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DISINFLATION, INEQUALITY, AND WELFARE IN A TANK MODEL

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We investigate the redistributive and welfare effects of disinflation in a two-agent New Keynesian model characterized by limited asset market participation and wealth inequality. We highlight two key mechanisms driving our long-run results: (1) the cash in advance constraint on firms working capital; (2) dividends endogeneity. These two channels point in opposite directions. Lower inflation softens the cash in advance constraint and, by raising labor demand, lowers inequality. But disinflation also raises dividends and this increases inequality. The disinflation is always welfare-improving for asset holders. We obtain ambiguous results for non-asset holders, who suffer substantial consumption losses during the transition. (*JEL* E31, E5, D3, D6)

I. INTRODUCTION

This paper investigates the short- and long-run effects of a monetary policy regime change, namely, a disinflation, on inequality and the welfare of different household groups.

Recent years have witnessed increasing concern for the distributive effects of monetary policies. A consensus exists that temporary contractionary shocks increase inequality (Coibion et al. 2012; Furceri, Loungani, and Zdzienicka 2018; Romer and Romer 1998). By contrast, empirical studies on the long-run effects of monetary regime changes have obtained contradictory results. Coibion, Gorodnichenko, and Koustas (2017) find that a reduction in the Fed inflation target causes strong cumulative effects on consumption and expenditures inequality. Using a different identification method for permanent inflation shocks and the Gini index which covers the full population, Davtyan (2017) finds that a disinflation lowers inequality in the United States. Some earlier country-specific studies document that higher inflation is correlated with a lower income share held by the poorest part of the population (Blejer and Guerrero 1990; Datt and Ravaillion 1998). Several studies document a positive cross country correlation between inflation and inequality over relatively long time spans, suggesting that a permanent disinflation should be associated with a long-run reduction in inequality (Albanesi 2007; Bulír 2001; Easterly and Fischer 2001; Li and Zou 2002; Nantob 2015; Romer and Romer 1998).

These mixed results call for a model that can provide some economic intuition for why the effects of disinflations might be ambiguous. Following Piketty (2015), there has been a great concern for the implications of increasing concentration in wealth holdings, and our purpose here is to investigate how wealth inequality determines the effects of disinflations. We investigate the redistributive and welfare effects of disinflation in an empirically realistic two-agent New Keynesian model (De Bortoli and Galí 2017; TANK henceforth) characterized by limited asset market participation (LAMP henceforth). Our model incorporates price and nominal wage rigidities and market imperfections such as financial frictions and firms monopoly power.

In addition to the traditional short-run effects, where non-asset holders cannot smooth their consumption during the disinflation episode, such

ABBREVIATIONS

CEE: Christiano et al. (2005)
CIA: Cash-in-Advance
DSGE: Dynamic Stochastic General Equilibrium
FOC: First-Order Condition
EMU: European Monetary Union
LAMP: Limited Asset Market Participation
NKPC: New Keynesian Phillips Curve
RT: Rule-of-Thumb
SGU: Schmitt-Grohé and Uribe
VAR: Vector Autoregression Models

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models allow for two channels of monetary policy non-neutrality in the long-run. The first one is the cost channel of monetary policy. Following Christiano et al. (2005; CEE henceforth), we model it as a cash-in-advance constraint on firms working capital (CIA henceforth), where the real financing cost is determined by the nominal interest rate. In this framework, a reduction in long-run inflation causes a permanent fall in the nominal interest rate which lowers the unit labor costs and raises labor demand. The second one is the endogeneity of price markups, and dividends, to inflation (Ascari 2004).

To sharpen our analysis, we take relative consumption of the two household groups as the preferred measure of inequality. In a nutshell, our results are as follows. In the long-run firms' dividends unambiguously increase. This, in turn, implies that consumption inequality also increases. By contrast, the lower cost of financing firms' working capital unambiguously reduces inequality. This happens for two reasons. The first one is that interest payments to asset owners unambiguously fall. The second one is that stronger labor demand raises labor incomes.

Transitional dynamics are quite different for the two household groups. Ricardian households anticipate the beneficial effect of the disinflation on their permanent income by immediately reducing their savings to smooth their consumption. This requires an investment fall, driving a reduction in labor demand that determines a contraction in the consumption of rule-of-thumb (RT) households.

We provide a formal welfare analysis of the disinflation. Welfare gains accrue to Ricardian households even in the short-run, when the economy contracts. By contrast, RT households suffer a welfare loss during the contraction period. These transitional effects may be alleviated if the monetary policy rule targets the output gap in addition to inflation. In this case, it takes more time to disinflate the economy, but the milder output contraction is associated with a smaller consumption loss of RT households. Thus we provide a new argument in favor of adopting a gradualist approach when implementing a disinflation, in addition to the standard imperfect credibility motive (King 1996). Note that the accommodative monetary policy also stimulates consumption of Ricardian households, and therefore it has a negligible impact on short-term inequality. In a way, the accommodative policy could be seen as the tide that lifts all boats in the short-run.

The paper adds to previous contributions on the welfare implications of inflationary regimes, which highlight the importance of different portfolio composition of different income groups, where the poor typically hold a relatively large proportion of their wealth in noninterest-bearing assets and inflation is a substitute for other forms of taxation (Albanesi 2007; Erosa and Ventura 2002; Menna and Tirelli 2017). Differently, we investigate the distributional implications of inflation regime choice which emerge as a consequence of the endogenous response of financial frictions, that is, the CIA constraint, and of firms monopoly power, that is, price markups.

Other studies focus on the distributional effects of monetary shocks in New Keynesian models. Gornemann et al. (2016) focus on matching frictions in the labor market and assume that all households hold identical portfolios of financial assets which provide self-insurance against consumption risk. Luettike (2018) allows for portfolio heterogeneity but imposes that capital is an illiquid asset. Our focus is different because we investigate the distributive effects of an inflation target change in a model of concentrated capital ownership, akin to Lansing (2015), Lansing and Markiewicz (2017), and Walsh (2017).

The rest of the paper is organized as follows. The next section reviews the literature. Section III describes the main features of the model. Section IV focuses on the results; Section V concludes.

II. LITERATURE REVIEW

Ascari and Ropele (2012a, 2012b) study the effects of a disinflation policy under the representative agent assumption. To capture the short- and long-run effects of disinflation on inequality we extend their model to account for financial market incompleteness and wealth inequality due to LAMP.[1]

This characterization of households behavior is associated to Mankiw's distinction between savers and spenders (Mankiw 2000) and is supported by microeconometric studies such as Anderson, Inoue, and Rossi (2016), who find

1. The Ascari and Ropele model accounts for additional frictions including external habits in consumption, variable capacity utilization, investment adjustment costs. We do not consider them here because their inclusion is inconsequential for our qualitative results (Proof available upon request). This choice inevitably implies that transitional dynamics become less persistent.

that in the United States the wealthiest individuals behave according to the permanent income hypothesis, but the poorest individuals disregard interest rate changes and adjust consumption to their disposable income dynamics.

The LAMP hypothesis has been popularized in a number of studies (Albonico, Paccagnini, and Tirelli 2016, 2017; Ascari, Colciago, and Rossi 2017; Bilbiie 2008; Colciago 2011; Furlanetto, Natvik, and Seneca 2013; Furlanetto and Seneca 2012; Galí, Lopez-Salido, and Vallés Liberal 2004, 2007; Motta and Tirelli 2012, 2015). It provides a reasonable approximation to the observed polarization in long-run wealth holdings: Iacoviello and Pavan (2013) document that 40% of the U.S. population has essentially no assets and no debt. Wolff (2010) shows that the top quintile of U.S. households owns about 90% of total financial wealth. Cowell, Karagiannaki, and McKnight (2017) provide similar figures for the Euro area.

If one is concerned with households responses to temporary shocks, the LAMP assumption is an admittedly rough-and-ready characterization of households heterogeneity.[2] Havranek and Sokolova (2016) perform a meta-analysis of the excess sensitivity of consumption to income growth and suggest that it is essentially explained by liquidity constraints. The response of their consumption should, therefore, be asymmetric to increases and decreases in income, and liquidity constraints should be endogenous to business cycle conditions. These features are captured by HANK models which are based on a detailed description of agents heterogeneity (Kaplan, Moll, and Violante 2016) and account for nominal rigidities.

However, De Bortoli and Galí (2017) show that a simple LAMP model is a tractable framework that captures reasonably well the main predictions of HANK models in response to monetary policy shocks. Furthermore, modeling endogenous borrowing constraints does not seem essential in our deterministic setting where the transition is characterized by a persistent monetary contraction which tightens borrowing constraints and possibly raises the share of constrained households. In this regard, our model seems prone to underestimate the short-run effects of the disinflation on inequality.

To incorporate the CIA constraint, we assume that a fraction ν of the wage bill is paid in advance. Empirical evidence broadly confirms the relevance of the CIA constraint (Barth and Ramey 2001; Chowdhury, Hoffmann, and Schabert 2006; Gaiotti and Secchi 2006; Henzel et al. 2009; Ravenna and Walsh 2006; Tillmann 2008), but considerable uncertainty exists about its effective strength. Our experiments are based on a conservative calibration, where ν never exceeds the rather small value estimated in Rabanal (2007).

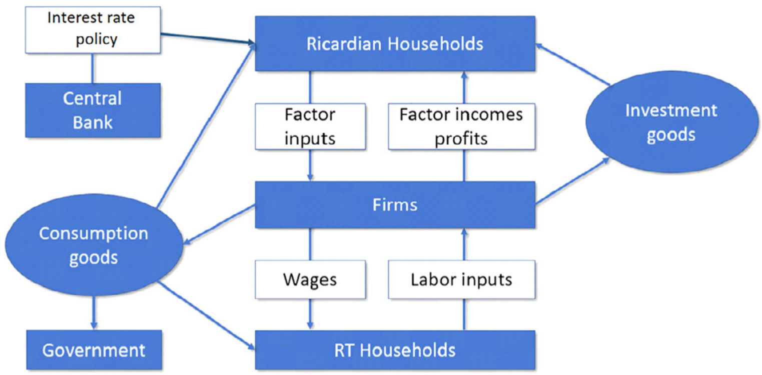
The characterization of price markups endogeneity to long-run inflation is non-trivial in our framework, where the strength of the dividends response to the disinflation has non-negligible effects on inequality. The two most commonly used formalisms for modeling price and wage setting, that is, the Calvo (1983) staggered contracts and the Rotemberg (1982) quadratic costs of price adjustment predict that dividends always increase after disinflation, but this happens for different reasons. Under Calvo markups fall, and the ensuing increase in output raises dividends. Under Rotemberg dividends increase because inflation adjustment costs fall and markups increase (Ascari and Rossi 2012).

The Rotemberg formalism intuitively strengthens the redistributive effects determined by the dividends increase, and the modeling choice of the price adjustment mechanism is therefore non-trivial for our purposes.

To discriminate between the two models, one might be tempted to exploit the fact that the long-run New Keynesian Phillips curve (NKPC) is negatively (positively) sloped in the Calvo (Rotemberg) model. Unfortunately, in this regard empirical evidence is inconclusive. Berentsen, Menzio, and Wright (2011) show positive relationships between the trend components of inflation and unemployment (negatively related to output). Beyer and Farmer (2007) study the low-frequency movements of inflation, unemployment, and the federal funds rate and find that they trend together. Benati (2015) investigates the long-run trade-off between inflation and the unemployment rate in the United States, the Euro area, the United Kingdom, Canada, and Australia using structural VARs. He cannot reject the null hypothesis of a vertical long-run NKPC for either country. The overall extent of uncertainty is so large that the data are compatible with a comparatively wide range of possible slopes

2. Note that recent contributions refer to individuals who are constrained by large spending commitments relative to their income and liquid assets holdings. This definition encompasses both asset-poor individuals and highly-leveraged holders of illiquid assets, typically residential estate (Ampudia et al. 2018; Kaplan and Violante 2014; Kaplan, Violante, and Weidner 2014).

FIGURE 1
Model Structure



of the long-run trade-off. For this reason, we will provide a detailed analysis of the redistributive effects of disinflation under both price-setting mechanisms.

Our concern for the long-run redistributive effects of monetary policy calls for a reconsideration of the inflation modeling strategy adopted in the literature. In sharp contrast with empirical evidence, disinflations cause a boom in New Keynesian models based on purely forward-looking price setting and rational expectations (Ball 1994) because inflation almost immediately jumps to the new long-run level. In fact inflation persistence is potentially inherent to episodes of monetary policy regime change, and it could be treated as a temporary phenomenon potentially explained by several concurring causes such as imperfect credibility (Erceg and Levin 2003; Gibbs and Kulish, 2017; Goodfriend and King 2005), inattention, myopia, bounded rationality (Branch and McGough 2009; Milani 2012). In our model temporary inflation persistence is obtained by assuming that inflation expectations are partly backward-looking, as in Galí and Gertler (1999).

An apparently convenient alternative, proposed by Ascari and Ropele (2012a) would be to assume that price-setting rules incorporate inflation indexation as in CEE. We cannot treat inflation indexation as a simple device that allows capturing inflation persistence. In fact, indexation limits the response of price markups to inflation regime changes, and therefore crucially affects our results concerning the long-run effects of disinflations on inequality. The widespread use of the indexation assumption in the price-setting equation has been criticized in Benati (2008, 2009), who shows that price indexation has become virtually irrelevant since the onset of the Great Moderation period.[3] Thus inflation indexation parameters should not be regarded as structural in the sense of Lucas (1976).

III. THE MODEL

Figure 1 summarizes the structure of the model.[4]

Ricardian households provide factor inputs (labor and capital) to firms. RT households only supply the labor input to firms and earn labor income. Firms use labor and capital inputs to produce the final goods bundle, which is used for consumption by both household groups, and for investment by Ricardian households.

Households share the same utility function

(1)
$$U_t^i = E_t \sum_{t=0}^{\infty} \beta^t \left\{ \ln(c_t^i) - \frac{\phi_1}{(1+\phi)} (h_t^i)^{(1+\phi)} \right\}$$

where $i = o, rt$ defines optimizing and RT households respectively, β is the subjective discount factor, c_t^i and h_t^i respectively are two standard Dixit–Stiglitz consumption and labor bundles:

$$c_t^i = \left[\int_0^1 c(z)_t^{\frac{\eta-1}{\eta}} dz \right]^{\frac{\eta}{\eta-1}} \tag{2}$$

3. Other studies support this conclusion. See, for instance, Sbordone (2006), Cogley and Sbordone (2008), Ascari, Castelnuovo, and Rossi (2011), and Hofmann, Peersman, and Straub (2012).

4. The full specification of the model is reported in the Appendix.

$$h_t^i = \left(\int_0^1 (h_t^j)^{\frac{\eta_w - 1}{\eta_w}} dj \right)^{\frac{\eta_w}{\eta_w - 1}} \tag{3}$$

The two conditions (2) and (3) allow to introduce monopolistic competition in the goods and labor markets.

We assume that optimizing (Ricardian) households are a fraction $(1 - \Omega)$ of the population, and the remaining RT, or non-Ricardian households, do not participate in financial markets and entirely consume their current disposable income in each period.

A. Labor market structure

For each labor type there is a monopolistically competitive market and the wage setting decision is delegated to a union. The representative union j is confronted with a downward-sloping demand function:

$$h_t^j = \left(\frac{w_t^j}{w_t} \right)^{-\eta_w} h_t^d$$

where w_t^j is the real wage for labor type j, h_t^d is the aggregate labor demand and w_t is the aggregate wage index, which reads as:

$$w_t = \left(\int_0^1 (w_t^j)^{(1-\eta_w)} dj \right)^{\frac{1}{(1-\eta_w)}}.$$

Following Galí et al. (2007), the fraction of Ricardian and non-Ricardian households is uniformly distributed across unions and the demand for each labor type is uniformly distributed across households. Households therefore supply the same amount of hours.

B. Budget constraints

Non-Ricardian agents just consume current labor income and do not accumulate wealth:

$$c_t^{rt} = w_t h_t^d \tag{4}$$

The Ricardian household's period budget constraint is:

$$c_t^o + K_{t+1}^o - (1-\delta) K_t^o + \frac{M_{t+1}^o}{P_t} = r_t^k K_t^o + w_t h_t^d + d_t^o + R_t \frac{M_t^o}{P_t} \tag{5}$$

where K^o, r^k respectively define the stock of capital and the real rental rate of capital; δ is the capital depreciation rate; d_t^o defines individual holdings of firms dividends; M^o defines money holdings which are used to finance firms' wage bills at the nominal gross rate R_t, P_t is the aggregate price level associated to (2).[5]

C. Firms

Retail Firms. Perfectly competitive retail firms assemble the wholesale goods into the final bundle which is used for either consumption or investment in physical capital. Their demand for goods produced by the wholesale producer z is

$$y_t(z^W) = \left(\frac{P_t^W(z^W)}{P_t^W} \right)^{-\eta} y_t^d \tag{6}$$

where y_t^d defines the amount of final goods that retail firms supply in the final goods market at the retail price P_t^W and $P_t^W = \left[\int_0^1 (P_t(z^W))^{1-\eta} dz \right]^{\frac{1}{1-\eta}}$ is the wholesale price index. Right from the outset, note that the zero profit condition requires

$$P_t^W y_t^W dz = P_t^R y_t^d \tag{7}$$

where P_t^R defines the price in the retail market.

Wholesale Firms. The representative wholesale firm produces good z using a standard Cobb–Douglas technology:

$$y_t(z) = (K_t(z))^{\vartheta} (h_t^d(z))^{(1-\vartheta)}. \tag{8}$$

Following SGU, real marginal costs, defined in terms of the final bundle price, are:

$$mc_t = \left(\frac{r_t^k}{\vartheta} \right)^{\vartheta} \left[\frac{w_t \left(1 + \nu \left(1 - \frac{1}{R_t} \right) \right)}{1 - \vartheta} \right]^{1-\vartheta} \tag{9}$$

where $\nu \left(1 - \frac{1}{R_t} \right)$ captures the impact of the CIA constraint.

D. Nominal Rigidities

Calvo Pricing. Under the Calvo specification a fraction $(1 - \alpha)$ of firms choose the optimal price P_t^* and the remaining α firms hold their price

5. Here we implicitly follow the financial sector characterization adopted in CEE, who assume that a financial intermediary collects money balances from Ricardian households and from the central bank. Such funds are then used to finance the working capital needs of firms, and what is left returns to ricardian households.

constant. The wholesale price index is:

$$P_t^W = [(1-\alpha)(P_t^{W*})^{1-\eta} + \alpha(P_{t-1}^W)^{1-\eta}]^{\frac{1}{1-\eta}}.$$

A crucial implication of Calvo pricing is that relative-price dispersion causes resource misallocation which impacts on firms profits.

As shown in SGU, integrating (6) over all firms yields:

$$y_t^W = y_t^d s_t^{Calvo} \tag{10}$$

where $y_t^d = C_t + I_t$ and

$$\begin{aligned} s_t^{Calvo} &= \int_0^1 \left(\frac{P_t(z)}{P_t}\right)^{-\eta} dz \\ &= \alpha\left(\pi_t\right)^{\eta} s_{t-1}^{Calvo} + (1-\alpha)\left[\frac{1-\alpha\pi_t^{\eta-1}}{[1-\alpha]}\right]^{\frac{-\eta}{1-\eta}} \end{aligned} \tag{11}$$

s_t^{Calvo} has a lower bound at 1 and that it matters up to first order when inflation is non-zero in steady state. From (10) it is easy to see that s_t^{Calvo} drives a wedge between the resources available for final use and the resources that firms must utilize to satisfy any given level of aggregate demand. This output loss causes a reduction in aggregate dividends. In fact from (7) and (10) we get

$$\frac{P_t^W}{P_t^R} = \frac{1}{s_t^{Calvo}}$$

therefore dividends of wholesale firms amount to

$$\begin{aligned} d_t^{Calvo} &= (P_t^W - MC_t) y_t^d s_t^{Calvo} \\ &= \left(\frac{\mu^{p,Calvo} - s_t^{Calvo}}{\mu^{p,Calvo}}\right) y_t^d \end{aligned} \tag{12}$$

and are crucial for the analysis of income inequality.

Rotemberg Pricing. In each period all firms can choose the optimal price subject to an adjustment cost:

$$Q_t^p = \frac{\xi_p}{2}\left(\frac{P_t(z)}{P_{t-1}(z)} - 1\right)^2 y_t \tag{13}$$

and dividends are:

$$d_t^{Rotemberg} = \left(\frac{\mu^{p,Rotemberg} - \frac{\xi_p}{2}(\pi_t - 1)^2}{\mu^{p,Rotemberg}}\right) y_t. \tag{14}$$

Labor Unions. Our modeling strategy here is characterized by two key assumptions. First, labor unions maximize a weighted average of agents' intertemporal utilities (Colciago, 2011):

$$E_t \sum_{s=0}^{\infty} (\beta)^s [(1-\Omega) U_{t+s}^o + \Omega U_{t+s}^{rt})].$$

Second, our characterization of wage dynamics incorporates a moderate but non-negligible amount of wage indexation, as documented in Hofmann, Peersman, and Straub (2012) and De Schryder, Peersman, and Wauters (2014).

Under Calvo we therefore assume that in each period $(1-\alpha_w)$ unions reoptimize the wage rate W_t^j. The remaining α_w unions index it to past inflation:

$$W_t^j = W_{t-1}^j \pi_{t-1}^{\chi_w}$$

To model wage stickiness under Rotemberg we posit that for each labor type j the wage adjustment cost is:

$$Q_t^w = \frac{\xi_w}{2}\left(\frac{W_t^j}{W_{t-1}^j(\pi_{t-1}^{\chi_w})} - 1\right)^2 h_t. \tag{15}$$

E. *Monetary Policy*

We assume that monetary policy follows the standard rule:

$$\frac{R_t}{R} = \left(\frac{\pi_t}{\pi_R^*}\right)^{\phi_\pi}\left(\frac{y_t}{y^*}\right)^{\phi_y} \tag{16}$$

where R, y_t, y^*, π_t, π^*, respectively denote the steady state gross nominal interest rate, the current and steady state output levels, the current and target gross inflation rates.

F. *Inflation Expectations*

Following our discussion in the introduction, inflation persistence is modeled by assuming that inflation expectations are partly backward-looking.

$$\widetilde{E}_t\{\pi_{t+1}\} = (1-\Psi)E_t\{\pi_{t+1}\} + \Psi\pi_{t-1} \tag{17}$$

where $E_t\{\pi_{t+1}\}$ defines the rational expectation of π_{t+1}. Inflation persistence allows to obtain that the disinflation causes short-run output losses consistent with estimated sacrifice ratios.

G. *Calibration*

We calibrate the model at quarterly frequency. All parameter values are reported in Table 1. A number of parameters are borrowed from CEE: the discount factor β is set to obtain a 3% real

TABLE 1
Calibration

Parameter	Value	Description
Households		
β	$1.03^{(-1/4)}$	Subjective discount factor
ϕ	1	Inverse of Frisch elasticity
η_w	21	Labor elasticity of substitution
Ω	0.3	Share of RT households
α_w	0.64	Calvo wage parameter
ξ_w	97.4	Rotemberg wage parameter
χ_w	0.5	Wage Indexation
Firms		
ϑ	0.36	Capital share in production
δ	0.025	Capital depreciation
η	6	Goods elasticity of substitution
α	0.6	Calvo price parameter
ξ_p	18.5	Rotemberg price parameter
ν	0–0.15	CIA parameter
Monetary authority		
ϕ_π	1.5	Inflation feedback
ϕ_y	0–0.1	Output gap feedback
Ψ	0.9	Inertia in inflation expectations

interest rate per annum; the capital income share parameter ϑ is set at 36%; the inverse of the Frisch elasticity, ϕ, is 1; the capital depreciation rate per quarter is 2.5%. The elasticities of substitution $\eta = 6$ and $\eta_w = 21$ imply that at zero inflation the steady state price and wage markups are 20% and 5% respectively. In CEE the ν parameter is set at 1. Rabanal (2007) estimates that ν has a posterior mean of 15%, with a large standard deviation, 13%. In the paper we study two cases, when ν is either 15% (full model) or zero.

Empirical DSGE-LAMP models estimate a substantial share of RT households. Earlier studies for the EMU obtain estimates for Ω in a range between 24% and 37% (Coenen and Straub 2005; Forni, Monteforte, and Sessa 2009). Albonico, Paccagnini, and Tirelli (2016, 2017) estimate a fraction of RT consumers at 50% in both the EMU and the United States. Galí, Lopez-Salido, and Vallés Liberal (2007) calibrate Ω at 0.5. We choose a conservative benchmark calibration by setting $\Omega = 0.3$.[6] The Taylor rule parameters take standard values $\phi_\pi = 1.5$, $\phi_y = 0.1$. The preference parameter ϕ_1 is calibrated to obtain that worked hours amount to 25% in the initial steady state.

Let us now turn to the calibration strategy adopted for the parameters that characterize nominal rigidities. In CEE the Calvo price and wage parameters, α and α_w respectively are 0.6 and 0.64 and full inflation indexation is assumed for non-optimizing firms and labor unions. In our benchmark exercise we maintain the CEE values for α and α_w. To obtain comparable inflation dynamics under the two price-setting mechanisms, we impose that the Calvo and Rotemberg formalisms yield identical slopes of the log-linearized price and wage Phillips curves up to first order approximation. Following Keen and Wang (2007), this requires that

$$\xi_p = \frac{(\eta - 1)\alpha}{(1-\alpha)(1-\beta\alpha)} = 18.5$$

$$\xi_w = \frac{(\eta_w - 1)\alpha_w}{(1-\alpha_w)(1-\beta\alpha_w)} = 97.4.$$

The wage indexation parameter is set at 0.5. This calibration falls in the mid-range of the cross-country estimates in López-Villavicencio and Saglio (2017). Parameter Ψ, which captures inertia in inflation expectations, is calibrated to obtain under Calvo pricing a sacrifice ratio of 1.31, in the lower range of the empirically plausible values documented in Ascari and Ropele (2012a).

IV. THE DISINFLATION EXPERIMENT

The disinflation experiment entails a transition from high- to low-inflation steady state, respectively defined as π^*_{old} and π^*_{new}. Following Ascari and Ropele (2012a), we assume that the Central Bank inflation target is reduced from $\pi^*_{old} = 1.05$ to $\pi^*_{new} = 1.02$.[7]

The log-run consequences of disinflation may be decomposed into *efficiency effects* that relate to average variables, and *redistributive effects* which affect relative consumption levels. We shall also account for the effects of disinflation during the transition, when RT households cannot exploit accumulated wealth to smooth consumption.

A. *Efficiency Effects of Disinflation*

Table 2 reports the steady state percentage variations of output (y), consumption (c), average firms markup (μ^p) and dividends (d), real wage (w), hours (h), capital (K), consumption–output ratio (c/y), price markup–dividend ratio (μ^p/d) and price dispersion/price adjustment cost–dividends ratio (s/d; Q^p/d).

6. Our results are robust for a larger share of RT households, namely, $\Omega = 0.5$.

7. We simulate the nonlinear first order conditions because approximating transitions with log-linear first-order conditions may bias results (Ascari and Merkl 2009). The model is numerically solved using DYNARE: http://www.cepremap.cnrs.fr/dynare/

TABLE 2
Steady State Percentage Variations

Aggregate Variables	$\nu = 0$ Calvo	$\nu = 0$ Rotemberg	$\nu = 0.15$ Calvo	$\nu = 0.15$ Rotemberg
y	0.49	−0.10	0.53	−0.06
c	0.50	0.11	0.54	0.15
μ^p	−0.14	0.02	−0.14	0.02
d	0.63	0.59	0.67	0.63
w	0.22	−0.03	0.33	0.08
h^d	0.23	−0.09	0.27	−0.05
K	0.46	−0.12	0.50	−0.08
c/y	0.01	0.21	0.01	0.21
μ^p/d	−0.77	−0.57	−0.81	−0.61
s/d; Q^p/d	−0.80	−0.70	−0.84	−0.74

To rationalize these results, we focus on the steady state real marginal cost and the capital–labor ratio, which are pinned down by the price markup:

$$(18) \qquad mc = \left(\frac{r^k}{\vartheta}\right)^{\vartheta}\left[\frac{w\left[1+\nu\left[1-\frac{1}{R}\right]\right]}{1-\vartheta}\right]^{1-\vartheta} = \frac{1}{\mu^{p,X}}; \quad X = Calvo, Rotemberg$$

$$(19) \qquad \frac{K}{h} = \left(\frac{\mu^{p,X} r^k}{\vartheta}\right)^{\frac{-1}{1-\vartheta}}.$$

where $r^k = \frac{1}{\beta} - 1 + \delta$ and $R = \frac{\pi}{\beta}$.

The inflation effect on dividends is twofold. On the one hand it affects price markups. On the other hand it generates either price-adjustment costs or price-dispersion losses that reduce dividends distributed to households. Consider first the case of a nonbinding CIA, that is, $\nu = 0$.

Calvo Pricing. Under Calvo pricing the steady state average markup

$$(20) \qquad \mu^{p,Calvo} = \frac{\eta}{\eta - 1}\frac{\left(1-\beta\alpha\pi^{-(1-\eta)}\right)}{\left(1-\beta\alpha\pi^{\eta}\right)} \left[\frac{1}{1-\alpha}\right]^{\frac{-1}{1-\eta}}\left(1-\alpha\pi^{(\eta-1)}\right)$$

is determined by two countervailing effects: (1) term $(1-\alpha\pi^{(\eta-1)})$ defines how lower inflation limits the erosion of nonoptimizing firms markups; (2) term $\frac{(1-\beta\alpha\pi^{-(1-\eta)})}{(1-\beta\alpha\pi^{\eta})}$ defines the lower markups chosen by optimizing firms in consequence of the expected lower inflation. Our calculations show that this latter effect dominates, and the average price markup falls.[8] As a result, the real wage unambiguously increases (see (18)). From (19) it is easy to see that this occurs because lower markups are associated to an increase in the capital–labor ratio. Furthermore, disinflation reduces price dispersion:

$$(21) \qquad s^{Calvo} = \frac{(1-\alpha)}{1-\alpha\pi^{\eta}}\left[\frac{1-\alpha\pi^{1-\eta}}{(1-\alpha)}\right]^{\frac{-\eta}{1-\eta}}$$

In the Appendix we document that the reduction in wage dispersion and wage markups is associated to an increase in the labor supply. As a result output and consumption increase. In spite of lower markups, the smaller output losses due to price dispersion cause an increase in firms profitability and in aggregate dividends.

Rotemberg Pricing. Disinflation unambiguously reduces price and wage adjustment costs. This, in turn, leaves room for an increase in consumption at any given level of aggregate supply:

$$(22) \qquad y^{Rotemberg} = \frac{y^d}{1 - \frac{\xi_p}{2}[\pi-1]^2 - \frac{\xi_w}{2}[\pi-1]^2\left(\frac{K}{h}\right)^{-\vartheta}}.$$

By contrast, the price markup

$$(23) \qquad \mu^{p,Rotemberg} = \frac{\eta}{[(\eta-1)+\eta(1-\beta)\xi_p(\pi-1)\pi]}$$

unambiguously increases, causing a supply reduction.[9] The markup increase explains why under Rotemberg the disinflation has less favorable effects on consumption and on the real wage. The ratio $\frac{c}{y}$ increases because the higher price markup reduces the capital–labor ratio and the investment share in steady state. The combination of higher markups and smaller price adjustment costs raises firms dividends.

Consider now the case of a binding CIA, that is, $\nu = 0.15$.

By holding the price markup constant in (18) it is straightforward to determine the effects of disinflation that occur through the CIA channel. The reduction in the interest payments on loans financing the wage bill is entirely absorbed by a real wage increase. This, in turn, stimulates a labor supply expansion which is matched by an

8. See Ascari and Rossi (2012) for a detailed discussion of this result.
9. An identical result obtains for the wage markup.

TABLE 3
Inequality Measures, Percentage Variations

Inequality Measures	$\nu = 0$ Calvo	$\nu = 0$ Rotemberg	$\nu = 0.15$ Calvo	$\nu = 0.15$ Rotemberg
c^{rt}/c^o	−0.05	−0.30	0.09	−0.16
wh/y	−0.03	−0.02	0.08	0.09

increase in the capital stock (see (19)). Given these results it is therefore obvious that both output and consumption must increase when the CIA binds.

B. Long-run Redistributive Effects of Disinflation

In this section we discuss closed-form solutions and Table 3 reports numerical calculations which support intuition when theoretical results are ambiguous. Using (8), (18), (19) we obtain the labor income share:

$$\frac{wh}{y} = \frac{1-\vartheta}{(\mu^{p,X})\left[1+\nu\left(1-\frac{\beta}{\pi}\right)\right]}.$$

Lower interest payments on the wage bill unambiguously raise $\frac{wh}{y}$. Under Calvo this latter effect is strengthened by the fall in price markups, whereas under Rotemberg the markup increase works in the opposite direction.

In our relatively simple framework, it is possible to obtain an analytical characterization of steady state inequality by focusing on consumption levels of the two household types:

$$c^{rt} = wh$$

$$c^o = wh\left(1+\frac{\nu}{1-\Omega}\left(1-\frac{1}{R}\right)\right) + \frac{\left(r^k-\delta\right)K}{1-\Omega} + \frac{d}{1-\Omega}; \quad R = \frac{\pi}{\beta}.$$

Consumption inequality is determined by the concentration of wealth holdings in the hands of Ricardian households. In addition to their labor income, in steady state they consume the net real return on physical capital $\frac{(r^k-\delta)K}{1-\Omega}$, the net interest payments on real money holdings which finance firms' wage bills $\frac{\nu}{\Omega}\left(1-\frac{1}{R}\right)wh$, and individual holdings of dividends, $\frac{d}{1-\Omega}$. As shown in the Appendix,

$$(24)\quad \frac{c^{rt}}{c^o} = \frac{1}{\left(1+\frac{\nu}{(1-\Omega)}\left(1-\frac{1}{R}\right)\right) + \left[[r^k-\delta]\vartheta + \frac{\mu^{p,X}-1-\frac{\epsilon\xi_p}{2}[\pi-1]^2}{s^{(1-\epsilon)}}\right] \times \frac{\left(1+\nu\left(1-\frac{1}{R}\right)\right)}{(1-\Omega)(1-\vartheta)}}$$

the fall in inflation reduces the importance of the CIA, and the relative consumption of RT households unambiguously increases for this reason. The dividend effect on relative consumption depends on the specific features of the price-setting mechanism. Under Rotemberg, the lower inflation rate raises dividends because the price markup increases (see Equation (23)) and because inflation adjustment costs fall. Under Calvo, disinflation has ambiguous effects because the price markup falls but the reduction in price dispersion has beneficial effects on dividends. Our calculations show that even in this latter case disinflation is associated with an increase in dividends that, in turn, raises consumption inequality. Our calibrated model predicts that under Rotemberg a relatively strongly binding CIA constraint, namely 33%, is needed to nullify the inequality between the two groups of households, whereas under Calvo a fall in inequality occurs only if at least 5% of the wage bill must be pre-financed.

TABLE 4
Sacrifice Ratios

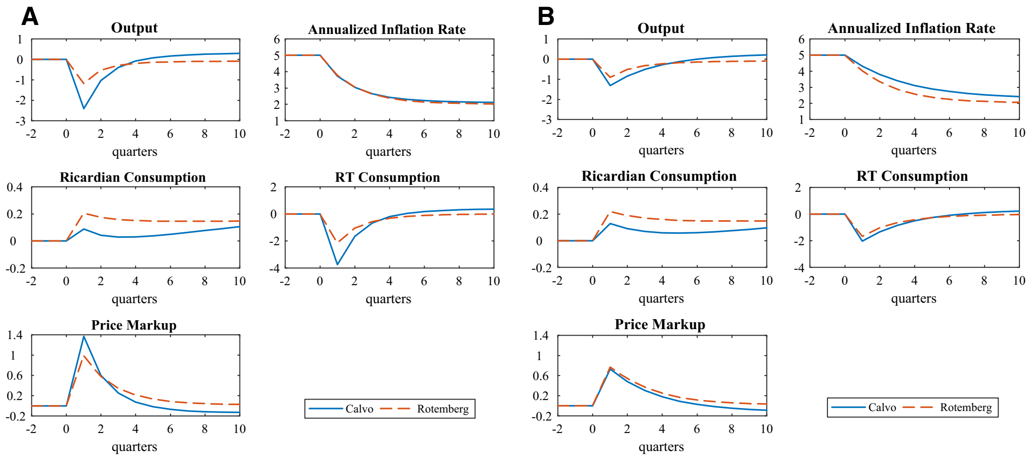
	SR_{y^d}	$SR_{c^{rot}}$	T y^d	T c^{rot}
Calvo				
$\nu = 0.15; \phi_y = 0$	1.31	2.09	5	5
$\nu = 0.15; \phi_y = 0.1$	1.04	1.71	6	7
Rotemberg				
$\nu = 0.15; \phi_y = 0$	0.73	1.36	5	5
$\nu = 0.15; \phi_y = 0.1$	0.72	1.38	6	7

C. Short-Run Dynamics and Inequality

In Figures 2A and 2B, we report transitions under the Calvo and Rotemberg price-setting mechanisms when the output gap feedback is either 0 or 0.1. Results are broadly consistent with the empirical findings reported in Ascari and Ropele (2012a): the disinflation causes short-run output losses. This outcome is driven by the permanent income effect of the disinflation

FIGURE 2

(A) Short-run Dynamics and Inequality; Full Model ($\nu = 0.15$); $\phi_y = 0$. (B) Short-run Dynamics and Inequality; Full Model ($\nu = 0.15$); $\phi_y = 0.1$



and by the real interest rate increase caused by inflation inertia, which induce Ricardian households to reduce investment in physical capital and to raise their consumption. RT households suffer a loss of disposable income due to the fall in both wages and worked hours. As a result we observe a sharp deterioration in RT consumption levels. The output contraction and the fall in RT consumption are less sharp if the Taylor rule incorporates a feedback on the output gap. In this case the milder recession is obtained at the cost of slowing down the pace of inflation convergence to the new target. In spite of the substantial degree of wage inertia imposed with our calibration, the transition to the low inflation steady state is always characterized by a sharp increase in price markups.

To measure the costs of disinflation we calculate sacrifice ratios, SR_X, for output and RT consumption (Table 4).

$$SR_X = \frac{1}{\pi^*_{old} - \pi^*_{new}} \sum_{t=0}^{T} \left(\frac{X_t - X^*_{old}}{X^*_{old}} \right) \tag{25}$$

where $X^*_{old} = y^*_{old}, c^{rot,*}_{old}$ defines output and RT consumption in the high inflation steady state, $\pi^*_{old} - \pi^*_{new}$ is the disinflation in percentage points, and T is the number of periods necessary for output to return to y^*_{old} after the initial contraction.[10] Losses for RT consumers are much larger than conventional measures of output sacrifice ratios.

D. Welfare Effects of Disinflation

The intertemporal welfare function in recursive form is

$$V^i_t = \ln(c^i_t) - \frac{\phi_1}{(1+\phi)} (h^i_t)^{(1+\phi)} + \beta E_t V^i_{t+1} \tag{26}$$

We define

(27)

$$V^i_{old} = \frac{1}{(1-\beta)} \left[\ln(c^i_{old}) - \frac{\phi_1}{(1+\phi)} (h^i_{old})^{(1+\phi)} \right]; \quad i = o, rt$$

as the predisinflation steady state value of V^i, and V^i_0 as the value of (26) at time zero, when the disinflation is implemented. Since the utility function is not cardinal, the numerator of the ratio needs to be transformed in a measure which can "quantify" the welfare cost (or gain) of disinflation. This is a standard methodology for measuring the welfare effects of business cycles in terms of a *consumption equivalent measure* (Krusell et al. 2009; Lucas 1987). Following Ascari and Ropele (2012a) and Ascari, Phaneuf, and Sims (2018), the *consumption equivalent*

10. To facilitate comparison between the two price setting mechanisms, T is the number of "sacrifice periods" observed under Calvo.

TABLE 5
Welfare Analysis (A) $\phi_y = 0$ and (B) $\phi_y = 0.1$

	Calvo	Rotemberg
(A) $\phi_y = 0$		
Consumpion equivalent measure during the sacrifice period		
γ^{o*}_{SR}	−0.94	−0.56
γ^{rt*}_{SR}	0.37	0.38
Total consumption equivalent measure		
γ^{o*}	−0.44	−0.23
γ^{rt*}	−0.51	−0.05
(B) $\phi_y = 0.1$		
Consumpion equivalent measure during the sacrifice period		
γ^{o*}_{SR}	−0.69	−0.49
γ^{rt*}_{SR}	0.23	0.31
Total consumption equivalent measure		
γ^{o*}	−0.44	−0.23
γ^{rt*}	−0.50	−0.05

measure is defined here as the constant fraction of consumption that households must give up to permanently reduce inflation:

$$\frac{1}{(1-\beta)}\left[\ln(c^i_{old}(1-\gamma^i)) - \frac{\phi_1}{(1+\phi)}(h^i_{old})^{(1+\phi)}\right] = V^i_0$$

$$\gamma^i = 1 - \exp[(1-\beta)(V^i_0 - V^i_{old})] \tag{28}$$

Disinflation is welfare improving when the welfare-based ratio is negative, and we read the negative values as welfare gains. Table 5 reports our results[11], where we also compute the consumption equivalent measure associated to the welfare losses incurred during the T periods of output sacrifice, γ^i_{SR},

$$\gamma^i_{SR} = 1 - \exp\left[\frac{V^i_{SR}}{A} - V^i_{OLD}(1-\beta)\right] \tag{29}$$

where $A = \sum_{t=1}^{T}\beta^t$, $V^i_{SR} = \sum_{t=1}^{T}\beta^t\left\{\ln(c^i_t) - \frac{\phi_1}{(1+\phi)}(h^i_t)^{(1+\phi)}\right\}$.

Note that γ^i is always negative, and Ricardian households are relatively better off under Rotemberg whereas the opposite result obtains under Calvo. This result is determined by the different markup responses that we observe in the long-run under the two price-setting mechanisms. The short-run welfare effects of the disinflation are instead quite different for the two groups. This cannot be a surprise given the different consumption dynamics discussed above. Table 5B shows that a more accommodative monetary policy stance can alleviate short run losses for RT consumers.

Consistent with the inequality results, our calibrated model predicts that under Rotemberg the difference in the total welfare gain of the two groups of households is nil with a relatively strongly binding CIA constraint, namely $\nu = 35\%$, whereas under Calvo the total welfare gain is the same for Ricardian and non-asset holders households when $\nu = 7\%$.

V. CONCLUSION

This paper investigates the distributional and welfare effects of disinflation in a TANK model where monetary policy nonneutrality is due to a CIA constraint on firms wage bill and to the endogeneity of firm dividends.

Our theoretical conclusions boil down to two simple predictions. In the long-run a disinflation unambiguously raises firms dividends, thus it can be associated to a reduction in inequality only if the cost channel of monetary policy, that is, the CIA effect, is sufficiently strong. Transitions to the lower inflation rate are temporarily characterized by a strong increase in inequality.

Our welfare analysis suggests that the overall effect of the disinflation is always beneficial. However the price-setting mechanism and the ensuing long-run effect on price markups are crucial to determine the distribution of benefits. In fact under Rotemberg pricing Ricardian households are relatively better off, whereas the opposite conclusion holds under Calvo pricing.

In all cases considered in the paper, short-run dynamics heavily penalize RT consumers. Shifting monetary policy toward a more accommodative stance can alleviate short-run losses but has negligible impact on inequality. Thus, if inequality is a source of political concern, the policy implication of the paper is that fiscal tools should be exploited to compensate losers during the disinflation process. We leave this for future research.

One important caveat concerns the rather crude representation of households heterogeneity we adopt in the paper. Our results might be better qualified in a HANK framework. We leave this for future research as well.

APPENDIX A: THE MODEL

HOUSEHOLDS

There is a continuum of households indexed by i, $i \in [0, 1]$. RT (rt) and Ricardian (o) households are respectively

11. Results are expressed in percentage values.

defined over the intervals $[0, \Omega]$ and $[\Omega, 1]$. The households utility function is:

$$U_t^i = E_t \sum_{t=0}^{\infty} \beta^t \left\{ \ln(c_t^i) - \frac{\phi_1}{(1+\phi)} (h_t^i)^{(1+\phi)} \right\}$$

where c_t^i denotes consumption, h_t^i denotes labor supply of a differentiated labor bundle.

CONSUMPTION BUNDLES

The consumption good is characterized by Dixit–Stiglitz preferences:

$$c_t^i = \left[\int_0^1 c(z)_t^{\frac{\eta-1}{\eta}} dz \right]^{\frac{\eta}{\eta-1}}$$

where $\eta > 1$ denotes the elasticity of substitution across different varieties of goods.

Demand for good z is:

$$c_t^i(z) = \left(\frac{P(z)_t}{P_t} \right)^{-\eta} c_t^i$$

where

$$P_t = \left(\int_0^1 p(z)_t^{(1-\eta)} dz \right)^{\frac{1}{1-\eta}}$$

is the aggregate price consumption index and $P(z)_t$ defines the price set by the firm producing good z.

RICARDIAN HOUSEHOLDS

The Ricardian households period budget constraint in real terms reads as:

$$c_t^o + i_t^o + m_t^o = r_t^k K_t^o + w_t h_t^d + \frac{d_t^o}{1-\Omega} + \frac{R_{t-1}}{\pi_t} m_{t-1}^o$$

where i_t^o denotes the real purchases of investment goods at time t. Ricardian households accumulate physical capital K_t^o and rent it out to firms at a real rental rate r_t^k. d_t^o defines individual holdings of firms dividends, m_t^o defines individual money holdings, which are used to finance firms' wage bills at the nominal rate R_t.

The capital stock evolves according to the following law of motion:

$$K_{t+1}^o = (1-\delta) K_t^o + i_t^o$$

where δ is the capital depreciation rate.

Following SGU, the Ricardian households first order conditions with respect to c_t^o, m_t^o, K_t^o, respectively are:

$$\frac{1}{c_t^o} = \lambda_t^o$$

$$\lambda_t^o = \beta R_t \frac{\lambda_{t+1}^o}{\widetilde{E}_t\{\pi_{t+1}\}}$$

$$\lambda_t^o = \beta \lambda_{t+1}^o (1 - \delta + r_{t+1}^k).$$

RULE-OF-THUMB HOUSEHOLDS

Non-Ricardian entirely consume their income in each period:

$$c_t^{rt} = h_t^d \int_0^1 w_t^j \left(\frac{w_t^j}{w_t} \right)^{-\eta_w}.$$

Their marginal utility of consumption is:

$$\frac{1}{c_t^{rt}} = \lambda_t^{rt}.$$

FIRMS

Firms compete monopolistically by producing good z according to the following technology:

$$y_t(z) = (K_t(z))^{\vartheta} (h_t(z))^{(1-\vartheta)}$$

Firms are subject to a cash in advance constraint on the wage bill:

$$m_{zt} = \nu w_t h_{zt}$$

where m_{zt} denotes the real money balances obtained by firm z and ν is the fraction of labor costs which is paid in advance. Firms financial needs are supplied by Ricardian households at the gross nominal interest rate.

Following SGU real marginal costs and factors demands are:

$$mc_t = \left(\frac{r_t^k}{\vartheta} \right)^{\vartheta} \left(\frac{w_t \left[1 + \nu \left(1 - \frac{1}{R_t} \right) \right]}{1-\vartheta} \right)^{1-\vartheta}$$

$$r_t^k = mc_t \vartheta \left(\frac{h_t}{K_t} \right)^{1-\vartheta}$$

$$w_t \left[1 + \nu \left(1 - \frac{1}{R_t} \right) \right] = mc_t (1-\vartheta) \left(\frac{K_t}{h_t} \right)^{\vartheta}$$

Price Setting

Calvo: According to the Calvo (1983) framework, each period a firm faces a constant probability $(1-\alpha)$ of being able to reoptimize prices. In other words, α denotes the degree of price stickiness.

The optimal price P_t^* is chosen in order to maximize the discounted value of expected future profits. Moreover, it is important to remind here that only Ricardian households own firms. Hence, the firms' maximization problem is:

$$\max_{P_t^*} E_t \sum_{s=0}^{\infty} (\beta\alpha)^s \frac{\lambda_{t+s}^o}{\lambda_t^o} (P_t^* - P_{t+s} mc_{t+s}) y_{t,t+s}(z)$$

subject to:

$$y_{t,t+s}(z) = \left(\frac{P_t^*}{P_{t+s}} \right)^{(-\eta)} y_{t+s}^d$$

where y_t^d is the aggregate demand and $\frac{\beta^s \lambda_{t+s}^o}{\lambda_t^o}$ denotes the stochastic discount factor of Ricardian households.

As shown in SGU the first order condition with respect to P_t^* is:

$$\sum_{s=0}^{\infty} (\beta\alpha)^s \frac{E_t(\lambda_{t+s}^o)}{\lambda_t^o} \left(\frac{P_t^*}{E_t(P_{t+s})} \right)^{(-\eta)} y_{t+s}^d \times \left[P_t^* - \frac{\eta}{\eta-1} E_t(P_{t+s} mc_{t+s}) \right] = 0$$

where $\frac{\eta}{\eta-1}$ is the markup which would obtain in absence of price stickiness. The price level is a weighted average of the prices set by optimizing and nonoptimizing firms:

$$P_t = [(1-\alpha)P_t^{*1-\eta} + \alpha(P_{t-1})^{1-\eta}]^{\frac{1}{1-\eta}}$$

Straightforward manipulations allow to obtain the average price markup over marginal costs, $\mu_t^{p,Calvo}$:

$$\mu_t^{p,Calvo} = \frac{1}{mc_t}\left[(1-\alpha)\left(\frac{P_t^*}{P_t}\right)^{1-\eta} + \alpha\left(\frac{1}{\pi_t}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}$$

Dividends

Dividends of wholesale firms amount to:

$$\begin{aligned} d_t^{Calvo} &= (P_t^W - MC_t)y_t^d s_t^{Calvo} \\ &= \left(\frac{P_t^R}{s_t^{Calvo}} - MC_t\right) y_t^d s_t^{Calvo} \\ &= \left(1 - s_t^{Calvo}\frac{MC_t}{P_t^R}\right) y_t^d \\ &= \left(1 - \frac{s_t^{Calvo}}{\left(\frac{MC_t}{P_t^R}\right)}\right) y_t^d \\ &= \left(1 - \frac{s_t^{Calvo}}{\mu^{p,Calvo}}\right) y_t^d \\ &= \left(\frac{\mu^{p,Calvo} - s_t^{Calvo}}{\mu^{p,Calvo}}\right) y_t^d \end{aligned}$$

Rotemberg: Under Rotemberg the firm maximizes discounted profits:

$$\max_{P_t(z)} E_t\left[\sum_{s=0}^{\infty}\beta^s\frac{\lambda_{t+s}^o}{\lambda_t^o}\left(\frac{P_{t+s}(z)}{P_{t+s}} - mc_{t+s}\right) y_{t+s}(z)\right]$$

subject to

$$y_{t+s}(z) = \left(\frac{P_{t+s}(z)}{P_{t+s}}\right)^{-\eta} y_{t+s}$$

and to a quadratic price adjustment cost:

$$\frac{\xi_p}{2}\left(\frac{P_t(z)}{P_{t-1}(z)} - 1\right)^2 y_t$$

where $\xi_p > 0$ measures the degree of nominal price rigidity.

In the symmetrical equilibrium, where price dispersion is absent by assumption, the FOC to the problem is:

$$\begin{aligned} mc_t = {} & \left(\frac{\eta-1}{\eta}\right) + \frac{\xi_p}{\eta}(\pi_t - 1)\pi_t - \beta\frac{\xi_p}{\eta}\frac{E_t\lambda_{t+1}^o}{\lambda_t^o} \\ & \times (\widetilde{E}_t\{\pi_{t+1}\} - 1)\widetilde{E}_t\{\pi_{t+1}\}\frac{E_t y_{t+1}}{y_t} \end{aligned}$$

where the real markup is

$$\mu_t^{p,Rotemberg} = \frac{1}{mc_t}$$

WAGE SETTING

Calvo

In each period a labor union faces a constant probability $(1-\alpha_w)$ of being able to reoptimize wages. In other words, α_w denotes the degree of wage stickiness.

Each optimizing union sets W_t^* to maximize a weighted average of the two household types utility functions, conditional to the probability that the wage cannot be reoptimized in the future.

$$L^u = E_t\sum_{s=0}^{\infty}(\beta\alpha_w)^s\{[(1-\Omega)U^o(c_{t+s}^o) + \Omega U^{rt}(c_{t+s}^{rt})] - U(h_{t+s})\}$$

L^u is maximized subject to the firms demand constraint

$$h_t^j = \left(\frac{W_t^j}{W_t}\right)^{-\eta_w} h_t^d$$

The first order condition is:

$$\begin{aligned} & E_t\sum_{s=0}^{\infty}(\beta\alpha_w)^s\lambda_{t+s}h_{t+s}^d\left(\frac{w_t^*}{w_{t+s}}\right)^{-\eta_w}\prod_{k=1}^{s}\left(\frac{\pi_{t+k}}{\pi_{t+k-1}^{\chi_w}}\right)^{(\eta_w)} \\ & \times\left[\frac{(\eta_w-1)}{\eta_w}\frac{w_t^*}{\prod_{k=1}^{s}\left(\frac{\pi_{t+k}}{\pi_{t+k-1}^{\chi_w}}\right)} - mrs_{t+s}\right] = 0 \end{aligned}$$

where

$$\lambda_{t+s} = [(1-\Omega)\lambda_{t+s}^o + \Omega\lambda_{t+s}^{rt}]$$

is the average marginal utility of consumption, $mrs_{t+s} = -\frac{U_{h,t+s}}{\lambda_{t+s}}$ defines the average marginal rate of substitution and $\frac{(\eta_w-1)}{\eta_w}$ is the markup that would prevail under flexible nominal wages and χ_w denotes wage indexation to past inflation. The aggregate real wage is a weighted average of the real wages set by optimizing and nonoptimizing unions:

$$w_t^{(1-\eta_w)} = (1-\alpha_w)w_t^{*(1-\eta_w)} + \alpha_w\left(\frac{\pi_{t-1}^{\chi_w}}{\pi_t}w_{t-1}\right)^{(1-\eta_w)}$$

Rotemberg

In each period all unions maximize

$$L^u = E_t\sum_{s=0}^{\infty}(\beta)^s\{[(1-\Omega)U^o(c_{t+s}^o) + \Omega U^{rt}(c_{t+s}^{rt})] - U(h_{t+s})\}$$

subject to firms labor demand

$$h_t^j = \left(\frac{W_t^j}{W_t}\right)^{-\eta_w} h_t^d$$

and to a quadratic adjustment cost:

$$\frac{\xi_w}{2}\left(\frac{W_t^j}{(\pi_{t-1}^{\chi_w})W_{t-1}^j} - 1\right)^2 h_t.$$

From the first order condition the wage setting (wage markup) equation is:

$$\mu_t^{w,Rotemberg} = \frac{w_t}{mrs_t} = \frac{\eta_w}{\eta_w - 1}$$
$$\times \left\{ 1 - \left[\begin{array}{c} \frac{\xi_w}{\eta_w}\left(\frac{w_t}{w_{t-1}}\frac{\pi_t}{\pi_{t-1}^{\chi_w}} - 1\right)\frac{w_t}{w_{t-1}}\frac{\pi_t}{\pi_{t-1}^{\chi_w}} + \\ -\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{\xi_w}{\eta_w}\left(\frac{w_{t+1}}{w_t}\widetilde{E}_t\{\pi_{t+1}\} - 1\right)\frac{h_{t+1}}{h_t}\frac{w_{t+1}}{w_t}\widetilde{E}_t\{\pi_{t+1}\} \end{array} \right] \right\}.$$

MARKET CLEARING

Consider the individual firm demand function:

$$y_t(z) = \left(\frac{P_t(z)}{P_t}\right)^{-\eta} y_t^d$$

where

$$y_t^d = c_t + i_t$$

defines absorption of resources for consumption and capital accumulation. Integrating over all firms yields:

$$y_t = s_t^X y_t^d$$

where $s_t^X (X = Calvo, Rotemberg)$ defines the output wedge, that is, the output costs of inflation under nominal rigidities.

s_t^{Calvo} denotes the resource cost determined by relative price dispersion in the Calvo model. As shown in SGU

$$s_t^{Calvo} = \int_0^1 \left(\frac{P_t(z)}{P_t}\right)^{-\eta} dz = \alpha(\pi_t)^{\eta} s_{t-1}^{Calvo} + (1-\alpha)\left(\frac{P_t^*}{P_t}\right)^{-\eta}$$

where $\frac{P_t^*}{P_t}$, given the characterization of the aggregate price index, must satisfy:

$$\alpha\pi_t^{(\eta-1)} + (1-\alpha)\left(\frac{P_t^*}{P_t}\right)^{(1-\eta)} = 1$$

SGU have shown that s_t^{Calvo} has a lower bound at 1 and that it matters up to first order when the deterministic steady state features a nonzero inflation rate.

Under Rotemberg the output wedge is determined by the output costs of price and nominal wage adjustments.

$$s_t^{Rotemberg} = \frac{1}{1 - \frac{\xi_p}{2}(\pi - 1)^2 - \frac{\xi_w}{2}\left(\frac{w_t}{w_{t-1}}\frac{\pi_t}{\pi_{t-1}^{\chi_w}} - 1\right)^2}.$$

Labor Market Equilibrium

The equilibrium on the labor market is given by:

$$h_t^s = \widetilde{s}_t^X h_t^d$$

where $h_t^d = \left(\frac{y_t}{K_t^{\vartheta}}\right)^{\frac{1}{(1-\vartheta)}}$ defines firms labor demand and $\widetilde{s}_t^X$ denotes the labor market wedge. $\widetilde{s}_t^{Rotemberg} = \frac{1}{1-\frac{\xi_w}{2}\left(\frac{w_t}{w_{t-1}}\frac{\pi_t}{\pi_{t-1}^{\chi_w}} - 1\right)^2}$; $\widetilde{s}_t^{Calvo}$ is the additional labor effort due to relative wage dispersion in the Calvo model. It evolves according to:

$$\widetilde{s}_t^{Calvo} = (1-\alpha_w)\left(\frac{w_t^*}{w_t}\right)^{(-\eta_w)} + \alpha_w\left(\frac{w_{t-1}}{w_t}\right)^{(-\eta_w)}\left(\frac{\pi_t}{\pi_{t-1}^{\chi_w}}\right)^{\eta_w}\widetilde{s}_{t-1}^{Calvo}$$

where

$$w_t^* = \left(\frac{w_t^{(1-\eta_w)} - \alpha_w w_{t-1}^{(1-\eta_w)}\left(\frac{\pi_{t-1}^{\chi_w}}{\pi_t}\right)^{(1-\eta_w)}}{(1-\alpha_w)}\right)^{\frac{1}{(1-\eta_w)}}.$$

APPENDIX B: STEADY STATE DERIVATION

In the following we present a recursive derivation of the steady state values for the variables discussed in the main text.

From the Ricadian households first order conditions

$$R = \frac{\pi}{\beta}$$

$$r^k = \frac{1}{\beta} - 1 + \delta.$$

Given that

$$s_t^{Calvo} = \int_0^1 \left(\frac{P_t(z)}{P_t}\right)^{-\eta} dz = \alpha(\pi_t)^{\eta} s_{t-1}^{Calvo} + (1-\alpha)\left(\frac{P_t^*}{P_t}\right)^{-\eta}$$
$$= \alpha\pi_t^{(\eta-1)} + (1-\alpha)\left(\frac{P_t^*}{P_t}\right)^{(1-\eta)} = 1$$

Steady state price dispersion under Calvo is:

$$s^{Calvo} = \frac{(1-\alpha)}{1-\alpha\pi^{\eta}}\left[\frac{1-\alpha\pi^{-(1-\eta)}}{(1-\alpha)}\right]^{\frac{-\eta}{1-\eta}}$$

Derivation of markups:

- Under Calvo:

$$\mu^{p,Calvo} = \frac{\eta}{\eta-1}\frac{(1-\beta\alpha\pi^{-(1-\eta)})}{(1-\beta\alpha\pi^{\eta})\frac{P^*}{P}}$$
$$= \frac{\eta}{\eta-1}\frac{(1-\beta\alpha\pi^{-(1-\eta)})}{(1-\beta\alpha\pi^{\eta})\left[\frac{1-\alpha\pi^{-(1-\eta)}}{(1-\alpha)}\right]^{\frac{1}{1-\eta}}}$$

- Under Rotemberg:

$$mc = \left(\frac{\eta-1}{\eta}\right) + \frac{\xi_p}{\eta}(1-\beta)(\pi-1)\pi$$

where the markup is

$$\mu^{p,Rotemberg} = \frac{1}{mc}.$$

The real wage therefore is $\frac{1}{1-\vartheta}$

$$w = (\mu^{p,X})^{-\frac{-1}{1-\vartheta}}\left(\frac{r^k}{\vartheta}\right)^{\frac{-\vartheta}{1-\vartheta}}\frac{1-\vartheta}{1+\nu\left(1-\frac{1}{R}\right)}.$$

To derive capital–labor ratio:

$$y_t(z) = (K_t(z))^{\vartheta}(h_t(z))^{(1-\vartheta)}$$

$$r_t^k = \frac{R_t w_t}{(1-\alpha)(k_{t-1})^{\alpha}(h_t)^{-\alpha}}\alpha(k_{t-1})^{\alpha-1}(h_t)^{1-\alpha}$$

$$\frac{k}{h} = (\mu^{p,X})^{-\frac{1}{1-\vartheta}} \left(\frac{r^k}{\vartheta}\right)^{\frac{-\vartheta}{1-\vartheta}} \frac{\vartheta}{r^k}$$

$$\frac{k}{h} = \left(\frac{\mu^{p,X} r^k}{\vartheta}\right)^{\left(\frac{-1}{(1-\vartheta)}\right)}$$

$$\begin{aligned}\frac{wh}{y} &= \frac{w}{\left(\frac{k}{h}\right)^{\vartheta}}\\ &= (\mu^{p,X})^{-\frac{1}{1-\vartheta}} \left(\frac{r^k}{\vartheta}\right)^{\frac{-\vartheta}{1-\vartheta}} \frac{1-\vartheta}{1+\nu\left(1-\frac{1}{R}\right)} \left(\frac{\mu^{p,X} r^k}{\vartheta}\right)^{\frac{\vartheta}{(1-\vartheta)}}\\ &= (\mu^{p,X})^{-1} \frac{1-\vartheta}{1+\nu\left(1-\frac{1}{R}\right)}\end{aligned}$$

To obtain $\frac{c^{rt}}{c^o}$ bear in mind that aggregate financial variables and returns are obtained aggregating individual holdings

$$(1-\Omega)k^o = K$$

$$(1-\Omega)m^o = \nu wh$$

$$(1-\Omega)d^o = \frac{\left(\mu^{p,X} - 1 - \frac{\epsilon\xi_p}{2}(\pi-1)^2\right)}{\mu^{p,X}} \frac{y}{s^{(1-\varepsilon)}}$$

where $\varepsilon = 0, 1$ characterizes the Calvo and Rotemberg cases respectively. Note that the inflation effect on dividends is twofold. On the one hand it affects price markups. On the other hand it generates "inflation adjustment" costs which reduce dividends distributed to households.

Individual consumption levels are

$$c^{rt} = wh = \frac{(1-\vartheta)}{\mu^{p,X}\left(1+\nu\left(1-\frac{1}{R}\right)\right)} y$$

$$\begin{aligned}c^o &= c^{rt}\left(1+\frac{\nu}{(1-\Omega)}\left(1-\frac{1}{R}\right)\right) + \frac{(r^k-\delta)K}{(1-\Omega)} + d^o\\ &= c^{rt}\left(1+\frac{\nu}{(1-\Omega)}\left(1-\frac{1}{R}\right)\right) + \frac{(r^k-\delta)}{(1-\Omega)}\frac{K}{y} y\\ &\quad + \frac{1}{(1-\Omega)} \frac{\left(\mu^{p,X} - 1 - \frac{\epsilon\xi_p}{2}(\pi-1)^2\right)}{\mu^{p,X} s^{(1-\varepsilon)}} y\end{aligned}$$

where $\frac{K}{y} = \left(\frac{\mu^{p,X} r^k}{\vartheta}\right)^{-1}$. As a result:

$$\frac{c^{rt}}{c^o} = \frac{1}{\begin{array}{c}\left(1+\frac{\nu}{(1-\Omega)}\left(1-\frac{1}{R}\right)\right)\\ +\left[\frac{(r^k-\delta)}{(1-\Omega)}\left(\frac{\mu^{p,X} r^k}{\vartheta}\right)^{-1} + \frac{1}{(1-\Omega)} \frac{\left(\mu^{p,X}-1-\frac{\epsilon\xi_p}{2}(\pi-1)^2\right)}{s^{(1-\varepsilon)}\mu^{p,X}}\right]\\ \times \frac{\mu^{p,X}\left(1+\nu\left(1-\frac{1}{R}\right)\right)}{(1-\vartheta)}\end{array}}$$

$$\frac{c^{rt}}{c^o} = \frac{1}{\begin{array}{c}\left(1+\frac{\nu}{(1-\Omega)}\left(1-\frac{1}{R}\right)\right)\\ +\left[(r^k-\delta)\frac{\vartheta}{r^k} + \frac{\mu^{p,X}-1-\frac{\epsilon\xi_p}{2}(\pi-1)^2}{s^{(1-\varepsilon)}}\right] \frac{\left(1+\nu\left(1-\frac{1}{R}\right)\right)}{(1-\Omega)(1-\vartheta)}\end{array}}.$$

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