Real Wage Rigidities and Disinflation Dynamics: Calvo vs. Rotemberg Pricing

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Abstract

Calvo and Rotemberg pricing entail a very different dynamics of adjustment after a disinflation once non-linear simulations are employed. In the Calvo model disinflation implies output gains and real wage rigidities generate a long-lasting boom in output. In Rotemberg model disinflation implies output losses and real wage rigidities cause an output slump along the adjustment path.

Keywords: Disinflation, Sticky Prices, Real Wage Rigidity, Nonlinearities
JEL classification: E31, E5.

1 Introduction

The Calvo (1983) price-setting mechanism produces relative-price dispersion among firms, while the Rotemberg (1982) model is consistent with a symmetric equilibrium. Despite this economic difference to a first order approximation the two models are equivalent and, as shown by Rotemberg (1987) and Roberts (1995), imply the same reduced form New Keynesian Phillips curve. Moreover, Nisticò (2007), shows that up to a second order approximation, if the steady state is efficient, both models imply the same welfare costs of inflation. Only recently, Lombardo and Vestin (2008) show that they might entail different welfare costs at higher order of approximation. Therefore, except for welfare consideration, there is widespread agreement in the literature that the two models imply the same dynamics. Furthermore, both models deliver the well-known result of immediate adjustment of the economy to the new steady state following a disinflation, despite nominal rigidities in price-setting (see, e.g., Ball, 1994 and Mankiw, 2001). In a very insightful paper Blanchard and Galí (2007), suggest that real wage rigidities is an important feature that restores realistic output cost of disinflation in the linearized Calvo model. Ascari and Merkl (2009), instead, show that studying the non-linear dynamics of the Calvo model, real wage rigidities actually create a boom in output, rather than a slump. A result which thus seems to be strongly at odds with the conventional view. In this paper, we show that the non-linear disinflation dynamics implied by the two pricing model is very different. In particular, the non-linear dynamics of the Rotemberg model restores results similar to the log-linear disinflation dynamics: (i) flexible real wage imply an immediate adjustment of output to its new steady state after a permanent disinflation; (ii) real wage rigidities imply a significant output slump along the adjustment path. Results on which there seems to be consensus in the literature. In sum, we state that inferring the effects of permanent shocks through log-linearized model would not lead to big mistakes, as in the Calvo model. Therefore, the Rotemberg model seems to be more robust to non-linearities.

2 The Model

2.1 Household

Given the separable utility function

$$U\left(C_t\left(h\right), N_t\left(h\right)\right) = \frac{C_t^{1-\sigma}}{1-\sigma} - d_n \frac{N_t^{1+\varphi}\left(h\right)}{1+\varphi},$$

and the budget constraint: $P_t C_t + \left(1+i_t\right)^{-1} B_t = W_t N_t - T_t + \Pi_t + B_{t-1}$, where i_t is the nominal interest rate, B_t are one-period bond holdings, W_t is the nominal wage rate, N_t is the labor input, T_t are lump sum taxes, and Π_t is the profit income, then the first order conditions with respect to C_t, B_t and N_t are:

$$\frac{1}{C_t^{\sigma}} = \beta E_t\left[\left(\frac{P_t}{P_{t+1}}\right)\left(1+i_t\right)\left(\frac{1}{C_{t+1}^{\sigma}}\right)\right] \quad (1)$$

$$\frac{W_t}{P_t} = -\frac{U_N}{U_C} = \frac{d_n N_t^{\varphi}}{1/C_t^{\sigma}} = d_n N_t^{\varphi} C_t^{\sigma}. \quad (2)$$

which represent the consumption Euler equation and the labor supply. We introduce real wage rigidities in the same way as Blanchard and Galí (2007), that is

$$\frac{W_t}{P_t} = \left(\frac{W_{t-1}}{P_{t-1}}\right)^{\gamma}\left(-\frac{U_{N_t}}{U_{C_t}}\right)^{1-\gamma}, \quad (3)$$

which means that for sufficiently high value of γ, the model implies a sluggish adjustment of real wages.

2.2 Firms and Price Settings

Final good producers use the following technology: $Y_t = \left[\int_0^1 Y_{i,t}^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}$. Their demand for intermediate inputs is therefore equal to $Y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\varepsilon} Y_t$.

The intermediate good sector is monopolistically competitive and the production function of each firm is given by: $Y_{i,t} = N_{i,t}$.

The Calvo model

The Calvo model assumes that each period there is a fixed probability $1-\theta$ that a firm can re-optimize its nominal price, i.e., $P_{i,t}^*$. The price setting problem becomes:

$$\begin{aligned} &\max_{\{P_{i,t}\}_{t=0}^{\infty}} \quad E_t \sum_{j=0}^{\infty} \mathcal{D}_{t,t+j}\theta^j \left[\frac{P_{i,t}^*}{P_{t+j}} - MC_{t+j}^r\right] Y_{i,t+j}, \\ &\text{s.t. } Y_{i,t+j} = \left[\frac{P_{i,t}^*}{P_{t+j}}\right]^{-\varepsilon} Y_{t+j} \end{aligned}$$

the equation for the optimal price is:

$$P_{i,t}^* = \frac{\varepsilon}{\varepsilon-1}\frac{E_t \sum_{j=0}^{\infty}\theta^j \mathcal{D}_{t,t+j} P_{t+j}^{\varepsilon} Y_{t+j} MC_{t+j}^r}{E_t \sum_{j=0}^{\infty}\theta^j \mathcal{D}_{t,t+j} P_{t+j}^{\varepsilon-1} Y_{t+j}}, \quad (4)$$

while the aggregate price dynamics is given by: $P_t = \left[\theta P_{t-1}^{1-\varepsilon} + (1-\theta)\left(P_{i,t}^{*}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$. The Calvo model is characterized by the presence of price dispersion which results in an inefficiency loss in aggregate production. In fact

$$N_t^d = \int_0^1 N_{i,t}^d di = \int_0^1 \frac{Y_{i,t}}{A_t} di = \frac{Y_t}{A_t} \underbrace{\int_0^1 \left[\left(\frac{P_{i,t}}{P_t}\right)^{-\varepsilon} di\right]}_{s_t} = s_t \frac{Y_t}{A_t}. \tag{5}$$

Schmitt-Grohé and Uribe (2007) show that s_t is bounded below at one, so that s_t represents the resource costs due to relative price dispersion under the Calvo mechanism. Indeed, the higher s_t, the more labor is needed to produce a given level of output. To close the model, the aggregate resource constraint is simply given by: $Y_t = C_t$.

The Rotemberg model
The Rotemberg model assumes that a monopolistic firm faces a quadratic cost of adjusting nominal prices, that can be measured in terms of the final-good and given by

$$\frac{\varphi}{2}\left(\frac{P_{i,t}}{P_{i,t-1}} - 1\right)^2 Y_t, \tag{6}$$

where $\varphi > 0$ determines the degree of nominal price rigidity. The adjustment cost increases in magnitude with the size of the price change and with the overall scale of economic activity, Y_t. The problem for the firm is then:

$$\max_{\{P_{i,t}\}_{t=0}^{\infty}} E_t \sum_{j=0}^{\infty} \mathcal{D}_{t,t+j} \left\{ \left(\frac{P_{i,t+j}}{P_{t+j}} - MC_{t+j}^r\right) Y_{i,t+j} - \frac{\varphi}{2}\left(\frac{P_{i,t+j}}{P_{i,t+j-1}} - 1\right)^2 Y_{t+j} \right\},$$
$$\text{s.t. } Y_{i,t+j} = \left[\frac{P_{i,t+j}}{P_{t+j}}\right]^{-\varepsilon} Y_{t+j}.$$

where $\mathcal{D}_{t,t+j} \equiv \beta^j \frac{U_c(t+j)}{U_c(t)}$ is the stochastic discount factor, $MC_{t+j}^r = \frac{W_{t+j}}{P_{t+j}A_{t+j}}$ is the real marginal cost function. Firms can change their price in each period, therefore, from the first order condition, after imposing the symmetric equilibrium, we get

$$1 - \varphi(\pi_t - 1)\pi_t + \varphi\beta E_t \left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \left[(\pi_{t+1} - 1)\pi_{t+1}\frac{Y_{t+1}}{Y_t}\right] = (1 - MC_t^r)\varepsilon. \tag{7}$$

where $\pi_t = \frac{P_t}{P_{t-1}}$. Since all the firms will employ the same amount of labor, the aggregate production function is simply given by $Y_t = N_t$. The aggregate resource constraint should take the adjustment cost into account, that is: $Y_t = C_t + \frac{\varphi}{2}(\pi_t - 1)^2 Y_t$. For what follows, it is important to note that the Rotemberg adjustment cost model creates an inefficiency wedge, Ψ_t, between output and consumption:

$$Y_t = \left[\frac{1}{1 - \frac{\varphi}{2}(\pi_t - 1)^2}\right] C_t = \Psi_t C_t. \tag{8}$$

In the Rotemberg model, the cost of nominal rigidities, i.e., the adjustment cost, creates *a wedge between aggregate consumption and aggregate output*, (8), because part of the output goes in the price adjustment cost. In the *Calvo* model, instead, the cost of nominal rigidities, i.e., price dispersion, creates *a wedge between aggregate employment and aggregate output*, (5), making aggregate production less efficient. Both of these wedges are *non-linear functions of inflation.* They are minimized at one when steady state inflation equals zero, while both wedges increase as trend inflation moves away from zero.

3 Disinflation

3.1 The Steady State and the Long-run Phillips Curve

We first look at the steady state of the two models, and in particular at the implications for the long-run Phillips Curve.

The Calvo model
Ascari (2004), Yun (2005), show that the long-run Phillips Curve is negatively sloped: positive long-run inflation reduce output, because it increases price dispersion. Higher price dispersion acts as a negative productivity shift, because $Y = \left(\frac{N}{s}\right)$. Thus, the steady state real wage lowers with trend inflation, and so does consumption and leisure, so that actually steady state employment increases. As a consequence, steady state welfare decreases.

The Rotemberg model
The long-run Phillips Curve in the Rotemberg model is equal to:

$$Y = \left[\frac{\frac{\varepsilon-1}{\varepsilon} + \frac{(1-\beta)}{\varepsilon}\varphi\left(\bar{\pi}-1\right)\bar{\pi}}{d_n\left(1-\frac{\varphi}{2}\left(\bar{\pi}-1\right)^2\right)^{\sigma}} \right]^{\frac{1}{\varphi+\sigma}}. \tag{9}$$

It is easy to show that this implies that $\bar{\pi} \geqq 1 \Longrightarrow \frac{dY}{d\bar{\pi}} > 0$, so that the minimum of output occurs at negative rate of steady state inflation, unless $\beta = 1$. This is a "time discounting effect": in changing the price, a firm would weight relatively more today adjustment cost of moving away from yesterday price, than the tomorrow adjustment cost of fixing a new price away from the today's one. As in the Calvo model, the discounting effect tends to reduce average mark-up. But unlike the Calvo model, there is no price dispersion that interact with trend inflation, and thus this is the only effect of trend inflation on the price setting decision. Indeed, the steady state mark-up is given by

$$markup = \left[\frac{\varepsilon-1}{\varepsilon} + \frac{(1-\beta)}{\varepsilon}\varphi\left(\bar{\pi}-1\right)\bar{\pi}\right]^{-1} \tag{10}$$

which is monotonically decreasing in $\bar{\pi}$, for positive trend inflation ($\bar{\pi} > 1$). The fact that the mark-up decreases with trend inflation makes output to increase with trend inflation. However, a fraction of output is not consumed, but it is eaten up by the adjustment cost. The higher trend inflation, the more output is produced, but the less is consumption. Opposite to the Calvo model, then, output is increasing with trend inflation, but, as in the Calvo model, employment is increasing, while consumption and welfare are decreasing with trend inflation (see Figure 1).[1]

[1] We consider the following rather standard parameters specification (see Section 3.2): $\sigma = 1$, $\beta = 0.99$, $\varepsilon = 10$, $\phi = 1$, $\theta = 0.75$. We set the cost of adjusting prices $\varphi = \frac{(\varepsilon-1)\theta}{(1-\theta)(1-\beta\theta)}$, to generate a slope of the log-linear Phillips curve equal to one we get in the Calvo model. However, none of the results qualitatively depends on the parameters values.

- Figure 1 about here -

As we will see, the opposite slope of the long-run Phillips Curve between the two models determines a very different short-run adjustment in the non-linear dynamics following a permanent shift in the central bank inflation target.

3.2 Disinflation and Real Wage Rigidities

We now look at an unanticipated and *permanent* reduction in the inflation target of the Central Bank (CB) from 4% to zero. We plot the path for output, inflation, nominal interest rate, and real wages under different degrees of real wage rigidities.[2] The CB follows a standard Taylor rule, i.e.,

$$\left(\frac{1+i_t}{1+\bar{\imath}}\right)=\left(\frac{\pi_t}{\bar{\pi}}\right)^{\alpha_\pi}\left(\frac{Y_t}{\bar{Y}}\right)^{\alpha_y}. \tag{11}$$

We consider the parameters specification, as in (1), which coincides with the one used by Ascari and Merkl (2009). We set $\alpha_\pi = 1.5$ and $\alpha_y = 0.125$.

The Calvo model
Figure 2 replicates Ascari and Merkl (2009) experiment. Real wage rigidities have a rather surprising implication on the economy dynamics: output increases after disinflation and overshoots above its new permanent natural level. The higher the degree of real wage rigidities γ, the more likely is the overshooting of output.

- figure 2 about here -

The intuition is straightforward. As shown by Ascari and Merkl (2009), unlike in the log-linear model, a disinflation experiment increases the permanent steady state level of output. With flexible real wages a disinflation leads to a short-run overshooting of the real wage over its new higher long-run value. With real wage rigidities, real wage adjusts sluggishly and cannot overshoot on impact. Real wage is thus lower along the adjustment, and this spurs output. Thus, the real wage overshooting is transferred to output.

The Rotemberg model
Under Rotemberg pricing the result is the other way round. Figure 3 shows that sluggish real wages cause an output slump along the adjustment path. The slump of output becomes more significant the higher the parameter of real wage rigidities, γ.

- figure 3 about here -

To give an intuition for these results, we need to look at the interplay between long-run effects and the short-run dynamic adjustment in the nonlinear models. Unlike the Calvo model, in the Rotemberg model a disinflation implies an immediate adjustment to a permanently lower level of output, hours and real wage. Real wage rigidities again prevent the immediate adjustment of the

[2] Figures 2-3 are obtained using the software DYNARE . The paths of all variables display the movement from a deterministic steady state to another one. DYNARE stacks up all the equations of the model for all the periods (we set equal to 100). The resulting system is solved en bloc by using the Newton-Raphson algorithm. The non-linear model thus is solved in its full-linear form, without any approximation.

real wage, that sluggishly decreases towards the new lower long-run level, thus depressing output. Hence, contrary to the Calvo model, the Rotemberg model exhibits a dynamics in line both with the conventional wisdom and the empirical evidence that real wage rigidities cause a significant output slump along the adjustment path (see, e.g., Blanchard and Galí, 2007).

4 Conclusion

We study the effect of a permanent disinflation in a New Keynesian model with real wage rigidities under the Rotemberg and the Calvo pricing models. We show that, if the Central Bank permanently and credibly reduces the inflation target, the Calvo model implies output gain, rather than cost, of disinflation, while the Rotemberg model implies output losses. Furthermore, in the Calvo model, real wage rigidities delivers the odd result of an overshooting of output above its new higher steady state level. On the contrary, in the Rotemberg model, sluggish real wages cause a significant output slump along the adjustment path, implying a significant trade-off between stabilizing inflation and output. This last result restores a conventional result on which there seems to be consensus in the literature (see, e.g., Blanchard and Galí, 2007).

5 References

Ascari, G. (2004): "Staggered Price and Trend Inflation: Some Nuisances". *Review of Economics Dynamics*, 7, 642-667.

Ascari, G., Merkl, C. (2009): "Real Wage Rigidities and the Cost of Disinflation". *Journal of Money Credit and Banking,* 41, 417-435.

Ball, L. (1994): "Credible Disinflation with Staggered Price-Setting". *American Economic Review*, 84, 282-89.

Blanchard O. and Galí J. (2007): "Real Wage Rigidities and the New Keynesian Model". *Journal of Money Credit and Banking*, 39, 35-66.

Calvo G. A. (1983): "Staggered Prices in a Utility-Maximizing Framework". *Journal of Monetary Economics,* 12, 383-398.

Lombardo G. and Vestin D. (2008): "Welfare Implications of Calvo vs. Rotemberg Pricing Assumptions". *Economics Letters*, 100, 275-279..

Mankiw, N. G. (2001): "The Inexorable and Mysterious Trade-off between Inflation and Unemployment". *Economic Journal*, 111, 45-61.

Nisticò S. (2007): "The Welfare Loss from Unstable Inflation", *Economics Letters*, 96, 51-57.

Roberts J., M. (1995): "New Keynesian Economics and the Phillips Curve". *Journal of Money, Credit and Banking*, 27, 975-84.

Rotemberg Julio, J. (1982): "Monopolistic Price Adjustment and Aggregate Output". *The Review of Economic Studies*, 49, 517-531.

Rotemberg Julio, J. (1987): "The New Keynesian Microfoundations". NBER Macroeconomics Annual, 63-129.

Schmitt-Grohe, S. Uribe, M. (2007): "Optimal Simple and Implementable Monetary and Fiscal Rules". *Journal of Monetary Economics*, 54, 1702-1725.

Yun, T., (2005): "Optimal Monetary Policy with Relative Price Dispersions". *American Economic Review*, 95, 89-109.

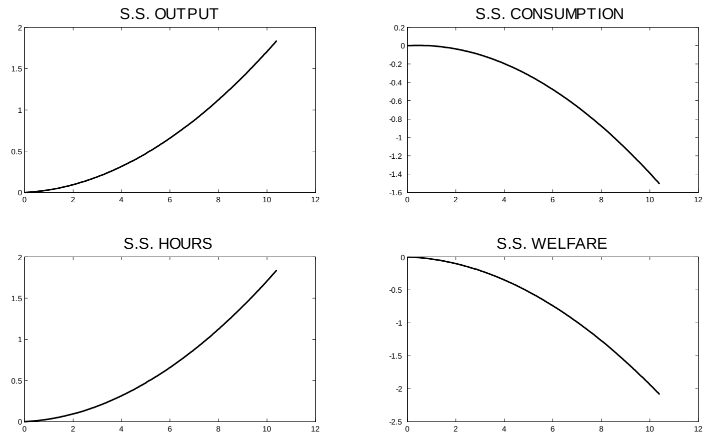

Fig. 1 Steady state deviations from zero inflation s.s. in the Rotemberg model

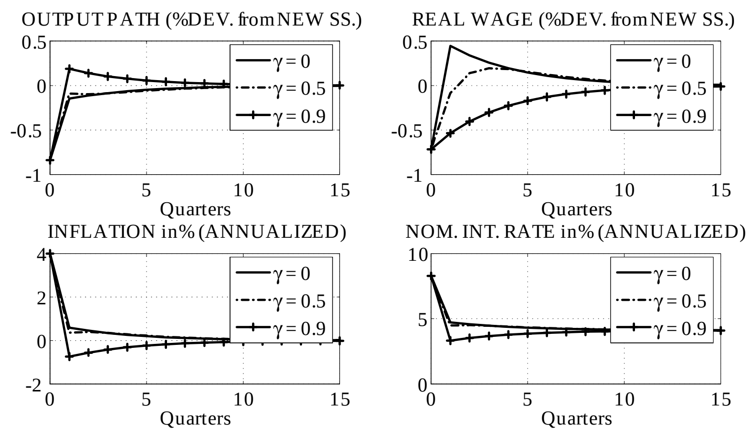

Fig. 2 Disinflation and real wage rigidities in the Calvo model.

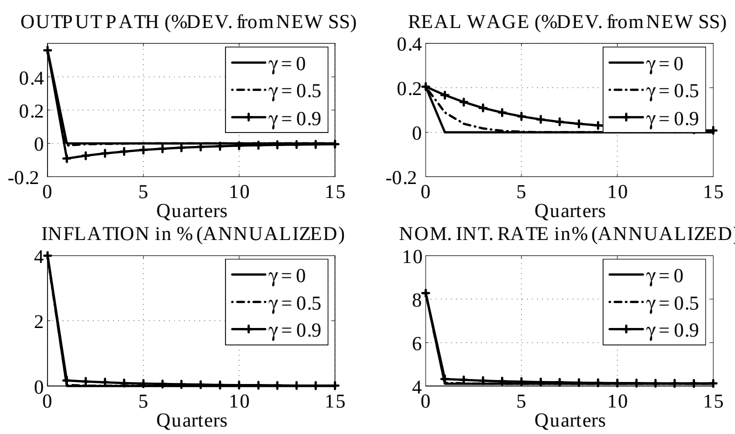

Fig. 3 Disinflation and real wage rigidities in the Rotemberg model