Micro-data on Nominal Rigidity, Inflation Persistence and Optimal Monetary Policy*

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Abstract

The popular Calvo model with indexation (Christiano, Eichenbaum and Evans (2005)) and sticky information (Mankiw and Reis (2002)) model have guided much of the monetary policy discussion. The strength of these approaches is that they can explain the persistence of inflation. However, both of these theories are inconsistent with the micro data on prices. In this paper, I evaluate the consequences of implementing policies that are optimal from the perspective of models that overlook the micro-data. To do so, I employ a Generalized Taylor Economy (GTE) (Dixon and Kara (2007)). While there is no material difference between the GTE and its popular alternatives in terms of inflation persistence, a difference arises when it comes to the micro-data: the GTE is consistent with the micro-data. The findings reported in the paper suggest that policy conclusions are significantly affected by whether persistence arises in a manner consistent with the micro-data and that policies that are optimal from the perspective of the models that are inconsistent with the micro-data can lead to large welfare losses in the GTE.

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1 Introduction

The Calvo model with indexation (i.e. the *IC* model) (Christiano et al. (2005), Smets and Wouters (2003)) has been a popular approach to monetary policy analysis[1]. According to this model, firms set their prices in nominal terms for a random duration, as in the Calvo model, but throughout the contract length the nominal price is updated according to recent inflation (i.e. indexation). The model was developed to better represent inflation dynamics. As is well known, the Calvo model has been inadequate in this respect.

There is, however, a familiar warning that something is wrong with the Calvo with indexation model. The idea that prices are indexed to an inflation index now appears to be a myth. That is, the notion of indexation implies that all firms in the economy continuously adjust their prices but this contradicts micro-evidence on prices[2]. The micro-evidence provided by the European Central Bank's Inflation Persistence Network for the Euro Area indicates that prices remain unchanged for several months[3]. Findings reported in Bils and Klenow (2004) and Nakamura and Steinsson (2007a) indicate the same conclusion for the US economy.

Therefore, while the assumption of indexation greatly improves the empirical performance of the Calvo model, there is a definite error that is induced through this assumption. Thus, this approach to monetary policy analysis is problematic and any policy recommendation that arises from this model is questionable at best.

The problem under discussion here is not just a matter of theoretical significance but is also a matter of practical importance. Models developed at the European Central Bank provide an excellent demonstration of its importance. These models include the New Area Wide Model (NAWW) (Christoffel, Coenen and Warne (2008)) and the model developed by Christiano, Motto and Rostagno (2008) (CMR). Smets (2008) notes that these models are "routinely used" at the European Central Bank for monetary policy analysis. CMR assume full indexation[4]. The NAWW model esti-

[1] See Schorfheide (2008) for a survey.

[2] see Woodford (2007) and Chari, Kehoe and McGrattan (2008)

[3] Dhyne, Alvarez, Bihan, Veronese, Dias, Hoffmann, Jonker, Lunnemann, Rumler and Vilmunen (2005) summarise the findings of the IPN.

[4] Note that in the CMR model, a different approach to indexation is adopted. It is assumed that prices are indexed to an "indexation" index, which is a weighted average of

mates that the degree of indexation in the Euro Area is lower than that in the CMR model and is around 40%. However, the reduced degree of indexation comes at a cost: in the NAWW model, the degree of nominal rigidity is much higher than what the micro-evidence on prices suggests. Specifically, according to this model, the proportion of firms that reset their contracts in a quarter is around 8%, whereas the micro-evidence provided by Dhyne et al. (2005) for the Euro Area indicates that this number is around 25%. It is not just that all prices change in each period, but also that the degree of nominal rigidity of the NAWW model is higher than suggested by the micro-evidence.

A question thus arises: what are the consequences of using a model for monetary policy analysis that overlooks the micro-evidence on prices? To answer this question, we require a model that is as successful as the Calvo with indexation in generating inflation persistence and, at the same time, is consistent with the micro-evidence on prices.

The first model that comes to mind is the sticky information (SI) model developed by Mankiw and Reis (2002), which is commonly viewed as a promising tool to replace the Calvo with indexation. In this model, there is an uncertain contract length, as in the Calvo model, and firm set prices for each period at the beginning of the contract, as in Fischer (1977). Therefore, prices are conditional on the information firms have when they set prices, so as the contract grows older information becomes increasingly out of date. The question then, is whether the sticky information model any better the Calvo with indexatio; the answer is no. It is not just the Calvo with indexation that is flawed; the sticky information model itself can be misleading for the same reasons. In fact, as Dixon and Kara (2008) argue, the model is similar to the Calvo with indexation in that, like the Calvo with indexation, it can generate inflation persistence and prices change every period. Therefore, the model generates inflation persistence at the cost of having prices change every period and, therefore, is inconsistent with the micro-data.

However, there is an alternative to these models, namely, the Generalized

past inflation and the central bank's time varying inflation objective. Specifically, in this model, the central bank changes its target every period and firms adjust their prices every period according to the central bank's objective. Their findings indicate that the weight on past inflation in such an index is around 10%. Given that number, they conclude that the degree of indexation in their model is low. This conclusion, however, is incorrect, as it ignores the effect of the time varying inflation objective assumption on prices. Regardless of the degree of indexation to past inflation, the prices remain fully indexed in the CMR model since the authors replace like with like.

Taylor Economy (GTE), which is outlined in Dixon and Kara (2007). The GTE generalizes the Taylor model to allow for sectoral heterogeneity with contract lengths suggested by the micro-data. In the GTE, not all prices change in each period consistent with the micro-data on prices. Dixon and Kara (2008) show that the GTE can potentially explain inflation persistence. Indeed, as I will show in section 3, there is no material difference between the GTE and its popular alternatives in terms of inflation persistence. Another desirable feature of the GTE approach is that it is general enough that it can be used to model any distribution of contract lengths including the one generated by the Calvo model. In fact, the framework on which the GTE is built is sufficiently general that it includes all the main approaches of modelling nominal rigidities as a special case. Hence, it provides a platform on which compare the inflation dynamics and monetary policy implications of alternative approaches.

Given that there is no material difference between the GTE approach and its popular alternatives when it comes to the macro-data but there is a difference when it comes to the micro-data, it is safe to conclude that the GTE provides a more plausible explanation of inflation persistence than its popular alternatives. Thus, it should provide more reliable insights about the choices policymakers face.

In this paper, I use the GTE to investigate the consequences of implementing a policy that is optimal from the perspective of the IC or SI models. I first discuss how policy conclusions are affected by whether inertia arises in a manner consistent with micro-evidence. I then consider the case in which the central bank employs a policy that is optimal from the perspective of a model that is inconsistent with the micro-data if the true economy is assumed to follow the GTE.

The conclusions of this paper are briefly summarised as follows: first, the results reported in the paper illustrate the potential for conclusions based on the IC and SI models to be misleading. This is because policy conclusions that arise from these models are significantly affected by the aspects of the models that are inconsistent with the micro-data. Second, the policy rules that are optimal from the perspective of the IC and SI models can lead to a large welfare loss in the GTE.

Section 2 outlines a macroeconomic framework that allows for the exploration of policy implications of the different models within a common environment. Section 3 derives a utility-based objective function for the central bank. Section 4 describes the calibration of the parameters. Section 5 evaluates the impulse response functions of the different price models. Section 6 presents the results. Section 7 concludes the paper.

2 The Model

The framework presented here is based on Dixon and Kara (2008). There, a framework was developed that encompasses all of the main price-setting frameworks. The approach of the model is to consider an economy consisting of many sectors differentiated by how long a contract lasts. When each sector has a Taylor-style contract we have a Generalized Taylor Economy (GTE). When each sector has a Fischer-style contract, we have a Generalized Fischer Economy (GFE). The Mankiw-Reis sticky-information (SI) model is a special case of the GFE. We also allow for indexation.

The exposition here aims to outline the basic building blocks of the model. I will first describe the structure of the contracts in the economy, then the price-setting process under different models and finally monetary policy.

2.1 Structure of the Economy

In this model, as in a standard DSGE model, there are three types of agents: households, the government and firms. Households and the government are both standard new Keynesian. There is a continuum of identical and infinitely lived households ($h \in [0, 1]$). The households derive utility from consumption and leisure. The government conducts monetary policy and levies a proportional tax τ_t on all goods. τ_t follows an $AR(1)$ process[5]. Corresponding to the continuum of households h there is a unit interval of firms, $f \in [0, 1]$. Each firm f is twinned with household h $(f = h)$[6]. A typical firm is standard new-Keynesian. It has a monopoly power over a specific product, for which the demand has a constant price elasticity θ. It operates a technology, $Y_{ft} = Z_t L_{ft}$, that transforms labour (L_{ft}) into output (Y_{ft}) subject to productivity shocks (Z_t). These products are then combined to produce the final consumption good Y_t. The production function or aggregator is Dixit-Stiglitz.

[5] The tax shock can be considered analogously to supply shocks.

[6] This assumption means that there is a firm- specific labour market. The implications of the firm-specific labour market assumption on inflation dynamics are well known (see for example Woodford(2003, p. 163-178) Dixon and Kara (2007) and Edge (2002)).

Our assumption on the structure of contracts is novel. We divide the unit interval into segments corresponding to sectors and cohorts within sectors. There are N sectors[7], $i = 1...N$, with sector shares α_i summing to unity $\left(\sum_{i=1}^{N} \alpha_i = 1\right)$. Contracts in sector i last for i periods. Within each sector i, there are i equally sized cohorts of unions and firms: in each period, one cohort comes to the end of its contract and starts a new one. A standard Taylor model is represented by an economy in which one sector (usually with $i = 2$ or 4) has a share of unity, the rest has zero. In the GTE, in each sector i there is a Taylor contract; in the GFE, a Fischer-style contract[8]. The SI model is a special case of the GFE.

The simple Calvo model is different from the GTE because price setters do not know how long the contract will last: in each period a fraction ω of firms chosen randomly start a new contract. However, the Calvo process can be described in deterministic terms at the aggregate level because firm-level randomness washes out. As shown in Dixon and Kara (2006a), the distribution of contract lengths across firms is given by $\alpha_i = \omega^2 i(1-\omega)^{i-1}$: $i = 1...\infty$, with mean contract length $T = 2\omega^{-1} - 1$ The Calvo model with indexation has the same structure in terms of contract lengths, but there is indexation throughout the contract life in response to past inflation.

2.2 Log-linearized Economy

In this section I will simply present the log-linearized macroeconomic framework[9]. The sectoral output level y_{it} can be expressed as a function of the sectoral price p_{it} relative to the aggregate price level p_t and aggregate output y_t, where the coefficient θ is the elasticity of demand (this is the log-linearisation of a CES production function relating intermediate outputs to aggregate output):

[7] N can be infinite.

[8] The model here differs from the one in Dixon and Kara(2008) in that Dixon and Kara(2008) assume that wages are sticky while goods prices are flexible, whereas here I assume that wages are flexible while goods prices are sticky This difference does not affect the equilibrium conditions, as the assumption that each household h is twinned with firm f. Thus, in Dixon and Kara(2008), a firm and a household can be thought of as the same entity. Herein, I assume that wages are flexible while goods prices are sticky since the other models are defined in terms of price-setting.

[9] Appendix A provide a detailed discussion of the underlying assumptions of the model and the derivation of the structural equations and therefore, the presentation here is kept brief. See also Dixon and Kara (2007) for a more detailed discussion.

$$y_{it} = \theta(p_t - p_{it}) + y_t \tag{1}$$

Sectoral price levels are given by the average price set in the sector, and the price is averaged over the i cohorts in sector i:

$$p_{it} = \frac{1}{i}\sum_{j=1}^{i} p_{ijt} \tag{2}$$

The log-linearised aggregate price index in the economy is the average of all sectoral prices:

$$p_t = \sum_{i=1}^{N} \alpha_i p_{it} \tag{3}$$

The inflation rate is given by $\pi_t = p_t - p_{t-1}$.

The Euler condition (23) from the representative household's consumption is given by

$$\tilde{y}_t = E_t\tilde{y}_{t+1} - \eta_{cc}^{-1}(r_t - E_t\pi_{ft+1} - rr_t^*) \tag{4}$$

where $\tilde{y}_t = y_t - y_t^N$ is the gap between actual output, y_t and the natural level of output, y_t^N. r_t is the nominal interest rate. $rr_t^N = r_t^N - E_t\pi_{t+1}^N = E_t y_{t+1}^N - y_t^N$ denotes the real interest rate when prices are flexible. and the tax rate(τ_t) is at its average level $(\bar{\tau})$. r_t^*, π_{ft}^* and y_t^* denote the nominal interest rate, the inflation rate and the output level when prices are flexible and the tax rate(τ_t) is at its average level $(\bar{\tau})$, respectively.

The natural level of output (i.e., the level of output when prices are flexible and the tax rate(τ_t) is at its average level $(\bar{\tau})$) is given by (derived in the Appendix).

$$y_t^N = \frac{1+\eta_{LL}}{\eta_{cc}+\eta_{LL}} z_t \tag{5}$$

where $z_t = \log Z_t$ is a productivity shock.

Finally, the productivity shocks $(z_t = \log Z_t)$ follow an $AR(1)$ process. In particular,

$$z_t = \rho_z z_{t-1} + \varepsilon_{zt} \tag{6}$$

where ε_{zt} is an $idd(0, \sigma_z^2)$.

2.3 Price-Setting Rules

Before defining the optimal price setting rules under different models, let us define the optimal price that would occur if prices were perfectly flexible ("the optimal flexible price"). The log-linearised version of the optimal flexible price in each sector[10] is given by

$$p_t^* = p_t + \gamma \tilde{y}_t + \frac{\tilde{\tau}_t}{(1 + \theta \eta_{LL})} \tag{7}$$

with the coefficient on output γ being:

$$\gamma = \frac{\eta_{LL} + \eta_{cc}}{1 + \theta \eta_{LL}} \tag{8}$$

Where $\eta_{cc} = \frac{-U_{cc}C}{U_c}$ is the parameter governing risk aversion, $\eta_{LL} = \frac{-V_{LL}H}{V_L}$ is the inverse of the labour elasticity, θ is the sectoral elasticity and the tax shocks ($\tilde{\tau}_t = \log(1 - \tau_t)$ follow an $AR(1)$ process: $\tilde{\tau}_t = \rho_\tau \tilde{\tau}_{t-1} + \varepsilon_{\tau t}$.

We can represent the alternative price-setting behaviour in terms of two general equations: one for the reset price in sector i (x_{it}) and one for the average price in sector i (p_{it}). For the GTE, these are[11]:

$$x_{it} = \sum_{j=1}^{i} \lambda_{ij} E_t p_{t+j-1}^* - a \sum_{j=1}^{i} \sum_{k=j}^{i} \lambda_{ij+k} \pi_{t+j-1} \tag{9}$$

$$p_{it} = \sum_{j=1}^{i} \lambda_{ij} \left(x_{it-j-1} + a \sum_{k=0}^{j-2} \pi_{t+k-1} \right) \tag{10}$$

where $\lambda_{ij} = \frac{1}{i}$ and $0 < a \leq 1$ measures the degree of indexation to the past inflation rate. Without indexation ($a = 0$), the reset price (9) in sector i is simply the average (expected) optimal price over the contract length (the

[10] Note that the optimal flexible price in each sector is the same. This is because it is based on the demand relation (1) which has the same two aggregate variables $\{p_t, y_t\}$ for each sector. Also, the shocks that hit the sectors are the same.

[11] I set discount factor (β) to 1. While this assumption simplifies the expositions, the results do not change significantly if I assume $\beta = 0.99$, which is the common assumption in the literature.

nominal price is constant over the contract length). Note that the reset prices will, in general, differ across sectors, since they take the average over a different time horizon. With indexation, the initial price at the start of the contract is adjusted to take into account future indexation over the lifetime of the contract. The average price in sector i (10) is related to the past reset prices and how far they have been indexed.

The two equations (9 and 10) can also represent the simple Calvo economy. To obtain the simple Calvo economy from (9), all reset prices at time t are the same ($x_{it} = x_t$), the summation is made with $i = \infty$ and $\lambda_{ij} = \omega(1-\omega)^{j-1} : j = 1...\infty$. and there is no indexation $a = 0$. Assuming $0 < a \leq 1$ extends these model to the case in which the prices are indexed to past inflation. The standard equation for the average price is obtained by setting $x_{it} = x_t$, and setting the summation as $i = \infty$ in (10).

In a GFE, the trajectory of prices is set at the outset of the contract. Suppose an $i-$ period contract starts at time t; then the sequence of prices chosen from t to $t+i-1$ is $\left\{E_t w^*_{t+s}\right\}_{s=0}^{s=i-1}$. Hence, the average price in sector i at time t is

$$p_{it} = \sum_{j=1}^{i} \lambda_{ij} E_{t-j+1} p^*_t \tag{11}$$

which is the average of the best guesses of each cohort for the optimal flexible price to be holding at t and embodies the "sticky information" idea in Fischer contracts: part of current prices are based on old information. In the GFE, since cohorts are of equal size within sector i, $\lambda_{ij} = \frac{1}{i}$. The Mankiw-Reis sticky-information (SI) model has $\lambda_{ij} = \omega\left(1-\omega\right)^{j-1} : j = 1..\infty$.

2.4 Monetary Policy Rules

I assume that the central bank follows a simple Taylor-type rule under which the interest rate reacts to the lagged interest rate, inflation and the output gap.

$$r_t = \phi_r r_{t-1} + \phi_\pi \pi_t + \phi_y \tilde{y}_t \tag{12}$$

The ϕ-coefficients in front of the targeting variables are chosen to minimise welfare loss.

To provide a measure of the relative performance of this policy rule in a given model, I also report its relative loss, which gives the ratio between the loss under the rule and the first best welfare level obtainable in that model.

The welfare level under the first best can be obtained by using Lagrangian methods. More specifically, this is the welfare level that can be obtained by maximising the welfare function subject to the equilibrium conditions. I obtain the first order conditions of this problem by differentiating the Lagrangian with respect to each of the endogenous variables and setting these conditions to zero. I then combine the first order conditions together with equilibrium conditions and calculate the implied welfare level[12].

3 Welfare Functions: Woodford's Approximation

In this section, a utility-based objection function is derived to provide a benchmark for evaluating the performance of alternative monetary policy rules. We can represent the welfare function for each model in terms of a general equation. For the GTE, the welfare function is given by (derived in Appendix B)

$$W_t = -\frac{U_c(C)C}{2} L_t + t.i.p \tag{13}$$

where C is the steady state consumption, $U_c(C)$ is the marginal utility of consumption and $t.i.p$ collects all the terms that are independent of policy. The loss function, L_t, is given by

$$L_t = (\eta_{cc} + \eta_{LL})\tilde{y}_t^2 + \theta\left(1 + \eta_{LL}\theta\right)\sum_{i=1}^{N}\sum_{j=1}^{i}\alpha_i\lambda_{ij}\left(p_{ijt} - p_t\right)^2 \tag{14}$$

where $\lambda_{ij} = \frac{1}{i}$. This expression implies that welfare loss depends on the variance of the output gap and on the cross-sectional price dispersion. When there is only one type of contract length in the economy, the function reduces to the welfare function in a standard one sector Taylor model.

The loss function reduces to the loss function in the Calvo model as in Woodford (2003, p. 396), when all reset prices at time t are the same ($p_{ijt} = p_{jt}$), the summation is made with $i = \infty$ and $\lambda_{ij} = \omega(1-\omega)^{j-1} : j = 1...\infty$ and there is no indexation. Woodford (2003) shows in the Calvo model and in its variant with indexation that, the welfare costs of cross-sectional price

[12] I use the Dynare's "olr" to perform these calculations

dispersion can be summarised in terms of variability of current and lagged inflation rates[13]. Thus, the loss function can be rewritten as

$$L_t = \left[(\eta_{cc} + \eta_{LL})\tilde{y}_t^2 + \frac{\omega^2}{1-\omega}\left(1 + \eta_{LL}\theta\right)\left(\pi_t - a\pi_{t-1}\right)\right] \tag{15}$$

The loss function gives the loss function in the sticky information model, as in Ball, Mankiw and Reis (2005) (p. 13), when $\lambda_{ij} = \omega\left(1-\omega\right)^{j-1}$: $j = 1..\infty$, $p_{ijt} = p_{jt}$,and $p_{jt} = E_{t-j+1}p_t^* - p_t$, When there is only one type of contract length in the economy $\left(\lambda_{ij} = \frac{1}{i}\right)$, the function reduces to the welfare function in a standard Fischer model. Ball et al. (2005) show that the cross-sectional price variability in the SI can be expressed in terms of aggregate variables

$$\sum_{j=1}^{i} \lambda_j \left(p_{jt} - p_t\right) = \sum_{j=1}^{i} \eta_j \left(p_t - E_{t-j}p_t\right) \tag{16}$$

where $\eta_j = \frac{\omega(1-\omega)^{j-1}}{\left(1-(1-\omega)^j\right)\left(1-(1-\omega)^{j+1}\right)}$.

4 The Choice of Parameters

I begin with a calibration in a GTE. I consider a special GTE : Calvo-GTE, in which the share of each duration across firms ($\alpha_i = \omega^2 i(1-\omega)^{i-1} : i = 1...\infty$) is the same as generated by the Calvo model. The discussions in Bils and Klenow (2004) and Nakamura and Steinsson (2007a) suggest that the Calvo distribution is not a bad approximation of empirical distribution. The two key parameters in this model are ω and γ. ω is the parameter that indicates the degree of nominal rigidity in the economy. $\gamma = \frac{\eta_{cc}+\eta_{LL}}{1+\eta_{LL}\theta}$ is the parameter on the output gap in the price setting equation for each sector. Following the literature (e.g. Walsh (2005), Woodford (2003)), I set $\theta = 7.88, \eta_{cc} = 1$, $\eta_{LL} = 1.2$. The implied value of $\gamma = 0.2$. Recent work of Nakamura and Steinsson (2007a) suggests $\omega = 0.25$[14]. There is no indexation ($a = 0$).

[13] In the GTE, this is not the case: the welfare costs of cross-sectional dispersion cannot be summarised in terms of variability of inflation and must be given explicitly in terms of variances of relative prices. This is mainly because in the GTE, there is a distribution of sector-specific reset prices in each period.

[14] Note that this number excludes sales and substitution-related prices changes. The Bils and Klenow (2004) dataset indicate a lower degree of nominal rigidity: $\omega = 0.4$ (see

In the IC model, the key parameters are a, ω and γ. A range of estimates for a and ω for the U.S. are reported in Table 1. The estimates of a indicate that the degree of indexation is around $0.66 - 0.84$. The estimates of ω indicate that the proportion of firms that set prices is between $0.07 - 0.17$. Given these numbers, I follow Rabanal and Rubio-Ramirez (2005) and set $a = 0.76$ and $\omega = 0.17$[15]. In the Calvo model, I also follow Rabanal and Rubio-Ramirez (2005) and set $\omega = 0.22$. In both models, as in the case of the Calvo-GTE, I set $\gamma = 0.2$.

To calibrate the SI model, I choose among the values estimated by Coibion (2008) and Mankiw and Reis (2007). The key parameters in this model are ω and γ. Coibion (2008) argues that low values of ω and γ are necessary for the model to match the persistence in the data. More specifically, he finds that the model comes closer to matching the data when $\gamma \cong 0.03$ and $\omega \cong 0.7$ (see Coibion(2008, p. 28, Figure 3)). Findings reported in Mankiw and Reis(2007, p. 610, Table 1) and in Kiley (2006, p.112, Table 3) indicate the same conclusion. Mankiw and Reis estimate that $\theta = 34.1$ and $\omega = 0.7$[16]. The value of $\theta = 34.1$, along with $\eta_{cc} = 1$ and $\eta_{LL} = 1.2$,implies that $\gamma = 0.05$. Thus, I follow Mankiw and Reis (2007) and set $\theta = 34.1$

Dixon and Kara (2008)). This is because Bils and Klenow (2004) include prices changes due to sales and substitutions. In any case, calibrating the Calvo-GTE by using $\omega = 0.4$ does not affect the conclusions significantly.

[15] Note that recent work by Levin, Onatski, Williams and Williams (2005) almost argues that the Calvo model without indexation matches the US data well. Specifically, it is argued that the degree of indexation in the US is as low as 13%. The Levin et al. (2005) conclusion is surprising because Levin et al. (2005) use a model that is very similar, if not identical, to that in Del-Negro, Schorheide, Smets and Wouters (2007). Unfortunately, there is no hint to be found in Levin et al. (2005) as to why the degree of indexation is substantially lower in their model. Searching for the reason would lead me beyond the scope of purpose of this paper. Therefore, here I take the Del-Negro et al. (2007) view, which reflects the common view. Recent work by Smets and Wouters (2007) replace the Dixit-Stiglitz aggregator with a more complicated aggregator (i.e. a Kimball aggregator (Kimball (1995))) and find that doing so reduces the degree of indexation. The degree of indexation in this model is 0.24. However, such an assumption has significant implications for optimal policy design. I leave this issue for a separate paper and here stick to the standard Dixit-Stiglitz aggregator.

[16] These values are based on maximum-likelihood estimates. The authors also estimate their model using Bayesian methods. In this case, the values are slightly lower: $\theta = 20.5$ and $\omega = 0.657$. Here I set the parameters at the maximum-likelihood estimates since Mankiw and Reis themselves use these estimates when reporting the impulse response function of inflation to monetary policy. In any case, using the Bayesian estimates rather than the maximum-likelihood estimates does not change results significantly.

and $\omega = 0.7$[17].There is no indexation. I will also report results with a lower value of ω and a higher value of γ.

Finally, I assume that the shocks processes are the same in all models. The productivity shocks follow an $AR(1)$ process. The serial correlation parameter is assumed to be $\rho_z = 0.95$, and the standard deviation of the shock is set to be $\varepsilon_{zt} = 0.007$. These are standard assumptions in the real business cycle literature. For the tax shocks, following Walsh (2005), the serial correlation parameter is calibrated as $\rho_\tau = 0.80$ and the standard deviation of the shock is set to be $\varepsilon_{\tau t} = 0.024$. Walsh obtains these values by estimating an $AR(1)$ process for detrended log fiscal variables, using the dataset on tax revenues complied by Blanchard and Perotti (2002).

5 Inflation Dynamics and Micro-evidence on Prices

One common way to assess a model's empirical validity is to see whether it can generate plausible responses to monetary policy shocks (Woodford (2003) and Mankiw and Reis (2002)). It is widely agreed that inflation exhibits a delayed response to monetary policy. That is, the maximum effect of a policy occurs sometime after the policy: that is, there is a hump-shaped response (Christiano et al. (2005)). To study the response of inflation to monetary policy in each model, I assume that the central bank follows a Taylor rule, under which the nominal interest rate responds to inflation and the output gap. Specifically, I consider a Taylor rule of the following form

$$r_t = \phi_r r_{t-1} + \phi_\pi \pi_t + \phi_y \tilde{y}_t - \xi_{rt} \tag{17}$$

where $\xi_{rt} = \rho_r \xi_{rt-1} + \varepsilon_{rt}$. The literature suggests that a simple rule provides a reasonable description of US monetary policy. Following Rudebusch (2002), I set $\phi_r = 0$, $\phi_\pi = 1.24$, $\phi_y = 0.33$ and $\rho_r = 0.92$[18]. Rudebusch (2002) argues that interest rate inertia may reflect responses to serially-correlated shocks rather than a desire to gradually change interest rates.

Under the calibrated parameters, I compute the impulse responses of in-

[17] Note, however, that $\theta = 34.1$ is implausibly high. θ is typically calibrated between 6 and 10.

[18] The same rule is used in Mankiw and Reis(2007).

flation for the IC and SI following a positive monetary policy shock[19]. I then compare the responses of inflation response in the Calvo-GTE. Figure 1a and Figure 1b display the inflation responses for the IC and SI, respectively. As is evident from these figures, the models fit the empirical evidence regarding how inflation responds to monetary policy shocks. In response to a monetary expansion in each model, inflation rises gradually, following the hump-shaped pattern found in empirical studies. For the sake of comparison, Figure 1a also plots the inflation response in the Calvo model. As is evident, the Calvo model cannot capture inflation dynamics: inflation always peaks on impact and is less persistent as compared to other models. Finally, Figure1c reports the inflation response in the Calvo-GTE. As the figure shows, the inflation response in the Calvo-GTE is very similar to that in the IC and the SI: inflation rises gradually and then follows a hump-shaped pattern.

Given these findings, it is safe to conclude that there is no material difference between the inflation response in the Calvo-GTE versus in the IC and SI models. However, a difference between the GTE and its popular alternatives arises when it comes to the micro-data. Namely, the GTE is consistent with the micro-evidence, whereas the IC and SI are not.

5.1 Discussion

It is important to note that the size of the inflation responses in the Calvo-GTE and the IC are very similar. However, inflation response in the SI is larger than those in the other models. Kiley(2006) finds that the IC model performs empirically better than the SI. This difference in responses seems to explain Kiley's (2006) finding. The reason why inflation response is larger in the SI model is easy to understand; as noted in Dixon and Kara(2008), in this model, the length of the contract does not affect price setting behaviour, whereas in the other two models it does. In the SI, firms set their prices according to the optimal flexible price, subject to information constraints As is well known, the staggered contract structure dampens the effect of a shock on prices.. Since in the SI model, the contract length does not influence price setting behaviour, the response of inflation is much larger than in the other models. If I were to assume that ω is lower, at, say $\omega = 0.25$, as in the Calvo-GTE, Figure 2 shows that, the scale of the response in the SI would

[19] All calculations are performed by using Dynare (see Juillard (1996))

be more in line with the scales in the IC and Calvo-GTE. The reason for this is also easy to understand. The optimal flexible price depends mainly on the general price level, which includes the prices of firms that set their prices with out of date information (i.e. uninformed firms). A lower ω indicates that the share of uninformed firms in the economy is higher. This implies that the aggregate price level will react sluggishly. This means that even the firms that set their prices with full information will not change their prices as much as they otherwise would. However, as Figure 2 further shows, with a lower ω,the model generates too much persistence[20]. This finding is line with the findings reported in Coibion(2008).

Mankiw and Reis (2002) argue that the key empirical fact that is hard to match is the delayed response of inflation. If one takes the Mankiw and Reis view, as this paper does, then the conclusion would be that all models considered in this paper are very similar.

5.2 Micro-evidence on Prices

The aspect of micro-data on which this paper mainly focuses involves the notion that nominal prices remain unchanged for several periods. In the IC model, the notion of indexation is inconsistent with this aspect of micro-data: indexation implies that every firm adjusts its price every period. The SI model is also inconsistent in this respect, as in that model, firms reset prices in every period. It is interesting to note that, like the IC, the SI also has indexation features. This can easily be seen by considering the simplest case of the GFE, that is, the simple Fischer economy with two-period contracts. In this economy, in any period, half of firms set their prices in t and the other half set their prices in $t-1$. Therefore, the average price is given by

$$p_t = p_{1t} + p_{2t}$$

where p_{1t} denotes the price set for t by firms that set their prices in t and p_{2t} denotes the price set for t by firms that set their prices in $t-1$. As discussed in section 2, p_{1t} is equal to the optimal flexible price and p_{2t} is equal to the expectation as of $t-1$ of the optimal flexible price[21]:

[20] Assuming $\gamma = 0.2$, instead of $\gamma = 0.05$, does not significantly change these conclusions.

[21] For simplicity, I assume that there are no tax shocks.

$$p_{1t} = p_t^* = p_t + \gamma \tilde{y}_t \quad (18)$$

$$p_{2t} = E_{t-1} p_t^* = E_{t-1} \left(p_t + \gamma \tilde{y}_t \right) \quad (19)$$

Note that equation (19) can be rewritten as

$$p_{2t} = p_{t-1}^* + E_{t-1} \left(\pi_t + \gamma \Delta \tilde{y}_t \right) \quad (20)$$

This equation clearly shows that in each period, the price level in sector 2 that is set at $t - 1$ is updated according to firm forecasts of inflation and output gaps throughout the contract length[22]. Therefore, the model has indexation features and, in this respect, is similar to the Calvo with indexation model.

6 Results

It is obvious from previous section that there is no material difference between the Calvo-GTE approach and its popular alternatives in terms of inflation persistence. A difference arises when it comes to micro-data: the GTE is consistent with respect to micro-data, whereas the IC and the SI are not.

Having established these facts, I can now use the Calvo-GTE to answer the following question: what are the consequences of implementing a policy rule that is optimal from the perspective of the IC and SI models if the true model is the GTE?

To answer this question, I first consider the case in which the central bank uses the IC model when formulating its monetary policy. More specifically, the central bank simulates the IC model to find the optimal reaction coefficients in the policy rule. I then compute the welfare loss under such a policy in the true economy (i.e. the Calvo-GTE). I then repeat the same experiment for the case in which the central bank uses the SI model when formulating its policy instead of the IC model. Before carrying out this experiment, it is essential to establish that the optimised $three-$ parameter

[22] Recent work by Trabandt (2007). (see also Angeloni, Aucremanne, Ehrmann, Gali, Levin and Smets (2006)) argues that the sticky information has very similar implications to the Calvo model with *full* indexation. Equation (20) clearly shows why that is the case: the coefficent on the indexation terms is the same as that in the Calvo model with full indexation.

rule performs well in each model. I will also discuss how policy conclusions are affected by whether inflation inertia arises in a manner consistent with the micro-data. Welfare levels (W) are expressed in terms of the equivalent percentage decline in terms of steady state consumption, which can be obtained by dividing W by $U_c C$. Welfare levels under optimal policy corresponds to those discussed in section 2.4.

6.1 Optimal Policy and Micro-evidence on Prices

In this section, I evaluate the performance of the optimised rule for each model. Table 2 displays the welfare losses under such a rule for each model when coefficients are chosen optimally. The losses reported in the table are expressed as ratios of the welfare losses in each model to the loss under the optimal monetary policy. As is evident from the table, the optimised rule performs reasonably well in each model: the relative loss in each model is less than 10%[23].

However, as Table 3 also shows, the models differ in their recommendations for the optimal policy. Reported are the optimal ϕ-coefficients that minimise the welfare loss in each model. A key difference arises when it comes to how aggressive the central bank should be in its response to inflation. According to the SI model, the central bank should respond aggressively to inflation. The coefficient of inflation in the policy rule is as high as 11. This finding is in line with the findings reported in Reis (2008). Reis (2008) studies optimal monetary policy by using the sticky information model and finds that the optimal value of ϕ_π is larger than the typical estimates of this parameter. For example, as noted earlier, Rudebusch estimates $\phi_\pi = 1.24$. Therefore, Reis (2008) concludes that "interest rates should respond more aggressively to inflation than they have". However, if one employs the IC model for the monetary policy analysis, the conclusion would be exactly the opposite; interest rates should respond less aggressively to inflation than they have. According to the IC model, the coefficient is much less than that suggested by the SI model and is around 0.6. The Calvo-GTE suggests a value of $\phi_\pi = 1.1$.

In tracing the source of the reasons for differences in policy recommendations, let me begin by considering the mechanism at work in the Calvo-GTE

[23] This level of relative loss has been considered to be reasonable by previous studies (see, for example, Levin and Williams (2003) and Huang and Liu (2005))

model. To understand the mechanism at work in the GTE, first note that price stickiness dampens the effect of a shock on prices. In other words, when prices are sticky, firms cannot change their prices as much as they would when prices are flexible. This sluggish adjustment means that a small change in prices implies a large change in the optimal prices of firms. This is because when firms reset their prices, they take into account the fact that they will have to charge the same price throughout the lenght of the contract. Since there is a trade-off between price stability and output gap stability, the large movements in firm prices require large movements in the output gap to control price stability. Therefore, a policy that reacts inflation strongly is costly. As a consequences, the coefficient of inflation in the policy rule is not large, with a value around 1.

Now consider the IC model. The finding that the central bank should not react to inflation strongly in this model is in line with the common finding in the literature that the best policy response based on the Calvo model with indexation is to let inflation adjust sluggishly (see, for example, Woodford (2003, p. 482-83)). This is due to the fact that the assumption of indexation alters the loss function of the central bank in an important way: the central bank aims to stabilise fluctuations in $(\pi_t - a\pi_{t-1})$, rather than π_t. To put it differently, stabilising fluctuations in inflation do not improve welfare, as the central bank cares about the fluctuations in $(\pi_t - a\pi_{t-1})$. On the contrary, given the policy trade-off, this policy would be very costly, as it would require larger output gap fluctuations. Table 3 confirms this intuition. Reported in the table are standard deviations of $\tilde{x}_t$, π_t and $\pi_t - a\pi_{t-1}$. Under the optimal Taylor rule, π_t is more volatile than $\pi_t - a\pi_{t-1}$. However, the volatility in π_t is irrelevant for welfare loss. For example, if the central bank reacts strongly to inflation, say $\phi_\pi = 1.1$,which is the value suggested by the Calvo-GTE model and holds other factors constant, π_t becomes less volatile; however, this leads to greater output variability and, therefore, higher welfare loss. Therefore, when the IC model is employed for monetary policy analysis, the conclusion is that it is costly to stabilise the fluctuations in inflation.

Finally, we can look at the SI. The question here is why the SI model favours a policy that reacts to inflation strongly. The main reason is that the policy trade-off that the central bank faces is less important than the policy trade-offs in the other models. That is, in this model reacting to inflation strongly requires smaller output gap movements to control inflation. The reason for this is an aspect of the model that is inconsistent with the micro-data: a different price can be chosen within the span of contract. In this model, the length of the contract does not affect price setting behaviour: regardless of the contract length, for any period t, the price set by a given firm will be its best guess at what the optimal flexible price will be in that period. In sharp contrast, in the GTE, the contract length does affect price-setting behaviour, as is also case in the Calvo model. As discussed in section 2.3, in the GTE,the reset price in sector i is the average optimal flexible price over the lenght of the contract. The nominal price is constant over the contract length. In the Calvo model, if ω is large, for example, then the firm gives more weight to the near future, since a large ω means that the price it sets now is less likely to survive, and vice versa. In the SI, prices also adjust sluggishly due to the fact that some firms adjust their prices while using out of date information. However, it appears that in a model in which price stickiness arises due to information rigidity, it is less costly to react to inflation strongly than in a model in which price stickiness arises due to staggered contracts. This can be demostrated by choosing a value of ω for the SI model that brings the model's predictions closer to those in the Calvo-GTE. All of the other parameters in the SI are calibrated as in the Calvo-GTE. A value of ω that brings the SI's predictions closer to those in the Calvo-GTE is $\omega = 0.1$, which is lower than the value of ω in the Calvo-GTE. As Table 5 shows, when $\omega = 0.1$, the policy recommendations of the SI model are very similiar to those of the Calvo-GTE. The relative losses in the two models are almost exactly the same and the optimal policy parameters are also very similar. It should also be noted that the value of $\omega = 0.1$ is much lower than what the model would require to explain the inflation persistence we observe in the data. This analysis thus allows me to conclude that the policy trade-off in the SI model is less severe and, therefore, it is less costly to react to inflation strongly.

The analysis above indicates that the features of the IC and SI models that are inconsistent with the micro-data on prices affect the degree of trade-off between inflation and output gap stabilization: the policy trade-off is severe in the IC model, whereas in the SI model it is not. To put it differently, the SI model underestimates the cost of output gap fluctuations, unless a sufficiently low value of ω is assumed, whereas the Calvo-GTE overestimates the cost. The importance of this point for optimal policy design can also be demonstrated by considering a policy that reacts to inflation and the lagged interest rate only (i.e., an extreme inflation-targeting policy). As discussed above, given the policy trade-off, such a policy would typically require larger output gap movements and, therefore, lead to larger welfare losses. This turns out not to be the case according to the SI. As the table shows, under the benchmark calibration, this policy does not visibly affect the welfare loss unless a substantially lower value of ω is assumed. Perhaps not surprisingly, the IC yields a very different conclusion: ignoring fluctuations in the output gap is very costly. The relative loss increases from 9% to 26%.The Calvo-GTE suggests that such a policy leads to larger welfare losses. However, the cost is not as high as what the IC model suggests. The relative loss increases from 7% to 9%. The more general conclusion from comparing the results in Tables 2 and 5 is that the IC and SI models can potentially provide a misleading assessment of outcomes under alternative policy rules.

Two conclusions emerge from this discussion. First, an optimised Taylor rule performs reasonably well across all models. Second, policy conclusions that arise from the SI and IC are significantly affected by the aspects of these models that are inconsistent with the micro-data on prices.

6.2 Robustness to the $Calvo - GTE$

I have shown that the optimised Taylor rule performs reasonably well across all models under consideration here and I have demonstrated that the aspects of the IC and SI that are inconsistent with the micro-evidence on prices affect policy conclusions. I now turn to my main question: how much welfare loss would be incurred if a central bank employed a model for monetary policy analysis that was inconsistent with the micro-evidence on prices?

I begin by considering the case in which the central bank formulates its policy by employing the IC model. I assume that the GTE is the true economy. This case is of particular interest, since the IC model guides much of the monetary policy discussion. Column 2 of Table 6 reports the welfare loss in the GTE under the rule that is optimal from the perspective of the IC model. As is evident from Table 6, employing a rule that is optimal from the perspective of the IC model can lead to a poor outcome in the Calvo-GTE. More specifically, the relative welfare loss in the Calvo-GTE is as high as 30%. Note that a higher degree of indexation can lead to even larger welfare losses. As a point of reference, column 4 of Table 6 repeats the same experiment as in Table 6 column 2 but assumes full indexation. That is $a = 1$,as in Christiano et al. (2005). Evidently, formulating monetary policy by assuming $a = 1$, can lead to a disastrous outcome in the Calvo-GTE: the relative welfare loss is as high as 137%.

Turning to the SI, Column 3 Table 6 shows the results of the same exercise as in Column 2 of Table 6 but assumes that the policy generating model is the SI. The results reported there indicate that the conclusion in the previous experiment carries over to a setting in which firms adjust their prices according to the Sticky-information model. When the SI is assumed, the relative loss is around 30%.according to in the Calvo-GTE

The conclusion, therefore, is that a policy that is optimal based on a model that is inconsistent with the micro-data can lead to significant welfare loss in an economy that is consistent with micro-evidence. This is the case even though all three approaches generate almost exactly the same degree of inflation persistence.

In light of the discussion in the previous section, the source of the large welfare losses in the Calvo-GTE is easy to identify. The SI recommends a larger value for ϕ_π. Such a policy would stabilise the fluctuations in inflation in the Calvo-GTE at the cost of significantly greater output gap variability. In contrast, the IC recommends a small value for ϕ_π. The resulting policy would not be sufficient to stabilise inflation in the Calvo-GTE.

7 Summary and Conclusions

The failure of the Calvo model to account for key macro-evidence has led to two main responses in the literature: the introduction of indexation to the Calvo model (IC) and the adoption of Fischer contracts and a Calvo distribution of contract lengths (Sticky Information) (SI). Both of these theories are inconsistent with the micro-data on prices, as all prices change at each period.

The purpose of this paper has been to investigate the consequences of employing models that are inconsistent with the micro-data for optimal monetary policy design. To do so, I used a Generalized Taylor Economy (GTE). The GTE is a generalisation of the simple Taylor model and explicitly allows for sectoral heterogeneity with the ranges of contract lengths suggested by the data. I consider a special case of the GTE, namely, the Calvo-GTE, in which the distribution of contract lengths is generated by the Calvo model, as in the IC and SI. The Calvo-GTE is consistent with the micro-data and can model inflation dynamics as well as its popular alternatives.

The findings reported in this paper suggest that policy conclusions are significantly affected by the aspects of the IC and SI models that are inconsistent with the micro-data on prices. More specifically, the aspects of the models that are inconsistent with these micro-data affect the degree of policy trade-off between price stability and output gap stability. Therefore, a failure to recognise the importance of micro-data can lead to misleading analysis regarding the policy trade-offs that policymakers face and may result in the design of policy rules that may not be appropriate for implementation. Indeed, policies that are optimal from the perspective of these models can lead to significant welfare losses in the Calvo-GTE.

I conclude, therefore, that the micro-data on prices are important for optimal monetary policy design. That is, it is a mistake to place undue emphasis on the macro-data at the expense of micro-data, as has been the case with many previous studies on this topic.

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Appendix:

A The Model

A.1 Households

The representative household h has a utility function given by

$$U_h = E_t \left[\sum_{t=0}^{\infty} \beta^t \left[U(C_{ht}) + V\left(1 - H_{ht}\right) \right] \right] \tag{21}$$

where C_{ht}, H_{ht} are household $h's$ consumption and hours worked respectively, t is an index for time, $0 < \beta \leq 1$ is the discount factor, and $h \in [0,1]$ is the household specific index.

The household's budget constraint is given by

$$P_t C_{ht} + \sum_{s^{t+1}} Q(s^{t+1} \mid s^t) B_h(s^{t+1}) \leq B_{ht} + \left(1 - \tau_t\right) W_{ht} H_{ht} + \Pi_{ht} + T_{ht} \tag{22}$$

where $B_h(s^{t+1})$ is a one-period nominal bond that costs $Q(s^{t+1} \mid s^t)$ at state s^t and pays off one dollar in the next period if s^{t+1} is realized. B_{ht} represents the value of the household's existing claims given the realized state of nature. W_{ht} is the nominal wage, Π_{ht} is the profits distributed by firms and $W_{ht}H_{ht}$ is the labour income. τ_t denotes the labour income tax[24]. Finally, T_t consists of transfers.

The first order conditions derived from the consumer's problem are as follows:

$$u_{ct} = \beta R_t E_t \left(\frac{P_t}{P_{t+1}} u_{ct+1} \right) \tag{23}$$

$$\sum_{s_{t+1}} Q(s^{t+1} \mid s^t) = \beta E_t \frac{u_{ct+1} P_t}{u_{ct} P_{t+1}} = \frac{1}{R_t} \tag{24}$$

$$W_{it} = \frac{\theta}{\theta - 1} \frac{1}{\left(1 - \tau_t\right)} \frac{V_L\left(1 - H_{it}\right)}{\frac{u_c(C_t)}{P_t}} \tag{25}$$

[24] Note that the labour tax is a policy variable and I assume that the government sets it equal across consumers. Therefore, τ does not have the subscript h.

Equation (23) is the Euler equation. Equation (24) gives the gross nominal interest rate. Equation (25) shows that the optimal wage. The index h is dropped in equations (23) and (25), which reflects our assumption of complete contingent claims markets for consumption and implies that consumption is identical across all households in every period ($C_{ht} = C_t$).

A.2 Firms

A typical firm in the economy produces a differentiated good which requires labour as the only input, with a CRS technology represented by

$$Y_{ft} = Z_t L_{ft} \tag{26}$$

$f \in [0, 1]$ is firm specific index. Differentiated goods Y_{ft} are combined to produce a final consumption good Y_t. The production function here is CES and corresponding unit cost function P_t

$$Y_t = \left[\int_0^1 Y_{ft}^{\frac{\theta-1}{\theta}} df \right]^{\frac{\theta}{\theta-1}}, \tag{27}$$

$$P_t = \left[\int_0^1 P_{ft}^{1-\theta} df \right]^{\frac{1}{1-\theta}} \tag{28}$$

The demand for the output of firm f is given by

$$Y_{ft} = \left(\frac{P_{ft}}{P_t} \right)^{-\theta} Y_t \tag{29}$$

The firm chooses $\{P_{ft}, Y_{ft}, L_{ft}\}$ to maximize profits subject to (26, 29), yields the following solutions for price, output and employment at the firm level given $\{Y_t, W_{ft}, P_t\}$.

$$P_{ft} = \frac{\theta}{\theta-1}\frac{W_{ft}}{Z_t} \tag{30}$$

$$Y_{ft} = \left(\frac{\theta}{\theta-1}\right)^{-\theta}\left(\frac{W_{ft}}{Z_t P_t}\right)^{-\theta} Y_t \tag{31}$$

$$L_{ft} = \left(\frac{\theta}{\theta-1}\right)^{-\theta}\left(\frac{W_{ft}}{Z_t P_t}\right)^{-\theta}\left(\frac{Y_t}{Z_t}\right) \tag{32}$$

Where $\frac{\theta}{\theta-1}$ measures the markup. Price is a markup over marginal cost, which depends on the wage rate (W_{ft}) and productivity shocks. Output and employment depend on the real wage, total output in the economy and productivity shocks.

Using (30), aggregating for firm f in sector i, substituting out for W_{it} in the resulting equation using the optimal labour supply condition (25), using the labour demand function (32) to substitute out for L_{it} and log-linearizing the resulting equation, I obtain the price level when prices are full flexible (7)[25]

$$p_t^* = p_t + \gamma y_t - \frac{(1+\eta_{LL})}{(1+\theta\eta_{LL})} z_t + \frac{\tilde{\tau}_t}{(1+\theta\eta_{LL})} \tag{33}$$

Note that the optimal flexible price in each sector is the same ($p_{it} = p_{it}^* = p_t^*$). This is because it is based on the demand relation (1) which has the same two aggregate variables $\{p_t, y_t\}$ for each sector. Also, the shocks that hit the sectors are the same.

Since the optimal flexible price is the same in each sector $p_{it} = p_t$, the output level when prices are fully flexible is given by.

$$y_t^* = \frac{(1+\eta_{LL})}{(\eta_{cc}+\eta_{LL})} z_t + \frac{\tilde{\tau}_t}{(\eta_{cc}+\eta_{LL})} \tag{34}$$

The natural level of output is obtained when there are no markup shocks:

$$y_t^N = \frac{(1+\eta_{LL})}{(\eta_{cc}+\eta_{LL})} z_t \tag{35}$$

This equation implies that the natural level output varies with the pro-

[25] I follow the notational convention that lower-case symbols represents log-deviations of variables from the steady state.

ductivity shocks.

B Derivation of the welfare function[26]

A second-order approximation of the period utility $U(C_t)$ around steady state yields:

$$U_t(C) = U_C(C)C(c_t + \frac{1-\eta_{cc}}{2}c_t^2) + t.i.p, \tag{36}$$

where c_t denotes the log-deviation of consumption from steady state, $t.i.p$ collects all the terms that are independent of policy and $O(\|a\|^3)$ summarizes all terms of the third or higher orders.

Using the fact that $c_t = y_t$ in the model and the definition $\hat{y}_t = y_t - \bar{y}_t$, (36) can be expressed in terms of the output gap

$$U_t(C) = U_C C\left(\hat{y}_t + \frac{1-\eta_{cc}}{2}\hat{y}_t^2 + (1-\eta_{cc})\hat{y}_t\bar{y}_t\right) + t.i.p + O(\|a\|)^3 \tag{37}$$

where $\bar{y}_t = \frac{(1+\eta_{LL})}{(\eta_{cc}+\eta_{LL})}\bar{z}_t$ denotes the level of output when there are no real disturbances and all shocks are set at their means.

Similarly, taking a second order approximation of $V(1-L_t)$ around steady state and using the definition $\hat{l}_t = l_t - \bar{l}_t$ yields

$$\int V\left(1-L_{ft}\right) = -V_L(1-L)L\int\left(\hat{l}_{ft} + \frac{(1+\eta_{ll})}{2}\hat{l}_{ft}^2 + (1+\eta_{ll})\hat{l}_{ft}\bar{l}_t\right) + t.i.p, \tag{38}$$

Substituting out $\hat{l}_{ft}$ using the production function gives

$$\begin{aligned}\int V\left(1-L_{ft}\right) &= -V_L(1-L_{ft})L\int\left(\hat{y}_{ft} + \frac{(1+\eta_{ll})}{2}\left(\hat{y}_{ft}^2 - 2\hat{y}_{ft}\hat{z}_t\right) + (1+\eta_{ll})\hat{y}_{ft}\bar{l}_t\right) + t.i.p \\ &= -V_L(1-L_t)L(E_f\left(\hat{y}_{ft}\right) + \frac{(1+\eta_{ll})}{2}E_f\left(\hat{y}_{ft}^2\right) \qquad (39) \\ &\quad -(1+\eta_{ll})\left(E_f\left(\hat{y}_{ft}\right)\hat{z}_t - E_f\left(\hat{y}_{ft}\right)\bar{l}_t\right)) + t.i.p \qquad (40)\end{aligned}$$

[26] Since I want to compare my results with that of Ball et al., I follow exactly the same steps as Ball et al when deriving the welfare function. (see also Woodford(2003)).

Defining $E_f(\hat{y}_{ft}) = \int \hat{y}_{ft} df$ and $Var_f(\hat{y}_{ft}) = E_f\left(\hat{y}_{ft}^2\right) - E_f(\hat{y}_{ft})^2$,taking a second order approximation of (28) and using the resulting expression to substitute for $E_f(\hat{y}_{ft})$,I obtain

$$\int V(1 - L_{ft}) = -V_L(1-L)L \begin{pmatrix} \hat{y}_t + \frac{(1+\eta_{ll})}{2}\hat{y}_t^2 + \frac{(\theta^{-1}+\eta_{ll})}{2} Var_f(\hat{y}_{ft}) \\ -(1+\eta_{ll})\left(\hat{y}_t \hat{z}_t - \hat{y}_t \bar{l}_t\right) \end{pmatrix} + t.i.p \tag{41}$$

Summing (37) with (41), using the steady-state relations $U_C(C)C = V_L(1-L)L$, $(1-\eta_{cc})\bar{y}_t = (1+\eta_{ll})\bar{l}_t$ and the definition of the natural level of output, I obtain

$$U_t(C) + V(1-L_t) = -\frac{U_C(C)C}{2}\left((\eta_{cc}+\eta_{ll})\left(\hat{y}_t - \hat{y}_t^N\right)^2 + (\theta^{-1}+\eta_{ll})Var_f(\hat{y}_{ft})\right) + t.i.p$$

Dropping all the hats from the output variables since the point of approximation is the same $(\bar{y}_t)$, using (29) to replace $Var_f(y_{ft})$, I obtain equation (13) in the text.

		ω	a
Smets and Wouters (2005)	Table 1, p. 167	0.13	0.66
Del-Negro et al. (2007)	Table 1, p. 132	0.17	0.76
Rabanal and Rubio-Ramirez (2005)	Table 1, p.1151	0.17	0.76
Justiniano and Primiceri (2008)	Table 1, p. 40	0.10	0.84

Table 1: Estimates of ω and a from the IC model

		Policy rule coefficients		
	(Relative) welfare loss	ϕ_r	ϕ_π	ϕ_y
IC	1.09	1.15	0.64	0.04
SI	1.00	2.53	10.77	0.19
$Calvo - GTE$	1.07	1.11	1.06	0.02

Table 2: Optimal Taylor rule

	Standard deviations (%)			(Relative) welfare loss
	$(\pi_t - \pi_{t-1})$	π_t	$\tilde{y}_t$	
IC; $\phi_\pi = 0.64$	0.02	0.05	0.78	1.09
IC; $\phi_\pi = 1.06$	0.02	0.04	0.93	1.14

Table 3: The IC model

		Policy rule coefficients		
	(Relative) Welfare Loss	ϕ_r	ϕ_π	ϕ_y
SI; $\gamma = 0.20$, $\omega = 0.10$	1.07	1.14	1.30	0.02
Calvo-GTE; $\gamma = 0.20$, $\omega = 0.25$	1.07	1.11	1.06	0.02

Table 4: The optimal Taylor rule in the SI with $\omega = 0.1$ and Calvo-GTE with $\omega = 0.1$ when all the other factors are the same

		Policy rule coefficients		
	(Relative) welfare loss	ϕ_r	ϕ_π	ϕ_y
IC	1.26	0.96	0.40	0.00
SI	1.00	1.18	3.90	0.00
Calvo-GTE	1.09	1.01	0.86	0.00

Table 5: Extreme inflation-targeting policy

True Model	Policy generating models			
	(1)	(2)	(3)	(4)
	Calvo$-GTE$	IC; $a = 0.76$	SI	IC; $a = 1$
Calvo$-GTE$	1.07	1.31	1.29	2.37

Table 6: Performance of policy rules that are optimal in the IC and SI when the true model is the Calvo-GTE

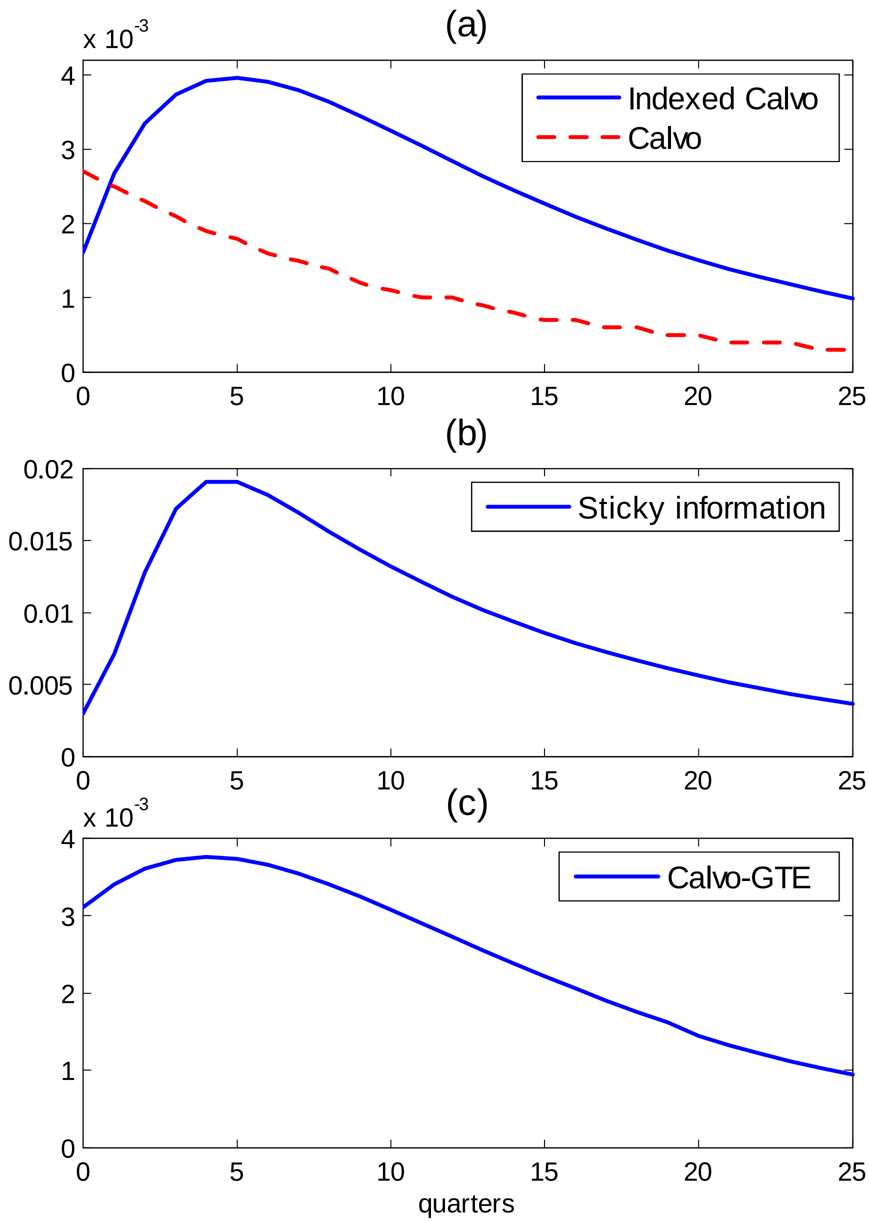

Figure 1: (a) Inflation responses in the Indexed-Calvo (IC) and Calvo (b) Inflation response in the SI. (c) Inflation response in the Calvo-GTE.

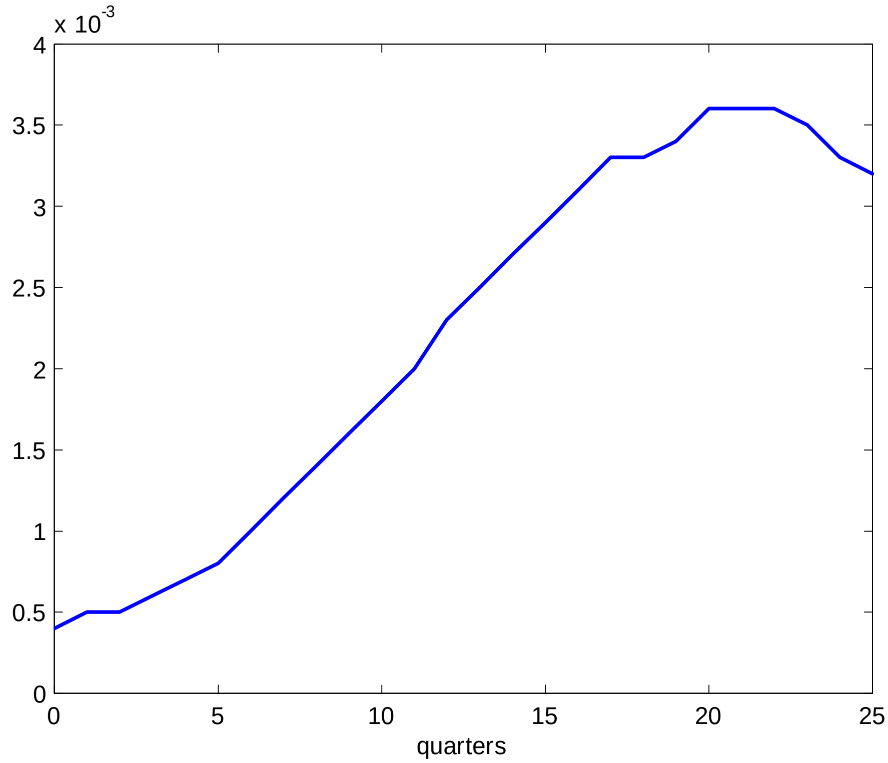

Figure 2: Inflation response in the SI when $\omega = 0.25$ ($\gamma = 0.05$)