US Economics Research

Barclays Underlying Inflation Gauge: Turn up the heat to hit 2%

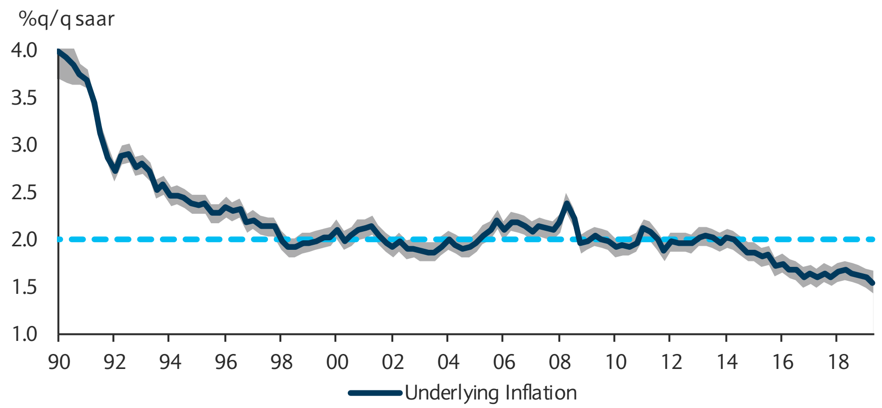
Jonathan Millar
+1 212 526 4876
jonathan.millar@barclays.com
BCI, US

Blerina Uruçi
+1 202 452 4774
blerina.uruci@barclays.com
BCI, US

www.barclays.com

- **The recent softening of core inflation has reignited debate about whether the FOMC is on track to meet its symmetric 2% inflation target. With markets pricing in outcomes where disinflation proves persistent, a number of FOMC participants have acknowledged downside risks to the longer-term inflation outlook.**
- **If history is any guide, the FOMC will look to some concept of underlying inflation – measures that attempt to strip away the effects of transitory influences on the inflation rate – to help assess the need to recalibrate policy.**
- **We introduce the Barclays Underlying Inflation Gauge, which forms an estimate by extracting information about inflation from signals including various measures of long-term inflation expectations, as well as anchored expectation Phillips Curves for core CPI and PCE inflation.**
- **Our approach aims to identify the level at which inflation would settle if the economy were maintained at full employment. This differs from many alternative measures, such as the trimmed inflation measures produced within the Federal Reserve System, which tend to focus on eliminating noise from various short-term influences. We think our methodology will prove useful to policymakers, since it corrects for transitory noise as well as the economy's cyclical position.**
- **We find that transitory pressures from relative import prices and other sources have been weighing on inflation. Even when we strip away these influences, we find that underlying PCE price inflation is currently running at about 1.6% – well short of the FOMC's 2% target. Absent an upward shift in long run expectations, the FOMC would need to let the economy run "hot" in order to achieve its mandate.**

FIGURE 1
Barclays Underlying Inflation Gauge



Note: Shaded region shows 95% confidence interval. Source: Barclays Research

PLEASE SEE ANALYST CERTIFICATIONS AND IMPORTANT DISCLOSURES STARTING AFTER PAGE 21

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Soft inflation: transitory or trend?

So far this year, financial markets have seen significant adjustments in the course of Federal Reserve policy. One was in January, when the FOMC moved to a "patient" stance and paused its tightening cycle. At that time, Fed Chair Powell said, "I would want to see a need for further rate increases. And for me, a big part of that would be inflation." The other was in June, when the FOMC first signalled its intention to loosen monetary policy, culminating with July's cut in the policy rate, designed to forestall negative implications of "global developments for the economic outlook as well as muted inflation pressures." As the FOMC weighs upcoming policy moves, a key question is whether the recent softening of inflation reflects transitory influences that are likely to fade, or more persistent headwinds.

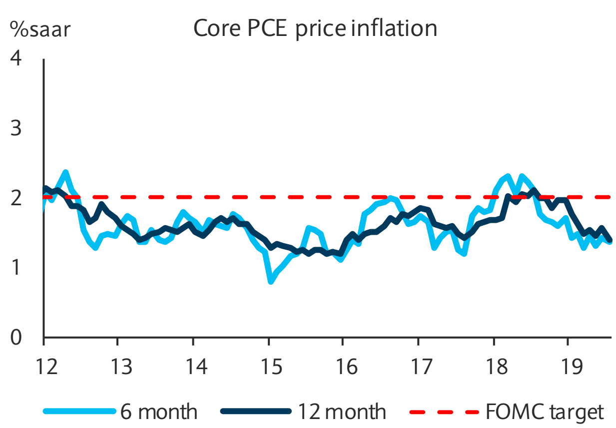
This year's softening of inflation is only the latest setback in the Fed's quest to boost inflation to its 2% target. Over the course of the expansion, the Fed's preferred inflation measure – the PCE price index – has consistently fallen short of this level. In mid-2018, this target appeared to be finally within reach, as late-cycle fiscal stimulus, combined with strengthened global demand, briefly pushed inflation to its target (Figure 2). But since then, measured inflation has softened against a backdrop of waning fiscal stimulus and fading global growth (Figure 3), calling into question the Fed's ability to attain its price stability mandate. With inflation generally hovering below 2% in recent years, despite the longest US economic expansion on record, one can reasonably argue that the brief acceleration of consumer prices toward the target in 2018 was the actual anomaly.

These recent developments demonstrate the importance of the FOMC's ability to gauge "underlying inflation". Within its existing inflation targeting framework, the Fed sets policy using a forward-looking approach that attempts to direct inflation toward the 2% target over the medium term, which usually corresponds to a position that is at least moving in the direction of full employment, if not at full employment. This involves not only looking through transitory influences affecting inflation in the short term, but thinking about where inflation will eventually settle if the economy is set on some glide path toward full employment. If this glide path does not put inflation on course to achieve dual mandate objectives, then some recalibration in the monetary policy stance is likely in order.

In this note, we introduce the Barclays Underlying Inflation Gauge, previewed in Figure 1. This measure is estimated using a unified framework that brings together signals from a

FIGURE 2

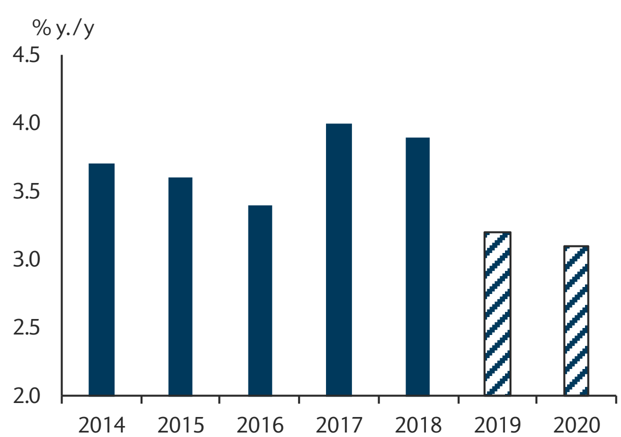
Core PCE price inflation has fallen back after having approached 2% in mid-to-late 2018



Source: Bureau of Economic Analysis, Barclays Research

FIGURE 3

Global GDP has decelerated this year after having firmed in 2017 and 2018



Note: Hatched bars denote forecasts. Source: Barclays Research variety of sources that provide information about long-run inflation. Our approach is fundamentally different from a number of prominent methods, which generally attempt to isolate some corrected measure of inflation by stripping away volatile components. Rather than excluding information, our approach treats underlying inflation as an unobserved variable, using a state-space approach that weighs information about long-run inflation from plausible signals. One benefit of this approach is that it brings to bear information from a multitude of sources, which – we hope – helps sidestep issues with bias that can arise with approaches that exclude data. Another benefit is that it isolates the concept of inflation that we believe, ultimately, should carry more weight within the Fed's forward-looking inflation targeting framework.

Our approach is an alternative to a number of competing measures of underlying inflation. This list includes estimators that exclude noisy components, including the standard "core" measures that strip away food and energy prices, as well as "trimmed" measures that, in any given period, exclude information about components of consumer spending whose prices show especially large fluctuations. Although these measures are widely used, we argue that they have meaningful flaws if the goal is to assess long-run inflation pressures, including biases that can arise from excluding data, and the fact that they do not adjust for the economy's cyclical position. Another set of alternative methods includes measures of long-term inflation expectations from consumer surveys, professional forecasters or financial markets. Although these measures seemingly reflect a concept of inflation that is similar to what we have in mind in our model, they provide mixed signals in practice – in part due to subtle differences in measurement approach.

Our measure most closely resembles the "kitchen sink" approach taken to form the New York Fed's Underlying Inflation Gauge (UIG). However, we approach the problem quite differently than the opaque method in that model, employing a Phillips Curve specification that helps pinpoint the inflation trend, and a more targeted set of indicators. This results in estimates that are less sensitive to cyclical influences, and more robust to changes in specification.

The main takeaway from our analysis is that – after correcting for the cyclical position of the economy and various transitory influences – underlying PCE price inflation seems to be running as much as 30 to 40bps below the FOMC's 2% target. Given estimated long-run differences between measures of the PCE and CPI concepts of inflation, our estimates put the current path of underlying CPI inflation somewhat higher, at about 2.0%. Our model delivers these results using a variety of specifications, and a number of other reasonable approaches seem to point to similar conclusions about where inflation is headed.

If our findings are correct, the FOMC will likely need to run the economy hot for some time in order to put inflation on a path that is consistent with its target. Such a policy stance may well produce better outcomes in terms of the Fed's price stability mandate, and may generate positive side effects in terms of income distribution and opportunity broadly consistent with its full employment mandate. However, such a course could also pose a number of important risks, heightening the possibility of generating financial imbalances, as well as political interference that in the long run may reduce the credibility of its commitment to control inflation. Ultimately, the committee will need to weigh this trade-off as it assesses the need for more accommodative policy to achieve its inflation target. Our outlook anticipates that the FOMC will put more weight on price stability objectives, as it considers these trade-offs going forward, sustaining tight labor market conditions with an eye to boosting inflation expectations. Consequently, we expect core PCE prices to accelerate to around 2.0% by 2020.

We begin our note by touching on the sources of this year's softening in inflation outcomes, which helps motivate subsequent discussion of alternative approaches to measuring underlying inflation. We describe the underlying logic of these approaches, and point out some potential shortcomings of these approaches that are often overlooked. The note then closes with a more thorough description of our Underlying Inflation Gauge, devoting a fair amount of attention to describing its robustness to reasonable changes in specification.

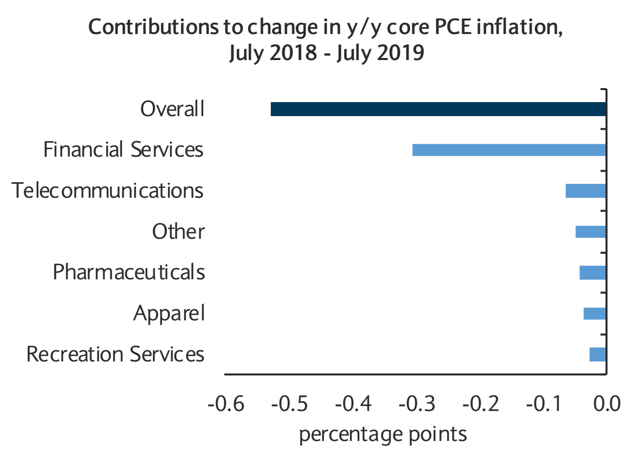
What are the sources of recent disinflation?

Core PCE price inflation hit its post-expansion zenith in the first half of 2018, hitting 2.3% on a 6m saar basis and 2.1% y/y in May 2018. Monthly inflation has softened since then, with core PCE price inflation falling to 1.4% on a 6m saar basis in January 2018 before rebounding to 1.7% 6m saar in July 2019. As shown in Figure 4, the deceleration of core PCE over the twelve months ended in July has mainly been driven by smaller contributions from categories that are often written off as idiosyncratic, including nondurable goods categories such as apparel and pharmaceuticals, and, particularly, the "financial services charges, fees and commissions" component of core services (henceforth, financial service charges). When these three categories are excluded, core PCE inflation was about 1.8% y/y in July – down just 0.1pp from a year earlier. This suggests that the argument that movements in a few categories largely "explain" the recent deceleration of core PCE has merit.

A number of components of core PCE seem to instil more noise than signal. Apparel prices, in particular, tend to be noisy. This noisiness reflects the fact that shoes and clothing tend to be subject to aggressive discounting, as well as measurement difficulties that arise because the unusually rapid product cycle for many types of apparel that can makes it difficult to generate suitable price comparisons over time. Recent changes to how apparel prices are collected have seemingly made measurement challenges for the apparel category more acute. In March, the Bureau of Labor Statistics (BLS) expanded the use of respondent data by adding a corporate dataset to the apparel component, which replaced the traditional in-store and website collection for each particular department store..[1] This seemingly led to a large change in the level of the index; in July, apparel prices were down 0.7% on a y/y basis,

FIGURE 4

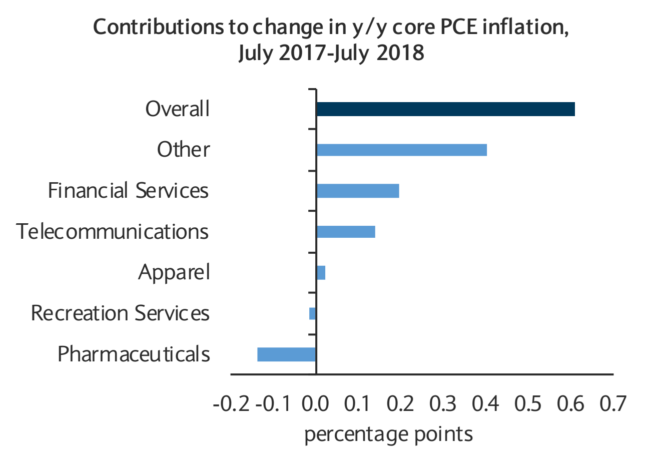
The deceleration of core PCE prices over the past year was driven by financial services and telecommunications…



Note: Electronics denotes "Video, Audio, Photographic, Information Processing Equipment, and Media". Source: Bureau of Economic Analysis; Barclays Research

FIGURE 5

…with many of the same categories having contributed to acceleration over the preceding twelve-month period



Note: Electronics denotes "Video, Audio, Photographic, Information Processing Equipment, and Media". Source: Bureau of Economic Analysis; Barclays Research

[1] The *new methodology* replaced internal data collected using the BLS's usual survey procedures with a much larger sample of data collected from a private data vendor. As with many categories, CPI estimates for this category are transposed by the BEA into broader estimates for overall PCE.

with declines concentrated after the methodological change was implemented in March. Although only time will tell, there are hints that this change could lower the average rate of inflation in this category, implying that historical estimates have been upwardly biased.[2]

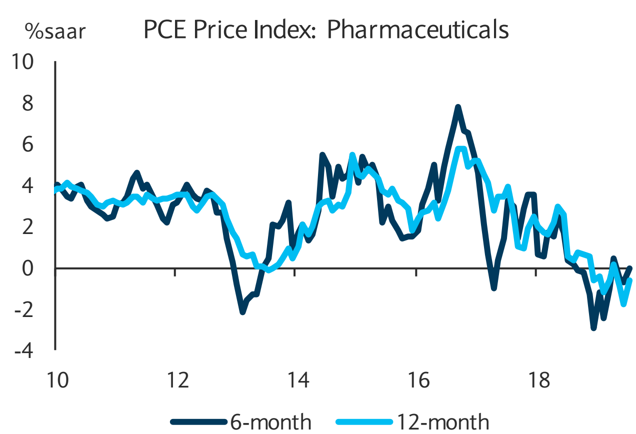
Apparel is not the only category in which inflation estimates are volatile or idiosyncratic. It is well known that overall movements in US pharmaceutical prices are affected by trends in the timing of US drug patent protections, with downward pressure in periods when a large number of patent expiries occur. Similar arguments can be made for the price index for financial services, which, for mechanical reasons, resembles a measure of lagged changes in the overall value of the stock market. This is because about a third of the nominal spending of this category is in "portfolio management and investment advice services" – which measures revenue that financial professionals receive for managing portfolios and providing investment advice. By construction, price changes for this category move up and down with the market value of assets under management, calculated using market data from the previous quarter. As with apparel, fluctuations in these and other volatile categories contribute more noise than signal from the perspective of forecasting, which seemingly justifies looking at price indices that strip out such components.

Excluding categories can create bias

Naturally, when we strip away such volatile categories, the evolution of the resulting inflation measure will tend to be much smoother. And, if the volatile categories have little persistence, it would not be surprising that the resulting measure is more closely correlated with overall inflation in the future than the measure with these volatile components included. Logic along these lines has contributed to interest in various measures of underlying inflation that remove volatile components, including the "core" measures of CPI and PCE price inflation that remove prices in the food and energy categories.

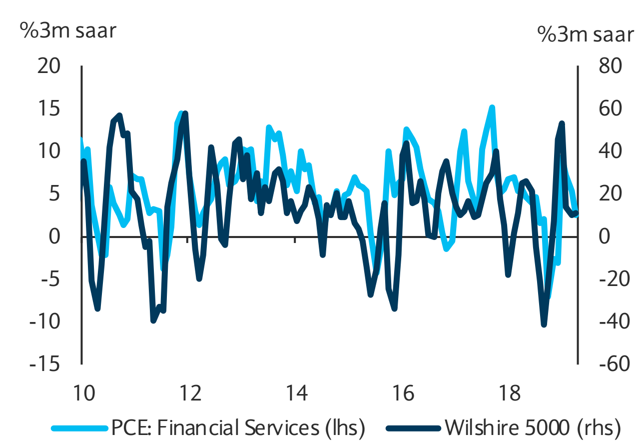
But does it make sense to assess the underlying level of inflation by simply stripping out these volatile components? In other words, does it make sense to argue that the FOMC is on course to achieve its inflation target because some measure of inflation that strips out volatile components is running close to 2%?

FIGURE 6
With a number of key US patents expiring, pharmaceutical prices have decelerated of late



Source: Bureau of Economic Analysis

FIGURE 7
Inflation in the portfolio management services and advice category tracks lagged stock market performance



Source: Bureau of Economic Analysis; Barclays Research

[2] Estimates using the available overlapping sample (July 2016 to December 2018) show smaller price increases in the apparel category, on average, using the new methodology. See related discussion in our *March US CPI Inflation Monitor*.

FIGURE 8

In hindsight, the 2018 acceleration may be an anomaly

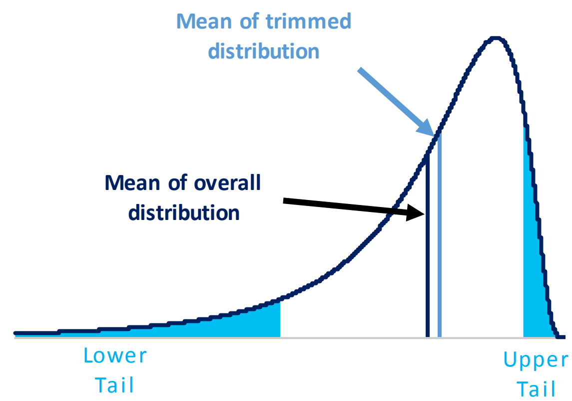
Contributions to y/y change, pp

	Jul-16	Jul-17	Jul-18	Jul-19
Core PCE	1.6	1.5	2.1	1.6
Core goods	-0.2	-0.1	-0.1	-0.1
Apparel	0.0	0.0	0.0	0.0
Pharmaceuticals	0.1	0.2	0.0	0.0
Other core goods	-0.3	-0.3	-0.2	-0.1
Core services	1.8	1.6	2.2	1.7
Healthcare	0.1	0.1	0.1	0.1
Financial	0.3	0.2	0.4	0.1
Telecommunications	-0.1	-0.1	0.0	-0.1
Other core services	1.3	1.3	1.7	1.5

Source: Bureau of Economic Analysis, Barclays Research

FIGURE 9

If the distribution of inflation across components is negatively skewed, then trimming will raise the mean



Source: Barclays Research

In our view, the answer is not clear cut. The fact that the smoother measure *correlates* better with future inflation outcomes does not imply that the current *level* of such a measure provides a superior indication of where the overall *level* of inflation is likely headed. One important flaw in this argument is that all of these measures are likely being affected by the level of slack in the economy, and a careful forecast should likely take this into account. But from a statistical standpoint, there is a more basic flaw: the mean rate of inflation for the smoothed components can differ substantially from the mean for the excluded components. This matters because the expected overall level of inflation depends on forecasts of both the included (persistent) components and the excluded (volatile) components. To form an unbiased forecast, we need to adjust for differences in means between the two series.

Failing to adjust for these differences could lead to meaningful biases. To illustrate using an extreme example, imagine a case where PCE is composed of two components – a volatile component and a persistent component. Price inflation for the volatile component, which accounts for 20% of spending, fluctuates randomly around zero in each period, with a range of possible outcomes. Price increases for the persistent component, which accounts for the remaining 80% of spending, are always 2%. In this case, the current rate of inflation in the persistent component will be a perfect predictor of its future value, while current inflation rates for the volatile component would be noise. But this does not mean that future rates of overall inflation will be around 2%. This is because the expected rate of increase in overall prices, after accounting for the different means and relative weights of the two components, is only 1.6%. In this case, a central bank that infers the underlying level of inflation using the level of inflation for the persistent components could make a serious policy error. In Appendix A, we provide a mathematical example that demonstrates this bias more formally.

This discussion raises questions about whether the most well-known proxies of underlying inflation – the measures of core CPI and core PCE price inflation – may, in fact, be biased. Both of these measures strip away prices for the food and energy categories, which are often thought to offer limited information about future inflation. The answer to this question seems to depend on the timespan considered. Recent research from the Cleveland Fed suggests that average rates of core PCE price inflation and overall PCE price inflation are very close over very long samples (1979-2017).[3] However, over shorter spans, sample averages can diverge substantially; with core PCE price inflation seemingly a downward-biased measure of underlying inflation in some periods (such as from 1995-2007), and an upward-biased measure in others (such as 1980-1985). That said, these shorter spans coincide with extended trends in the relative price of crude oil, which reflect geopolitical events and structural influences that often bear little relation to the stance of monetary policy. Given the presence of these extended price movements, and the large share of energy in the PCE basket (4-5%, in recent decades), we retain the common approach of looking through fluctuations in the food and energy components.

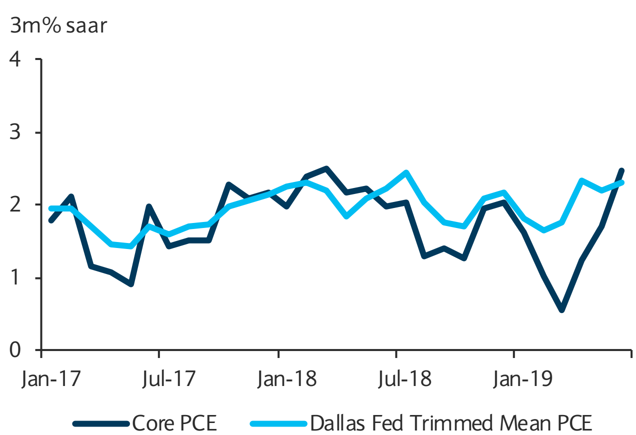
If it's not one thing, it's another: the trimmed mean approach

The idea that overall inflation in any given period is distorted by idiosyncratic movements in some categories has motivated a number of alternative measures of underlying inflation produced by regional Federal Reserve banks. Among these measures are the trimmed mean and trimmed median measures of CPI inflation produced by the Cleveland Fed, the trimmed mean measure of PCE price inflation from the Dallas Fed, and—most recently—the measure of trimmed median PCE price inflation from the Cleveland Fed.

The idea of these measures is to get at underlying inflation by excluding the components of the overall price index with the most extreme price changes in any given month. For the trimmed mean measures, this is accomplished by ordering each of the components in a given month by the rate of change in price relative to the preceding month, and then excluding values in the upper and lower tails. The trimmed median measure is chosen in a similar fashion, except that the upper and lower tails include all but the median observation. This idea is similar to the above discussion of excluding volatile components, except that the procedure is more disciplined in the sense that the volatile components vary each month according to an explicit criterion. For the trimmed mean CPI, the size of the tails to be excluded is informed by goodness-of-fit measures based on their fit to a centred, longer-term average of overall inflation. Historical analyses using these trimmed measures generally show that they perform better as an inflation predictor, in terms of goodness-of-fit.[4]

FIGURE 10

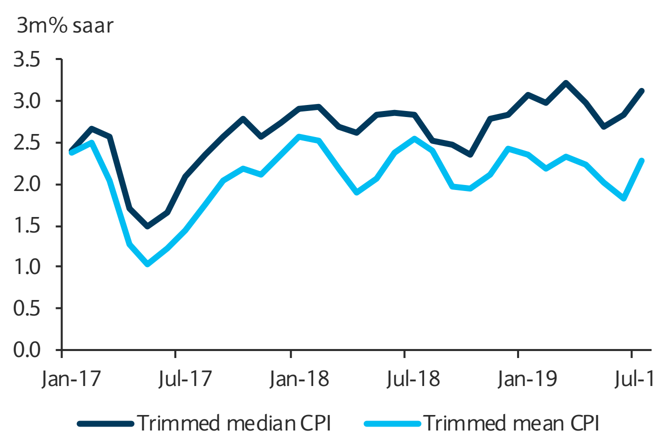
The Dallas Fed trimmed-mean measure of PCE price inflation continues to hover at around 2% saar



Source: Dallas Federal Reserve, BEA, Barclays Research

FIGURE 11

The Cleveland Fed's trimmed mean and median measures of CPI inflation have softened modestly of late



Source: Cleveland Federal Reserve, BLS, Barclays Research

[3] See Daniel Carroll and Randal Verbrugge of the Cleveland Fed, "*Behavior of a New Median PCE Measure: A Tale of Tails*", July 2019

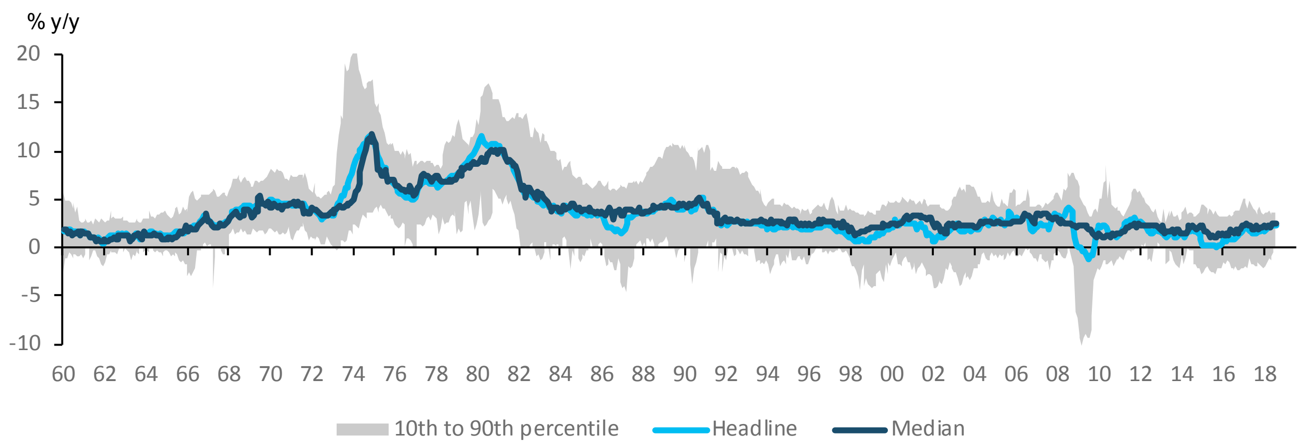
[4] For example, see "*Trimmed-Mean Inflation Statistics: Just Hit the One in the Middle*" by B. Meyer and G. Venkatu, Federal Reserve Bank of Cleveland, Working paper #12-17, 2012.

As we noted earlier, this is a somewhat different conception of underlying inflation than the "trend" concept we have in mind with our underlying inflation gauge. In particular, there is no explicit effort to correct these measures for effects from aggregate fundamentals such as economic slack, or relative import prices. Although the process of trimming does tend to remove some of these cyclical movements, this is not an intent of these measures.

Instead, the motivation behind trimmed measures mainly stems from the fact that the distribution of monthly price changes across expenditure components tends to have "fat tails".[5] In such a situation, it is easy to envision how measures of overall inflation in any given month could be volatile, swinging up and down depending by the preponderance of observations in either tail. Hence, it is easy to see how an estimator that trims away the upper and lower tails might narrow in on the central tendency of the distribution more efficiently. Researchers have found that excluding monthly price changes from both tails helps to eliminate month-to-month volatility, and that these exclusions make measures of central tendency more stable through time.

FIGURE 12

Negative skew in the distribution of monthly inflation across PCE categories poses a challenge for trimmed inflation measures



Source: San Francisco Federal Reserve

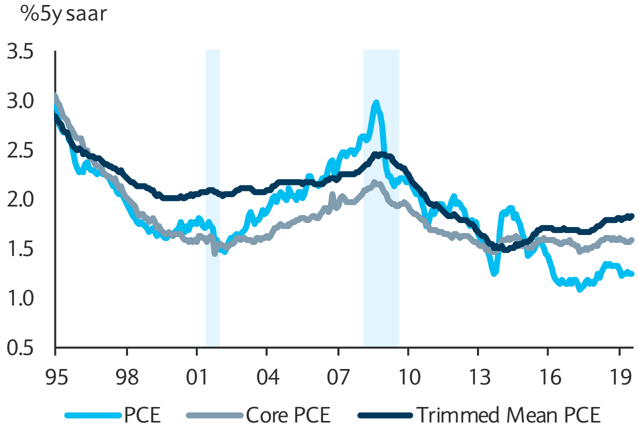
In practice, a key issue with these estimators is the potential for bias in the presence of skewness in the distribution of inflation outcomes. To illustrate, Figure 9 considers a case where the distribution of inflation outcomes across categories has a long tail at its low end. In a case where the lower tail is longer than the upper tail, potential gains from trimming in terms of smoothness would come at the expense of upward bias.[6] As it turns out, this situation seems to describe the monthly distribution of PCE prices across components (Figure 12). Our main takeaways from this representation is that that skewness in the PCE subcomponents does not appear to be stable over time, making it challenging for trimmed mean types of inflation measures to correct for the bias that comes from skewness. In addition, the data seem to have become more skewed recently, suggesting the current signal from trimmed measures of inflation may be less reliable – i.e current trimmed mean measures likely overestimate the underlying measure of inflation. And finally, we notice that the skewness appears to increase during periods of recessions and slowdowns, probably driven by the fact that cyclically-sensitive components will tend to exhibit large swings during these periods.

[5] For discussion, see "*Trimmed mean PCE inflation*" by Jim Dolmas of the Federal Reserve Bank of Dallas, July 25, 2005.

[6] Recent Cleveland Fed research discusses this issue in more detail, showing that monthly PCE inflation outcomes across categories often have negative skew. See Daniel Carroll and Randal Verbrugge of the Cleveland Fed, "*Behavior of a New Median PCE Measure: A Tale of Tails*", July 2019.

FIGURE 13

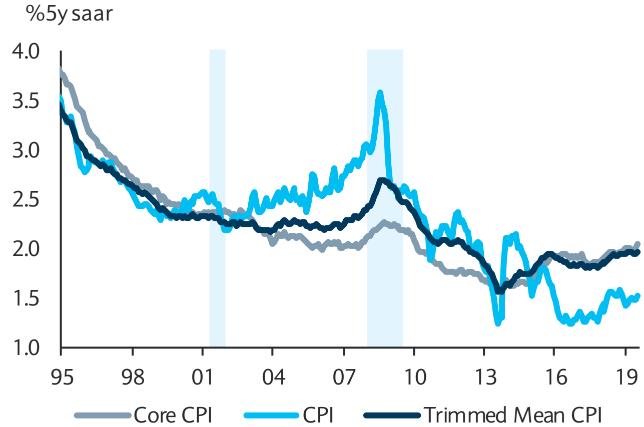
Trimmed PCE price inflation tends to run above PCE price inflation, using longer-term averages



Source: Bureau of Economic Analysis; Dallas Federal Reserve

FIGURE 14

Trimmed CPI inflation currently is in line with core CPI inflation, but well above overall CPI inflation



Source: Bureau of Labor Statistics; Cleveland Federal Reserve

Some trimmed estimators attempt to rectify this situation by trimming the two tails asymmetrically: That is, trimming a little less from the lower tail, and a little more from the upper tail, thereby shifting the sample mean of the estimator so that it lines up over time with that of the overall PCE inflation. For example, the Dallas Trimmed Mean PCE inflation measure applies this technique, trimming off 24% of the lower tail and 31% of the upper tail, with the same trim applied throughout the historical sample. By contrast, the trim used for the Cleveland Fed trimmed-mean CPI is symmetric, removing 8% of the weight from both the upper and lower tails. Naturally, the median CPI also has a symmetric trim.

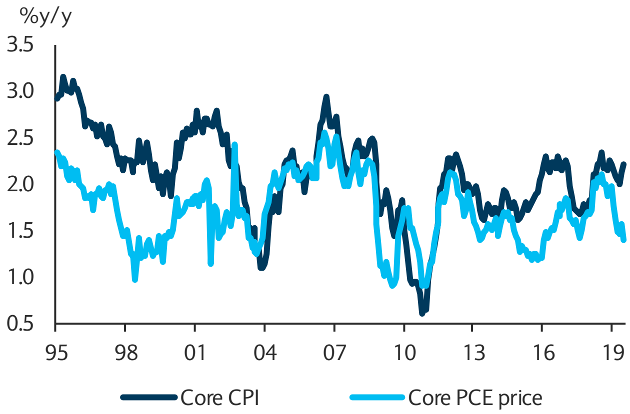
But these techniques would likely prove inadequate if the distribution is becoming negatively skewed over time.[7] Ultimately, the extent of distortions from skew can only be assessed using data. Figure 13 and Figure 14 assess skew by comparing longer-term averages of conventional measures of inflation to the trimmed mean estimators. Figure 13 compares the five-year annualized rates of change in core PCE prices, PCE prices, and the trimmed-mean PCE. As one can see, the longer-term average of trimmed-mean inflation has exceeded PCE, for the most part, since 1995 – the period of relatively anchored US inflation. Apart from a few episodes over this period, the trimmed-mean estimator has consistently exceeded core PCE inflation. In recent years, the shortfall between PCE price inflation and longer-term trimmed mean inflation has been about 0.5pp, while the shortfall for core PCE price inflation has been about 0.2pp. While it is difficult to draw definitive conclusions from a limited time span of data, these gaps are consistent with what we would expect to see if the distribution of PCE price inflation across components was becoming more negatively skewed.

That said, issues with bias do not seem as acute for the trimmed-mean CPI measure. Figure 14 compares the five-year annualized rates of change in the core CPI, headline CPI, and the trimmed-mean CPI. In this case, long-run inflation from the trimmed-mean measure usually tracks between the core and overall CPI measures. In recent years, longer-term inflation according to the trimmed-mean CPI estimator has been running about 40bps above the overall CPI measure, and right on top of the core CPI measure. This might lead some to conclude that the trimmed CPI might be superior to the trimmed-mean PCE as a measure of underlying inflation. If so, then the current level of trimmed mean CPI – around 2% – might

[7] The optimal trim was last revisited in 2009, when the trim was adjusted to put less weight on both tails, but asymmetrically less weight on the right tail.

FIGURE 15

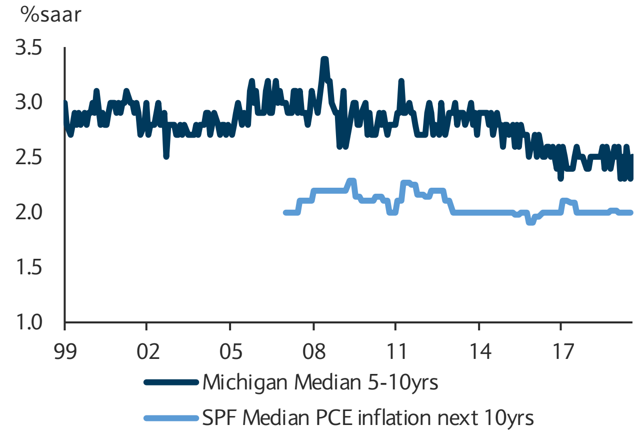
Core CPI inflation nearly always runs above core PCE price inflation



Source: Bureau of Labor Statistics, Bureau of Economic Analysis

FIGURE 16

The Michigan Survey measure of median 5-10 year inflation expectations has edged downward since 2015



Source: Bloomberg, Haver Analytics

already be consistent with the inflation target. This logic would make sense if the goal is to assess underlying inflation for the CPI, but if the object of interest is PCE price inflation – the stated benchmark – then the trimmed mean CPI inflation would need to be well above recent levels to achieve the target. As shown in Figure 15, CPI inflation typically runs above PCE price inflation by about 30-40bps, according to longer-term averages. For this reason, trimmed-mean CPI inflation is an upward-biased measure of the PCE concept of inflation, which matters most to the Fed.

Survey and market-based measures

Underlying inflation can also be assessed by measuring expectations of inflation over an extended time horizon, either directly by way of surveys or indirectly through market-based measures. Since these expectations are for a long time horizon, they are likely less affected by – but not necessary unaffected by – cyclical factors than the core and trimmed measures. There are three broad categories of such measures, each of which provides a somewhat different picture about the underlying level of inflation.

The first category includes measures that survey households directly, most notably the median measure of long-run inflation expectations from the University of Michigan (UM) Survey of Consumers. This measure is formed by telephoning a representative panel of consumers, who are asked, "By about what percent per year do you expect prices [in general] to go (up/down) on the average, during the next 5 to 10 years?". As one can see in Figure 16, the median response to this question varied within a remarkably tight range around 3% y/y from 1999-2014, when it began to edge downward. From 2015 to present, this measure has dropped roughly 0.7pp. However, interpreting this is difficult because the basket of products being evaluated by Michigan respondents is unclear, and likely varies by correspondent and by period. So, for example, the median long-run inflation rate may have declined because survey respondents have gradually internalized the Fed's 2% inflation benchmark (announced in January 2012) when forming expectations. Hence, the slide since 2015 could be akin to measurement error.

The second approach, taken by the Survey of Professional Forecasters (SPF), is to take the central tendency of forecasts from a panel of professional economists. These professionals are likely more informed about the basket of goods being evaluated and about the mechanics of the economy than households. Figure 16 and Figure 17 show available histories for two available SPF measures, one which measures median expected annual changes in the CPI price index over the next ten years, and an analogous measure for the PCE. Unlike the UM measure, both of these measures have remained remarkably close to 2.0% y/y. However, this approach may also pose problems, for a couple of reasons. The first is that forecasters typically write down a "modal" forecast, as opposed to a conditional expectation that weights to all possible outcomes. Hence, the measure can be misleading if the distribution of future inflation outcomes is skewed. Second, such expectations may not be representative: quite a few members of the SPF panel are former staff members of Federal Reserve banks.

A final set of measures are those based on the price that financial markets place on inflation compensation – so-called "breakeven" measures. One is the five-year forward measure of annual inflation compensation over the following five years, which is derived by comparing yields for US government securities with and without inflation protection. As one can see from Figure 17, available data for this measure tend to be more variable than other long-term inflation proxies, and have been persistently lower since around 2015. These fluctuations can also be difficult to interpret, for a few reasons. First, inflation-protected securities from the US Treasury (TIPS) offer compensation for changes in the CPI index, which, for reasons discussed earlier, measures a different basket of goods than the Fed's preferred PCE measure. Second, market-based expectations can be distorted by the premiums that buyers pay to bear inflation risk and liquidity risk, which could lead to a bias that varies over time.

Measures from the Phillips Curve

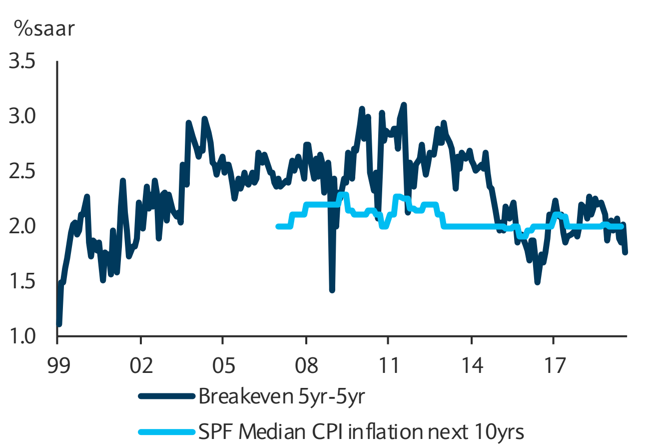
Another method to assess underlying inflation is to use fitted Phillips curves. The advantage of this approach is that it provides a natural framework to cleanse observed inflation from the effects of noise, economic slack and other fundamentals. The disadvantage is that these may be sensitive to specification errors, including the possibility that the relationship between inflation and slack may be changing over time.

Here, we perform a number of simulations that aim to identify the underlying level of inflation after controlling for model fundamentals. We estimate use a Phillips curve specification fitted to core PCE price inflation, with controls for:

- Long-run inflation expectations, which we proxy using the median projection of 5-10 year PCE inflation from the SPF and a fitted constant to account for measurement bias;

FIGURE 17

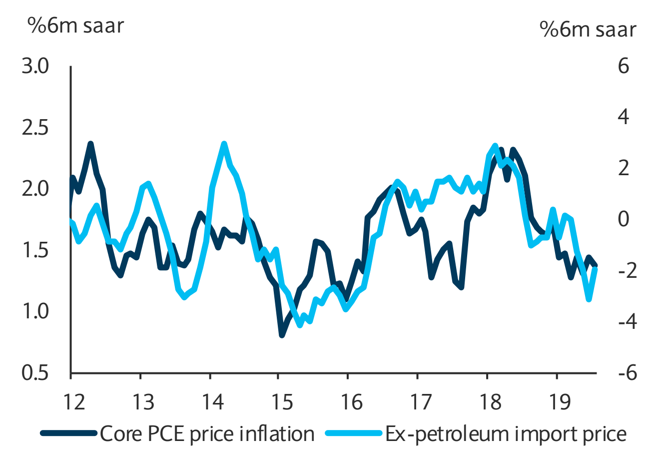
Breakeven inflation measures have been persistently lower since around 2015



Source: Bloomberg, Haver Analytics

FIGURE 18

Declining import prices have contributed to the softness of core PCE inflation this year, much as in 2015-16



Source: Bureau of Labor Statistics, Bureau of Economic Analysis

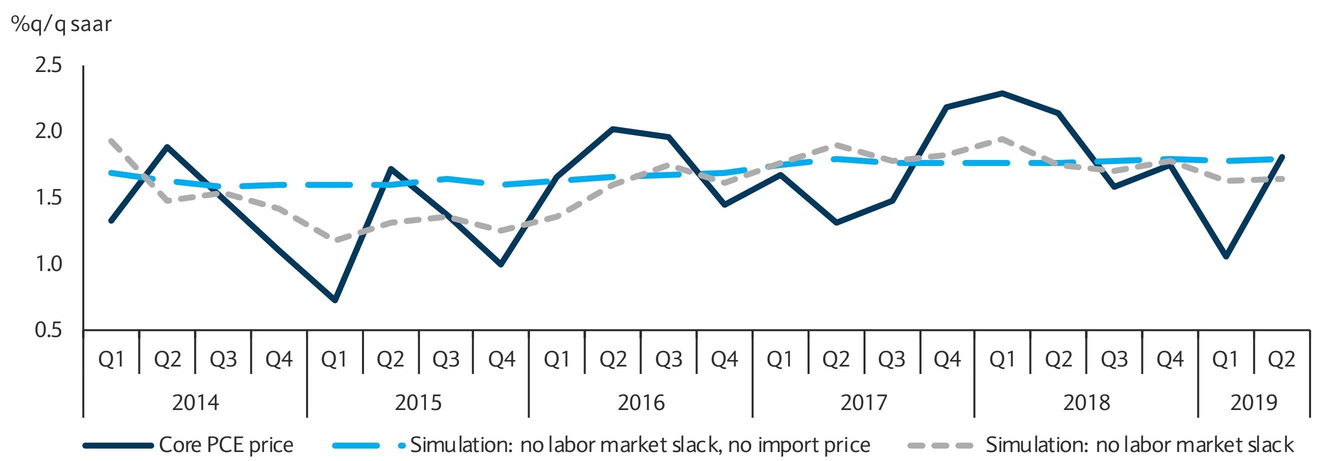
- The unemployment rate gap, measured using the difference between the unemployment rate and the Congressional Budget Office (CBO) estimate of the NAIRU[8]; and
- The rate of change in relative import prices (measured using the Census Bureau's price index for non-petroleum imports), multiplied by the overall share of imports in GDP.[9]

We form our estimate using quarterly data from Q1 1988 to Q2 2019 – a period when the parameters of the Phillips Curve were plausibly stable, in our view. However, results are similar when we adjust the beginning of the sample forward or backward a few years.

A useful byproduct of this Phillips Curve approach is that it helps illuminate the role of import prices in driving trends in US consumer price inflation. According to recent estimates from the San Francisco Fed, imported content accounts for approximately 10.2% of total expenditures in the core PCE category after accounting for direct imports of final consumer goods and content imported through intermediates.[10] Unfortunately, effects from imports are obscured in the official estimates, which do not include a breakdown of how foreign and domestic prices affect overall inflation index. But clearly, the US often inherits disinflation from abroad. As shown in Figure 18, trends in ex-petroleum import prices (denoted by the light blue line) have seemingly weighed on core PCE price inflation (denoted by the dark blue line) in recent years. This influence was evident during the 2015-16 global industrial slowdown (when falling import prices contributed to softness in core PCE price inflation), in 2017-2018 (when strengthened global demand helped push domestic inflation toward the 2% target), and so far in 2019 (as renewed softness in global activity has contributed to domestic disinflationary pressures).

FIGURE 19

Simulations from our fitted Phillips Curve suggest that underlying inflation is running about 10-20bps below the target



Source: Barclays Research

8 We use the version of the NAIRU from the CBO that adjusts for effects from the period of extended unemployment benefits following the global financial crisis.

9 Note that these estimates measure the price of imports as they enter the US, prior to the application of any relevant tariffs.

10 See the *data appendix* for *How much do we spend on imports?*, by Galina Hale, Bart Hobijn, Fernanda Nechio, and Doris Wilson, Federal Reserve Bank of San Francisco Economic Letter 2019-01, January 2019.

The light grey line in Figure 19 shows a simulated path of core PCE price inflation from Q1 2014 onward using the fitted Phillips Curve, assuming a counterfactual scenario where the unemployment rate gap had remained closed, and relative import prices evolve in line with historical averages.[11] According to these estimates, the underlying level of inflation has generally been running between 1.7 and 1.8% y/y since 2013 – about 20-30bps below the SPF measure. This discrepancy is reflected in the constant we included to capture measurement error in the long-run inflation proxy, which subtracts about 17bps from the SPF measure.[12]

As a side note, the simulations verify that relative import prices have played an important role in determining the recent trajectory of domestic inflation. According to the estimates, relative import prices subtracted about 30bps from domestic inflation in 2015 on a Q4/Q4 basis, had a roughly neutral effect from 2016-2018, and reduced inflation by about 15bps, on average, in H1 2019. When assessing these effects, it is important to keep in mind that these estimates will not account for effects of recent increases in US tariffs, as the import price index is measured prior to payment of these levies by domestic importers.

In addition to possible instability in the Phillips Curve, a notable drawback of this Phillips Curve approach is that the simulation of underlying inflation will closely match the contour of the inflation proxy, with level adjustments. Unlike our unified approach, this measure also does not weigh alternative measures of long-run inflation expectations, which tend to vary more over time than the SPF measure. Hence, we may be neglecting potentially important information about the Fed's credibility, asymmetries in the distribution of future inflation outcomes, and other influences.

Unified approach: the Barclays Underlying Inflation Gauge

Rather than attempting to get at underlying inflation by directly excluding information about volatile components, our approach regards underlying inflation as an unknown ("state") variable, and attempts to extract information from available signals. The benefit of this approach is that it weighs information from a multitude of sources, and, hopefully, sidesteps issues with bias that can arise with approaches that exclude inflation components (including trimmed measures).

The trajectory of the unobserved state variables is estimated using a Kalman Filter technique. In broad terms, the idea of the Filter is to draw information about how unobserved state variables are evolving over time using signals from a set of observed variables. Signals are chosen that – according to common sense or theoretical consideration – should be affected by the unobserved variables, with allowance for additional effects from observed variables ("controls") and from unobserved random disturbances. The estimation basically works from some broad specification for how the state variables will evolve through time (such as a random walk), and then refines this estimate using information from the various signals.

As signals of underlying inflation, we draw information from the measures of long-term inflation expectations and from the Phillips Curve. For long-term inflation expectations, we include measures for both CPI and PCE inflation, specifically:

- The median SPF ten-year inflation measures for both CPI and PCE price inflation,
- the 5-to-10 year median expectation from the Michigan survey,

[11] We perform this simulation by having inflation follow the dynamic path implied by the estimated Phillips Curve model, with all other model variables taking the values assumed under the counterfactual. For the relative import price term, we assume that the rate of change in nominal import prices is equal to its average from Q1 1988-Q4 2013. This rate of increase is slower than core PCE inflation, in part because imports are weighted more heavily towards goods – whose relative prices tend to decrease over time.

[12] The fitted constant is estimated at -17bps, with a 90% confidence interval of (-37bps, 3bps).

- and the forward-looking 5-10 year breakeven measure discussed earlier.[13]

We also draw information from Phillips Curves, including separate signals from both (1) core CPI and (2) core PCE inflation. The Phillips Curve is constructed as in the anchored specification above, with the proxy of long-run inflation replaced by the unknown state variable. Hence, any signal that the model extracts about underlying inflation from observed CPI or PCE inflation estimates should be cleansed of effects from included fundamentals such as slack and relative import prices. Appendix B outlines this specification in detail.

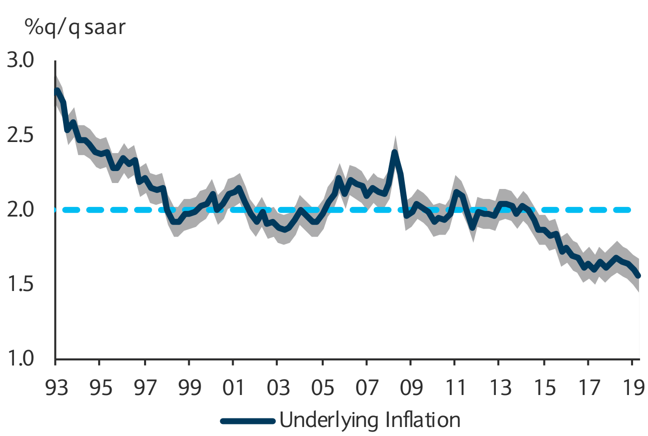
We apply our filter to available quarterly data for each of our signal variables using available data from Q1 1988 through Q2 2019. As with the previously discussed Phillips Curve estimates, our results are qualitatively similar when we adjust the beginning of the sample forward or backward a few years. One notable feature of the Kalman Filter is that it can still be applied when data for the signals is not available for the entire sample. We exploit this property for our estimates, as data availability is sporadic for many of the measures of long-run inflation expectations. In particular, even though estimates for the SPF measure for CPI inflation span the period from Q4 1979 to Q2 2019, data are patchy from Q4 1979 to Q1 1991. Similarly, even though some readings of Michigan inflation expectations are available as far back as Q1 1981, there are lengthy gaps until Q2 1990. Meanwhile, data for the other two measures have relatively limited timespans: the market-based measures of breakeven inflation only begin in Q1 1999, while the SPF series for PCE inflation begins in Q1 2007. Data for all other observed system variables are available throughout the estimation period.

Baseline specification

Our baseline estimates of underlying PCE price inflation are from a system that treats the natural rate of unemployment as given, using the latest available estimates from the CBO. Estimates from this baseline specification are shown in Figure 20, with a 95% confidence interval.[14] Our model's estimates of underlying CPI price inflation (not shown) would be 0.4pp above these estimates. As one can see, our model estimates that underlying PCE inflation was a fair bit above 2% until the mid-90s, when it stabilized in a narrow range

FIGURE 20

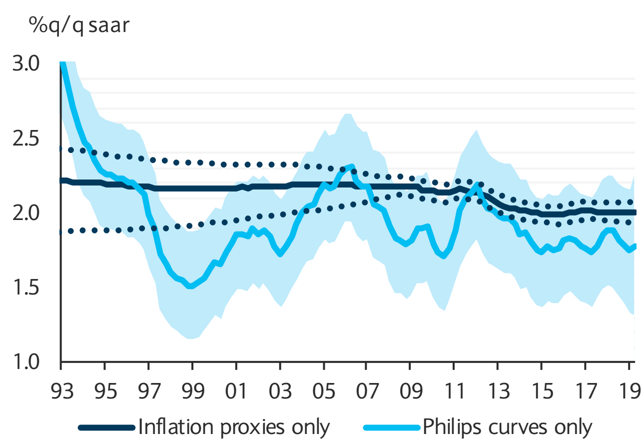
Our baseline specification estimates that underlying PCE price inflation has slipped 30-40bps below 2% since 2015



Note: Smoothed estimates; 95% confidence interval is shaded. Source: Barclays Research

FIGURE 21

The post-2015 drop in underlying inflation is informed by both groups of signals



Note: Smoothed estimates; dashed lines and shaded areas indicate 95% confidence interval. Source: Barclays Research

[13] We include shift factors that adjust for long-term differences in the levels of core CPI and core PCE price inflation, and for the lack of clarity about the concept of inflation measured by the Michigan survey measure.
[14] A table with the estimated coefficients from this model is shown in Appendix B.

around 2%. It remained in the vicinity of 2% until around 2014, when it began to slip below the target. Since the time that the Fed initiated its tightening cycle at end-2015, our measure has been persistently running 30-40bps below the 2% target. Unlike observed PCE prices, our measure shows little or no sign of an acceleration in 2018, suggesting that firming import prices and other transitory factors explained much of the runup last year. By the first half of 2019, our model's estimate was at about 1.6% y/y – at the low end of its post-2015 range.

The persistent shortfall in recent years between our estimate of underlying PCE inflation and the target reflects the fact that measured inflation has shown no appreciable pickup as slack in the labor market has diminished. This is a challenge to the usual relationship between slack and inflation embedded in the Phillips Curve, which suggests that inflation should currently be running above 2% if long-run inflation expectations were anchored at the target. The model also cannot reconcile this discrepancy using relative import prices, which show no consistent post-2015 pattern (Figure 18). Mechanically, the model squares the circle by marking down its estimate of underlying inflation.

Figure 21 illustrates about how the model uses information from the various signals to refine its estimate. The dark line in the figure shows estimates from a specification that includes only the four proxies of long-run inflation as signals, while the grey line shows estimates using signals from only the two Phillips Curves. The estimate using the proxies persistently runs at around 2.2% until about 2014, when it drops to about 2%. However, the confidence interval behind this estimate is relatively wide until around 2007 because the model has difficulty pinning down the long-run difference between the levels of PCE and CPI inflation using the available signals. The confidence interval narrows substantially in 2007, when the model gains a signal from the SPF measure of long-run PCE price inflation.[15] With this new signal in hand, the model places higher confidence on its estimate, including the drop in expectations around 2014. Meanwhile, the specification using the Phillips Curves infers that underlying inflation has generally run below 2% from the mid-1990s onward, but with a wide confidence interval. When these two groups of signals are combined, there is a clear tension between the signals about underlying inflation from the Phillips Curve (volatile, and generally below 2%) and signals from the proxies of expected inflation (smooth, and generally above 2%). The model reconciles this tension by putting weight on both signals, resulting in the relatively smooth set of estimates shown in Figure 20, which lie somewhere between those in Figure 21. This weighting implies, unambiguously, that underlying inflation dropped over the course of 2015, consistent with information from both sets of signals.

Specification with the natural rate of unemployment

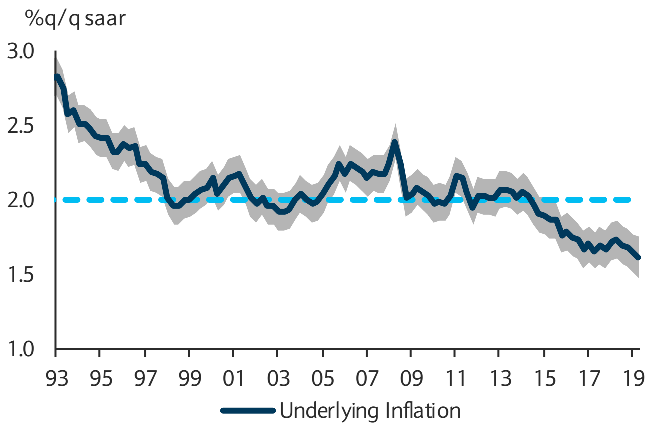
Because our baseline specification takes the path of the natural rate of unemployment as given, it does not allow for the possibility that our proxy for this variable from the CBO is mis-measured. If this is the case, the model may be unduly affected by the CBO estimate, which rules out the possibility that soft inflation is explained by favourable supply developments that have driven down the natural rate (such as the effect on work incentives of the lower income taxes in the 2017 Tax Cuts and Jobs Act).

To allow for such a possibility, we re-estimate our model with the natural rate of unemployment treated as an unobserved state variable. Estimates using this specification are shown in Figure 22 and Figure 23. As one can see from Figure 22, this change in specification does not materially affect the time series of underlying inflation estimates, which, as before, are estimated with a very narrow confidence interval. By contrast, Figure 23 shows that the filter has difficulty pinning down the natural rate of unemployment with

[15] The drop in the estimate of underlying inflation in 2014 is not driven solely by the slide in long-run expectations from Michigan survey; we obtain similar results when we exclude the Michigan measure from the set of signals.

FIGURE 22

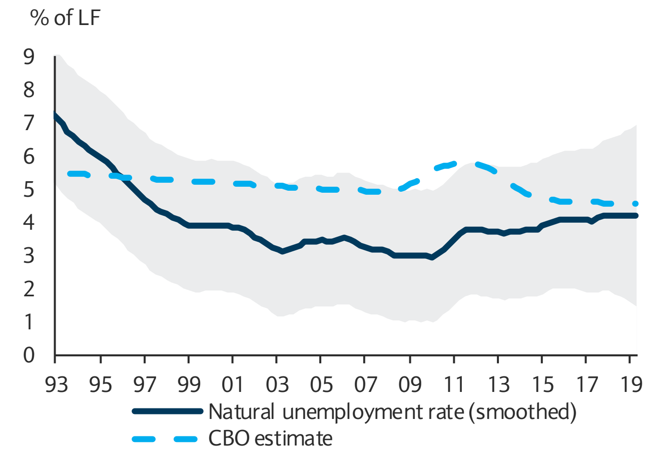
The estimate of underlying PCE price inflation is little affected when we also treat the NAIRU as unobserved…



Note: Estimates use two-sided filter. Source: Barclays Research

FIGURE 23

… even though our model is unable to locate the natural rate of unemployment with much precision



Note: Estimates use two-sided filter. Source: Barclays Research

much precision: the point estimates are largely flat from the mid-1990s onward, with wide confidence intervals that nearly always encompass the CBO estimate. As is the case with any estimate of the natural rate using Phillips Curves, the lack of precision reflects the small coefficient on the measure of the unemployment rate gap, which has the effect of expanding the range of plausible gaps that can be reconciled with a given range of inflation. Despite this lack of precision, there is no indication from these estimates that supply developments help explain the recent softening of inflation; if anything, the estimates indicate that the natural rate has edged up in recent years.

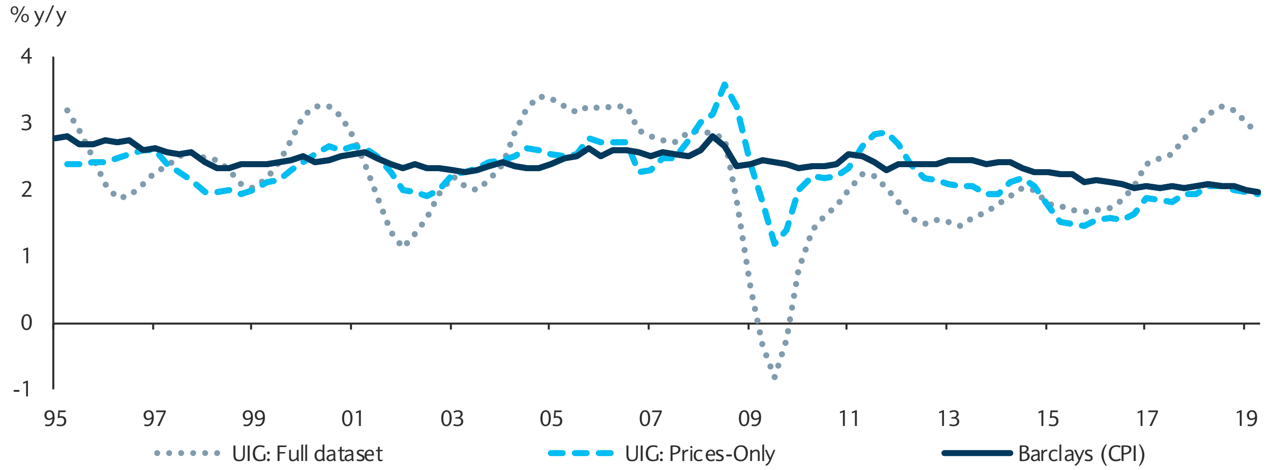
Comparison with the New York Fed's Underlying Inflation Gauge (UIG)

The New York Fed's UIG is formed using a factor model approach that extracts information from a large set of financial and economic variables. The UIG includes two estimates that use different datasets. The first is a "prices-only" measure that includes CPI detail, import and export prices, and the trimmed-mean PCE. The second "full data set" measure augments the dataset with aggregate monthly data and indicators for real activity, various financials, and the money stock.

Figure 24 compares paths of underlying CPI inflation from our model and from the UIG. One takeaway from this chart is that our estimates are much more stable than the estimates from the New York Fed, which seem to be much more susceptible to fluctuations from cyclical influences and other factors. This reflects differences in what each indicator is attempting to measure: In our view, the UIG focuses on forecasting movements in inflation that will arise within the next few years, while our measure narrows in on where inflation is likely to settle when the economy returns to full employment. Both types of information are no doubt useful, but we believe that our measure better captures the concept of inflation that the Fed's forward-looking policy framework is best equipped to address.

FIGURE 24

Our underlying inflation gauge is less prone to transitory fluctuations than the two versions of the New York Fed's UIG



Note: The Barclays gauge is adjusted to include a model coefficient that adjusts for the difference between CPI and PCE price inflation; the UIG is converted from monthly to quarterly by forming an implied monthly index, then taking the quarterly average; Source: Barclays, New York Federal Reserve

Discussion

We think that our underlying inflation measure helps cut through the haze from available indicators. Our indicator tells a clear story about US underlying inflation, which is estimated to have hovered close to 2% from the mid-to-late 1990s until around 2015. Our estimates suggest that underlying inflation moved to a lower trajectory over the course of 2015 – a period when lift-off from the zero lower bound was being widely discussed – and later implemented (in December 2015). The lower trajectory of underlying inflation since then could indicate that the FOMC's decision to initiate a hiking cycle, with inflation still a fair bit below 2%, may have undermined the credibility of its 2% target. More specifically, the move possibly signalled to markets the difficulty, in practice, of the FOMC following through on future promises to hold rates "lower for longer" to stimulate the economy when the policy rate has hit the zero lower bound. If this is the case, long-run inflation expectations would adjust to account for the likelihood of extended periods with inflation running below target.

Putting this interpretation issue aside, our estimates underscore the policy dilemmas currently facing the Federal Reserve. Our model suggests that underlying inflation will generally run about 30-40bps below the target when the economy is at full employment. If this is the case, to reach its target when the economy is in expansion, the Fed would need to consistently adopt an easier policy stance than otherwise, running the economy "hot" in order to push inflation above its underlying level. Ideally, such an approach would gradually push up underlying inflation to levels consistent with the 2% target, so that the FOMC can normalize policy. But the Fed would require credibility to pull this off, and the process may pose risks. One risk is that inflation expectations become unanchored – especially if the Fed succumbs to political pressures to sustain tight labor market conditions even after inflation expectations have risen to desired levels. Above-trend activity during the transition period could also lead to an accumulation of financial excesses, raising the danger of deeper and more prolonged downturns. Such financial stability risks are especially salient given the proximity of the effective lower bound for the policy rate, which likely limits the Fed's ability to resuscitate the economy in such a scenario. The FOMC will need to weigh these risks as it weights its policy options going forward.[16]

[16] Our economics team discusses these policy tradeoffs in much more detail in our 2019 Equity Gilt Study piece, *Beyond Inflation Targeting: Reconsidering tools, targets and theories*, April 2019.

Appendix A: An example of bias from exclusion

To illustrate this idea, consider a simple example where the overall PCE bundle is composed of two goods, good X and good Y. Let π_t denote the rate of inflation in the overall price index at time t, let π_t^X denote the inflation rate for X and let π_t^Y denote inflation for Y. Assume that good X accounts for a constant share of PCE expenditures s_X, so that good Y accounts for the remaining share $1 - s_X$. Applying a Törnqvist approximation, the overall rate of inflation in any given period will be a weighted average of the inflation rates for X and Y:

1. $$\pi_t = s_X \cdot \pi_t^X + (1 - s_X) \cdot \pi_t^Y.$$

Assume that the inflation rate for X is a constant μ^X plus a mean-zero noise term ε_t^X (which need not have a symmetric distribution):

2. $$\pi_t^X = \mu^X + \varepsilon_t^X,$$

and that inflation rate for Y follows an autoregressive process in which it gradually moves toward a longer-term mean μ^Y, with some mean-zero error term ε_t^Y:

3. $$\pi_t^Y = \alpha \cdot \pi_{t-1}^Y + (1 - \alpha)\mu^Y + \varepsilon_t^Y,$$

where $0 \leq \alpha < 1$. We assume that the two error terms are independent. Given this setup, we can call X the volatile inflation component and Y the persistent inflation component.

Given that inflation for good X has no persistence, current values of π_t^X provide no information about inflation at any positive time horizon *n*:

4. $$E_t \pi_{t+n}^X = \mu^X,$$

whereas current values of inflation for Y provide information about inflation in future periods:

5. $$E_t \pi_{t+n}^Y = (1 - \alpha^n)\mu^Y + \alpha^n \pi_t^Y.$$

For both components, the unconditional expectation of each component of inflation is equal to its mean; that is, $E[\pi_{t+n}^X] = \mu^Y$ and $E[\pi_{t+n}^Y] = \mu^Y$.

Using the Törnqvist approximation from above, expected inflation at any positive time horizon *n* for the overall PCE bundle is:

6. $$E_t \pi_{t+n} = s\mu^X + (1 - s)[(1 - \alpha^n)\mu^Y + \alpha^n \pi_t^Y],$$

which is a linear function of current inflation for the persistent good Y. In the long run as *n* The unconditional expectation $E[\pi_{t+n}]$ is simply $s\mu^X + (1 - s)\mu^Y$. It follows that the best predictor of overall inflation would be from an estimated simple linear regression of the form:

7. $$\pi_{t+n} = a_0 + a_0 \pi_t^Y + e_t,$$

where, in a sufficiently large sample, the estimated coefficients would converge in probability to

$$a_0 = s\mu^X + (1 - s)(1 - \alpha^n)\mu^Y \quad \text{and} \quad a_1 = (1 - s)\alpha^n.$$

From these equations, we make two observations First, since the specification above is the best estimator in this case, it must outperform any linear estimator, including a linear regression of overall inflation on its own lags. Since this estimator will have the smallest mean squared error of all estimators, it follows by definition that the correlation that π_{t+n}

with the persistent component of inflation π_t^Y must be higher than its correlation with current overall inflation π_t^Y.

Second, it does not follow from the previous observation that the current *level* of the inflation for the persistent component π_t^Y is itself a better predictor of overall inflation than the current *level* of overall inflation. This is because, in the absence of adjustments, the level of inflation in the persistent component is generally a *biased* indicator of overall inflation at any time horizon:

8. $$E[\pi_t^Y - \pi_{t+n}] = s(\mu^Y - \mu^X),$$

whereas the current level of overall inflation in this case is an unbiased indicator: $E[\pi_t - \pi_{t+n}] = 0$.[17] To be sure, in this model, the current level of inflation will tend to be a much noisier indicator of future inflation than the persistent component, but it is not obvious that effects of this noise outweigh effects of the bias.

Appendix B: State space model of underlying inflation

In this section, we specify the state-space model used for estimating measures of underlying inflation. Our model consists of equations that relate signals to unobserved state variables and controls, as well as a state-space equation that describe the evolution of unobserved state variable. All variables use quarterly averages, with inflation measured as an annualized rate of change.

Our basic system involves five signal equations. The first signal is drawn from an expectations-augmented Phillips Curve equation for core PCE inflation, constrained such that core PCE inflation will converge to its long-run expected level – provided that both the unemployment rate gap and the gap between import inflation and core PCE inflation is zero. The second signal is from an analogous equation for core CPI inflation. In both equations, we interpret this long-run expected level of inflation as "underlying inflation" for core PCE prices, with a level adjustment in the second Phillips Curve to allow for a long-run divergence between core CPI and core PCE price inflation.

Signals from Phillips Curve:

1. $$\pi_t^{PC} = (1 - b_1 - b_2)\pi_t^* + b_1\pi_{t-1}^{PC} + b_2\pi_{t-2}^{PC} + b_U(u_t - u_t^N) + b_{M1}s_t^M(\pi_t^M - \pi_{t-1,4q}^{PC}) + b_{M2}s_{t-1}^M(\pi_{t-1}^M - \pi_{t-2,4q}^{PC}) + b_e e_t^2 + e_t^1,$$

2. $$\pi_t^{CC} = (1 - c_1 - c_2)(\pi_t^* + \pi^{CC}) + c_1\pi_{t-1}^{CC} + c_2\pi_{t-2}^{CC} + c_U(u_t - u_t^N) + c_M s_t^M(\pi_t^M - \pi_{t-1,4q}^{CC}) + b_{M2}s_{t-1}^M(\pi_{t-1}^M - \pi_{t-2,4q}^{CC}) + e_t^2,$$

where e_t^1 and e_t^2 are uncorrelated mean-zero random disturbances that are serially uncorrelated through time, each with constant variance.[18] Note that the disturbance for core CPI inflation (e_t^2) also appears in the equation for core PCE price inflation because most components of CPI are used as source data for the PCE estimates (and not vice versa). The variable π_t^M is the rate of inflation in non-petroleum import prices from the BLS, s_t^M is the nominal share of non-petroleum imports in overall US GDP, while the measures $\pi_{t-1,4q}^{PC}$ and $\pi_{t-1,4q}^{CC}$ are the four-quarter rates of inflation in core CPI prices and the core CPI. Meanwhile, $u_t - u_t^N$ measures the unemployment rate gap, where u_t is the (U3) unemployment rate from the Household Survey and u_t^N is the natural unemployment rate.

The second set of signals are embedded in measures of long-run inflation expectation from consumer surveys, forecast surveys, and markets. These include the median 5 to 10 year

[17] This equation follows by taking an unconditional expectation of equation (6) using the properties that $E[\pi_{t+n}^Y] = \mu^Y$ and $E[\pi_{t+n}^Y] = \mu^Y$, then rearranging terms.

[18] We experimented with versions of the model where these disturbances were allowed to be serially correlated, and found that allowing this flexibility delivered no qualitative changes to the results.

measure of inflation expectations from the Michigan Consumer Survey ($\pi_t^{M5/10}$), median 10-year ahead expectations of PCE price inflation (π_t^{SPC10}) and CPI inflation (π_t^{SCC10}) from the Survey of Professional forecasters, as well as the breakeven measure of inflation 5-10 years ahead implied by yields on TIPS and treasury bonds ($\pi_t^{BE5/10}$). These signal equations are specified as follows:

3. $\pi_t^{M5/10} = (1 - d_1 - d_2)\pi_t^* + d_1\pi_{t-1}^{M5/10} + d_2\pi_{t-2}^{M5/10} + e_t^3$

4. $\pi_t^{SPC10} = (1 - f_1 - f_2)\pi_t^* + f_1\pi_{t-1}^{SPC10} + f_2\pi_{t-2}^{SPC10} + e_t^4$

5. $\pi_t^{SCC10} = (1 - g_1 - g_2)(\pi_t^* + \pi^{CC}) + g_1\pi_{t-1}^{SCC10} + g_2\pi_{t-2}^{SCC10} + e_t^5$

6. $\pi_t^{BE5/10} = (1 - h_1 - h_2)(\pi_t^* + \pi^{CC}) + h_1\pi_{t-1}^{BE5/10} + h_2\pi_{t-2}^{BE5/10} + e_t^6$,

where the error terms e_t^3, e_t^4, e_t^5 and e_t^6 are mutually independent, serially uncorrelated mean-zero random disturbances, each with constant variance.

All four equations assume a autoregressive functional form in which the measure will converge to underlying inflation in the absence of disturbances. However, the measure can diverge from underlying inflation in any given period when it is hit by measurement errors of other disturbances. In the two cases where the relevant concept is core CPI inflation rather than core PCE price inflation (π_t^{SCC10} and $\pi_t^{BE5/10}$), we adjust underlying inflation by the same level shift factor (π^{CC}) used in the core CPI Phillips Curve in equation (2).

Finally, our system includes a state space equation that describes the evolution of our unknown state variables. In the basic model, this state space includes underlying inflation. We assume that underlying inflation follows a random walk:

TABLE A

State space model results: Baseline Specification

	Signals from Phillips Curve			
	(1)		**(2)**	
Underlying inflation	0.68 (0.118)		0.48 (0.049)	
Lag (-1)	0.25 (0.104)		0.23 (0.067)	
Lag (-2)	0.07		0.29	
Unemployment gap	-0.06 (0.036)		-0.11 (0.028)	
Relative import prices	0.39 (0.079)		0.17 (0.099)	
Relative import prices (-1)	-0.13 (0.089)		-0.13 (0.096)	
	Signals from long run inflation expectations			
	(3)	**(4)**	**(5)**	**(6)**
Underlying inflation	0.84	0.05	0.13	0.25
Lag (-1)	0.08 (0.277)	1.01 (0.145)	0.51 (0.079)	0.64 (0.105)
Lag (-2)	0.08 (0.090)	-0.06 (0.141)	0.36 (0.069)	0.12 (0.091)
	Shift adjustment factors			
	(3)	**(4)**	**(5)**	**(6)**
Michigan inflation gap	0.85 (0.080)	-	-	-
CPI - PCE inflation gap	-	-	0.41 (0.089)	0.41 (0.089)

Source: Barclays Research

7. $\pi_t^* = \pi_{t-1}^* + v_t^1$,

where the disturbance v_t^1 is serially uncorrelated with constant variance, and is independent from any of the other disturbances in the system. In our augmented system that also estimates the natural rate of employment, we include an additional state equation which specifies describes the NAIRU as a random walk:

8. $u_t^N = u_{t-1}^N + v_t^2$,

where v_t^2 is a serially uncorrelated disturbance term that is also independent from any of the other disturbances in the system.

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