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Abstract

This paper evaluates state-dependence in monetary policy transmission mechanism under Calvo and Rotemberg price adjustment schemes. Although the two models are equivalent to first order, they produce very different results once considered at a higher order. In particular, the Rotemberg model produces more state-dependence compared to the Calvo model. The result is reversed once the macroeconomic wedges are eliminated from the models.

JEL codes: E30, E32, E50, E52.

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1 Introduction

This paper evaluates the state-dependent effects of monetary policy in calvo-pricing and rotemberg-pricing models. To that end, I calibrate the two versions of the model to be identical to first order, however solve the models via a second order approximation. In the latter case, the effects of monetary shocks depend on the initial state vector. First, I simulate both variants of the model many times. The generated sample of points can be considered as the ergodic distribution of the state vectors. I next compute the responses of output and inflation to a policy shock at each realization of the state vectors. The state-dependent effects of policy shocks are more pronounced in the Rotemberg model than in the Calvo model. When I shut down the wedges in both models[1] the results are reversed.

This paper is related to the literature that compares Calvo and Rotemberg price setting schemes. Ascari and Rossi (2012) show that under trend inflation, the two models behave differently in response to macroeconomic shocks. Miao and Ngo (2018) compare the behaviour of Calvo and Rotemberg models at the zero lower bound. They show that the Calvo model generates larger deflations and deeper recessions. Additionally, they argue that the models without wedges behave similarly. The current paper also finds that in the two models without wedges policy shocks have similar average effects across the state space. However, the response variability of the variables is considerably higher in the Calvo version of the model. From the methodological perspective, the current research is closest to Sims and Wolf (2017) who compare state-dependent effects of fiscal policy in a New Keynesian model with Calvo and Rotemberg price adjustment schemes. This paper differs from theirs in focusing on asymmetries in monetary policy transmission mechanism.

2 Models

I present two otherwise identical New Keynesian models with different pricing schemes. Both models are populated by a representative household, a representative competitive final goods firm, a continuum of competitive monopolists that produce intermediate goods, and a central bank.

The household maximizes the present discounted value of flow utility from consump-

[1] The Calvo model creates a wedge between aggregate hours and aggregate output, through price dispersion. The Rotemberg model assumes a quadratic cost of adjusting prices, that generates a wedge between output and consumption.

tion, and labor(leisure):

$$U(C_t, N_t) = E_0 \sum_{t=0}^{\infty} \beta^t d_t \{\ln C_t - \gamma \frac{N^{1+\psi}}{1+\psi}\} \tag{1}$$

The optimality conditions for the household are given by:

$$\frac{\partial U(t)}{\partial N_t} = \frac{\partial U(t)}{\partial C_t} w_t \tag{2}$$

$$\frac{\partial U(t)}{\partial C_t} = E_t \frac{\partial U(t+1)}{\partial C_{t+1}} \frac{1+i_t}{1+\pi_{t+1}} \tag{3}$$

(1) is the labor supply schedule and (2) is the consumption Euler equation. C_t is consumption, N_t is labor supply, and w_t is the real wage. Next, i_t and π_t are the interest rate and the inflation rate, respectively. Finally, d_t is a preference shock:

$$\ln d_t = \rho_d \ln d_{t-1} + e_{d,t}, \quad e_{d,t} \sim (0, \sigma_d^2) \tag{4}$$

The monetary policy rule is given by:

$$i_t = (1-\rho_i)i + \rho_i i_{t-1} + (1-\rho_i)[\phi_\pi(\pi_t - \pi) + \phi_Y(\ln Y_t - \ln Y)] + e_{i,t} \tag{5}$$

Y_t is output and $e_{i,t}$ is monetary policy shock($e_{i,t} \sim N(0, \sigma_i^2)$). The entries without time subscript denote corresponding non-stochastic steady-state values.

Intermediate producers operate according to a constant returns to scale technology in labor, with a common productivity shock:

$$Y_{j,t} = A_t N_{j,t} \tag{6}$$

where A_t follows an $AR(1)$ process:

$$\ln A_t = \rho_A \ln A_{t-1} + e_{a,t}, \quad e_{a,t} \sim N(0, \sigma_a^2) \tag{7}$$

Real marginal cost is common to all intermediate firms:

$$mc_t = \frac{w_t}{A_t}$$

2.1 Calvo Pricing

According to Calvo (1983), in each period a firm j keeps its previous price with probability θ and adjusts its price with probability $1-\theta$. Inflation is given by:

$$\pi_t = [(1-\theta)(1+\pi_t^{op})^{1-\epsilon} + \theta]^{\frac{1}{1-\epsilon}} - 1 \tag{8}$$

where

$$\frac{1+\pi_t^{op}}{1+\pi_t} = \frac{\epsilon}{\epsilon-1}\frac{X_{1,t}}{X_{2,t}}u_t \tag{9}$$

$$X_{1,t} = \frac{\partial U(t)}{\partial C_t}Y_t mc_t + \beta\theta E_t(\pi_{t+1}+1)^{\epsilon}X_{1,t+1} \tag{10}$$

$$X_{2,t} = \frac{\partial U(t)}{\partial C_t}Y_t + \beta\theta E_t(\pi_{t+1}+1)^{\epsilon-1}X_{2,t+1} \tag{11}$$

$$\ln u_t = \rho_u \ln u_{t-1} + e_{u,t}, \;\; e_{u,t} \sim N(0,\sigma_u^2) \tag{12}$$

Aggregate output satisfies:

$$Y_t = \frac{A_t N_t}{\Delta_t} \tag{13}$$

Δ_t describes the dynamics of price dispersion and is given by:

$$\Delta_t = ((1-\theta)(\pi_t^{op}+1)^{-\epsilon} + \theta\Delta_{t-1})(\pi_t+1)^{\epsilon} \tag{14}$$

Finally, the resource constraint is given by:

$$Y_t = C_t \tag{15}$$

2.2 Rotemberg Pricing

In Rotemberg (1982), each intermediate firm j faces quadratic costs of adjusting prices in terms of final goods:

$$\frac{\eta}{2}(\frac{P_{j,t}}{P_{j,t-1}} - 1)^2 Y_t \tag{16}$$

where η is the adjustment cost parameter.

In symmetric equilibrium, the firms choose the same price and produce the same quantity. Inflation evolves as:

$$1-\eta\pi_t(\pi_t+1)+\eta\beta E_t[\frac{\frac{\partial U(t+1)}{\partial C_{t+1}}}{\frac{\partial U(t)}{\partial C_t}}\pi_{t+1}(\pi_{t+1}+1)\frac{Y_{t+1}}{Y_t}]=(1-u_t mc_t)\epsilon \tag{17}$$

The resource constraint and aggregate output are given by:

$$Y_t=\Phi_t C_t,\ \ \Phi_t=\frac{1}{1-\frac{\eta}{2}(\pi_t)^2} \tag{18}$$

$$Y_t=A_t N_t \tag{19}$$

2.3 Calibration

The parameter values are set to match the conventional values in the literature. I set $\theta=0.75$ in the Calvo model. The latter implies that price contracts last, on average, 4 quarters. The parameter η in the Rotemberg model is set to $\eta=\frac{\theta(\epsilon-1)}{(1-\theta)(1-\theta\beta)}=58.25$. This ensures that the two models are equivalent to first order. Table 1 below summarizes the parameter values used in the quantitative simulations. The assigned parameter values imply that productivity shocks explain about 42.5 percent of the unconditional variance of output. Meanwhile, preference, price markup and monetary policy shocks account for 49, 6.5 and 2 percent of the unconditional variance of output, respectively.

Table 1. Parameter Values

Parameter	Description	Value/Target
β	Time discount factor	0.99
γ	Labor disutility	$\bar{N}=\frac{1}{3}$
ψ	Inverse of Frisch elasticity	2
θ	Price stickiness in Calvo model	0.75
η	Price stickiness in Rotemberg model	$\frac{\theta(\epsilon-1)}{(1-\theta)(1-\theta\beta)}$
ϵ	Price elasticity of demand	6
ρ_i	Interest rate smoothing	0.8
Φ_π	Inflation response	1.5
Φ_y	Output response	0.15
π	Inflation target	0
ρ_d	Preference shock persistence	0.6
ρ_A	Productivity shock persistence	0.9
ρ_u	Price markup shock persistence	0.8
σ_d	SD-preference shock	0.03
σ_A	SD-productivity shock	0.01
σ_u	SD-price markup shock	0.02
σ_i	SD-monetary policy shock	0.0015

Notes: The table shows the baseline parameter values used simulations. $\bar{N}$ denotes the steady-state value of labor supply.

3 Main Results

For each version of the model, I generate 5500 periods of data and discard the first 500 periods as a burn-in. From the remaining 5000 state vectors, I compute the generalized impulse response functions to an expansionary one standard deviation shock to monetary policy. The impulse responses are computed via simulations similar to Koop et. al. (1996). Given the vector of initial states, the model is simulated by drawing random sequences of shocks. These are control simulations. Next, the same sequence of shocks is taken and a monetary impulse is added. The model is simulated with the latter realization of shocks. This procedure is repeated 100 times. The response is the difference between the mean paths of the simulations with the impulse and the control simulations. Table 2 reports key statistics on the mean, minimum, and maximum values of output and inflation responses to a policy shock across the 5000 simulated state vectors. It also presents the standard

Table 2. State-dependent effects of monetary policy under Calvo and Rotemberg pricing

		Calvo Benchmark	Rotemberg Benchmark	Calvo $\Delta = 1$	Rotemberg $\Phi = 1$
Output	Minimum	0.3005	0.1594	0.2875	0.3247
	Maximum	0.3557	0.4531	0.3752	0.3358
	Mean	0.3283	0.3327	0.3289	0.3296
	Standard Deviation	0.0079	0.0387	0.0128	0.0015
	First order	0.33	0.33	0.33	0.33
Inflation	Minimum	0.1338	0.1394	0.1119	0.1605
	Maximum	0.1978	0.1799	0.2116	0.1678
	Mean	0.1650	0.1640	0.1645	0.1637
	Standard Deviation	0.0091	0.0053	0.0144	0.0009
	First order	0.16	0.16	0.16	0.16

Notes: The table shows statistics for output and inflation responses to a monetary shock in the Calvo and Rotemberg variants of the New Keynesian model. To compute the numbers in the table, I generate 5500 periods from the model, drop the first 500 periods as a "burn-in", and compute the generalized impulse responses at each of the remaining 5000 state vectors. The statistics are computed from the resulting distribution of responses.

deviations of responses to provide a measure of volatility.[2] The average responses for output and inflation are very close to one another in two models. Meanwhile, output response in the benchmark Rotemberg model is considerably more volatile than in the benchmark Calvo model. The standard deviation of output response in Robemberg model is nearly five times larger than in Calvo model. The min-max range of output response in Rotemberg model is $0.16 - 0.45$ while in Calvo model it is just $0.3 - 0.36$. At the same time, inflation response distribution across the states is more dispersed in the Calvo model than in the Rotemberg model. In the Rotemberg model, output costs of a price change vary significantly across the states due to quadratic adjustment term. The Calvo model, by contrast, does not assume direct output costs of price adjustment. Instead, it creates a price dispersion term that produces a wedge between output and labor and acts as a productivity shift. Furthermore, price dispersion is a backward-looking variable and cannot produce sudden changes in output. The proceeding analysis shows that, under zero-trend inflation, the price dispersion actually dampens asymmetries in policy transmission mechanism. In sum, the Rotemberg model generates more state dependence in output than the Calvo model. This result is in line with that of Sims and Wolf (2017), who find similar results for state-dependent effects of fiscal policy.

I next assess state-dependent effects of monetary policy when the aggregate wedges are eliminated from both models. In the Calvo model, I set the relative price dispersion to

[2]The statistics are computed based on maximum responses of output and inflation in percentage terms. Both in Calvo and Rotemberg models, the latter coincide with the impact responses.

be one, $\Delta_t = 1$.[3] In the Rotemberg model, I eliminate the price adjustment costs from the aggregate resource constraint, $\Phi_t = 1$. At the same time, these costs of are still borne by firms.[4] The third and the fourth columns of Table 2 report the simulation results for both economies without wedges. Compared to the benchmark, the Calvo model without the aggregate wedge amplifies asymmetries in the monetary transmission mechanism. The mean responses of output and inflation are similar to one anther in the two versions of the Calvo model. Meanwhile, the standard deviation of responses in the model without a wedge is notably larger than that in the benchmark model. In fact, the price dispersion term mitigates state-dependence in policy transmission as it introduces an inertial mechanism in the model for its backward looking behavior.

As for the Rotemberg model, eliminating the aggregate wedge, on the contrary, dampens the state-dependent effects of monetary policy. Shutting down the output costs of price adjustment lowers the variability of output response across the states. The latter translates into weaker state-dependence in inflation response through lower variability of marginal cost response. Note that the latter results are quite different from that of Miao and Ngo (2019) who find that the two variants of the NK models behave similarly once the wedges are eliminated.

4 Conclusion

This paper studies asymmetric effects of monetary policy in both the Calvo and Rotemberg models of price stickiness. Although the models are identical to first order, there are notable differences in state-dependent effects of policy shifts. I find that the Rotemberg model generates more state dependence in output than the Calvo model. These results are reversed when the price dispersion term and the aggregate resource cost are eliminated from the models.

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[3] One could alternatively adopt the assumption of industry-specific labor markets as in Eggertsson and Woodford (2003). As a result, price dispersion ceases to be a state variable.

[4] The price adjustment costs are simply rebated to the household.

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