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Is Rotemberg pricing justified by macro data?[☆]

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HIGHLIGHTS

- In money macro, Rotemberg and Calvo pricing are two popular forms of sticky prices.
- Rotemberg pricing has grown in popularity due to its computational advantage.
- Rotemberg pricing better fits U.S. data due to differences at the zero lower bound.
- Our results indicate the recent shift to Rotemberg pricing is justified by the data.

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ABSTRACT

Structural models used to study monetary policy often include sticky prices. Calvo pricing is more common but Rotemberg pricing has become popular due to its computational advantage. To determine whether the data supports that change, we estimate a nonlinear New Keynesian model with a zero lower bound (ZLB) constraint and each type of sticky prices. The models produce similar parameter estimates and the filtered shocks are nearly identical when the Fed was not constrained, but the Rotemberg model has a higher marginal data density and it endogenously generates more volatility at the ZLB, which helps explain data from 2008–2011.

1. Introduction

Structural models used to study monetary policy often include sticky prices. The most common ways to introduce sticky prices are with Rotemberg (1982) price adjustment costs and Calvo (1983) random price changes. With Rotemberg pricing firms choose identical prices because they face the same cost, whereas with Calvo pricing firms differ based on when their price was last reset. Therefore, the Calvo model contains one additional state variable that tracks firm price dispersion.

Historically linear models provided a good approximation of the data, but the 2008 recession caused many central banks to reduce their policy rate to its zero lower bound (ZLB). The ZLB created a kink in the monetary policy rule, which required nonlinear solution and estimation techniques to accurately assess its empirical implications. Unlike linear models, the solution time in nonlinear models increases with the number of state variables. As nonlinear methods became more important, Rotemberg pricing increased in popularity.[1] To determine whether US data supports that change, we estimate a nonlinear New Keynesian model with a ZLB and each type of sticky prices.

The two pricing mechanisms produce the same dynamics with a first-order approximation of the model when trend inflation is zero

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[1] This is especially true for nonlinear estimation (Gust et al., 2016; Aruoba et al., 2016; Plante et al., forthcoming). Papers that use Calvo pricing include Fernández-Villaverde et al. (2015), Maliar and Maliar (2015), and Nakata (2015).

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or there is full indexation to inflation, but differences occur when those conditions do not hold or the solution is based on a higher-order approximation.[2] We assume full indexation to trend inflation to focus on the role of the ZLB and higher order moments. The two models produce similar parameter estimates and the filtered shocks are nearly identical when the Fed was not constrained, but the Rotemberg model has a higher marginal data density and it endogenously generates more volatility at the ZLB, which helps explain data from 2008–2011.[3]

The paper proceeds as follows. Section 2 lays out the model with Rotemberg and Calvo pricing, including the solution and estimation procedures. Section 3 compares the parameter estimates, data densities, impulse responses, shocks, and frequency/duration of ZLB events. Section 4 concludes.

2. Structural models

2.1. Households

A representative household chooses $\{c_t, n_t, b_t\}_{t=0}^{\infty}$ to maximize expected lifetime utility, $E_0 \sum_{t=0}^{\infty} \tilde{\beta}_t[\log(c_t - hc_{t-1}^a) - \chi n_t^{1+\eta}/(1+\eta)]$, where $\chi > 0$, $1/\eta$ is the Frisch elasticity of labor supply, c is consumption, c^a is aggregate consumption, h is the degree of external habit persistence, n is labor hours, b is the real value of a privately-issued 1-period nominal bond, E_0 is an expectation operator conditional on information in period 0, $\tilde{\beta}_0 \equiv 1$, and $\tilde{\beta}_t = \prod_{j=1}^{t>0} \beta_j$. To introduce fluctuations in the real interest rate, the discount factor, β, is time-varying and follows

$$\log \beta_t = (1-\rho_\beta)\log \bar{\beta} + \rho_\beta \log \beta_{t-1} + \sigma_\upsilon \upsilon_t,$$
$$0 \le \rho_\beta < 1, \ \upsilon \sim \mathbb{N}(0,1), \tag{1}$$

where $\bar{\beta}$ is the discount factor along the steady state growth path. The choices are constrained by $c_t + b_t = w_t n_t + i_{t-1} b_{t-1}/\pi_t + d_t$, where π is the gross inflation rate, w is the real wage rate, i is the gross nominal interest rate, and d is a real dividend. The household's optimality conditions imply

$$w_t = \chi n_t^\eta (c_t - hc_{t-1}^a),$$
$$1 = i_t E_t[q_{t,t+1}/\pi_{t+1}],$$

where $q_{t,t+1} \equiv \beta_{t+1}(c_t - hc_{t-1}^a)/(c_{t+1} - hc_t^a)$ is the pricing kernel between periods t and $t+1$.

2.2. Firms

The production sector consists of a continuum of monopolistically competitive intermediate goods firms owned by households and a final goods firm. Intermediate firm $f \in [0,1]$ produces a differentiated good, $y_t(f)$, according to $y_t(f) = z_t n_t(f)$, where $n(f)$ is the labor hired by firm f and $z_t = g_t z_{t-1}$ is technology. The deviations from the steady state growth rate, $\bar{g}$, follow

$$\log g_t = (1-\rho_g)\log \bar{g} + \rho_g \log g_{t-1} + \sigma_\varepsilon \varepsilon_t,$$
$$0 \le \rho_g < 1, \ \varepsilon \sim \mathbb{N}(0,1). \tag{2}$$

Each intermediate firm chooses its labor to minimize its costs, $w_t n_t(f)$, subject to its production function. The final goods firm purchases $y_t(f)$ units from each intermediate firm to produce the final good, $y_t \equiv [\int_0^1 y_t(f)^{(\theta-1)/\theta} df]^{\theta/(\theta-1)}$, where $\theta > 1$ measures the elasticity of substitution between intermediate goods. It then maximizes dividends to determine its demand function for intermediate good f, $y_t(f) = (p_t(f)/p_t)^{-\theta} y_t$, where $p_t = [\int_0^1 p_t(f)^{1-\theta} df]^{1/(1-\theta)}$ is the price level.

2.2.1. Model 1: price adjustment costs

Following Rotemberg (1982), each intermediate firm faces a cost to adjusting its price, $adj_t(f) = \varphi[p_t(f)/(\bar{\pi} p_{t-1}(f)) - 1]^2 y_t/2$, where $\varphi > 0$ scales the size of the cost and $\bar{\pi}$ is the gross inflation rate along the steady state growth path. Firm f chooses its price, $p_t(f)$, to maximize the expected discounted present value of future dividends, $E_t \sum_{k=t}^{\infty} q_{t,k} d_k(f)$, where $q_{t,t} \equiv 1$, $q_{t,k} \equiv \prod_{j=t+1}^{k>t} q_{j-1,j}$, and $d_t(f) = (p_t(f)/p_t) y_t(f) - w_t n_t(f) - adj_t(f)$. In symmetric equilibrium, firms choose the same price, so the optimality condition implies

$$\varphi(\hat{\pi}_t - 1)\hat{\pi}_t = 1 - \theta + \theta(w_t/z_t) + \varphi E_t[q_{t,t+1}(\hat{\pi}_{t+1} - 1)\hat{\pi}_{t+1}(y_{t+1}/y_t)],$$

where $\hat{\pi}_t \equiv \pi_t/\bar{\pi}$. When $\varphi = 0$, $w_t/z_t = (\theta-1)/\theta$, which is the inverse of the gross price markup.

2.2.2. Model 2: staggered prices

Following Calvo (1983), a fraction, ω, of intermediate firms cannot choose their price in a given period. Those firms index their price to steady-state inflation, so $p_t(f) = \bar{\pi} p_{t-1}(f)$. A firm that can set its price at t chooses p_t^* to maximize the expected discounted present value of future dividends, $E_t \sum_{k=t}^{\infty} \omega^{k-t} q_{t,k} d_k^*$, where $d_k^* = [(\bar{\pi}^{k-t} p_t^*/p_k)^{1-\theta} - (w_k/z_k)(\bar{\pi}^{k-t} p_t^*/p_k)^{-\theta}] y_k$. The optimality condition is given by $p_t^*/p_t = \theta x_{1,t}/((\theta-1)x_{2,t})$, where

$$x_{1,t} = (c_t - hc_{t-1})^{-1} y_t w_t/z_t + \omega E_t[\beta_{t+1}\hat{\pi}_{t+1}^{\theta} x_{1,t+1}],$$
$$x_{2,t} = (c_t - hc_{t-1})^{-1} y_t + \omega E_t[\beta_{t+1}\hat{\pi}_{t+1}^{\theta-1} x_{2,t+1}].$$

The aggregate price index and the level of price dispersion, $\Delta_t \equiv \int_0^1 (p_t(f)/p_t)^{-\theta} df$, are given by

$$\omega(\pi_t/\bar{\pi})^{\theta-1} = 1 - (1-\omega)(\mu x_{1,t}/x_{2,t})^{1-\theta},$$
$$\Delta_t = (1-\omega)(\mu x_{1,t}/x_{2,t})^{-\theta} + \omega \hat{\pi}_t^{\theta} \Delta_{t-1},$$

where $\mu = \theta/(\theta-1)$. Therefore, aggregate output is given by $y_t = z_t n_t/\Delta_t$, where $n_t \equiv \int_0^1 n_t(f)$.

2.3. Monetary policy

The central bank sets the gross nominal interest rate according to

$$i_t = \max\{\underline{\imath}, i_t^*\}, \quad i_t^* = (i_{t-1}^*)^{\rho_i} (\bar{\imath}\hat{\pi}_t^{\phi_\pi} (c_t/(\bar{g}c_{t-1}))^{\phi_c})^{1-\rho_i} \exp(\sigma_\nu \nu_t), \ 0 \le \rho_i < 1, \ \nu \sim \mathbb{N}(0,1),$$

where $\underline{\imath}$ is the lower bound, i^* is the notional rate, ϕ_π and ϕ_c are the responses to deviations of inflation from target and deviations of consumption growth from its steady state, and $\bar{\imath}$ and $\bar{\pi}$ are the inflation and interest rate targets, which equal their values along the steady state growth path.

2.4. Equilibrium

Given the unit root in technology, the model does not have a steady state. To make the model stationary, we redefine variables that grow in terms of technology (i.e., $\tilde{x}_t \equiv x_t/z_t$). In both models, the equilibrium system includes the stochastic processes, the ZLB constraint, the bond market clearing condition, $b_t = 0$, the aggregation rule, $\tilde{c}_t = \tilde{c}_t^a$, and the following equations:

$$\tilde{\lambda}_t = \tilde{c}_t - h\tilde{c}_{t-1}/g_t, \tag{3}$$
$$\tilde{w}_t = \chi n_t^\eta \tilde{\lambda}_t, \tag{4}$$
$$1 = i_t E_t[\beta_{t+1}(\tilde{\lambda}_t/\tilde{\lambda}_{t+1})(1/(g_{t+1}\bar{\pi}\hat{\pi}_{t+1}))], \tag{5}$$
$$i_t^* = (i_{t-1}^*)^{\rho_i}(\bar{\imath}\hat{\pi}_t^{\phi_\pi}(g_t\tilde{c}_t/(\bar{g}\tilde{c}_{t-1}))^{\phi_c})^{1-\rho_i}\exp(\sigma_\nu \nu_t). \tag{6}$$

[2] See, for example, Ascari et al. (2011), Ascari and Rossi (2012), Lombardo and Vestin (2008), and Nisticò (2007).

[3] Miao and Ngo (2014) compare the two pricing mechanisms in a calibrated nonlinear model with a ZLB constraint.