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The Great Recession and the inflation puzzle

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HIGHLIGHTS

- High unemployment was not met with deflation after the Great Recession.
- A Phillips curve with time-varying parameters fits the data reasonably well.
- Inflation expectations have become better anchored.
- The slope of the Phillips curve has flattened.
- The importance of import-price inflation has increased.

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ABSTRACT

Notwithstanding high unemployment following the Great Recession, inflation in the United States has been remarkably stable. We find that a traditional Phillips curve describes the behavior of inflation reasonably well since the 1960s. Using a non-linear Kalman filter that allows for time-varying parameters, we find that three factors have contributed to the observed stability of inflation: inflation expectations have become better anchored and to a lower level; the slope of the Phillips curve has flattened; and the importance of import-price inflation has increased.

1. Introduction

Despite high unemployment rates and perceived large output gaps following the Great Recession, inflation in the United States has remained surprisingly stable. The literature has offered several explanations for this apparently puzzling behavior of inflation. For example, Stock and Watson (2010) refer to significant changes in inflation dynamics in the United States over the past 50 years due to structural changes in the economy, namely, a falling energy share, a rising share of services, and improved monetary policy making. Ball and Mazumder (2011) find that downward wage rigidity and a flatter Phillips curve have played a role, and other studies have emphasized the role of globalization among other factors (IMF, 2006).

We assess how the determinants of inflation have evolved over time by fitting a standard open-economy Phillips curve to the US data. The novelty of our approach is that we use a non-linear Kalman filter with time-varying coefficients to examine the behavior of key parameters over time.

Our findings suggest that a traditional Phillips curve describes the behavior of inflation reasonably well in the period following the crisis. The observed stability of inflation is a result of the interaction of three factors: (i) better anchored inflation expectations; (ii) a flatter Phillips curve; and (iii) a greater role of imported inflation.

2. Model and estimation

2.1. Model

The model we use is a standard unemployment-based Phillips curve (see, for example, Ball and Mazumder, 2011). To assess the changing dynamics of inflation, we also allow the Phillips curve's parameters to vary over time. The Phillips curve is

$$\pi_t = \pi_t^e - k_t(u_t - u_t^*) + \gamma_t \widehat{\pi}_t^m + \varepsilon_t^\pi, \quad (1)$$

where π_t is the headline consumer price index (CPI) inflation, π_t^e is inflation expectations, u_t is the unemployment rate, u_t^* is the

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non-accelerating inflation rate of unemployment (NAIRU) over the medium term, $\widehat{\pi}_t^m$ is inflation in the relative price of imports (deviation from average), and ε_t^{π} is a cost-push shock. The key parameters of the Phillips curve (the slope κ_t and the importance of import-price inflation γ_t) are assumed to be time varying. Inflation expectations, the unemployment gap, and the NAIRU are assumed to evolve as follows:

$$\pi_t^e = \theta_t \overline{\pi}_t + (1-\theta_t)\,\pi_{t-1}^4 \quad (2)$$

$$\left(u_t - u_t^*\right) = \rho\left(u_{t-1} - u_{t-1}^*\right) + \varepsilon_t^{(u-u^*)}, \quad (3)$$

with

$$u_t^* = u_{t-1}^* + \varepsilon_t^{u^*}, \quad (4)$$

where $\overline{\pi}_t$ is long-run inflation expectations, π_{t-1}^4 is year-over-year headline CPI inflation (lagged one quarter), and θ_t is a time-varying weight attached to long-run inflation expectations that reflects the stability of inflation expectations. The parameters $(k_t, \gamma_t, \theta_t)$ are assumed to be constrained random walks (k_t and $\gamma_t \geq 0$ and $0 \leq \theta_t \leq 1$), while ρ, the persistence of the unemployment gap, is assumed to be constant ($0 \leq \rho \leq 1$).

2.2. Data

The data are measured at a quarterly frequency and are seasonally adjusted. The sample period covers 1961Q1–2012Q2. The relative price of imports is the import-price deflator relative to the gross domestic product (GDP) deflator. All inflation rates are annualized. The series for long-run inflation expectations is sourced from the Federal Reserve Board.

2.3. Non-linear Kalman filter with state constraints

Because our Phillips curve is non-linear in the parameters, we employ a non-linear extended Kalman filter (see Javier et al., 2011). The Kalman filter is

$$x_t = Fx_{t-1} + w_t \quad w_t \sim N(0, Q) \quad (5)$$

$$z_t = h(x_t) + v_t \quad v_t \sim N(0, R), \quad (6)$$

where x_t represents the state equations (in our case, $x_t \in [\kappa_t, \theta_t, \gamma_t, u_t - u_t^*]$), z_t represents the measurement equations, and h is a non-linear differentiable function.

The forward recursions of the filter are as follows.

Prediction	
State	$x_{t\|t-1} = x_{t\|t-1} + w_{t\|t-1}$
Covariance	$P_{t\|t-1} = F_{t-1}P_{t-1\|t-1}F_{t-1}{}' + Q$
Update	
Measurement	$\tilde{y}_t = \tilde{z}_t - h(\hat{x}_{t\|t-1})$
Covariance	$S_t = H_t\, P_{t\|t-1}H'_t + R$
Kalman gain	$K_t = P_{t\|t-1}H'_t S_{t-1}$
State	$\hat{x}_t = \hat{x}_{t\|t-1} + K_t\tilde{x}_t$
Covariance	$\hat{P}_t = (I - K_t H_t)P_{t\|t-1}$

Since h cannot be applied directly to the covariance matrix, the measurement matrix is the Jacobian:

$$H_{t-1} = \left.\frac{\partial h}{\partial x}\right|_{\hat{x}_{t-1|t-1}}. \quad (7)$$

This essentially linearizes h around the current estimate of the state vector in each prediction step.

In addition, the Kalman filter recursions are adjusted whenever the updated state vector does not satisfy the inequality constraints described in Section 2. Specifically, when one of the constraints is binding, the updated state vector is determined by a minimization problem subject to the constraints[1]:

$$\hat{x}_t^* = \min_x (x_t - \hat{x}_t)' P^{-1} (x_t - \hat{x}_t). \quad (8)$$

Essentially, this revised state vector satisfies the constraints while remaining as close as possible to the original estimate of the state vector.

The backward recursions of the filter (smoothing) for $t = T-1, \ldots, 0$ are as follows.

Kalman gain	$K_{t\|t} = P_{t\|t}H'_t P_{t+1\|t}^{-1}$
State	$\hat{x}_{t\|T} = \hat{x}_{t\|t} + K_{t\|t}(\hat{x}_{t+1\|T} - \hat{x}_{t+1\|t})$
Covariance	$P_{t\|T} = P_{t\|t} + K_{t\|t}(P_{t+1\|T} - P_{t+1\|t})K'_{t\|t}$

Similar to the forward recursions, the backward recursions are adjusted whenever the state vector does not satisfy the inequality constraints using Eq. (8).

2.4. Estimation

The parameters are estimated in two steps. First, we impose the constraints described in Section 2 and estimate 10-year rolling regressions with non-linear least squares, assuming that all parameters and the NAIRU are constant in each rolling window. These results yield initial estimates of the shock variances of k_t, θ_t, γ_t, and R. Second, we use constrained maximum likelihood to estimate the parameters.

For the parameters relating the evolution of the unemployment gap and the NAIRU (Eqs. (3) and (4)), we use the following assumptions. The persistence of unemployment gap shocks is initialized at 0.9, and the variance of unemployment gap shocks is assumed to be larger than the variance of NAIRU shocks. There is a potential identification problem in determining the relative variance of unemployment gap and NAIRU shocks, the signal-to-noise ratio S. Thus, for robustness, we calibrate two different versions of the model, one where the NAIRU is assumed to be relatively stable ($S = 15$) and one where it is relatively flexible ($S = 5$). Imposing the signal-to-noise ratio allows us to reduce the number of parameters to be estimated by one.

Our final assumption relates to how far the maximum likelihood estimates of the shock variances can deviate from the initial conditions explained above. Essentially, we restrict the shock variances to be less than or equal to those obtained from rolling regressions. This guarantees that the variability of the parameters is constrained relative to the estimates from the rolling regressions while maximizing the fit of the Phillips curve (i.e., the variance of cost-push shocks is strictly lower than the average shock variance obtained from rolling regressions).[2]

3. Results

Fig. 1 displays the one-quarter-ahead predictions (filtered) and the full-sample estimates (smoothed) of the NAIRU, inflation expectations, and the predicted values of the Phillips curve. We find that the results are qualitatively very similar for the filtered and smoothed estimates, irrespective of whether the NAIRU is assumed to be stable or flexible. Moreover, with exception of a handful of

[1] For a rigorous discussion of the extended Kalman filter with state constraints, see Dan and Chia (2002).

[2] The empirical findings are qualitatively very similar if the shock variances are assumed to be strictly larger than those obtained from rolling regressions. These results are available from the authors on request.