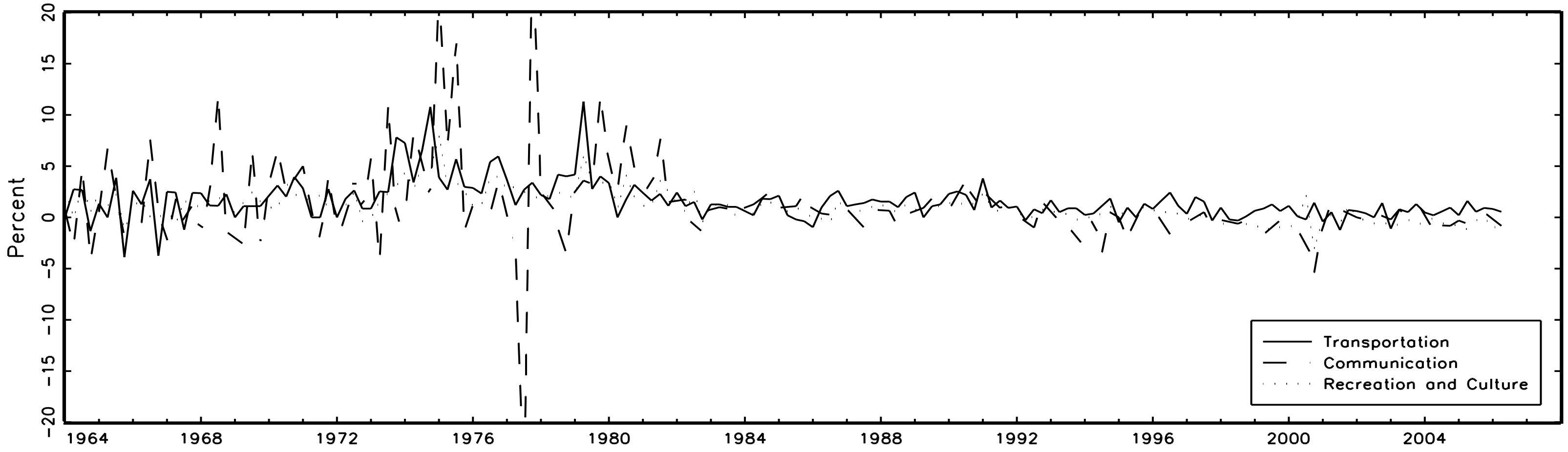


**Figure 4: PCE Inflation – United Kingdom 1964Q2-2006Q3 continued**

Panel A: Transportation, Communication and Recreation




Panel B: Education and Miscellaneous

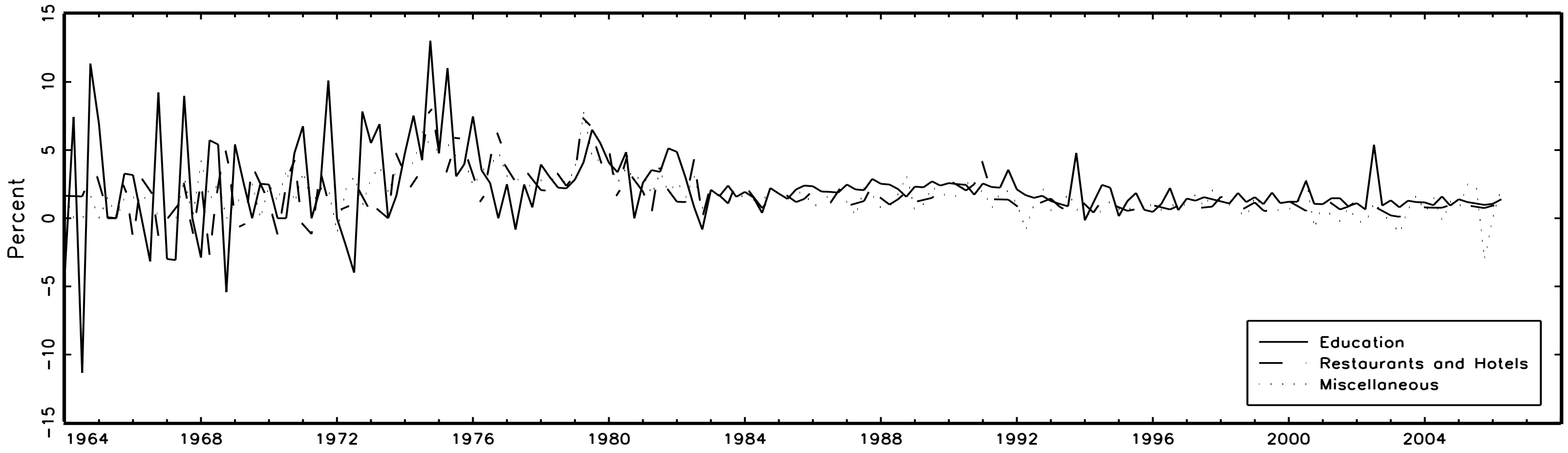


**Figure 5: De-noised Core Inflation - United States 1967Q1-2007Q4**

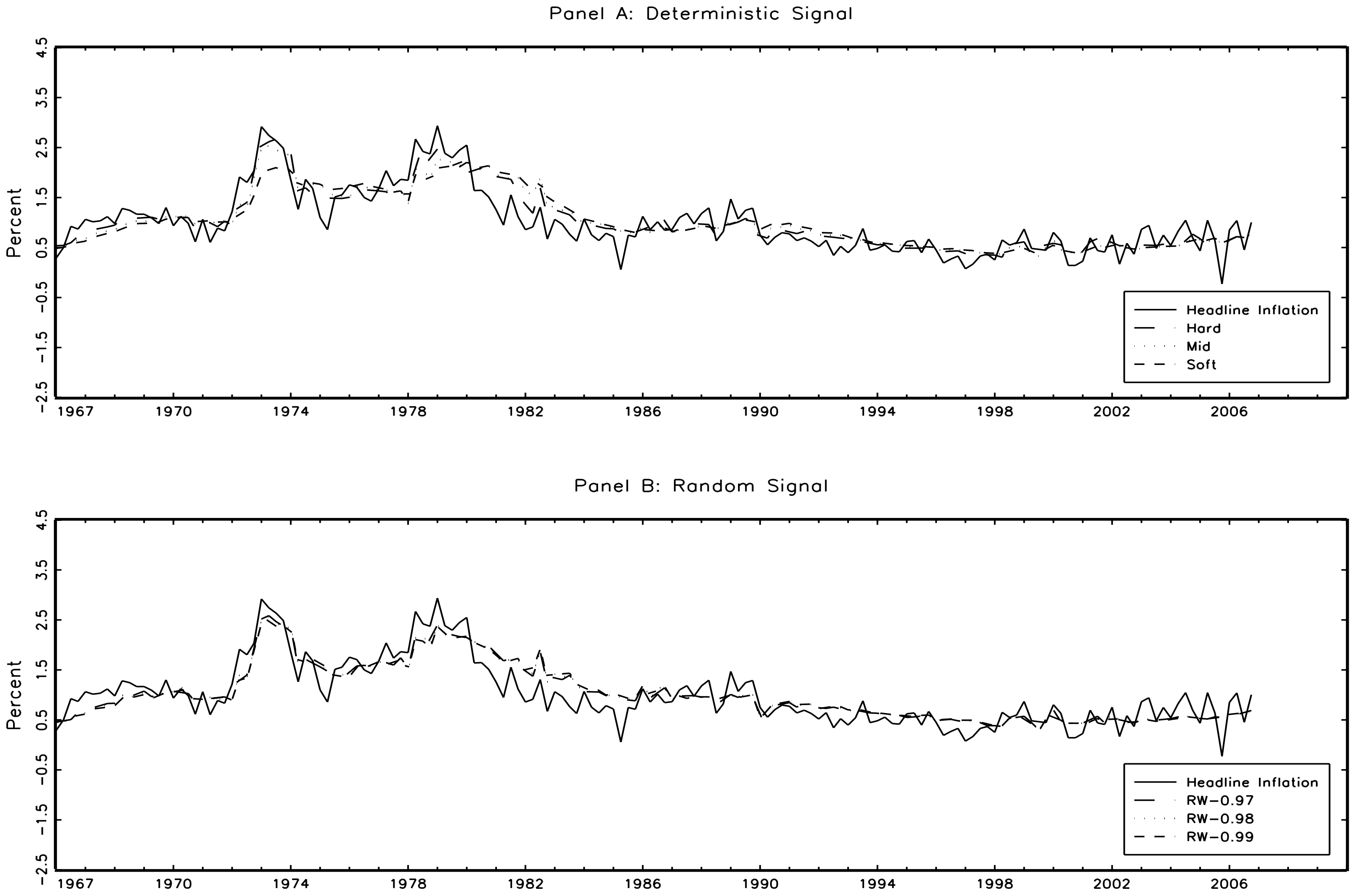


**Figure 6: Other Core Inflation Estimates - United States 1967Q1-2007Q4**

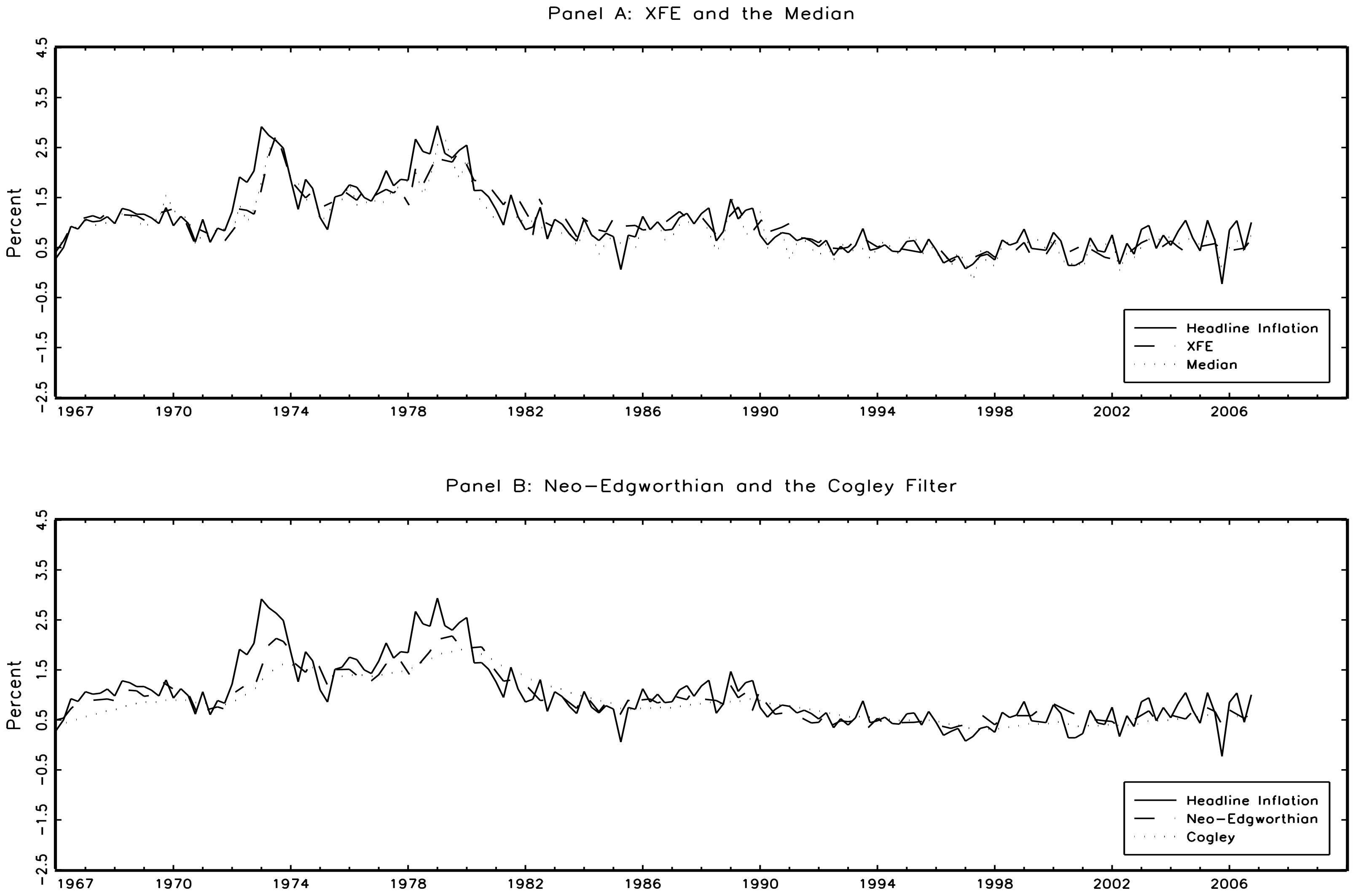
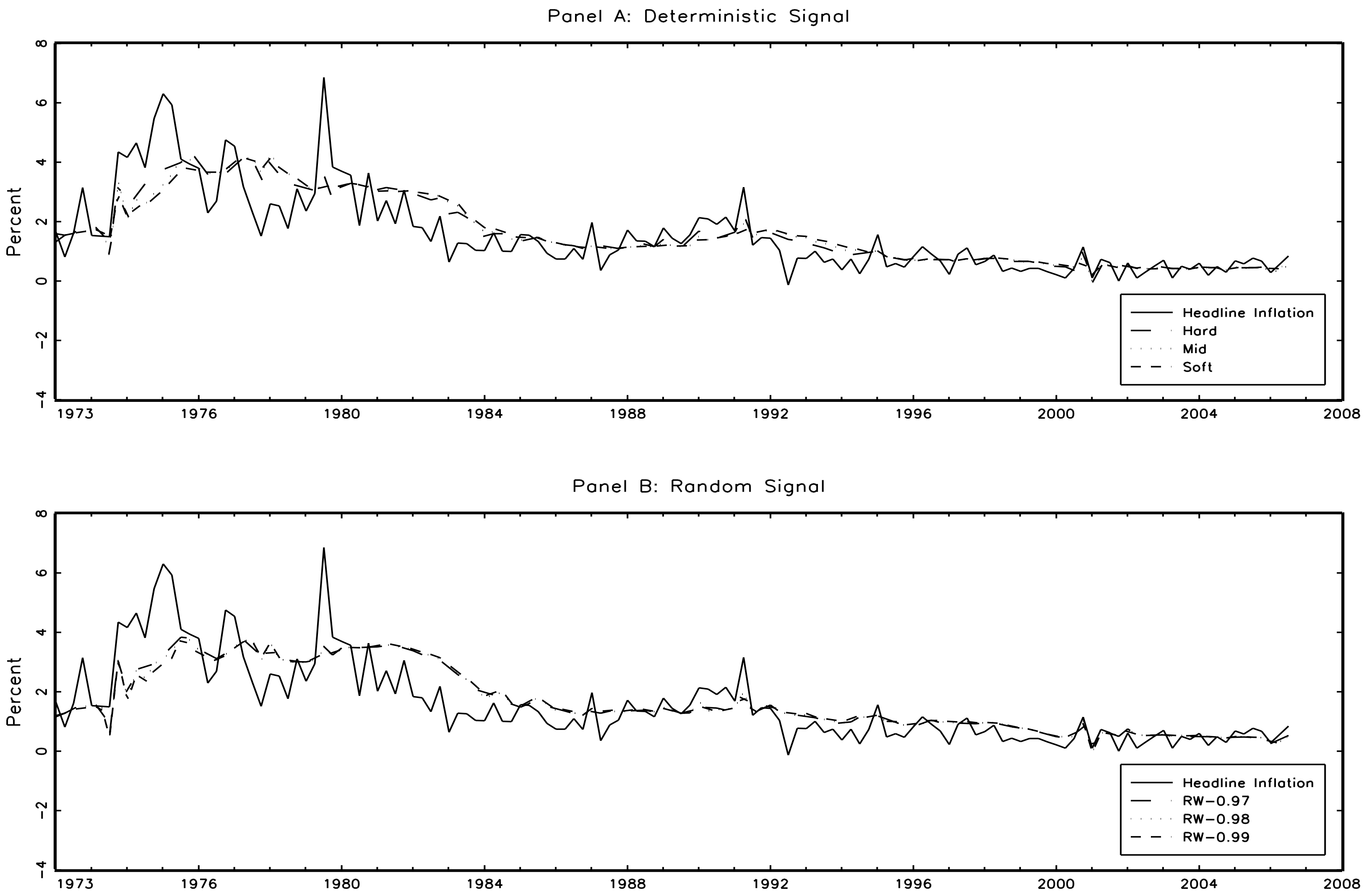


**Figure 7: De-Noised Core Inflation - United Kingdom 1972Q1-2006Q3**



## Figure 8: Other Core Inflation Estimates – United Kingdom 1972Q1-2006Q3