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Appendix

A Ramsey-Optimal Policy and Variety

The four first-order conditions with respect to labor, inflation, labor in the consumption sector, and the number of product varieties next period, obtained by solving the Ramsey problem (5) are, respectively:

$$
\begin{aligned}
L_t &: -h_L(L_t) - (1-\delta)\eta_{1,t}\frac{Z_t}{f_E} + \theta(N_t)\eta_{2,t}L_{C,t}h_{LL}(L_t)\left(1-\frac{\kappa}{2}\pi_t^2\right) \\
&\quad + \eta_{3,t}h_{LL}(L_t)\frac{f_E}{Z_t} - \eta_{3,t-1}(1-\delta)\left(h_{LL}(L_t)\frac{f_E}{Z_t} - \frac{L_{C,t}h_{LL}(L_t)}{N_t}\right) \\
&\quad = 0, \\
\pi_t &: -\frac{\pi_t}{1-\frac{\kappa}{2}\pi_t^2} - \eta_{2,t}\left[\begin{array}{c}\theta(N_t)\pi_t L_{C,t}h_L(L_t) + (1-\theta(N_t))\pi_t \\ +(1+2\pi_t) + \beta(1-\delta)\pi_{t+1}(1+\pi_{t+1})\frac{N_t}{N_{t+1}}\frac{\kappa\pi_t}{1-\frac{\kappa}{2}(\pi_{t+1})^2}\end{array}\right] \\
&\quad + \eta_{2,t-1}(1-\delta)\frac{N_{t-1}}{N_t}\left(1-\frac{\kappa}{2}\pi_{t-1}^2\right)\frac{1+\frac{\kappa}{2}\pi_t^2+2\pi_t}{\left(1-\frac{\kappa}{2}\pi_t^2\right)^2} \\
&\quad = 0, \\
L_{C,t} &: \frac{1}{L_{C,t}} + (1-\delta)\eta_{1,t}\frac{Z_t}{f_E} + \theta(N_t)\eta_{2,t}h_L(L_t)\left(1-\frac{\kappa}{2}\pi_t^2\right) + \eta_{3,t-1}(1-\delta)\frac{h_L(L_t)}{N_t} = 0, \\
N_t &: \beta\frac{\epsilon(N_{t+1})}{N_{t+1}} + \eta_{1,t} - \eta_{1,t}\beta(1-\delta) - \beta\eta_{2,t+1}\theta'(N_{t+1})\left(1-\frac{\kappa}{2}\pi_{t+1}^2\right)\left[1-L_{C,t+1}h_L(L_{t+1})\right] \\
&\quad - \eta_{2,t}\beta(1-\delta)\kappa\pi_{t+1}(1+\pi_{t+1})\frac{N_t}{N_{t+1}^2}\frac{1-\frac{\kappa}{2}\pi_t^2}{1-\frac{\kappa}{2}\pi_{t+1}^2} \\
&\quad + \beta^2(1-\delta)\eta_{2,t+1}\kappa\pi_{t+2}(1+\pi_{t+2})\frac{1-\frac{\kappa}{2}\pi_{t+1}^2}{1-\frac{\kappa}{2}\pi_{t+2}^2}\frac{1}{N_{t+2}} + \beta(1-\delta)\eta_{3,t}\frac{1-L_{C,t+1}h_L(L_{t+1})}{N_t^2} \\
&\quad = 0,
\end{aligned}
$$

where we used $\epsilon(N_t) \equiv \frac{\rho'(N_t)}{\rho(N_t)}N_t$ in the last equation.

The non-stochastic steady state is such that:

$$-h_L(L) - (1-\delta)\eta_1 + \theta(N)\eta_2 L_C h_{LL}(L)\left(1 - \frac{\kappa}{2}\pi^2\right)$$
$$+\eta_3 h_{LL}(L) - \eta_3(1-\delta)h_{LL}(L)\left(1 - \frac{L_C}{N}\right) = 0,$$

$$-\frac{\pi}{1-\frac{\kappa}{2}\pi^2} - \eta_2\left[\begin{array}{c}\theta(N)\pi L_C h_L(L) + [1-\theta(N)]\pi \\ +(1+2\pi) + \beta(1-\delta)\pi(1+\pi)\frac{\kappa\pi}{1-\frac{\kappa}{2}(\pi)^2}\end{array}\right] + \eta_2(1-\delta)\frac{1+\frac{\kappa}{2}\pi^2+2\pi}{1-\frac{\kappa}{2}\pi^2} = 0,$$

$$\frac{1}{L_C} + (1-\delta)\eta_1 + \theta(N)\eta_2 h_L(L)\left(1-\frac{\kappa}{2}\pi^2\right) + \eta_3(1-\delta)\frac{h_L(L)}{N} = 0,$$

$$\beta\frac{\epsilon(N)}{N} + \eta_1[1-\beta(1-\delta)] - \beta\eta_2\theta'(N)\left[1-\frac{\kappa}{2}\pi^2\right][1-L_C h_L(L)]$$
$$-(1-\beta)\beta(1-\delta)\kappa\frac{\eta_2\pi(1+\pi)}{N} + \beta(1-\delta)\eta_3\frac{1-L_C h_L(L)}{N^2} = 0,$$

$$[\theta(N)-1]\left[1-\frac{\kappa}{2}\pi^2\right] + \kappa[1-\beta(1-\delta)](1+\pi)\pi$$
$$-\theta(N)\left(1-\frac{\kappa}{2}\pi^2\right)L_C h_L(L) = 0,$$

$$\delta N - (1-\delta)\left(L - L^C\right) = 0,$$

$$[1-\beta(1-\delta)]h_L(L) - \beta(1-\delta)\frac{1-L_C h_L(L)}{N} = 0,$$

where the first four equations are the steady-state versions of the first-order conditions outlined above, and the last three correspond to the constraints of the Ramsey problem in Table 3.

When is a steady state with zero inflation $\pi = 0$ a solution to the Ramsey problem? To answer this question, conjecture that $\pi = 0$ in steady state. The first-order condition for the choice of inflation (the second equation above) then implies that the Lagrange multiplier on the Phillips curve is zero:

$$\eta_2 = 0.$$

Naturally, the constraint associated to imperfect price adjustment is not binding in steady state when there is zero inflation. The other conditions evaluated at this equilibrium imply (we use the notation $\beta^{-1} = 1 + r$, so r is the discount rate):

$$1 + (1-\delta)\frac{\eta_1}{h_L(L)} - \frac{\eta_3}{L}\varphi\left[\delta + \left[\theta(N) - 1\right](r+\delta)\right] = 0,$$
$$1 + (1-\delta)\eta_1 L_C + (1-\delta)\frac{\theta(N) - 1}{\theta(N)}\frac{\eta_3}{N} = 0,$$
$$\epsilon(N) + (r+\delta)\eta_1 N + (1-\delta)\frac{1}{\theta(N)}\frac{\eta_3}{N} = 0,$$
$$\frac{\theta(N) - 1}{\theta(N)} = L_C h_L(L),$$
$$\delta N = (1-\delta)\left(L - L^C\right),$$
$$h_L(L) N = \frac{1-\delta}{r+\delta}\frac{1}{\theta(N)}.$$

The second and third equations imply:

$$1 + (1-\delta)\eta_1 L_C - \epsilon(N)\left[\theta(N) - 1\right] - \left[\theta(N) - 1\right](r+\delta)\eta_1 N = 0. \tag{11}$$

But the fourth and sixth equations imply:

$$\left[\theta(N) - 1\right](r+\delta) N = (1-\delta) L_C,$$

which substituted into (11) yields:

$$\epsilon(N) = \frac{1}{\theta(N) - 1}.$$

This proves the result.

B Price Indexation

In this Appendix, we outline some of the implications of price indexation for Ramsey-optimal monetary policy. We assume that rather than paying the adjustment cost when deviating from zero-inflation, as implied by (1), firms index to *past inflation* and pay an adjustment cost given by[24]:

$$pac_t(\omega) \equiv \frac{\kappa}{2}\left[\frac{p_t(\omega)}{p_{t-1}(\omega)}\left(\frac{p_{t-1}(\omega)}{p_{t-2}(\omega)}\right)^{-\gamma} - 1\right]^2 \frac{p_t(\omega)}{P_t} y_t^D(\omega), \tag{12}$$

[24] A simple indexation scheme whereby firms index to a constant inflation rate $\tilde{\pi}$, rather than past inflation, would merely imply that the optimal long-run inflation rate is uniformly increased by the constant $\tilde{\pi}$, without affecting any of the other results.

where $\gamma \in [0,1]$ is the *indexation parameter*. Under this indexation scheme, it can be easily shown that the long-run Phillips curve becomes:

$$\mu(\pi) - 1 = \frac{\theta}{(\theta - 1)\left\{1 - \frac{\kappa}{2}\left[(1+\pi)^{1-\gamma} - 1\right]^2\right\} + \kappa\frac{r+\delta}{1+r}(1+\pi)^{1-\gamma}\left[(1+\pi)^{1-\gamma} - 1\right]} - 1. \quad (13)$$

Note that this nests the no-indexation case when $\gamma = 0$ and the full-indexation case when $\gamma = 1$. Under full indexation, however, the steady-state inflation rate will be *indeterminate*: There is no long-run cost of using inflation ((12) evaluated at the steady-state implies $pac = 0$) and no benefit of inflation (the long-run Phillips curve (13) is vertical $\mu = \theta/(\theta - 1)$). For values of γ in the open interval $(0,1)$, our long-run results change as follows. The optimal rate of inflation (deflation) is increasing (in absolute value) with the indexation parameter γ. When indexation is almost full (γ is close to 1) the optimal rate of long-run inflation (deflation) is indeed very large.

The reasons why indexation implies larger deviations from long-run price stability are twofold: First, indexation lowers the welfare cost associated with a given long-run inflation rate (the steady-state adjustment cost $PAC = \frac{\kappa}{2}\left((1+\pi)^{1-\gamma} - 1\right)^2 Y^C$ is decreasing in γ). Second, indexation causes the long-run Phillips curve to steepen, and hence requires larger inflation rates to achieve a certain change in long-run markup. Figure B.1 illustrates this mechanism, plotting the LRPC for a positive indexation parameter (in dashed-dot line) along with the LRPC for no indexation previously plotted in Figure 1 (solid line). The figure illustrates that in order to achieve a certain movement in long-run markup, necessary in order to bring it closer to the benefit of variety, a higher value of long-run inflation (or deflation) needs to be chosen by the central bank.

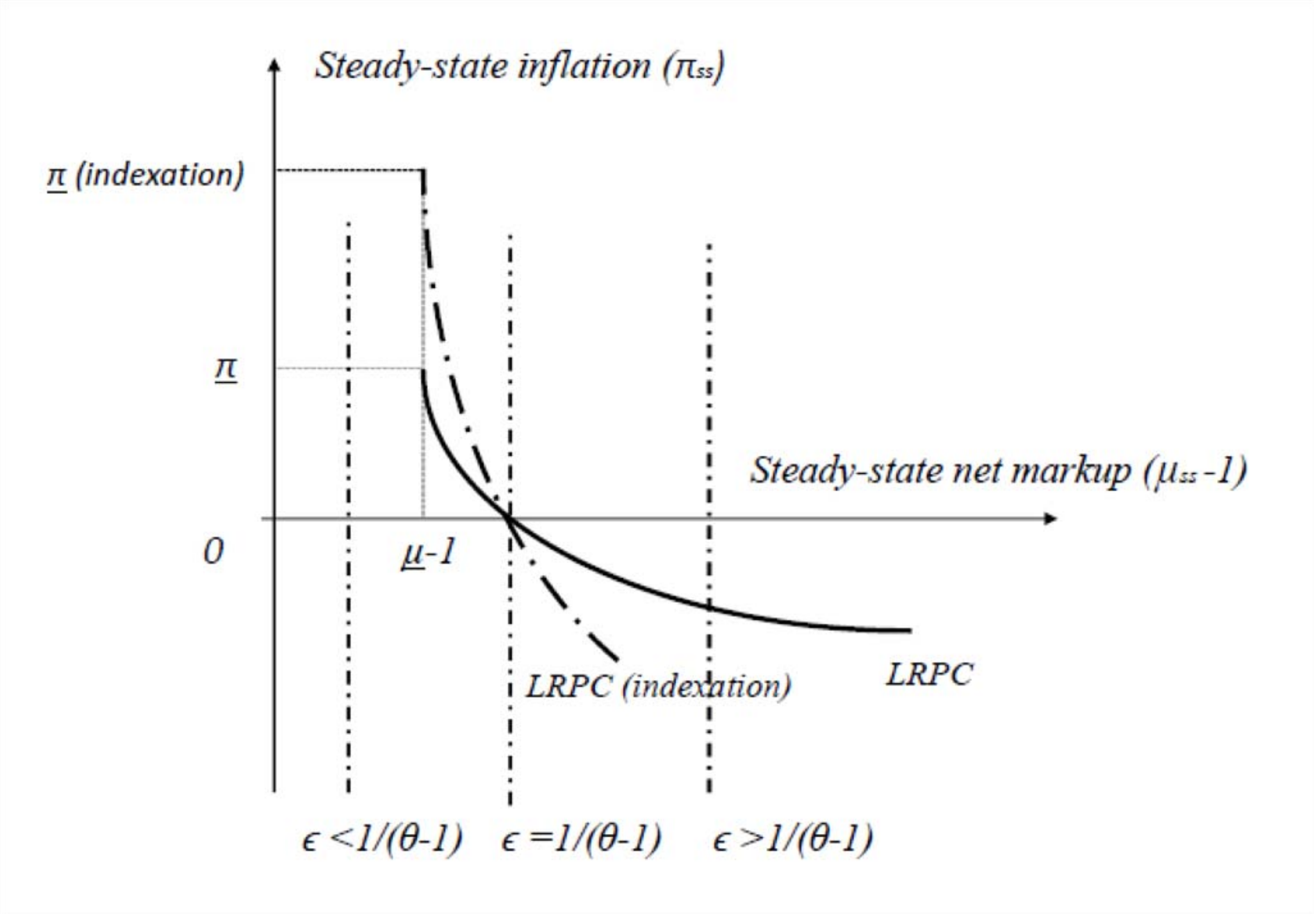

Figure B.1: The Long-run Phillips curve with and without indexation (dashed and solid curve, respectively).

Figure B.2 illustrates these results quantitatively, plotting the optimal long-run rate of inflation for C.E.S. preferences as a function of the indexation parameter γ, for the two extreme value of the benefit of variety: $\epsilon = 0$ and $\epsilon = 1$, respectively.[25] For empirically plausible degrees of indexation (estimated for instance by Smets and Wouters, 2007, in the range between 0.25 and 0.5), optimal long-run inflation rates range from around 6 percent inflation (for $\epsilon = 0$) to around 10 percent deflation (for $\epsilon = 1$). A similar picture occurs under translog preferences (not plotted), where the optimal long-run rate of inflation, given $\sigma = 0.353$, ranges from 1.03 percent under no indexation to approximately 10 percent when $\gamma = 0.9$ (results are available upon request).

[25] The domain of γ is restricted to values lower than 0.9 because, for larger values, the optimal rate of long-run inflation (deflation) becomes extremely large (close to 600 percent inflation and 300 percent deflation, respectively, for $\gamma = 0.99$).

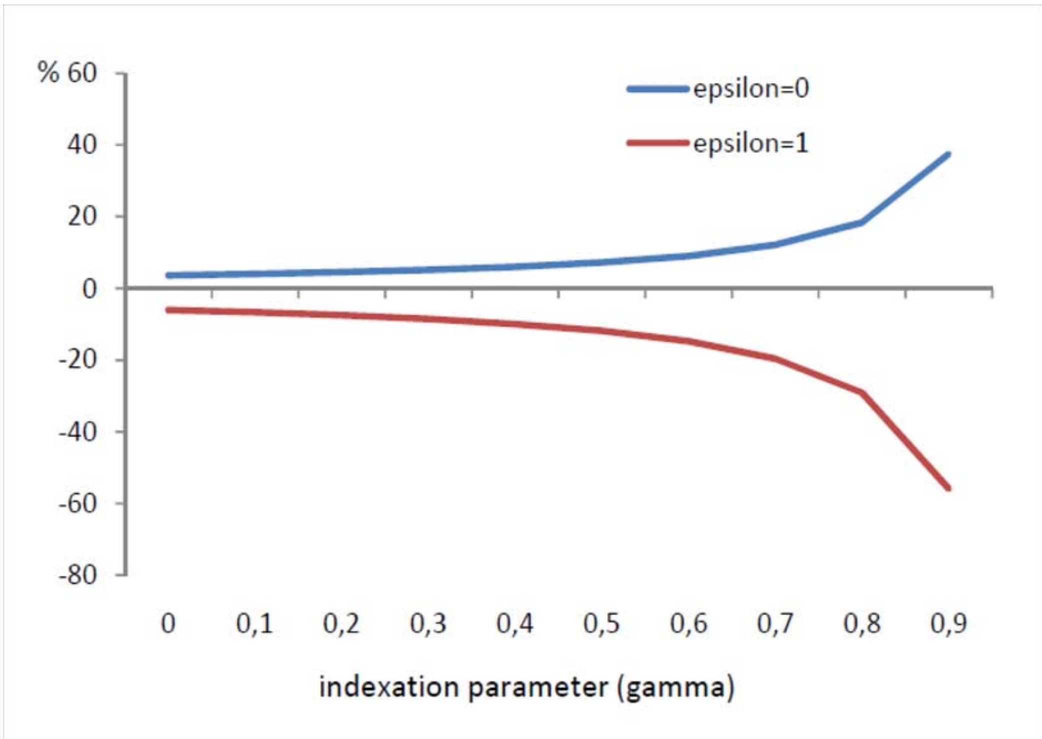

Figure B.2: The optimal long-run inflation rate as a function of the indexation parameter γ.

Figure B.3 illustrates the implications of price indexation for short-run optimal policy, by plotting the impulse responses to a productivity shock under C.E.S. preferences with no benefit from variety ($\epsilon = 0$) for two extreme values of the indexation parameter γ (0 and 0.9). Indexation, by the same logic that applied to the long run, implies higher optimal variation in short-run inflation rates and the price level. But the implied movements are still quantitatively small: The maximum value of inflation is 0.25 basis points (attained after 10 quarters), translating into an increase in the price level of 3.7 percent. Most importantly, the paths of real variables (consumption, hours, and number of firms) are invariant to the indexation parameter: Indexation makes inflation less costly, but it also makes the Phillips curve more vertical, meaning that a larger inflation rate has a smaller effect on real variables.[26] We therefore conclude that indexation affects significantly the optimal monetary policy prescriptions in the long run, but not in the short run.

[26] A similar result occurs under translog preferences: Responses of real variables are invariant to the degree of indexation, and optimal deflation under indexation attains a maximum of 0.06 basis points after 10 quarters, translating into a fall in the price level of around 1 percent; results are available upon request.

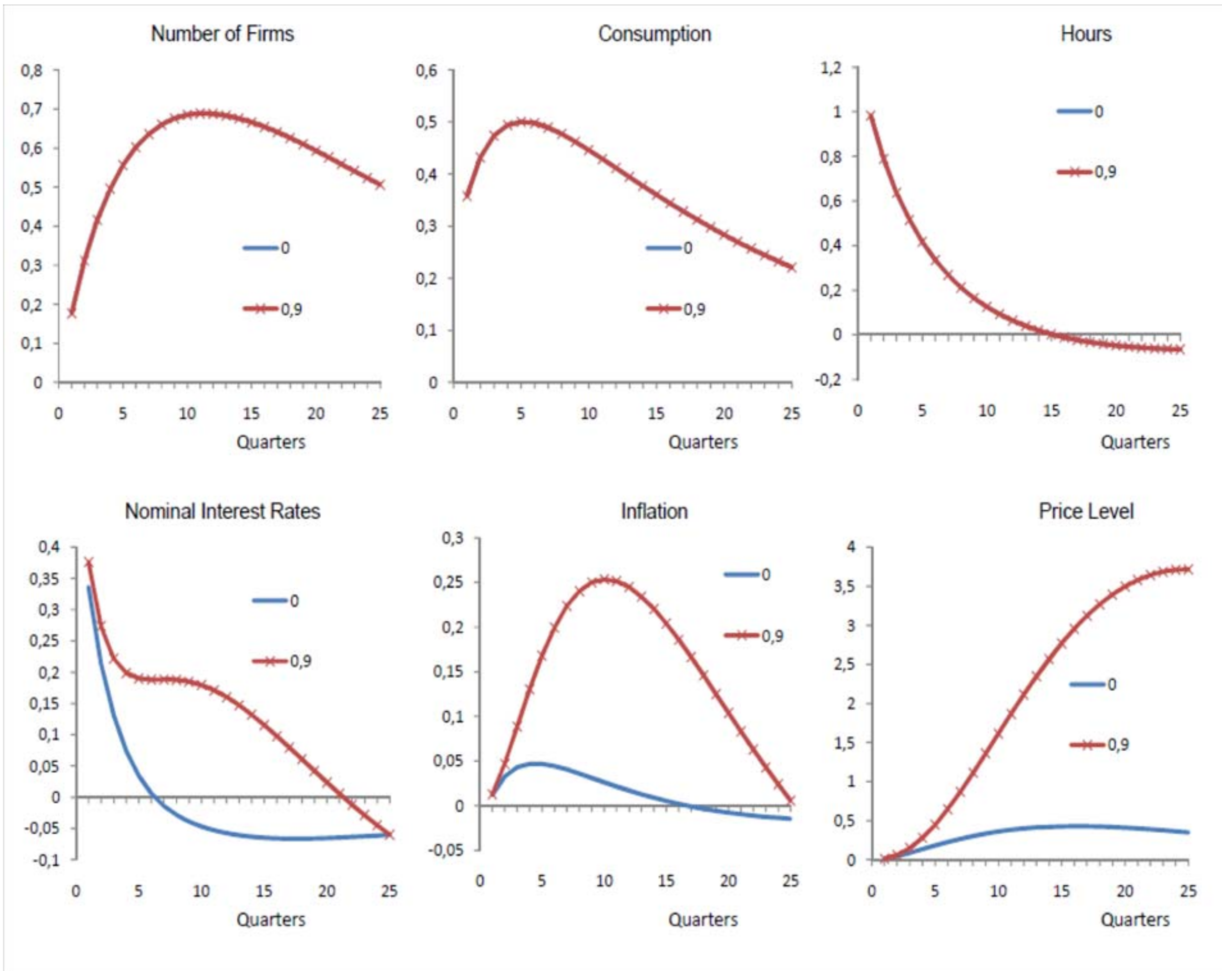

Figure B.3: Impulse responses to a productivity shock for C.E.S. preferences with $\epsilon = 0$ under Ramsey policy, under no indexation $\gamma = 0$ (blue line) and indexation (red, crossed line) $\gamma = 0.9$. Inflation and interest rate are in basis points deviations, the rest in percentage deviations from steady state.