A MODEL OF THE FED'S VIEW ON INFLATION

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Abstract—We develop a medium-size semistructural time series model of inflation dynamics that is consistent with the view, often expressed by central banks, that three components are important: a trend anchored by long-run expectations, a Phillips curve, and temporary fluctuations in energy prices. We find that a stable long-term inflation trend and a well-identified steep Phillips curve are consistent with the data, but they imply potential output declining since the new millennium and energy prices affecting headline inflation not only via the Phillips curve but also via an independent expectational channel.

I. Introduction

> Inflation is characterized by an underlying trend that has been essentially constant since the mid-1990s. . . Theory and evidence suggest that this trend is strongly influenced by inflation expectations that, in turn, depend on monetary policy. In particular, the remarkable stability of various measures of expected inflation in recent years presumably represents the fruits of the Federal Reserve's sustained effort since the early 1980s to bring down and stabilize inflation at a low level. The anchoring of inflation expectations . . . does not, however, prevent actual inflation from fluctuating from year to year in response to the temporary influence of movements in energy prices and other disturbances. In addition, inflation will tend to run above or below its underlying trend to the extent that resource utilization—which may serve as an indicator of firms' marginal costs—is persistently high or low.
>
> Janet Yellen (2016)

THE quote by Janet Yellen reflects a view, widely shared by policymakers and central bankers, that maintains that three components matter for inflation dynamics: trend expectations, oil prices, and the degree of resource use in the economy. Similarly, most macroeconomic modeling is based on these three core ideas: some measure of slack affects short-term fluctuations of inflation via a Phillips curve; monetary policy, via expectations, shapes its long-run trend; and oil price and other idiosyncratic shocks explain the volatile component of headline inflation. While models that incorporate these ideas use a variety of auxiliary assumptions (e.g., on the nature of expectations, the functional form of key equations, and the channels of propagation of the shocks), these three components remain the building blocks of a shared narrative. In this paper, we call this broadly and loosely defined understanding of inflation dynamics the "Fed's view."

Recent empirical evidence has challenged this view. Indeed, the literature presents a wide range of contrasting findings, including on the existence, stability, and steepness of the slope of the Phillips curve and regarding the degree of anchoring of inflation expectations.[1] First, many studies have found the Phillips curve to be unstable, hard to identify, and weak or disappearing in recent samples (see results and discussions in IMF, 2013; Ball & Mazumder, 2011; Blanchard, Cerutti, & Summers, 2015; and McLeay & Tenreyro, 2018). Second, Phillips curve-based forecasting models have been shown to perform poorly with respect to naive benchmarks, pointing to the irrelevance of slack measures for explaining inflation dynamics (see Atkeson & Ohanian, 2001; Stock & Watson, 2007, 2009; Dotsey, Fujita, & Stark, 2011; Cecchetti et al., 2017; and Forbes, Kirkham, & Theodoridis, 2018, for recent evidence and relevant discussion). Third, a small but increasingly important literature has challenged the idea that expectations are fully anchored and forward looking. For example, papers have connected the "missing disinflation puzzle" of the post-2008 crisis period to the partial disanchoring of consumers' inflation expectations that in turn can be accounted for by the evolution of oil prices (see Coibion & Gorodnichenko, 2015, and Coibion, Gorodnichenko, & Kamdar, 2017).

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[1] A survey of the extensive empirical literature on the PC is beyond the scope of this paper. For a recent survey of the New Keynesian Phillips curve focusing on univariate limited-information methods, see Mavroeidis, Plagborg-Møller, and Stock (2014). For a review of results using full-information methods to estimate dynamic stochastic general equilibrium (DSGE) models, see An and Schorfheide (2007). Nakamura and Steinsson (2013) review the use of microeconomic data to study price dynamics. Coibion et al. (2017) discuss the incorporation of survey data on inflation expectations in models of inflation dynamics. Other surveys, providing complementary approaches, include Henry and Pagan (2004), Ólafsson (2006), Rudd and Whelan (2007), Nason and Smith (2008), Gordon (2011), and Tsoukis, Kapetanios, and Pearlman (2011).

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This paper revisits some of the evidence on the reduced-form Phillips curve, in the spirit of Phillips (1958), by assessing the Fed's view of inflation dynamics through the lens of a stylized statistical model that is informed by economic theory and incorporates economic expectations while allowing for deviations from perfect information and full rationality. Our modeling strategy can be defined as semistructural since it incorporates minimal identifying assumptions from a general class of economic models but lets the data speak on key aspects, such as expectation formation, the nature of the Phillips curve, and the role of oil prices. In this sense it occupies the middle ground between a fully specified dynamic stochastic general equilibrium (DSGE) model and a vector autoregressive (VAR) model.

Our specification in reduced form is compatible with and nests several potentially different forward- and backward-looking structural Phillips curve models, including the standard New Keynesian Phillips curve (NKPC), in which inflation is a purely forward-looking process, driven by expectations of future real economic activity. Moreover, the model allows survey data on agents' expectations on inflation to depart from the full-information rational expectations benchmark without imposing any specific form of information frictions. We do not require either of the two surveys to be an efficient and unbiased predictor of future inflation and allow for temporary and permanent deviations from a rational forecast, potentially capturing measurement and observational errors, as well as a time-dependent bias in inflation expectations.

A key feature of the approach is the modeling of oil prices and the different channels through which energy prices can affect inflation. One way is through production marginal costs and the Phillips curve: oil prices can affect the business cycle component and hence codetermine the output gap.[2] Furthermore, in the model, oil disturbances can affect headline prices directly via energy services, which are part of the consumption basket, but also potentially via expectation formation, in line with the findings of Coibion and Gorodnichenko (2015). These two channels are captured by studying the differential impact of a second cycle, which we label the energy price cycle, on headline and core inflation. The cycle captures the potential common dynamics of oil prices, inflation expectations, and inflation, but it does not affect the domestic output gap and the real variables.[3]

Inflation is modeled as being driven by three components: (a) long-term inflation expectations; (b) a stationary stochastic cycle, which captures multivariate and lagged commonalities in real, nominal (including energy prices); and labor market variables at business cycle frequencies, with this cycle connecting the output gap to prices and their expectations via a Phillips curve relationship and to unemployment via Okun's law; and (c) a stationary stochastic cycle capturing the common dynamics of oil prices, inflation expectations, and CPI inflation but not affecting real variables. The model also identifies other key economic objects such as output potential, trend employment, and equilibrium unemployment, in the form of unit root trends.

Results suggest that the Phillips curve is alive and well and has been fairly stable since the early 1980s.[4] Importantly, our cycle decomposition shows that the business cycle is not always the dominant component. Large oil price fluctuations can move prices away from the real-nominal relationship by direct impaction energy services prices and by shifting consumers' expectations away from the rational forecast ("disanchoring" them), and hence inducing expectation-driven fluctuations in prices. This result confirms the intuition of Coibion and Gorodnichenko (2015). We provide confirmation of the importance of using expectational data to identify both trend inflation and the Phillips curve while dealing with disturbances to expectations that, albeit reflected in inflation, are unrelated to real variables and fundamentals. From a policy perspective, the stable inflation trend is an indication of the Fed's success in anchoring expectations. However, our results also point to the challenges that policymakers have to overcome in guiding expectations and stabilizing the economy in the presence of large energy price disturbances.

There are several by-products of our analysis: we obtain a model-consistent estimate of the output gap and potential output; we also assess the stability of Okun's law and the quality of core inflation as an indicator of underlying inflation. Indeed, our approach generates an indicator of cyclical inflation that is clean not only from the direct effect of oil prices, as is the case for core inflation, but also from their indirect effects.

The paper starts with a brief discussion of our methodology and related literature in the remainder of this section. In section II we introduce a stylized model of inflation dynamics that provides the intuition for our approach. In sections III and IV, we specify the empirical model, while in sections V and VI, we discuss empirical results. The last section concludes. The online appendix provides details on the Bayesian estimation of the model, an out-of-sample forecasting evaluation, additional results, and color charts for all of the models discussed in the paper.

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[2] A large and important literature has analyzed the connection between demand and supply oil shocks and the business cycles (Baumeister & Kilian, 2016; Hamilton, 2013; Kilian & Vigfusson, 2017).

[3] Our assumption of an energy price cycle orthogonal to the business cycle and not affecting the real variables should not be seen as literally present in the data structure. It is a convenient statistical device that helps tease out components in the price dynamics at higher frequencies than those of the standard business cycle and that can have weak or negligible impact on the U.S. output gap and labor market.

In an extension of the model that includes proxies of global economic activity, we analyze whether the energy price cycle reflects global demand and the commodity price cycle. Our results suggest that the energy price cycle is associated with oil supply shocks and financial shocks in the commodity markets rather than global demand.

[4] While we observe that a fixed parameter model is able to capture a stable Phillips curve from the 1980s, it is possible that time variation in the parameters or stochastic volatility may be important over a longer sample (see Stock & Watson, 2007; Mertens & Nason, 2017). We do not explore this possibility in this paper. Indeed, estimation uncertainty is likely to obfuscate all gains coming from a more sophisticated model.

A. *Contribution and Related Literature*

From the statistical point of view, the model has a number of attractive features: it does not rely on arbitrary preliminary detrending of the data, which may create distortions; it contains a rich lag structure allowing us to capture dynamic heterogeneity among variables; it allows us to perform conjunctural analysis and historical decompositions of variables into cyclical and trend components; and it is sufficiently efficient and parsimonious to be used as a forecasting tool. The unit root trend common to inflation and inflation forecasts can be related to agents' long-term expectations, under the assumption that the law of iterated expectations holds (see Beveridge & Nelson, 1981, and Mertens, 2016). In fact, the impact of all transitory components has to be zero in the long run.[5]

Our econometric representation is general in the sense described but has a structure that is motivated by the objective of parsimony. Indeed, our model can be understood as a restricted VAR model where, by adopting minimal economic restrictions to identify the potentially different dynamic components of inflation, we induce "informed" parsimony, thereby helping with signal extraction and forecasting. The proposed decomposition leads to a rather complex state-space form. In order to deal with this complexity, we estimate the model using Bayesian methods. A Bayesian approach in the context of a similar but simpler model has been proposed by Planas, Rossi, and Fiorentini (2008), who implement a Bayesian version of the work of Kuttner (1994), by Grant and Chan (2017), who propose a Bayesian model comparison focusing on trend-cycle decompositions of output and, more recently, by Lenza and Jarociński (2016). The latter paper is the closest to our work but focuses on estimating measures of the output gap in the euro area rather than on providing a decomposition that can be used for studying the drivers of inflation dynamics. Our paper also shares a similar approach and methodology with Del Negro et al. (2017), who employ a flexible VAR model that incorporates long-term survey expectations, to estimate common trends and study the natural rate of interest in the United States.

Our work builds on the tradition of structural time series models (see Harvey, 1985), where observed time series are modeled as the sum of unobserved components: common and idiosyncratic trends, and cycles. In doing this, and by focusing on inflation dynamics, this paper relates to the literature on the output gap, the Phillips curve, and trend inflation estimation with unobserved components models, started by Kuttner (1994). Similar to Baştürk et al. (2014) and Lenza and Jarociński (2016), we do not prefilter data to stationarity but model their low-frequency behavior by allowing for trends. As in Gordon (1982) and Basistha and Startz (2008), we use multiple real activity indicators to increase the reliability of the output gap estimates. Also, our work relates to a number of papers that have studied trend inflation in unobserved component models augmented with data on medium- to long-term inflation expectations, as, for example, Clark and Doh (2014), and Mertens (2016).

II. A Stylized Model for Inflation Dynamics

At the core of our empirical approach lies a stylized full information rational expectations model for inflation and output. In this section we discuss the intuition and basic building blocks. We assume that inflation and output can be decomposed into three components: (a) independent trends determining output potential μ_t^y and trend inflation μ_t^π, (b) a common stationary cycle relating nominal and real variables (the output cycle is interpreted as the output gap) $\widehat{\psi}_t$, and (c) some independent (white noise) disturbances to output and inflation, ψ_t^y and ψ_t^π, that can be thought of as classic measurement error or idiosyncratic shocks. We have

$$y_t = \mu_t^y + \widehat{\psi}_t + \psi_t^y, \tag{1}$$

$$\pi_t = \mu_t^\pi + \delta_\pi \widehat{\psi}_t + \psi_t^\pi, \tag{2}$$

where the independent trends are assumed to be unit-root processes (with a drift in output):

$$\mu_t^y = \mu_0 + \mu_{t-1}^y + u_t^y, \tag{3}$$

$$\mu_t^\pi = \mu_{t-1}^\pi + u_t^\pi. \tag{4}$$

The economic interpretation of the different trend and cycle components is standard (see, for example the discussion in Yellen, 2015). The output trend (the output potential, capturing the long-term growth of the economy) is usually thought of as driven by technological innovation. Inflation fluctuates around a longer-term trend that at least in recent times, has been essentially stable. Theory relates this trend inflation to inflation expectations that, in turn are shaped by the conduct of monetary policy—for example, by policymakers' targets. Shocks of a different nature can have an impact on marginal production costs and modify the intensity of resource utilization in the economy, temporarily pushing output away from its balanced growth path. The shortfall of actual GDP from potential output is the output gap $\widehat{\psi}_t$. The slack in the economy is reflected in the short-run cyclical fluctuations of inflation around its trend, in the presence of price rigidity. This relationship is generally described by an expectations-augmented Phillips curve in theoretical models. Finally, a nontrivial fraction of the quarter-to-quarter variability of inflation and output is attributable to independent and idiosyncratic shocks.

In line with the econometric literature on the output gap, we assume that $\widehat{\psi}_t$ is a stationary process with stochastic cyclical behavior. The simplest process allowing for such a

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[5] A discussion on the conditions under which survey data can be employed to study the PC is in Adam and Padula (2011).

stochastic cycle is an AR(2) process with complex roots of the form

$$\widehat{\psi}_t = \alpha_1 \widehat{\psi}_{t-1} + \alpha_2 \widehat{\psi}_{t-2} + \upsilon_t. \tag{5}$$

Indeed, the AR(2) model can be written in a different and slightly more general form, displaying its pseudo-cyclical behavior more clearly,

$$\begin{aligned} \widehat{\psi}_t &= \rho\cos(\lambda)\widehat{\psi}_{t-1} + \rho\sin(\lambda)\widehat{\psi}^*_{t-1} + \upsilon_t, \\ \widehat{\psi}^*_t &= -\rho\sin(\lambda)\widehat{\psi}_{t-1} + \rho\cos(\lambda)\widehat{\psi}^*_{t-1} + \upsilon^*_t, \end{aligned} \tag{6}$$

where the parameters $0 \leq \lambda \leq \pi$ and $0 \leq \rho \leq 1$ can be interpreted, respectively, as the frequency of the cycle and the damping factor on the amplitude while $\widehat{\psi}^*_t$ is a modeling auxiliary cycle and υ_t and υ^*_t are uncorrelated white noise disturbances (see Harvey, 1990).[6] The disturbances make the cycle stochastic rather than deterministic, and if $\rho < 1$, the process is stationary.

By assuming an output gap that is a stationary solution to an AR(2) process, the model in equations (1) and (2) admits a hybrid expectations-augmented New Keynesian Phillips curve connecting the cyclical components of output, inflation, and inflation expectations of the form

$$\widehat{\pi}_t = \sum_{i=1}^{2} \delta_i \widehat{\pi}_{t-i} + \beta \mathbb{E}_t \left[\widehat{\pi}_{t+1}\right] + \kappa \widehat{y}_t + \varepsilon_t, \tag{7}$$

where hats indicate deviations from trends.[7] In this model, rational expectations agents correctly form model-consistent expectations about inflation, that is,

$$\begin{aligned} \mathbb{E}_t\left[\pi_{t+1}\right] &= \mathbb{E}_t\left[\mu^{\pi}_{t+1} + \delta_\pi \widehat{\psi}_{t+1} + \psi^{\pi}_{t+1}\right] \\ &= \mu^{\pi}_t + \delta_\pi(\alpha_1 \widehat{\psi}_t + \alpha_2 \widehat{\psi}_{t-1}) \\ &= \mu^{\pi}_t + \delta_{exp,1} \widehat{\psi}_t + \delta_{exp,2} \widehat{\psi}_{t-1}. \end{aligned}$$

The model can be written, in a compact reduced-form representation in terms of the common cycle, the trend common to inflation and inflation expectations, and the trend capturing output potential (as well as the idiosyncratic disturbances):

$$\begin{pmatrix} y_t \\ \pi_t \\ \mathbb{E}_t\left[\pi_{t+1}\right] \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \delta_\pi & 1 \\ \delta_{exp,1} + \delta_{exp,2}L & 1 \end{pmatrix} \begin{pmatrix} \widehat{\psi}_t \\ \mu^{\pi}_t \end{pmatrix} + \begin{pmatrix} \mu^{y}_t \\ 0 \\ 0 \end{pmatrix} + \begin{pmatrix} \psi^{y}_t \\ \psi^{\pi}_t \\ 0 \end{pmatrix}. \tag{8}$$

In principle, this simple set of equations can also accommodate different specifications for the Phillips curve under suitable parameter restrictions. For example, an AR(1) $\widehat{\psi}_t$ would be the solution to a purely forward-looking New Keynesian Phillips curve. It also nests the backward-looking "Old-Keynesian" Phillips curve connecting output gap and prices, as in the triangle model of inflation (see Gordon, 1982, 1990).

Also, in line with the interpretation proposed, it is worth noting that trend inflation corresponds to the long-run forecast for inflation, which implies

$$\lim_{h\to\infty} \mathbb{E}_t[\pi_{t+h}] = \mu^{\pi}_t, \tag{9}$$

in the spirit of Beveridge and Nelson (1981) and that trend output informs expectations of growth in the long run:

$$\lim_{h\to\infty} \mathbb{E}_t[y_{t+h}] = \lim_{h\to\infty} \{\mu_0 h + \mu^{y}_t\}. \tag{10}$$

While such a stylized rational expectations model can provide the gist of the intuition for our econometric model, it is likely to be too simple as an empirical representation of business cycle dynamics.[8] First, it does not allow for dynamic heterogeneity, and hence nominal and real variables fluctuate only as contemporaneously connected by the slack in the economy, in contrast with the evidence that prices and labor market variables respond with lags to the slack in production. In fact, output is linked to unemployment via Okun's law and to inflation via the Phillips curve relationship, which may involve lagging dynamics. These fundamental relationships connect potentially different measures of the slack in the economy, such as the output gap and the cyclical component of unemployment (i.e., the difference between the unemployment rate and its normal long-run level [equilibrium unemployment])[9] and inform fluctuations at business cycle frequency in other real and nominal variables.

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[6] It is straightforward to show that the model can be rewritten as

$$(1 - 2\rho\cos(\lambda)L + \rho^2 L^2)\widehat{\psi}_t = (1 - \rho\cos(\lambda)L)\upsilon_t + (\rho\sin(\lambda)L)\upsilon^*_t.$$

Hence, under the restriction $\sigma^2_{\upsilon} = 0$, the solution of the model is an AR(2), otherwise an ARMA(2,1). The intuition for the use of the auxiliary cycle is closely related to the standard multivariate AR(1) representation of univariate AR(p) processes.

[7] Empirical studies often feature hybrid Phillips curves to account for inflation persistence (a recent survey is in Tsoukis et al., 2011). Several different mechanisms have been proposed in the literature to introduce hybrid Phillips curves such as indexation assumptions (Galí & Gertler, 1999), state-contingent pricing (Dotsey, King, & Wolman, 1999), or deviations from rational expectations assumption (Erceg & Levin, 2003; Milani, 2007).

[8] An estimated version of this model provides an unsatisfactory representation of the structure of the data. Results are available in the online appendix D.

[9] For example, the measure of slack that is adopted in policy analysis by the Fed is obtained as the difference between the unemployment rate and the Congressional Budget Office's (CBO) historical series for the long-run natural rate (as in Yellen, 2015).

Second, in modeling price dynamics, forecasters and policymakers often distinguish between changes in energy and food prices, which enter into headline inflation, and movements in the prices of other goods and services, that is, core inflation.[10] This is because food and energy prices tend to be extremely volatile and influenced by factors that are disconnected from the slack in the economy and are beyond the control of monetary policy. Examples are international political events, as is the case for oil price, as well as weather or diseases and for food and beverages.[11] This decomposition is important to study how slack in real output is transmitted to prices, by separating the direct impact of energy price shocks onto energy products from their role as cost push shocks in production.

Finally, it has been argued in the literature that once inflation expectations are admitted to a forward- or backward-looking Phillips curve equation, it is also possible that economic disturbances affect prices without any intermediating transmission through the output gap or other measures of slack in the economy (Sims, 2009). In this spirit, Coibion and Gorodnichenko (2015) argue that the absence of disinflation during the Great Recession can be explained by the rise of consumers' inflation expectations between 2009 and 2011 due to the increase in oil prices in this period. Also, while macrovariables are likely to be affected by nonclassical measurement error, agents' expectations, as captured by consumers' and professional forecasters' surveys, are likely to be only partially in line with national accounting definitions of aggregate prices and can introduce measurement errors and biases of a different nature.[12]

In the next section, we present an empirical model that expands on the core model to accommodate these possibly important aspects of business cycle and inflation dynamics.

III. An Empirical Trend-Cycle Model

Our benchmark empirical model expands on the core rational expectations model presented in the previous section to incorporate a rich information set, including output, employment, and the unemployment rate (as measures of real activity and labor market developments), CPI inflation, core CPI inflation, and consumers' and professionals' forecasts for one-year-ahead inflation (as proxies for economic agents' inflation expectations), and oil prices to proxy for energy prices. To capture the complex dynamics relationships among the variables, we generalize the stylized model presented in the previous section by incorporating dynamic heterogeneity in the relationship linking real variables, labor market outcomes, and prices and by allowing for deviations from perfect rationality.

Our model provides an empirical specification of a number of key macroeconomic concepts. A unit root trend with drift provides a time-varying measure of output potential, while the trend in employment or unemployment captures the evolution of equilibrium unemployment. The cyclical component of unemployment connects to fluctuations in output at business cycle frequency via an Okun's law that involves the output gap and its lagged value. This allows business cycle fluctuation to have dynamic heterogeneity and the labor market to respond with a lag to the slack in the economy. A unit root trend, common to headline and core CPI inflation and inflation expectations, captures the inflation trend shaping long-term expectations. The slack in the economy is reflected in the short-run cyclical fluctuations of inflation (and expectations) via a Phillips curve relationship involving the output gap and its lagged value that accommodates for a slow adjustment of prices to slack in the presence of nominal rigidities. Also, oil prices are allowed to co-move along the business cycle and possibly its 0 due to demand effects or markup shocks. The fact that the cyclical component of output informs economy-wide lead-lag fluctuations in both labor market and nominal variables supports the interpretation of the output gap as a measure of the business cycle.

We also design the model to be able to account for several potential deviations from the rational expectations benchmark. In particular, we allow for (a) oil price disturbances to affect prices either directly via energy prices in headline CPI or via economic agents' forecasts by inducing a transitory disanchoring of expectations, with a stationary cycle connecting oil prices, expectations, and inflation but not the measure of slack in the economy; (b) a time-varying bias, that is, a permanent disanchoring of expectations in the form of unit root processes; and (c) nonclassic measurement error in the variables and other sources of colored noise.

We summarize these modeling choices in the following assumptions:

Assumption 1. CPI headline inflation, core CPI inflation and, agents' inflation expectations (consumers' and professional forecasters') share a common random walk trend (viz. trend inflation).

Assumption 2. Real output, employment, and unemployment have independent trends modeled with unit roots, with a drift for output and employment (i.e., potential output and equilibrium employment/unemployment, respectively).

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[10] The price index for total consumer price (headline) inflation π_t is decomposed as

$$\pi_t = \pi_t^c + \upsilon_1 \pi_t^{en} + \upsilon_2 \pi_t^{food}, \tag{11}$$

where π_t^c is core CPI inflation and π_t^{en} and π_t^{food} are, respectively, the growth rate for prices of consumer energy goods and services and prices of food, both expressed relative to core CPI prices; and υ_1, and υ_2 are the weights of energy and food in total consumption. In the rest of the paper, we focus on the energy price component and abstract from food prices. Interestingly, both commodities are subject to the effect of global factors, and a few papers have reported a substantial share of comovement between energy and food prices (Baumeister & Kilian, 2014).

[11] While the Federal Reserve's inflation objective is defined in terms of the overall change in consumer prices, core inflation is considered to provide a better indicator than total inflation for the developments in prices in the medium term.

[12] For example, especially in consumer surveys, the forecast horizon may be loosely defined while the relevant price index may be left unspecified. Also, projections are often reported at different frequencies and can have different forecasting points.

Assumption 3. Business cycle fluctuations in output are described by a stationary process with stochastic cycling in the form of an ARMA(2,1) process with complex roots (i.e., output gap).

Assumption 4. Inflation, inflation expectations, and output are connected by a Phillips curve relationship defined as a moving average of the output gap and its first lag.

Assumption 5. Labor market variables are linked to output via the Okun's law, defined as a moving average of the output gap and its first lag.

Assumption 6. Oil prices co-move with the business cycle via a moving average of the output gap and its first lag (business cycle component of oil prices).

Assumption 7. Inflation expectations and inflation are connected, via a moving average of order one, to an ARMA(2,1) cycle in oil prices (energy cycle).

Assumption 8. All variables can have an idiosyncratic ARMA(2,1) cycle component, possibly capturing nonclassic measurement error, differences in definitions, and other sources of noise.

Assumption 9. Agents' (consumers and professional forecasters) expectations have independent idiosyncratic unit roots without drift, capturing time-varying bias in the forecast.

Assumption 10. All components are mutually orthogonal.

A key and novel feature of our modeling strategy is to allow the oil prices to affect and be affected by both the standard business cycles and what we define as an energy price cycle. Fluctuations in the latter component are reflected in prices and inflation expectations without affecting output and the labor market. This orthogonality assumption is a convenient statistical device helpful in teasing out components in the price dynamics that have weak or negligible impact on the U.S. output gap and labor market and that may happen at frequencies different from those of the standard business cycle frequency range.

For the purpose of this analysis, the University of Michigan (UoM) consumer survey and the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasts (SPF) one-year-ahead inflation forecast were chosen as proxies for consumers' and professionals' expectations because they both have relatively long histories and are available at quarterly frequency. Both target CPI inflation, either explicitly, as is the case for the SPF, or implicitly, by surveying consumers, as is the case for UoM. For both surveys, we employ the median expected price change in the four quarters following the date of the survey, which is consistent with our use of year-on-year inflation. Data incorporated in the model are at quarterly frequency, with the sample starting in Q1 1984 and ending in Q2 2018. All variables enter the model in levels, except for price variables, which are transformed to the year-on-year inflation rate (see table 1 for details).

TABLE 1.—DATA AND TRANSFORMATIONS

Variable	Symbol	Mnemonic	Transformation
Real GDP	y_t	y	Levels
Employment	e_t	e	Levels
Unemployment rate	u_t	u	Levels
Oil price	oil_t	oil	Levels
CPI inflation	π_t	π	YoY
Core CPI inflation	π_t^c	π^c	YoY
UoM: Expected inflation	$F_t^{uom}\pi_{t+4}$	uom	Levels
SPF: Expected CPI	$F_t^{spf}\pi_{t+4}$	spf	Levels

The table lists the macroeconomic variables used in the empirical model. "UoM: Expected inflation" is the University of Michigan twelve-months-ahead expected inflation rate. "SPF: Expected CPI" is the Survey of Professional Forecasters, four-quarters-ahead expected CPI inflation rate. The oil price is the West Texas Intermediate Spot oil price.

Our model in $x_t := \{y_t, e_t, u_t, oil_t, \pi_t, \pi_t^c, F_t^{uom}\pi_{t+4}, F_t^{spf}\pi_{t+4}\}$ can be written as

$$\begin{pmatrix} y_t \\ e_t \\ u_t \\ oil_t \\ \pi_t \\ \pi_t^c \\ F_t^{uom}\pi_{t+4} \\ F_t^{spf}\pi_{t+4} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ \delta_{e,1} + \delta_{e,2}L & 0 & 0 \\ \delta_{u,1} + \delta_{u,2}L & 0 & 0 \\ \delta_{oil,1} + \delta_{oil,2}L & 1 & 0 \\ \delta_{\pi,1} + \delta_{\pi,2}L & \gamma_{\pi,1} + \gamma_{\pi,2}L & \phi_\pi \\ \delta_{\pi^c,1} + \delta_{\pi^c,2}L & \gamma_{\pi^c,1} + \gamma_{\pi^c,2}L & \phi_{\pi^c} \\ \delta_{uom,1} + \delta_{uom,2}L + \delta_{uom,3}L^2 & \gamma_{uom,1} + \gamma_{uom,2}L & \phi_{uom} \\ \delta_{spf,1} + \delta_{spf,2}L + \delta_{spf,3}L^2 & \gamma_{spf,1} + \gamma_{spf,2}L & \phi_{spf} \end{pmatrix} \times \begin{pmatrix} \widehat{\psi}_t \\ \psi_t^{EP} \\ \mu_t^\pi \end{pmatrix} + \begin{pmatrix} \psi_t^y \\ \psi_t^e \\ \psi_t^u \\ \psi_t^{oil} \\ \psi_t^\pi \\ \psi_t^{\pi^c} \\ \psi_t^{uom} \\ \psi_t^{spf} \end{pmatrix} + \begin{pmatrix} \mu_t^y \\ \mu_t^e \\ \mu_t^u \\ \mu_t^{oil} \\ 0 \\ 0 \\ \mu_t^{uom} \\ \mu_t^{spf} \end{pmatrix} \qquad (12)$$

where ϕ_π, ϕ_{π^c}, ϕ_{uom}, and ϕ_{spf} are normalized to have unitary loading of inflation and inflation expectations on trend inflation.[13] It is worth noting that our empirical specification in equation (12) would reduce to the stylized rational

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[13] In the empirical model, the series are standardized so that the standard deviations of their first differences are equal to 1. For this reason, we

expectations model in equation (8), under suitable parametric restrictions. In online appendix D, we report a number of simplified models and their estimation results to show the impact of different assumptions on the final specification of the model.

Like the output gap in equation (6), the energy cycle and the idiosyncratic ARMA(2,1) stationary cycles can be written in the following form:

$$\begin{pmatrix}\psi_t^j\\ \psi_t^{*j}\end{pmatrix} = \rho^j \begin{pmatrix}\cos(\lambda^j) & \sin(\lambda^j)\\ -\sin(\lambda^j) & \cos(\lambda^j)\end{pmatrix}\begin{pmatrix}\psi_{t-1}^j\\ \psi_{t-1}^{*j}\end{pmatrix} + \begin{pmatrix}\upsilon_t^j\\ \upsilon_t^{*j}\end{pmatrix}, \quad \begin{pmatrix}\upsilon_t^j\\ \upsilon_t^{*j}\end{pmatrix} \sim \mathcal{N}(0, \varsigma_j^2 I_2), \tag{13}$$

where $j \in \{EP, x_1, \ldots, x_n\}$ and ψ^{*j}, as discussed, is a term capturing an auxiliary cycle. For stationarity, we impose $0 < \lambda^j \leq \pi$ and $0 < \rho^j < 1$ for all cycles, including the output gap.

There are four main advantages to modeling the stationary components as restricted ARMA(2,1) processes. First, this representation nests an AR(2), the simplest linear process able to display pseudocyclical behavior of the type it is associated with the business cycle and other economic cycles. Second, it allows for an explicit characterization of the relevant cyclical parameters, frequency and decay rate, over which it is possible to specify transparent priors. Third, it is a very parsimonious representation with a small number of parameters and hence the estimation of many stationary components is computationally feasible. Fourth, the presence of an additional MA(1) component is potentially able to accommodate for additional persistence in the data.

As discussed, the common and idiosyncratic trends are random walks (with and without drifts—μ_0^j) that can be written as

$$\mu_t^j = \mu_0^j + \mu_{t-1}^j + u_t^j, \quad u_t^j \sim \mathcal{N}(0, \sigma_j^2).$$

All of the stochastic disturbances in the model are assumed to be mutually orthogonal and Gaussian. Finally, it is worth noting that the common and idiosyncratic trends in inflation and inflation expectations are identified up to a constant (Bai & Wang, 2015, for a discussion on identification). For the sake of interpretation, we attribute the constant to the common trend so that it is on the same scale as the observed inflation variables.

IV. Bringing the Model to the Data

Our estimation strategy builds on the approach recently suggested by Harvey, Trimbur, and Van Dijk (2007): it adopts modern Bayesian techniques to support the estimation of “structural” trend-cycle models like those of Harvey (1985). In estimating the model, we elicit prior distributions that are either uniform over the range of the model parameters compatible with our modeling choices (i.e., $0 < \lambda^j \leq \pi$ and $0 < \rho^j < 1$) or weakly informative and in the form of very diffuse normal and inverse gamma priors. Table 2 reports the parameters of our prior distributions.

Table 2.—Prior Distributions

Name	Support	Density	Parameter 1	Parameter 2
δ, γ, ϕ and τ	$\mathbb{R}$	Normal	0	1,000
σ^2 and ς^2	$(0, \infty)$	Inverse-gamma	3	1
ρ	[0.001, 0.970]	Uniform	0.001	0.970
λ	[0.001, π]	Uniform	0.001	π

Prior distribution for the model parameters adopted in estimating the model with U.S. data. All of the priors are uniform over the range of the model parameters compatible with our modeling or weakly informative. Boundaries of the uniform priors ensure that the stochastic cycles are stationary and correctly specified according to the restrictions described in Harvey (1990).

We maximize and simulate the posterior distributions with a Metropolis-within-Gibbs algorithm that is structured in two blocks. In the first block, we estimate the state-space parameters by the Metropolis algorithm, and in the second block, we use the Gibbs algorithm to draw unobserved states conditional on model parameters. Relevant details and references are in the text and appendix A.[14]

An important question concerns the role of the priors in identifying the model. Figure 1 illustrates prior and posterior distributions for the variance of the error terms of the unobserved components, the frequency and persistence of the two common cycles, and the coefficients for the common cycles.[15] The charts provide a good indication on whether data provide enough information to identify the model parameters. Indeed, the posterior distributions are well peaked and not shaped by the priors, and they show that the data are very informative in estimating the many parameters of the model—in particular, the variance of the shocks of the common components and the frequencies of the cycles. Importantly, the posterior distributions of the coefficients for the common cycles indicate that coefficients equal to 0 have negligible probability to be drawn in both cases. Moreover, our results are robust to changes in the parameters of the distributions of the more informative priors. See appendix C.

V. Trends and Cycles in the U.S. Economy

We start by analyzing economic trends identified and estimated by the model in the next section and then move to economic cycles in the following one. We compare our assessment of trend-cycle dynamics with the estimates by the Congressional Budget Office (CBO) and the Board of Governors of the Federal Reserve.

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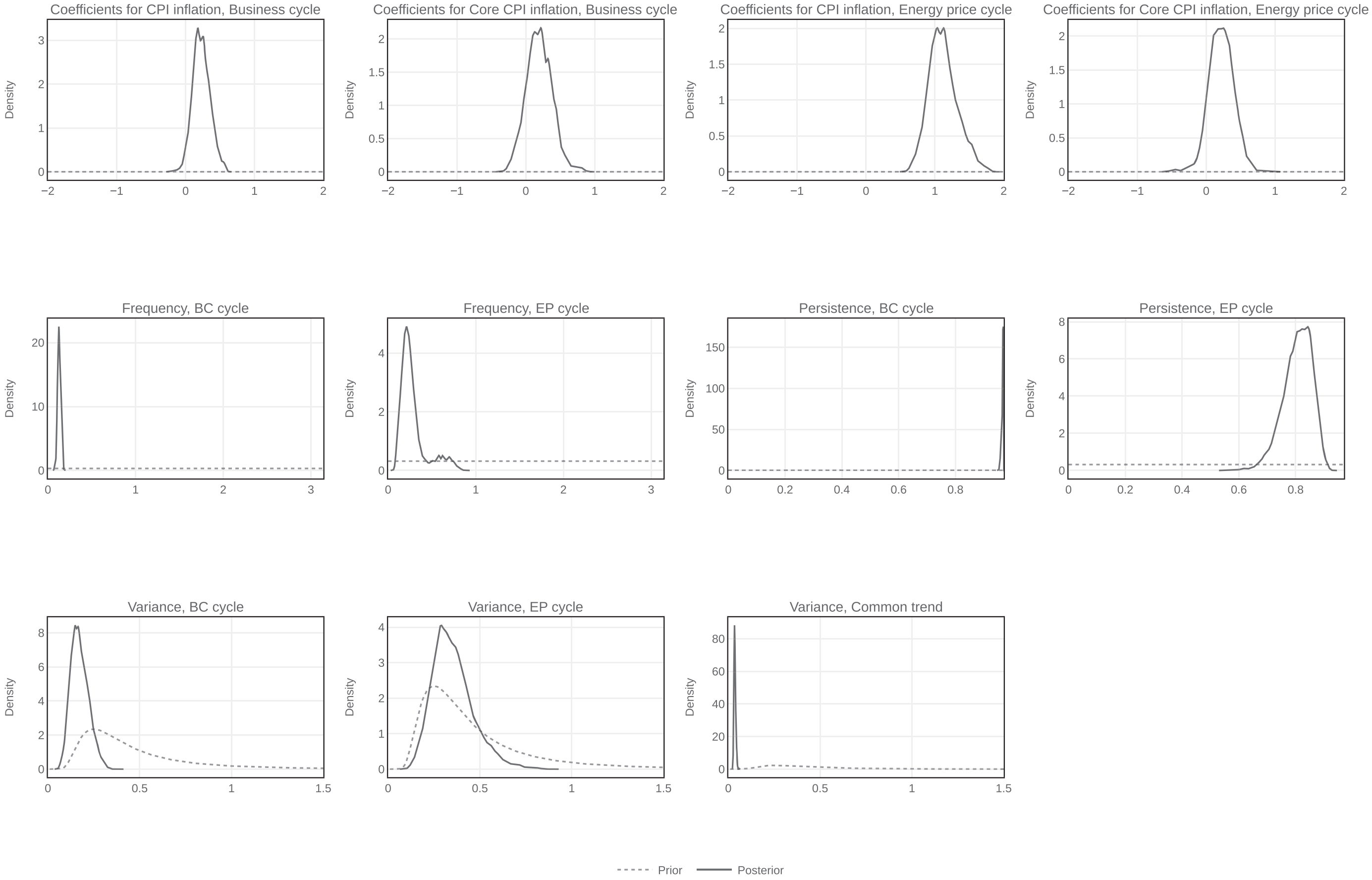
normalize ϕ_π, ϕ_{π^c}, ϕ_{uom}, and ϕ_{spf} to the reciprocal of the standard deviation of the first difference of the respective variable.

[14] The lags for the survey variables in equation (12) are implemented by including the auxiliary cycle ψ_t^{*j} from equation (13).

[15] The posterior distributions of the full set of model parameters can be found in appendix B.

FIGURE 1.—PRIOR AND POSTERIOR DISTRIBUTIONS



Prior distributions (dotted) and posterior distributions (solid) of the coefficients for the common cycles of CPI inflation and core CPI inflation, frequency of the common cycles, persistence of the common cycles, variance of the shocks to the common cycles, and common trend.

A. *Trend Inflation, Equilibrium Unemployment, and GDP Potential*

The model delivers very smooth and stable trends. Figure 2 plots real GDP, employment, unemployment, and oil prices against the median of the estimated independent trends, along with coverage bands (at 68% darker shade and 90% lighter shade coverage rate). Output trend, which can be thought of as a measure of potential output, is compared with the corresponding measure provided by the CBO. While both trends are equally stable, they provide a different description of long-term growth in the United States. Since 2001, the model-implied trend lies below the CBO trend, implying that while the CBO's reading of the data is that the U.S. economy had only just reached its potential at the precrisis peak in 2008, our model signals an overheating of the economy from 2006 to 2008 and a marked slowdown of trend growth in the last part of the sample.

Figure 2 also compares the model-implied measure of equilibrium unemployment against the CBO's measure for the natural rate of unemployment (NAIRU). The two measures coincide in the first part of the sample and then diverge post-2000. While our model provides a very stable unemployment trend hovering around 6% and with a temporary and small increase around the financial crisis in 2008, the CBO NAIRU shows a slow and persistent decline of the trend continuing through the crisis.[16]

The trend in the oil price shows a hump-shaped increase in the second half of the sample that may be related to the global increase in oil demand post-2000. In our model, trends are jointly estimated with the cyclical components. Hence, the differences between our estimated trends and those of the Fed and the CBO have relevant implications for the reading of business cycle dynamics. This will be analyzed in section VE.

The inflation trend common to headline CPI, core CPI inflation, and consumers' and professional forecasters' inflation expectation variables is shown in figure 3. Trend inflation is roughly stable from 2000 to 2010 and, interestingly,

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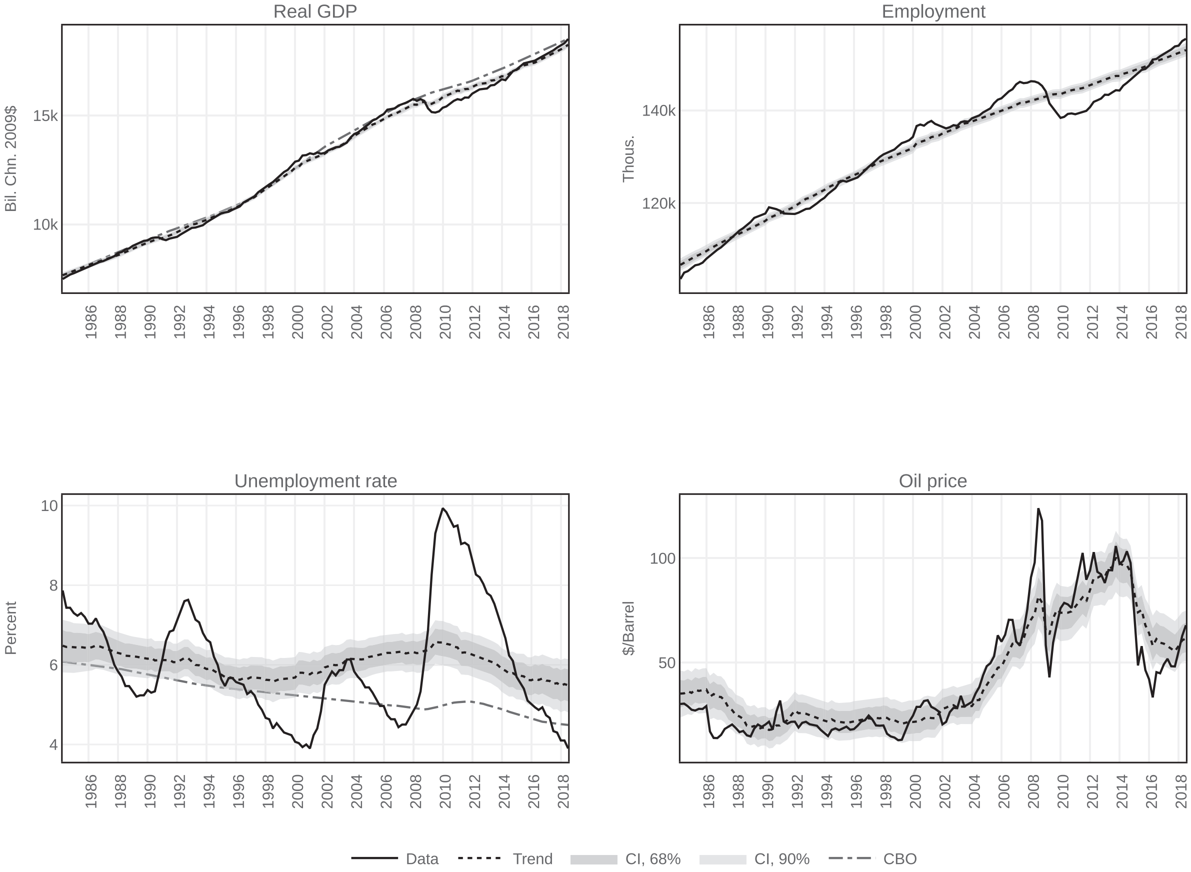
[16] In the baseline model, we include employment measured as number of employed people. However, an important concern relates to the behavior of the employment-to-population ratio (or active population), which has shown a marked decline since the Great Recession, standing at 61% in November 2019, down from a precrisis level at 63%. In a robustness exercise reported in online appendix E, we substitute employment with employment-to-population ratio in the model. While all of the results reported in this section are robust to the inclusion of this variable, the model captures a persistent decline in the equilibrium trend of the participation rate following the Great Recession.

Figure 2.—Independent Trends of Output, Employment, Unemployment, and Oil Prices



Oil prices are dotted. Coverage intervals at 68% coverage (dark shade) and 90% coverage (light shade), as estimated by the model. The figure also reports the measures of potential outputs and NAIRU estimated by the CBO (dash-dot).

is closely tracked by the SPF median forecast. UoM expectations, however, show large and persistent deviations from the common trend (long-term inflation expectations) since 2004. We interpret this sizable time-varying idiosyncratic trend as a bias in consumers' expectations. The unit-root inflation trend can be connected to the long-term inflation expectations of rational agents under the assumption that the law of iterated expectations holds (see Beveridge & Nelson, 1981, and Mertens, 2016). This interpretation is supported by figure 4 where CPI inflation is plotted against the implied trend and the median ten-year-ahead SPF inflation forecast. The chart provides a visual validation of our interpretation that the model trend estimate captures long-term expectations.

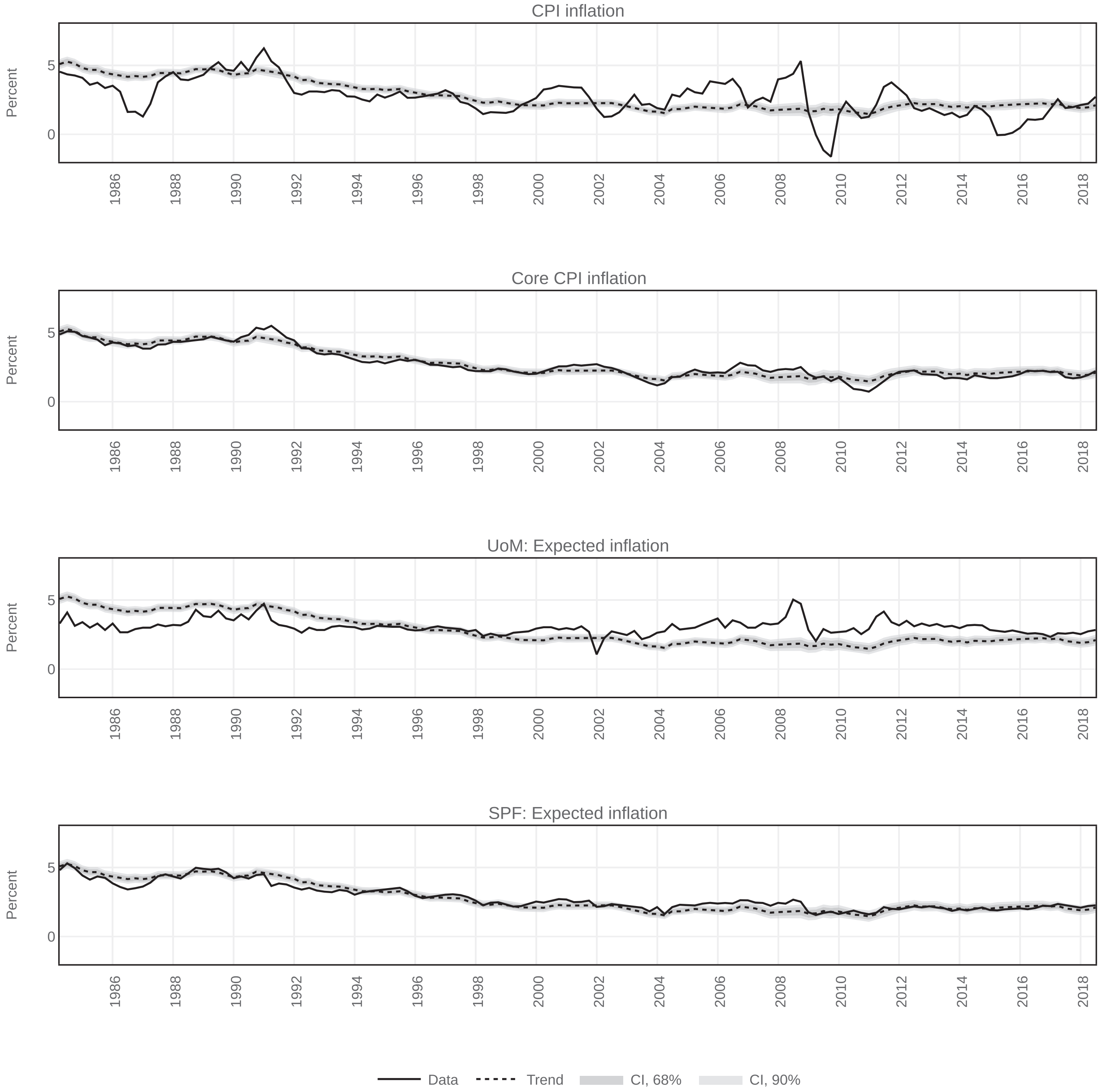
B. *Business and Energy Price Cycles*

Figure 5 shows the estimated common cycles in both the time and frequency domains and their contribution to headline CPI inflation. The first cycle provides a direct measure of the slack in the economy and captures fluctuations of output around its potential. It also connects real, labor market, and nominal variables and hence can be interpreted as a measure of the business cycle. For this reason, in what follows, we refer to it, with a slight abuse of terminology, as a "business cycle." The upper and middle panels in figure 5 report the median of the posterior distribution of the business and energy price cycles with relative coverage intervals at 68% coverage (dark shade) and 90% coverage (light shade). The lower panel shows the associated spectral densities and coverage bands. The charts indicate that the business cycle is quite regular and much less volatile than the energy price cycle. The spectral shape shows that the business cycle contributes to the inflation spectral shape with a relatively well-defined peak and with a cycle between seven and eight years' periodicity. Conversely, the energy price cycle occupies a broader range of frequencies with a less well-defined peak and a periodicity about half as long as that of the business cycle.

C. *Historical Decomposition*

Figure 6 shows the historical decomposition of the stationary components of the eight variables of interest into common and idiosyncratic cycles, as provided by the model. First, the business cycle captures almost entirely the fluctuations around trend in real output, employment, and unemployment. A negligible idiosyncratic component is visible only in unemployment and almost nonexistent in output and employment. This indicates that our measure of the output gap captures

FIGURE 3.—TREND COMMON TO INFLATION



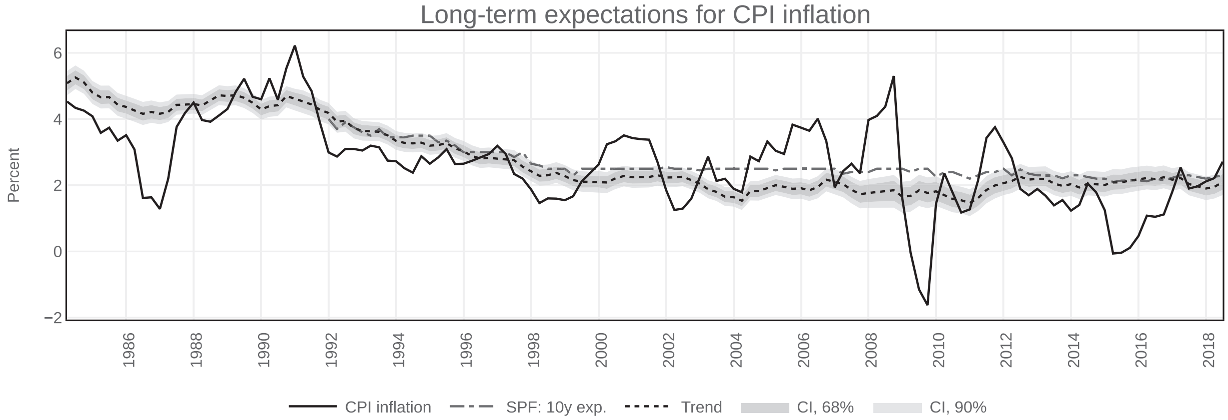
CPI inflation, core CPI inflation, and inflation expectations (dotted), with coverage intervals at 68% coverage (dark shade) and 90% coverage (light shade), as estimated by the model.

the slack in the economy well and is transmitted, via the lagged Okun's law relationship, to the labor market. It should be stressed that lags are important in describing the delayed transmission from output dynamics to the labor market and may capture different types of labor market frictions.

Second, a nonnegligible share of oil price fluctuations is due to the comovement of this variable with the slack in the economy, along the business cycle. This may be due either to the demand effect of the U.S. economy onto global oil prices or the role of oil shocks as markup shocks in the aggregate production function.

Third, the slack in the economy is reflected in price dynamics via the Phillips curve, which captures the lower-frequency dynamics in the inflation cycle and accounts for a sizable share of the variation in CPI inflation and most of the variation in core CPI inflation. This "real" component dominates SPF expectations while it provides a sizable but not dominant share of variation in consumers' expectations. In our model, the Phillips curve is a lagged relationship connecting prices, expectations, and output and, hence, labor market variables, in the spirit of the empirical relationship uncovered by Phillips (1958). A discussion about its steepness may be slightly misleading since a reduced-form relation between prices and unemployment would involve different lags of our business cycle. Nonetheless, in figure 7, we compare a scatter plot showing how the business cycle components of CPI

FIGURE 4.—LONG-TERM EXPECTATIONS FOR CPI INFLATION



Common trend (dotted), with coverage intervals at 68% coverage (dark shade) and 90% coverage (light shade), as estimated by the model. The chart also reports the measure of ten-year expectations for CPI inflation from the Survey of Professional Forecasters (dash-dot).

and unemployment would be related to a scatter plot of (demeaned) CPI and unemployment variables. The linear fit has a slope of -0.39 for the model-based measures, against a slope of -0.14 for a naive estimate.[17] This is a rough way to assess the strength of the Phillips curve identified by our model against that of a naive estimate of its steepness.

Fourth, the stationary component of CPI inflation is dominated by the energy price cycle. This can be explained by the fact that energy prices are one of the components of the CPI basket and tend to be extremely volatile with a weak correlation with the slack in the national economy. Notice also that while small, the energy price component is also visible and nonnegligible in core CPI inflation where, by construction, energy prices are removed. This suggests that oil shocks have an impact on core CPI inflation indirectly via expectations and not via the output gap or other measures of slack in the economy. In fact, as suggested by Coibion and Gorodnichenko (2015), household expectations are not fully anchored and respond strongly to oil price changes. Conversely, as observed above, the SPF median forecast tracks the unit-root trends, while its cyclical component is dominated by the persistent business cycle component. In other words, the SPF forecasts are relatively unaffected by the volatile and less persistent energy price component. In this respect, the dynamics of the median SPF forecast seem to be consistent with a rational forecast.

Finally, overall, the cyclical part of inflation is well captured by the two common components and little is left to idiosyncratic forces. However, the two common cycles are not in any sense synchronized. This sheds light on some of the puzzling behavior of inflation since 2008. From 2011 to mid-2012, the inflation cycle is supported by oil prices, while the Phillips curve exerts negative pressure. The opposite is true from 2015 to the end of 2016, when oil prices drag inflation down while the Phillips curve exerts a small upward pressure.

D. *The Role of Oil*

Oil shocks can affect price dynamics via several different channels. First, as cost-push shocks in production, they affect prices via the Phillips curve. Also, oil prices can fluctuate due to U.S. internal demand along the business cycle. These channels are directly captured by the common business cycle that connects the slack in the economy to oil prices and inflation. Second, they directly affect the prices of energy services that enter the consumption basket of headline CPI without affecting the output gap. This second channel is likely to explain most of the contribution of the energy price cycle to headline CPI inflation. Third, they can generate nonfundamental movement in consumers' inflation expectations and shift prices via this mechanism. This third channel is likely to explain the energy price cycle component in consumers' expectations and, importantly, in core CPI inflation, which excludes energy prices. Overall, this channel is quantitatively nondominant in price dynamics, albeit potentially very important since it is not under the control of standard monetary policy.

Much of the historical differences in inflation expectations between households and professional forecasters can be accounted for by the contribution of oil prices. This was originally observed by Coibion and Gorodnichenko (2015), who also attribute to oil shocks a sizable effect on consumer expectations. In our framework, the effect can only be present through common stationary cycles and trends. However, our results show a large idiosyncratic trend component in oil prices that, by construction, does not affect CPI inflation. Figure 8 plots it against the idiosyncratic consumers' expectation trend and provides suggestive evidence that consumer price expectations may actually have a persistent component related to oil prices. Our framework leaves it as unmodeled and to future research.

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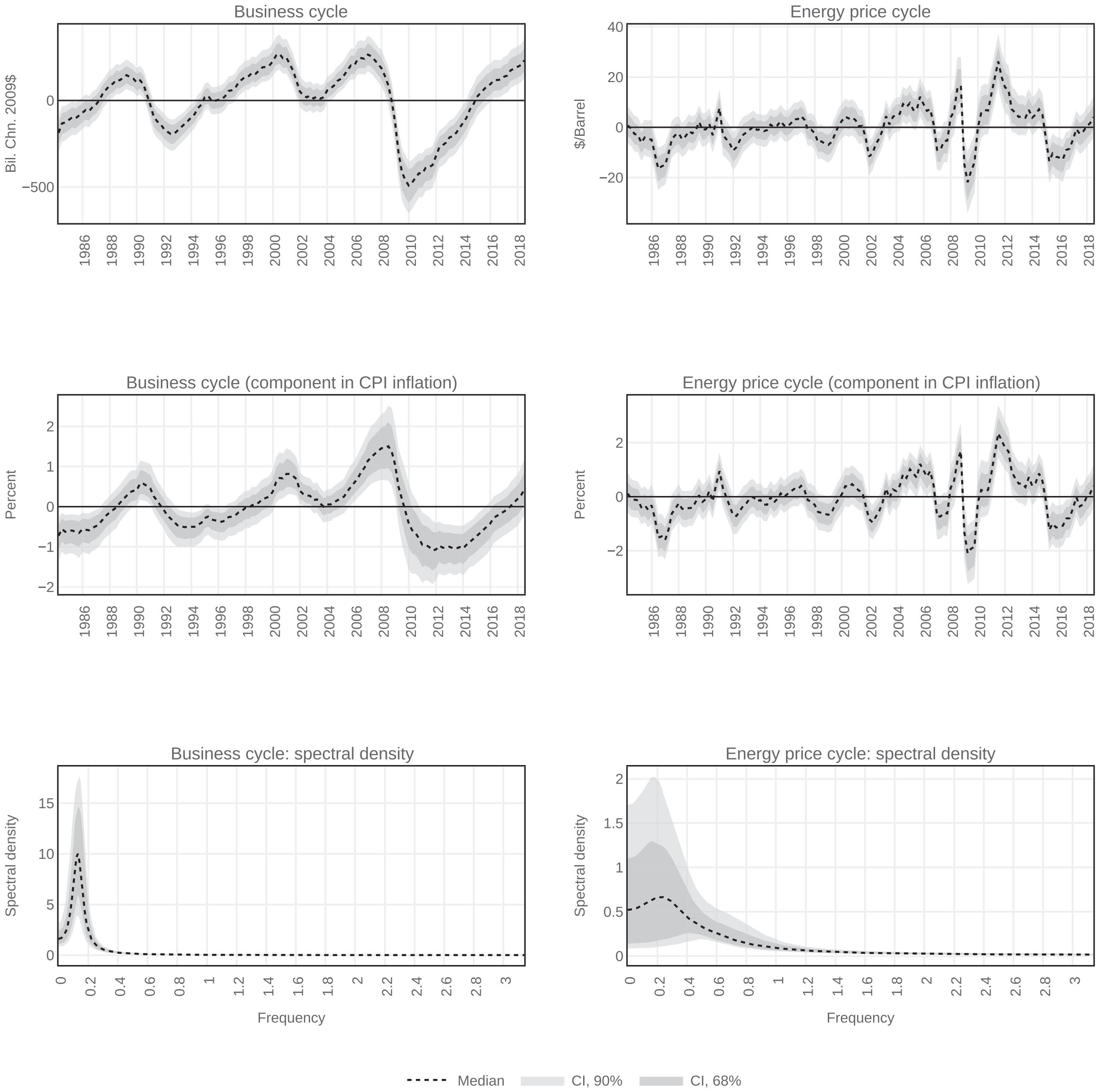
[17] The black filled circles represent points the the post–Great Recession subsample (from 2008 to 2018). Interestingly, the years since the beginning of the last recession seem to be described by the regular pattern in the data, albeit they trace a larger than usual cycle.

FIGURE 5.—BUSINESS AND ENERGY PRICE CYCLES



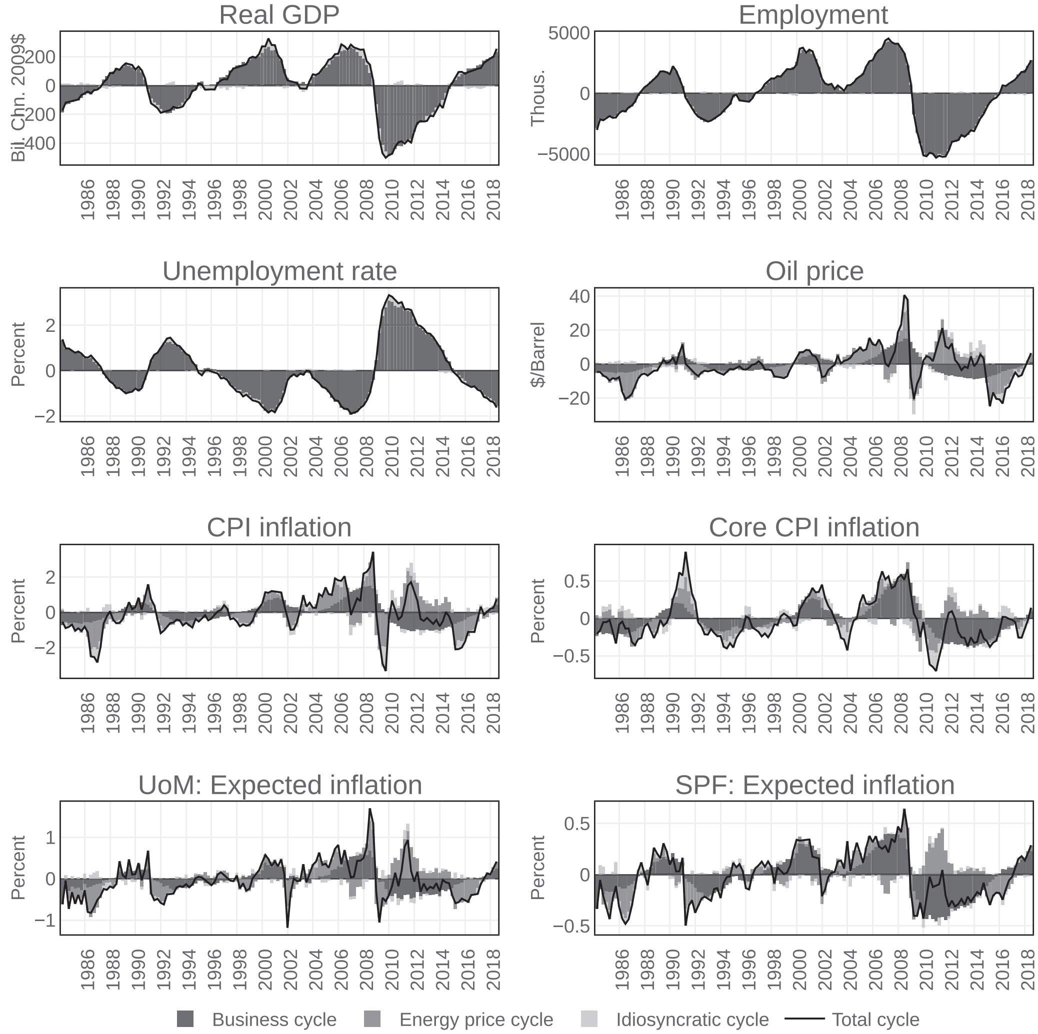
Top: Business cycle and energy price cycle, with coverage intervals at 68% coverage (dark shade) and 90% coverage (light shade). Middle: Business cycle and energy price cycle components in CPI inflation, with coverage intervals at 68% coverage (dark shade) and 90% coverage (light shade). Bottom: parametric spectrum of the Business cycle and energy price cycle.

E. The Output Gap and a Narrative of the Great Recession

In the narrative emerging from the model, the output gap has a crucial role. Figure 9 reports the model-based output gap as well as the gap published by the CBO and the one by the Fed Greenbooks. The model's and the CBO/Fed business cycle dating of the turning points perfectly coincides as the peaks and troughs alignment shows. However, the model-consistent measure and the other two differ in their assessment of the degree of slack in the economy since 2001. In fact, at the time of the slowdown of 2001–2002, our model indicates that the economy went from overcapacity to trend growth but, unlike the CBO's, does not identify a protracted period of slack.

Notably the model attributes a smaller share of the reduction in GDP following the Great Recession to its cyclical component, as compared to the CBO's and by the Fed Greenbook's estimates, and hence projects a lower output potential with a marked slowdown in output trend growth that starts before the last recession but becomes manifest in its aftermath (in figures 2 and 9). The CBO has a more optimistic assessment of the trend growth and attributes the slowdown since the early millennium to a very deep contraction in the

FIGURE 6.—HISTORICAL DECOMPOSITION OF THE CYCLES, AS ESTIMATED BY THE MODEL



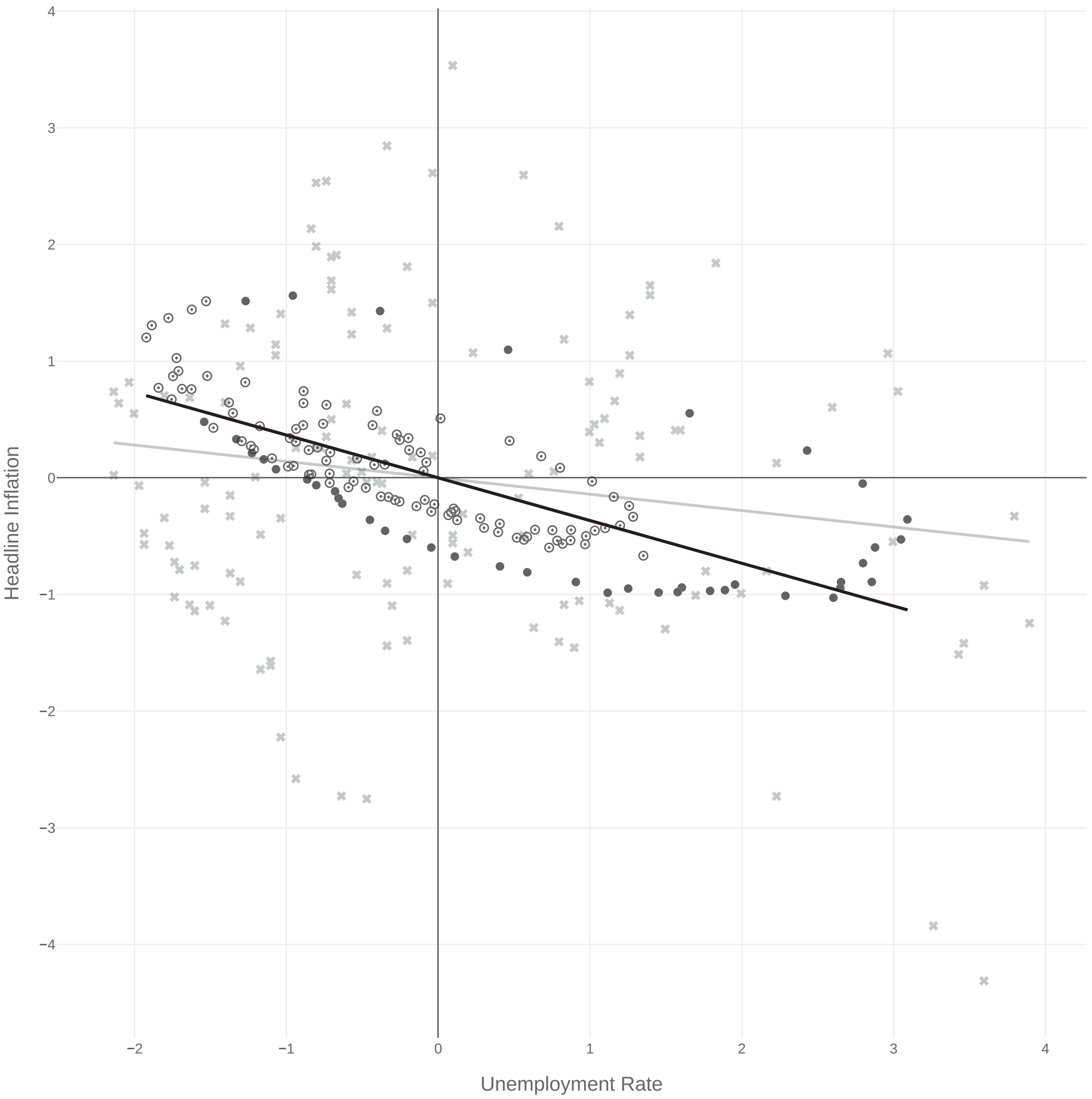
The chart reports the business cycle, energy price cycle, and idiosyncratic cycle.

cyclical component of output. Its estimated output gap considers the U.S. economy to have been below potential since 2001 and even at the height of the peak preceding the Great Recession, when the U.S. economy was supported by the unusual dynamics in the real estate market.

It is important to observe that the two different narratives are the specular image of the question regarding the stability of the Phillips curve. Our model's estimate of the output gap is informed by loose priors on trends, the inflation trends implicit in agents' expectations, and, above all, the multivariate links connecting prices to the labor market and output. In doing this, it assumes the stability of the Phillips curve and Okun's law. It finds that the data match this description but show a substantial decline in output potential (and a roughly constant equilibrium unemployment). Conversely, a view of the U.S. economy assuming a very stable potential output would imply a widening output gap and hence a flattening of the Phillips curve. Both interpretations are plausible. The two different narratives of the economic developments since 2001 are based on different and untestable assumptions about the long-run behavior of output and other variables, and there is no obvious criterion on the basis of which we can choose the "correct" one (see, for example, the discussion on trends in Sims, 2000).

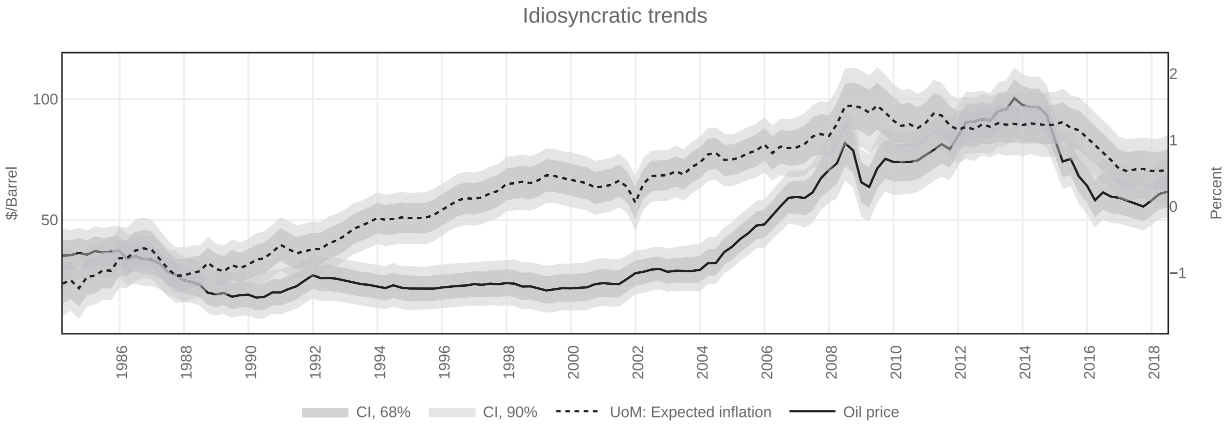
Several narratives are compatible with the model's assessment. For example, Hall et al. (2017) have pointed to a lower productivity growth trend preceding the Great Recession and, using a growth accounting framework, have argued that the slowdown was due to the long-term trend in labor force participation and TFP growth. The slowdown in the pre–Great Recession period may have been masked by the dot-com bubble first and the financial boom later, possibly in line with Borio, Disyatat, and Juselius (2017). This "productivity view" is captured in our model by a trend slowdown starting at the beginning of the millennium. In addition, the model attributes part of the slowdown since 2008 to the trend, in line with the "hysteresis view" on the postcrisis period according to which deep recessions can cause hysteresis in the form of

Figure 7.—Slope of the Phillips Curve



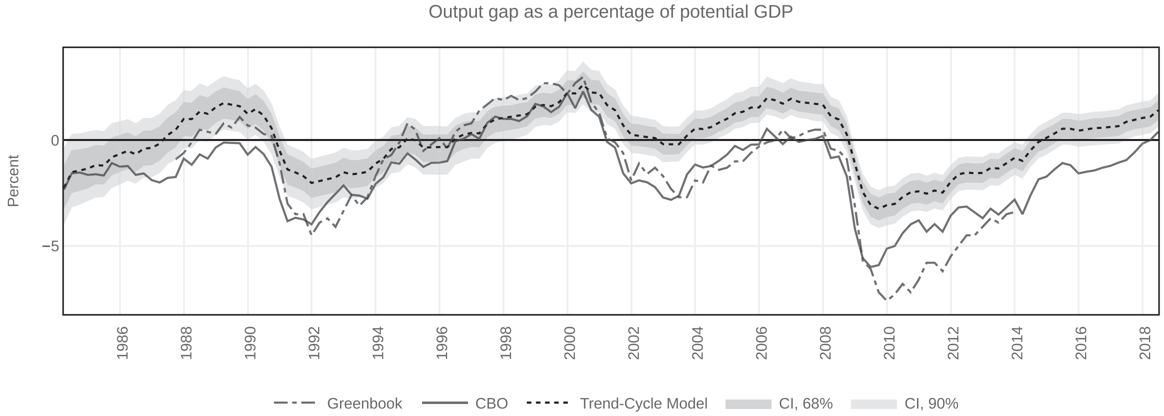
Business cycle component of CPI inflation against the business cycle component of the unemployment rate (circles with a dot) and the corresponding bivariate linear regression line (black line). The black filled circles represent points for the post–Great Recession subsample (from 2008 to 2018). The chart also plots de-meaned CPI inflation against the de-meaned unemployment rate (gray crosses) and the corresponding bivariate linear regression line (gray line).

Figure 8.—Idiosyncratic Trends of Oil Prices (Left) and UOM Expected Inflation (Right)



Coverage intervals at 68% coverage (dark shade) and 90% coverage (light shade), as estimated by the model.

FIGURE 9.—OUTPUT GAP AS A PERCENTAGE OF POTENTIAL GDP



Output gap (dotted), with coverage intervals at 68% coverage (dark shade) and 90% coverage (light shade), as estimated by the model. The model-based estimate of the output gap is obtained by rescaling the business cycle to match the GDP scale and by summing to it the output idiosyncratic cycle component. The chart also reports the output gap from the CBO (solid) and the Fed's Greenbook (dash-dot).

permanent (or very persistent) changes to potential output (see the discussion in Blanchard et al., 2015, as an example).[18]

Let us stress here that one should not see our results as supporting the view that the Great Recession was mild, given our estimate of the output gap. Rather, our results support a pessimistic assessment of long-run trends in the wake of the financial crisis, although the model is unable to identify whether the source of this persistent slowdown is demand or supply factors (see also the discussion in Coibion, Gorodnichenko, & Ulate, 2018).[19]

VI. Global Factors in U.S. Inflation

In recent years, the potential impact of globalization on price dynamics has drawn attention from both policymakers and academics. The literature has suggested that the increase in international trade has had a negative impact on the strength of the domestic Phillips curve relationship and increased the significance of global slack and exchange rates in relation to CPI. Several channels have been proposed, including the increasing impact of demand from emerging markets that has affected volatility in commodity prices, the increased price competition and the greater role of supply chains that have reduced firms' pricing power, or that the reduced bargaining power of local workers has weakened the role for domestic slack (see Galí, 2010, for a theory-informed discussion of the literature on the topic).

Indeed, a number of empirical works have identified a sizable global common factor in inflation dynamics (Ciccarelli & Mojon, 2010, and Mumtaz, Simonelli, & Surico, 2011) or proposed to add a measure of global slack (Borio & Filardo, 2007; Castelnuovo, 2010), supply chain intensity (Auer & Fischer, 2010; Auer, Levchenko, & Sauré, 2017), or exchange rates (Forbes, Hjortsoe, & Nenova, 2017) in the econometric specifications of price equations.

In our analysis, we have so far abstracted from these considerations. We instead focused on the energy price cycle, which we extracted as a process that is orthogonal to domestic slack and not reflected in the output gap and the labor market conditions in the United States. An important question is whether the energy price cycle reflects global demand and commodity price cycles, as suggested, for example, by Delle Chiaie, Ferrara, and Giannone (2018). To try to address this question, we estimate a new version of the model that expands the benchmark specification by including the two different measures of global activity: (a) the Baltic Dry Index and index of global cargo shipments, initially proposed by Kilian (2009) but taken in levels, and the measure of global industrial production proposed by Baumeister and Hamilton (2019) and based on the OECD methodology.[20]

In this new specification, all the variables in the model are allowed to load onto the U.S. business cycle as a reflection of the global significance of the U.S. economy both in terms of share of world GDP and as driver of global economic activity. As in the benchmark specification, U.S. GDP and labor market variables do not load on the energy price cycle,

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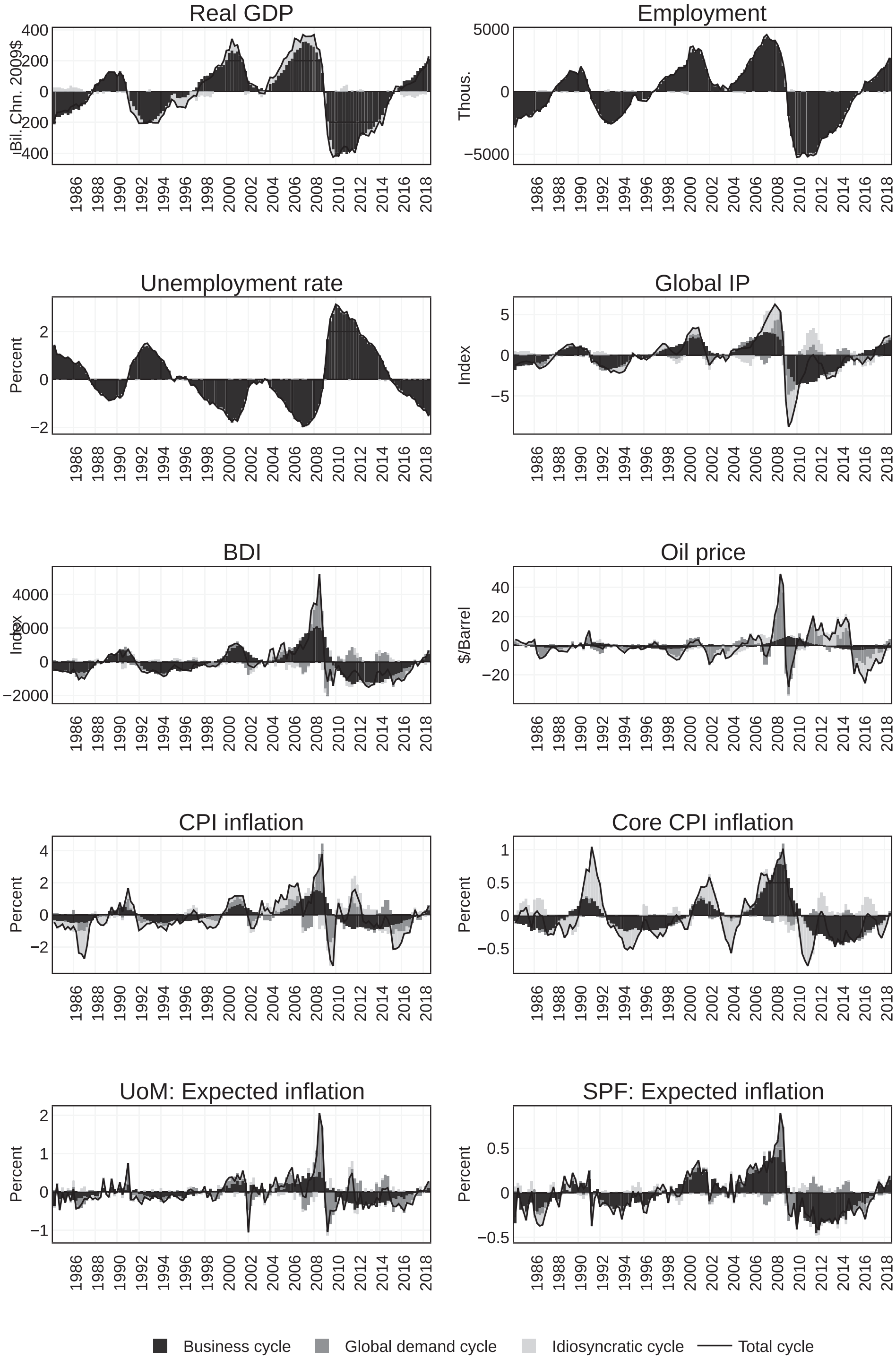
[18] Blanchard et al. (2015), using multicountry data but not a model-based approach, conclude that several recessions of different natures are followed by lower growth. They conclude that "in many cases, the correlation between recessions and subsequent poor economic performance reflects reverse causality: the realization that growth prospects are lower than was previously assumed naturally leads to both a recession and subsequent poor performance." However, in other cases "hysteresis, and perhaps even super-hysteresis may indeed also be at work."

[19] Coibion et al. (2018) observe that "one should draw little inference from the evolution of estimates of potential GDP about the persistence of GDP changes; these estimates fail to exclusively identify supply shocks that should drive potential GDP and instead also respond to transitory demand shocks. The fact that most of the output declines observed since the Great Recession are now attributed to declines in potential GDP would imply little other than that these declines have been persistent because estimates of potential GDP fail to adequately distinguish between the underlying sources of changes in GDP."

[20] In an explorative analysis reported in online appendix F, we provide scatter plots and correlation coefficients for the business and the energy price cycles in relation to three variables measuring global activity: the Baltic Dry Index, the global industrial production (GIP), and the Global Condition Index (GCI) of Cuba-Borda, Mechanick, and Raffo (2018).

FIGURE 10.—HISTORICAL DECOMPOSITION OF THE CYCLES, AS ESTIMATED BY THE MODEL



The chart reports the business cycle, energy price cycle, and idiosyncratic cycle.

while all the others, including the Baltic Dry Index and global industrial production, can have an impact on it.[21]

In the new specification, the decomposition of the U.S. variables in terms of the BC and the EP is largely unchanged, despite the introduction of global variables, as reported in figure 10. This is reassuring and shows that results are robust. However, the new model offers interesting insights on the role of global shocks in the U.S. inflation dynamics. First, the U.S. business cycle drives a large portion of the global economy and hence of the global business cycle fluctuations. This is visible in the large share of the two global indicators explained by the U.S. business cycle component and is due

[21] Online appendix F reports details of the model and additional charts.

to both the U.S. weight in world GDP but also to the share of the global activity that is synchronized on the U.S. business cycle. Second, the energy price cycle now explains a sizable share of the Baltic Dry Index and oil prices but a smaller share of global industrial production. A possible interpretation is that the fluctuations captured by the energy price cycle are due to oil supply shocks and possibly financial shocks in the commodity markets rather than to global demand factors. Interestingly, in the global model, the spectral shape of the energy price cycle is well defined and peaks in a range higher than business cycle frequencies.

VII. Conclusion

The results reported in this paper point to a well-identified and steep Phillips curve relationship in reduced form that captures a cyclical component CPI inflation with maximum power at around eight years, periodicity but also points to deviations from the standard rational expectations formulation since we identify a sizable cycle in CPI inflation that is unrelated to real domestic variables and captures the correlation between inflation expectations and oil prices. This cycle, which is of slightly shorter periodicity than the business cycle and is more volatile, points to a channel through which oil price developments temporarily affect consumer price expectations away from the nominal-real relationship captured by the Phillips curve. In the presence of large oil price shocks, this component may dominate and cloud the signal on cyclical inflation. The energy price component appears to be determined by global factors such as oil supply shocks and financial shocks in the commodity markets.

Interestingly, this energy price cycle is associated with both core and CPI inflation, which suggests that even core inflation provides a clouded signal of fundamental (trend and cyclically driven) inflationary pressures. This result provides motivation to the signal extraction approach we have proposed for the identification of the cyclical component of inflation. As for the real variables, the model's estimate of potential output identifies a slowdown around the beginning of the millennium that becomes more evident in the wake of the Great Recession. Our results are compatible with both the productivity view of Hall et al. (2017) and the "hysteresis view" of Blanchard et al. (2015). The implication is that our estimate of the output gap differs from that of the CBO's since the beginning of the productivity slowdown. While the CBO's view is that the U.S. economy was growing around potential before the 2008 crisis and below it since then, our model points to growth above potential between 2006 and 2008 and again since 2015.

Although it is not possible to discriminate between these different views that ultimately depend on different beliefs on the long-run behavior of output, our model, based on the joint analysis of output, labor market, prices, and expectations, provides a plausible narrative that is consistent with the data and can be interpreted in a transparent way. We believe that it provides a useful model-consistent benchmark for the policy debate.

From the policy perspective, our findings suggest that a problematic issue for the central bank is that, facing volatile and persistent oil price dynamics, consumer expectations can deviate from a stable trend and affect price dynamics. Our conclusions are therefore quite open-ended. The Fed's view that inflation is dominated by three components is supported by the data. However, the ability of the Central Bank to anchor expectations is limited, especially because oil affects consumer expectations persistently and independent of the state of the real economy.

REFERENCES

Adam, Klaus, and Mario Padula, "Inflation Dynamics and Subjective Expectations in the United States," *Economic Inquiry* 49:1 (2011), 13–25. 10.1111/j.1465-7295.2010.00328.x

An, Sungbae, and Frank Schorfheide, "Bayesian Analysis of DSGE Models," *Econometric Review* 26:2–4 (2007), 113–172. 10.1080/07474930701220071

Atkeson, Andrew, and Lee E. Ohanian, "Are Phillips Curves Useful for Forecasting Inflation?," *Quarterly Review* 25 (2001), 2–11. 10.21034/qr.2511

Auer, Raphael, and Andreas M. Fischer, "The Effect of Low-Wage Import Competition on U.S. Inflationary Pressure," *Journal of Monetary Economics* 57:4 (2010), 491–503. 10.1016/j.jmoneco.2010.02.007

Auer, Raphael A., Andrei A. Levchenko, and Philip Sauré, "International Inflation Spillovers through Input Linkages," Swiss National Bank working paper 2017-03 (2017).

Bai, Jushan, and Peng Wang, "Identification and Bayesian Estimation of Dynamic Factor Models," *Journal of Business and Economic Statistics* 33:2 (2015), 221–240. 10.1080/07350015.2014.941467

Ball, Laurence, and Sandeep Mazumder, "Inflation Dynamics and the Great Recession," *Brookings Papers on Economic Activity* 42:1 (2011), 337–405. 10.1353/eca.2011.0005

Basistha, Arabinda, and Richard Startz, "Measuring the NAIRU with Reduced Uncertainty: A Multiple-Indicator Common-Cycle Approach," this REVIEW 90:4 (2008), 805–811. 17980872

Bastürk, Nalan, Cem Çakmakli, S. Pinar Ceyhan, and Herman K. Van Dijk, "Posterior-Predictive Evidence on US Inflation Using Extended New-Keynesian Phillips Curve Models with Non-Filtered Data," *Journal of Applied Econometric* 29:7 (2014), 1164–1182.

Baumeister, Christiane, and James Hamilton, "Structural Interpretation of Vector Autoregressions with Incomplete Identification: Revisiting the Role of Oil Supply and Demand Shocks," *American Economic Review* 109:5 (2019), 1873–1910. 10.1257/aer.20151569

Baumeister, Christiane, and Lutz Kilian, "Do Oil Price Increases Cause Higher Food Prices?," *Economic Policy* 29:80 (2014), 691–747. 10.1111/1468-0327.12039

——— "Lower Oil Prices and the U.S. Economy: Is This Time Different?," *Brookings Papers on Economic Activity* 47:2 (2016), 287–357. 10.1353/eca.2016.0029

Beveridge, Stephen, and Charles R. Nelson, "A New Approach to Decomposition of Economic Time Series into Permanent and Transitory Components with Particular Attention to Measurement of the Business Cycle," *Journal of Monetary Economics* 7:2 (1981), 151–174. 10.1016/0304-3932(81)90040-4

Blanchard, Olivier, Eugenio Cerutti, and Lawrence H. Summers, "Inflation and Activity: Two Explorations and Their Monetary Policy Implications," Peterson Institute for International Economics working paper series WP15-19 (2015).

Borio, Claudio, Piti Disyatat, and Mikael Juselius, "Rethinking Potential Output: Embedding Information about the Financial Cycle," *Oxford Economic Papers* 69:3 (2017), 655–677.

Borio, Claudio E. V., and Andrew Filardo, "Globalisation and Inflation: New Cross-Country Evidence on the Global Determinants of Domestic Inflation," Bank for International Settlements working paper 227 (May 2007).

Castelnuovo, Efrem, "Tracking U.S. Inflation Expectations with Domestic and Global Indicators," *Journal of International Money and Finance* 29:7 (2010), 1340–1356. 10.1016/j.jimonfin.2010.03.006

Cecchetti, Stephen G., Michael Feroli, Peter Hooper, Anil K. Kashyap, and Kermit Schoenholtz, "Deflating Inflation Expectations: The Implications of Inflation's Simple Dynamics," CEPR discussion paper 11925 (March 2017).

Ciccarelli, Matteo, and Benoît Mojon, "Global Inflation," this REVIEW 92 (2010), 524–535.

Clark, Todd E., and Taeyoung Doh, "Evaluating Alternative Models of Trend Inflation," *International Journal of Forecasting* 30:3 (2014), 426–448. 10.1016/j.ijforecast.2013.11.005

Coibion, Olivier, and Yuriy Gorodnichenko, "Is the Phillips Curve Alive and Well After All? Inflation Expectations and the Missing Disinflation," *American Economic Journal: Macroeconomics* 7 (2015), 197–232. 10.1257/mac.20130306

Coibion, Olivier, Yuriy Gorodnichenko, and Rupal Kamdar, "The Formation of Expectations, Inflation and the Phillips Curve," NBER working paper 23304 (2017).

Coibion, Olivier, Yuriy Gorodnichenko, and Mauricio Ulate, "The Cyclical Sensitivity in Estimates of Potential Output," *Brookings Papers on Economic Activity* 49:2 (2018), 343–441. 10.1353/eca.2018.0020

Cuba-Borda, Pablo, Alexander Mechanick, and Andrea Raffo, "Monitoring the World Economy: A Global Conditions Index," Board of Governors of the Federal Reserve System notes 2018-06-15 (June 2018).

Del Negro, Marco, Domenico Giannone, Marc P. Giannoni, and Andrea Tambalotti, "Safety, Liquidity, and the Natural Rate of Interest," *Brookings Papers on Economic Activity* 48:1 (2017), 235–316. 10.1353/eca.2017.0003

Delle Chiaie, Simona, Laurent Ferrara, and Domenico Giannone, "Common Factors of Commodity Prices," *Research Bulletin* 51 (2018).

Diebold, Francis X., and Roberto S. Mariano, "Comparing Predictive Accuracy," *Journal of Business and Economic Statistics* 13:3 (1995), 253–263.

Dotsey, Michael, Shigeru Fujita, and Tom Stark, "Do Phillips Curves Conditionally Help to Forecast Inflation?," Federal Reserve Bank of Philadelphia working paper 11-40, (2011).

Dotsey, Michael, Robert G. King, and Alexander L. Wolman, "State-Dependent Pricing and the General Equilibrium Dynamics of Money and Output," *Quarterly Journal of Economics* 114:2 (1999), 655–690. 10.1162/003355399556106

Erceg, Christopher J., and Andrew T. Levin, "Imperfect Credibility and Inflation Persistence," *Journal of Monetary Economics* 50:4 (2003), 915–944. 10.1016/S0304-3932(03)00036-9

Forbes, Kristin, Ida Hjortsoe, and Tsvetelina Nenova, "Shocks versus Structure: Explaining Differences in Exchange Rate Pass-Through across Countries and Time," Monetary Policy Committee Unit, Bank of England discussion paper 50 (July 2017).

Forbes, Kristin J. Lewis Kirkham, and Konstantinos Theodoridis, "A Trendy Approach to UK Inflation Dynamics," CEPR discussion papers 12652 (January 2018).

Galí, Jordi, "Commentary: Inflation Pressures and Monetary Policy in a Global Economy," *International Journal of Central Banking* 6:1 (2010), 93–102.

Galí, Jordi, and Mark Gertler, "Inflation Dynamics: A Structural Econometric Analysis," *Journal of Monetary Economics*, October 44:2 (1999), 195–222.

Giannone, Domenico, Michele Lenza, and Giorgio E. Primiceri, "Prior Selection for Vector Autoregressions," this REVIEW 97:2 (2015), 436–451.

——— "Priors for the Long Run," *Journal of the American Statistical Association* 114:526 (2019), 565–580. 10.1080/01621459.2018.1483826

Gordon, Robert, "Inflation, Flexible Exchange Rates, and the Natural Rate of Unemployment," in Martin Neil Baily, ed., *Workers, Jobs, and Inflation* (Washington, DC: Brookings Institution, 1982).

——— "US Inflation, Labor's Share, and the Natural Rate of Unemployment" (pp. 1–34), in Heinz Konig, ed., *Economics of Wage Determination* (New York: Springer-Verlag, 1990).

——— "The History of the Phillips Curve: Consensus and Bifurcation," *Economica* 78:309 (2011), 10–50.

Grant, Angelia L., and Joshua C. C. Chan, "A Bayesian Model Comparison for Trend-Cycle Decompositions of Output," *Journal of Money, Credit and Banking* 49:2–3 (2017), 525–552. 10.1111/jmcb.12388

Hall, Robert, Mark Watson, James Stock, and John Fernald, "The Slow Recovery in Output after 2009," Society for Economic Dynamics 2017 meeting paper 610 (2017).

Hamilton, James D., "Oil Prices, Exhaustible Resources and Economic Growth" (pp. 29–63), in Roger Fouquet, ed., *Handbook on Energy and Climate Change* (Northampton, MA: Elgar, 2013).

Harvey, Andrew C., "Trends and Cycles in Macroeconomic Time Series," *Journal of Business and Economic Statistics* 3:3 (1985), 216–227.

——— *Forecasting, Structural Time Series Models and the Kalman Filter* (Cambridge: Cambridge University Press, 1990).

Harvey, David, Stephen Leybourne, and Paul Newbold, "Testing the Equality of Prediction Mean Squared Errors," *International Journal of Forecasting* 13:2 (1997), 28–291. 10.1016/S0169-2070(96)00719-4

Harvey, Andrew C., Thomas M. Trimbur, and Herman K. Van Dijk, "Trends and Cycles in Economic Time Series: A Bayesian Approach," *Journal of Econometrics* 140:2 (2007), 618–649. 10.1016/j.jeconom.2006.07.006

Henry, S. G. B., and A. R. Pagan, "The Econometrics of the New Keynesian Policy Model: Introduction," *Oxford Bulletin of Economics and Statistics* 66 (2004), 581–607. 10.1111/j.1468-0084.2004.00094.x

IMF, "The Dog That Didn't Bark: Has Inflation Been Muzzled or Was It Just Sleeping?" (pp. 79–96), in IMF, ed., *World Economic Outlook, October 2013: Transitions and Tensions* (Washington, DC: International Monetary Fund, April 2013).

Kilian, Lutz, "Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market," *American Economic Review* 99:3 (2009), 1053–1069. 10.1257/aer.99.3.1053

Kilian, Lutz, and Robert J. Vigfusson, "The Role of Oil Price Shocks in Causing U.S. Recessions," *Journal of Money, Credit and Banking* 49:8 (2017), 1747–1776. 10.1111/jmcb.12430

Kuttner, Kenneth N., "Estimating Potential Output as a Latent Variable," *Journal of Business and Economic Statistics* 12:3 (1994), 361–368.

Lenza, Michele, and Marek Jarociński, "An Inflation-Predicting Measure of the Output Gap in the Euro Area," European Central Bank working paper series 1966 (September 2016).

Mavroeidis, Sophocles, Mikkel Plagborg-Møller, and James H. Stock, "Empirical Evidence on Inflation Expectations in the New Keynesian Phillips Curve," *Journal of Economic Literature* 52:1 (2014), 124–188. 10.1257/jel.52.1.124

McLeay, Michael, and Silvana Tenreyro, "Optimal Inflation and the Identification of the Phillips Curve," Centre for Macroeconomics discussion paper 1815 (April 2018).

Mertens, Elmar, "Measuring the Level and Uncertainty of Trend Inflation," this REVIEW 98:5 (2016), 950–967.

Mertens, Elmar, and James M. Nason, "Inflation and Professional Forecast Dynamics: An Evaluation of Stickiness, Persistence, and Volatility," Crawford School of Public Policy, Australian National University CAMA working paper 2017-60 (September 2017).

Milani, Fabio, "Expectations, Learning and Macroeconomic Persistence," *Journal of Monetary Economics* 54:7 (2017), 2065–2082. 10.1016/j.jmoneco.2006.11.007

Mumtaz, Haroon, Saverio Simonelli, and Paolo Surico, "International Comovements, Business Cycle and Inflation: A Historical Perspective," *Review of Economic Dynamics* 14:1 (2011), 176–198. 10.1016/j.red.2010.08.002

Nakamura, Emi, and Jón Steinsson, "Price Rigidity: Microeconomic Evidence and Macroeconomic Implications," *Annual Review of Economics* 5:1 (2013), 133–163. 10.1146/annurev-economics-061109-080430

Nason, James M., and Gregor W. Smith, "Identifying the New Keynesian Phillips Curve," *Journal of Applied Econometrics* 23:5 (2008), 525–551. 10.1002/jae.1011

Ólafsson, Thorvardur Tjörvi, "The New Keynesian Phillips Curve: In Search of Improvements and Adaptation to the Open Economy," Department of Economics, Central Bank of Iceland (September 2006).

Phillips, A. W., "The Relation between Unemployment and the Rate of Change of Money Wage Rates in the United Kingdom, 1861–1957," *Economica* 25:100 (1958), 283–299.

Planas, Christophe, Alessandro Rossi, and Gabriele Fiorentini, “Bayesian Analysis of the Output Gap,” *Journal of Business and Economic Statistics* 26:1 (2008), 18–32. 10.1198/073500106000000576

Rudd, Jeremy, and Karl Whelan, “Modeling Inflation Dynamics: A Critical Review of Recent Research,” *Journal of Money, Credit and Banking* 39 (2007), 155–170. 10.1111/j.1538-4616.2007.00019.x

Sims, Christopher A., “Using a Likelihood Perspective to Sharpen Econometric Discourse: Three Examples,” *Journal of Econometrics* 95:2 (2000), 443–462. 10.1016/S0304-4076(99)00046-9

——— “Inflation Expectations, Uncertainty, the Phillips Curve, and Monetary Policy” in Jeff Fuhrer, Yolanda K. Kodrzycki, Jane Seddon Little, and Giovanni P. Olivei, eds., *Understanding Inflation and the Implications for Monetary Policy: A Phillips Curve Retrospective* (Cambridge, MA: MIT Press, 2009).

Stock, James H., and Mark W. Watson, “Why Has US Inflation Become Harder to Forecast?,” *Journal of Money, Credit and Banking* 39:S1 (2007), 3–33. 10.1111/j.1538-4616.2007.00014.x

——— “Phillips Curve Inflation Forecasts” (pp. 99–202), in Jeff Fuhrer, Yolanda K. Kodrzycki, Jane Sneddon Little, and Giovanni P. Olivei, eds., *Understanding Inflation and the Implications for Monetary Policy: A Phillips Curve Retrospective* (Cambridge, MA: MIT Press, 2009).

Tsoukis, Christopher, George Kapetanios, and Joseph Pearlman, “Elusive Persistence: Wage and Price Rigidities, the New Keynesian Phillips Curve and Inflation Dynamics,” *Journal of Economic Surveys* 25:4 (2011), 737–768. 10.1111/j.1467-6419.2009.00622.x

Yellen, Janet L., “Inflation Dynamics and Monetary Policy,” speech at the Philip Gamble Memorial Lecture, University of Massachusetts, Amherst, Amherst, MA, September 24, 2015.

——— “Macroeconomic Research after the Crisis,” speech at The Elusive “Great” Recovery: Causes and Implications for Future Business Cycle Dynamics, 60th Annual Economic Conference, Federal Reserve Bank of Boston, October 2016.