What is a Realistic Value for Price Adjustment Costs in New Keynesian Models?*

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Abstract

Rotemberg's [1982] price adjustment costs framework is a popular sticky price specification; yet, the data provides little information on the magnitude of those costs. This paper finds a plausible range of parameterizations for those price adjustment costs. Our results show that the specific size of the price adjustment costs depends on the average markup of price over real marginal cost and the average time firms wait to reoptimize their price. In particular, the price adjustment costs are higher when the average markup is lower and the mean time between price reoptimizations is longer.

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1 Introduction

Sticky prices is a feature incorporated into many dynamic stochastic general equilibrium models that enables monetary policy shocks to generate real effects on output. The size and persistence of output's response depends, in part, on the degree of price stickiness.[1] In models with either Taylor's [1980] pricing contracts or Calvo's [1983] random probability of price adjustment, the pricing specification is often calibrated based on the evidence that firm prices adjust, on average, once a year.[2] Empirical studies, however, fall short in providing a plausible estimate of the size of the price adjustment costs introduced in Rotemberg [1982]. As a result, the degree of price stickiness in models with Rotemberg [1982] pricing can be inadvertently too high or too low depending on the calibration of the price adjustment costs.

This paper finds a range of plausible values for Rotemberg's [1982] price adjustment costs. The exact size of price adjustment costs depends on assumptions made regarding the size of the average markup of price over marginal cost and the average time firms have between opportunities to reoptimize their price. To calculate the magnitude of the price adjustment costs, we derive the New Keynesian Phillips curves for the Rotemberg [1982] and Calvo [1983] pricing specifications and compare the coefficients on real marginal cost in both specifications.[3] We then show that the size of those adjustment costs rises as the markup of price over real marginal cost falls and as the average time between price reoptimization opportunities increases.[4] Our findings assist economists both in parameterizing price adjustment costs and in evaluating estimates of those costs in New Keynesian models of the business cycle.[5]

The remainder of the paper is organized as follows. Section 2 presents the Rotemberg [1982] and Calvo [1983] pricing specifications and derives the New Keynesian Phillips curve for each model. Section 3 uses those results to calculate a plausible value for Rotemberg's [1982] price adjustment costs as a function of the average markup of price over marginal cost and the length of time firms, on average, wait to reoptimize their price. Section 4 concludes.

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[1] Chari, Kehoe, and McGrattan [2000] show that quick price adjustment prevents models from producing persistent output effects.

[2] Rotemberg and Woodford [1997] present survey evidence supporting this claim.

[3] Ireland [2004] also refers to this relationship between the Rotemberg [1982] and Calvo [1983] pricing specifications but does not show explicitly how price adjustment costs are related to the average markup of price over marginal cost and the average time firms wait to reoptimize their price.

[4] While the microfoundations of the Rotemberg [1982] and Calvo [1983] pricing specifications are different, the resulting inflation dynamics produced by each model are the same. This identical macroeconomic behavior allows us to calibrate the Rotemberg [1982] specification by appealing to the microeconomic evidence relevant to the Calvo [1983] specification.

[5] Ireland [1997, 2001, 2003] and Kim [2000] estimate Rotemberg's [1982] price adjustment costs but have no method of evaluating the plausibility of their estimates.

2 The Models

This section outlines two popular sticky price models: the Rotemberg [1982] price adjustment costs model and the Calvo [1983] model of random price adjustment. We begin by presenting the perfectly competitive final goods market and the monopolistically competitive intermediate goods market that is common to both models. Our examination then focuses on outlining the individual features of the Rotemberg [1982] and Calvo [1983] models. In both cases, the pricing equations can be simplified to generate the New Keynesian Phillips curve where the current inflation rate is a function of the current period's real marginal cost and next period's expected inflation rate. By comparing the coefficients for both models, we can isolate a realistic value for Rotemberg's [1982] price adjustment costs in terms of the average markup of price over marginal cost and the average time firms wait to reoptimize their price.

In both models, the representative final goods firm is a perfectly competitive producer of y_t. That firm purchases $y_t(z)$ units of each intermediate good $z \in [0,1]$ at a price of $P_t(z)$. The final good, y_t, then is a Dixit and Stiglitz [1977] aggregate of intermediate goods, $y_t(z)$, such that:

$$y_t = \left[\int_0^1 y_t(z)^{(\varepsilon-1)/\varepsilon} dz\right]^{\varepsilon/(\varepsilon-1)}, \tag{1}$$

where $-\varepsilon$ is the price elasticity of demand for the intermediate good $y_t(z)$. The representative final goods firm seeks to maximize its profits:

$$P_t y_t - \int_0^1 P_t(z) y_t(z) dz \tag{2}$$

subject to (1), which yields the following demand equation for the zth intermediate good:

$$y_t(z) = \left(\frac{P_t(z)}{P_t}\right)^{-\varepsilon} y_t. \tag{3}$$

Since the perfectly competitive final goods firm earns zero profits in equilibrium, the combination of (2) and (3) indicates that P_t is the following nonlinear aggregate price index:

$$P_t = \left[\int_0^1 P_t(z)^{1-\varepsilon} dz\right]^{1/(1-\varepsilon)}. \tag{4}$$

The intermediate goods firms are monopolistically competitive producers of differentiated products. The zth firm hires labor, $n_t(z)$, and rents capital, $k_t(z)$, in perfectly competitive markets to produce its output, $y_t(z)$, according to a Cobb-Douglas production function:

$$y_t(z) = (k_t(z))^{\alpha}(n_t(z))^{1-\alpha}. \tag{5}$$

Each intermediate goods firm seeks to minimize its costs:

$$q_t k_t(z) + w_t n_t(z) \tag{6}$$

subject to (5), where q_t is the real rental rate of capital and w_t is the real wage. The resulting capital and labor demands are characterized as follows:

$$\psi_t \alpha [n_t(z)/k_t(z)]^{1-\alpha} = q_t, \tag{7}$$

$$\psi_t (1-\alpha)[k_t(z)/n_t(z)]^{\alpha} = w_t, \tag{8}$$

where ψ_t is the Lagrange multiplier from the cost minimization problem. Substituting (7) and (8) into (6), the zth firm's production costs can be stated as:

$$\psi_t y_t(z), \tag{9}$$

where alternatively ψ_t is interpreted as the real marginal cost of producing an additional unit of output. Since the real wage and rental cost of capital are economy wide costs, the capital-labor ratio and the real marginal cost will be the same for all intermediate goods firms.

2.1 Price Adjustment Costs Model

One sticky price specification used by Ireland [1997, 2001, 2003], Kim [2000], and others is based on Rotemberg's [1982] quadratic cost of nominal price adjustment. Specifically, each intermediate goods firm pays an increasing and convex cost measured in terms of aggregate output when the size of its price increase deviates from the steady state inflation rate, π. This cost is given by the following equation:

$$\frac{\phi_P}{2}\left(\frac{P_t(z)}{\pi P_{t-1}(z)} - 1\right)^2 y_t, \tag{10}$$

where $\phi_P \geq 0$ measures the degree of the price adjustment cost. Higher values of ϕ_P indicate greater price stickiness, while $\phi_P = 0$ implies that prices for intermediate goods are perfectly flexible.

Each intermediate goods firm, given its price adjustment cost in (10), seeks to maximize its present discounted value of profits for its owners:

$$E_t\left[\sum_{j=0}^{\infty} \beta^j \lambda_{t+j} \frac{D_{t+j}(z)}{P_{t+j}}\right], \tag{11}$$

where λ_t is the owners' marginal utility of an additional dollar of profits in period t and β is the discount factor. $D_t(z)/P_t$ measures the real value of an intermediate goods firm's profits during period t:

$$\frac{D_t(z)}{P_t} = \frac{P_t(z)}{P_t} y_t(z) - \psi_t y_t(z) - \frac{\phi_P}{2}\left(\frac{P_t(z)}{\pi P_{t-1}(z)} - 1\right)^2 y_t. \tag{12}$$

An intermediate goods firm's profit maximization problem then is converted into an unconstrained maximization problem by substituting its profits equation, (12), and its product demand equation, (3), into (11):

$$E_t \sum_{j=0}^{\infty} \beta^j \lambda_{t+j} \left[\left(\frac{P_{t+j}(z)}{P_{t+j}} \right)^{1-\varepsilon} y_{t+j} - \psi_{t+j} \left(\frac{P_{t+j}(z)}{P_{t+j}} \right)^{-\varepsilon} y_{t+j} - \frac{\phi_P}{2} \left(\frac{P_{t+j}(z)}{\pi P_{t-1+j}(z)} - 1 \right)^2 y_{t+j} \right].$$

Solving the profit maximization problem with respect to $P_t(z)$ yields the following first-order condition for an intermediate goods firm:

$$\begin{aligned} 0 \;=\; & (1-\varepsilon)\lambda_t \left(\frac{P_t(z)}{P_t} \right)^{-\varepsilon} \left(\frac{y_t}{P_t} \right) + \varepsilon \lambda_t \psi_t \left(\frac{P_t(z)}{P_t} \right)^{-\varepsilon-1} \left(\frac{y_t}{P_t} \right) \\ & - \phi_P \lambda_t \left(\frac{P_t(z)}{\pi P_{t-1}(z)} - 1 \right) \left(\frac{y_t}{\pi P_{t-1}(z)} \right) \\ & + \beta E_t \left[\phi_P \lambda_{t+1} \left(\frac{P_{t+1}(z)}{\pi P_t(z)} - 1 \right) \left(\frac{P_{t+1}(z) y_{t+1}}{\pi P_t(z)^2} \right) \right]. \end{aligned} \tag{13}$$

Since ψ_t and y_t are the same for all intermediate goods firms, every firm sets the same price. The combination of that result and (4) indicates that $P_t(z) = P_t$. Making this substitution into (13) yields the following equation:

$$\begin{aligned} 0 \;=\; & (1-\varepsilon)\lambda_t + \varepsilon \lambda_t \psi_t - \phi_P \lambda_t \left(\frac{\pi_t}{\pi} - 1 \right) \left(\frac{\pi_t}{\pi} \right) \\ & + \beta \phi_P E_t \left[\lambda_{t+1} \left(\frac{\pi_{t+1}}{\pi} - 1 \right) \left(\frac{\pi_{t+1}}{\pi} \right) \left(\frac{y_{t+1}}{y_t} \right) \right], \end{aligned} \tag{14}$$

where $\pi_t = P_t/P_{t-1}$. At its steady state, (14) simplifies to

$$\psi = \frac{\varepsilon - 1}{\varepsilon}. \tag{15}$$

Linear approximation of (14) around its steady state is given by

$$\widehat{\pi}_t = (\varepsilon - 1)/\phi_P \widehat{\psi}_t + \beta E_t \widehat{\pi}_{t+1}, \tag{16}$$

where $\widehat{\pi}_t$ and $\widehat{\psi}_t$ are the percent deviations of π_t and ψ_t from their respective steady states. Thus, (16) indicates that inflation is a function of expected inflation and real marginal cost. The relationship in (16) derived using price adjustment costs also is identical to the New Keynesian Phillips curve derived by Gali and Gertler [1999] and Sbordone [2002] using Calvo [1983] pricing. Therefore, we can find a realistic value for ϕ_P by comparing the coefficient on marginal cost in (16) with its corresponding value in the New Keynesian Phillips curve derived using Calvo [1983] pricing.

2.2 Calvo [1983] Pricing Model

Another sticky price specification used by Yun [1996], Erceg, Henderson, and Levin [2000], and others is a variation of Calvo [1983]. Specifically, a constant fraction of firms, $(1-\eta)$, are able to reoptimize their price, $P_t(z)$, each period. The remaining fraction of firms, η, can only increase their price by the steady state inflation rate, π. Therefore, a non-reoptimizing firm that last adjusted its price j periods ago charges a price of $\pi^j P_{t-j}(z)$. That rule allows the aggregate price index, (4), to be rewritten as follows:

$$P_t = \left[(1-\eta)P_t(z)^{1-\varepsilon} + \eta\left(\pi P_{t-1}\right)^{1-\varepsilon}\right]^{1/(1-\varepsilon)}. \tag{17}$$

In the steady state, (17) simplifies to

$$P = P(z). \tag{18}$$

Linear approximation of (17) around its steady state is given by

$$\widehat{P}_t = (1-\eta)\widehat{P}_t(z) + \eta\widehat{P}_{t-1}. \tag{19}$$

The staggered price setting behavior of Calvo [1983] makes an intermediate goods firm's profit maximization problem dynamic. The price reoptimizing firm seeks to set a price, $P_t(z)$, that maximizes the present value of expected future profits to its owners:

$$E_t\left[\sum_{j=0}^{\infty}\beta^j\eta^j\lambda_{t+j}\frac{D_{t+j}(z)}{P_{t+j}}\right], \tag{20}$$

where λ_t is the owners' marginal utility of an additional dollar of profits in period t, β is the discount factor, and $D_t(z)/P_t$ measures the real value of an intermediate goods firm's profits in period t:

$$\frac{D_{t+j}(z)}{P_{t+j}} = \left(\frac{\pi^j P_t(z)}{P_{t+j}}y_{t+j}(z) - \psi_{t+j}y_{t+j}(z)\right). \tag{21}$$

When (21) and (3) are substituted into (20), the optimizing firm's profit maximization problem is

$$E_t\left[\sum_{j=0}^{\infty}\beta^j\eta^j\lambda_{t+j}\left(\left(\frac{\pi^j P_t(z)}{P_{t+j}}\right)^{1-\varepsilon} - \psi_{t+j}\left(\frac{\pi^j P_t(z)}{P_{t+j}}\right)^{-\varepsilon}\right)y_{t+j}\right]. \tag{22}$$

Taking the derivative of (22) with respect to $P_t(z)$ yields the following first-order condition:

$$\sum_{j=0}^{\infty}\beta^j\eta^j E_t\left[\left(\lambda_{t+j}y_{t+j}\right)\left((1-\varepsilon)P_t(z)\left(\pi^{-j}P_{t+j}\right)^{\varepsilon-1} + \varepsilon\psi_{t+j}\left(\pi^{-j}P_{t+j}\right)^{\varepsilon}\right)\right] = 0. \tag{23}$$

Using the steady state value in (18), the steady state relationship for (23) is

$$\psi = \frac{\varepsilon - 1}{\varepsilon},$$

which is identical to the steady state relationship for the Rotemberg [1982] price adjustment costs model, (15). The linear approximation of (23) around its steady state then is equal to

$$\widehat{P}_t(z) = (1 - \beta\eta) \sum_{j=0}^{\infty} \beta^j \eta^j \left(\widehat{P}_{t+j} + \widehat{\psi}_{t+j} \right). \tag{24}$$

Finally, substituting (19) into (24) and setting $\widehat{\pi}_t = \widehat{P}_t - \widehat{P}_{t-1}$ enables us to generate the New Keynesian Phillips curve equation utilized by Gali and Gertler [1999] and Sbordone [2002]:

$$\widehat{\pi}_t = [(1 - \eta)(1 - \beta\eta)/\eta]\widehat{\psi}_t + \beta E_t \widehat{\pi}_{t+1}. \tag{25}$$

Given (25), we can now find a plausible value for ϕ_P in Rotemberg's [1982] price adjustment costs model.

3 Results

The New Keynesian Phillips curves produced using the Rotemberg [1982] and Calvo [1993] pricing specifications, (25) and (16), respectively, have the same structure:

$$\widehat{\pi}_t = b\widehat{\psi}_t + \beta E_t \widehat{\pi}_{t+1}. \tag{26}$$

Thus, the coefficient on real marginal cost in (26), b, is the link between Rotemberg's [1982] price adjustment costs parameter, ϕ_P, and Calvo's [1983] constant fraction of reoptimizing firms, $(1 - \eta)$. In the Rotemberg [1982] specification, the coefficient on marginal cost is

$$b = (\varepsilon - 1)/\phi_P, \tag{27}$$

while in the Calvo [1983] specification the coefficient is

$$b = (1 - \eta)(1 - \beta\eta)/\eta. \tag{28}$$

By setting the coefficient in (27) equal to (28) and solving for ϕ_P, we generate the following relationship between the price adjustment costs parameter, ϕ_P, and the constant fraction of reoptimizing firms, $(1 - \eta)$:

$$\phi_P = [(\varepsilon - 1)\eta]/[(1 - \eta)(1 - \beta\eta)]. \tag{29}$$

The result in (29) indicates that a realistic value for ϕ_P depends on the constant fraction of reoptimizing firms, $(1 - \eta)$, the price elasticity of demand, ε, and the discount factor, β. All of those parameters are straightforward to calibrate. We begin by setting β equal to 0.99. The value set for ε usually is expressed in terms of the gross steady state markup of price over marginal cost, μ. That markup is just the inverse of the steady state real marginal cost, which is identical in both of our models. As a result, μ is a function of ε such that:

$$\mu = \varepsilon/(\varepsilon - 1).$$

Since assumptions in the sticky price literature about the steady state markup range from 10% to 40%, we examine four different values for μ: $\mu = 1.1$ ($\varepsilon = 11$), $\mu = 1.2$ ($\varepsilon = 6$), $\mu = 1.3$ ($\varepsilon = 4.3$), and $\mu = 1.4$ ($\varepsilon = 3.5$). Parameterization of $(1 - \eta)$ is often set based on the average frequency at which a firm reoptimizes its price. In the Calvo [1983] framework, the average frequency of price reoptimization is $1/(1 - \eta)$. Carlton [1986] shows that firms, on average, set new prices every 4 to 13 months depending on the product. Therefore, we examine values for the average frequency of price reoptimization at intervals of 4, 6, 12, and 15 months which in a quarterly model translates into values for $(1 - \eta)$ of 0.75, 0.50, 0.25, and 0.20, respectively.

Table 1: The Implied Value of the Price Adjustment Costs, ϕ_P

	Percent of Reoptimizing Firms, $(1-\eta)$			
Steady State Markup	0.20	0.25	0.50	0.75
$\mu = 1.1$	192.308	116.505	19.802	4.430
$\mu = 1.2$	96.154	58.252	9.901	2.215
$\mu = 1.3$	64.103	38.835	6.601	1.477
$\mu = 1.4$	48.077	29.126	4.950	1.107

Table 1 shows the implied value of ϕ_P in the Rotemberg [1982] price specification based on different assumptions for the steady state markup, μ, and the percent of reoptimizing firms, $(1 - \eta)$. Our results show that the value for ϕ_P varies from 1.107 to 192.308 depending on the parameterization of μ and $(1 - \eta)$. As the assumptions on μ and $(1 - \eta)$ are restricted, the range of realistic values for ϕ_P narrows. Suppose, for example, μ is set to 1.2 and $(1 - \eta)$ is assumed to be between 0.20 and 0.25, the range of plausible values for ϕ_P then would be between 58.252 and 96.154. Overall, the size of ϕ_P increases as the steady state markup, μ, declines and decreases as the percent of reoptimizing firms, $(1-\eta)$, increases. That is, the aggregate price response is more sluggish when firms have less market power (i.e., lower markups) and when firms, on average, go longer between opportunities to reoptimize their price.

Our results benefit both calibrated and estimated models with Rotemberg [1982] price adjustment costs. In calibrated models, assumptions for μ and $(1-\eta)$ determine the value for ϕ_P. In estimated models, an estimated value of ϕ_P given a value for μ is used to generate an implied value for $(1 - \eta)$. That value then is compared with empirical estimates to evaluate the plausibility of the estimated value for ϕ_P. For example, Ireland's [2001] estimates for ϕ_P of 72.01 and 77.10, assuming $\mu = 1.20$, implies an average of 12 to 15 months between price reoptimization opportunities, which is consistent with empirical evidence.

4 Conclusion

Price stickiness is an important feature in many New Keynesian models because it enables monetary policy shocks to have real effects on the economy. One of the most popular sticky price specifications is Rotemberg's [1982] model of price adjustment costs. The data, however, provides little information on the exact size of those costs. Without a reliable measure of the costs, New Keynesian models are likely to produce inaccurate responses in real variables to a monetary policy shock. This paper remedies the problem by finding a measure of Rotemberg's [1982] price adjustment costs that is consistent with parameter values which are straightforward to calibrate.

Our results show that the realistic value for Rotemberg's [1982] price adjustment costs depends on the average steady state markup of price over marginal cost and the amount of time firms, on average, wait between price reoptimizations. Specifically, the value of those price adjustment costs is higher when the steady state markup is lower and the average wait time for price reoptimization is longer. By establishing that relationship, macroeconomists can now parameterize calibrated New Keynesian models with more precision and evaluate estimated New Keynesian models with more accuracy.

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