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Micro Data on Nominal Rigidity, Inflation Persistence and Optimal Monetary Policy

Engin Kara
University of Bristol

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Centre for Structural Econometrics
University of Bristol Department of Economics
8 Woodland Road, Bristol BS8 1TN, UK.
http://www.efm.bris.ac.uk/cse/
econ-cse@bristol.ac.uk

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

Engin Kara†

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Abstract

The popular Calvo model with indexation (Christiano, Eichenbaum and Evans (2005)) and sticky information (Mankiw and Reis (2002)) models 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 two models: the model proposed by Gali and Gertler (1999) and the Generalized Taylor Economy (GTE). These models can explain the persistence of inflation and are 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 illustrate the potential for conclusions from the models that ignore the micro-data to be misleading.

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†Economics Department, The University of Bristol, Bristol, BS8 1TN. E-mail: engin.kara@bristol.ac.uk.

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 (see Woodfrod (2003), the Calvo model has been inadequate in this respect. In the *IC* model inflation depends on expected inflation, past inflation and the output gap.

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 as a result of this assumption. Thus, this approach to monetary policy analysis is problematic and any policy recommendations that arises from this model are 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 (ECB) 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 ECB for monetary policy analysis. CMR assume full indexation[4]. The NAWW model estimates that the degree of

[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

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. Thus, from the perspective of the micro-data, the practical advice of economists at the ECB is based on models that are faulty.

Might it be the case that these models are "routinely" used for monetary analysis at the ECB because modellers at the ECB think that the assumption of indexation does not affect the policy conclusions that arise from the model? If this is true, then this calls for an examination of whether policy conclusions are affected by whether inflation persistence in a manner consistent with the micro-data. This paper aims to examine the consequences of using a model for monetary policy analysis that overlooks the micro-evidence on prices. This requires 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 is any better

assumed that prices are indexed to an "indexation" index, which is a weighted average of 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.

than the Calvo with indexation, and; the answer is that it is not. It is not just the Calvo with indexation that is flawed; the SI model itself can be misleading for the same reasons. In fact, as Dixon and Kara (2010b) show, the model is similar to the Calvo with indexation in that, like thealtter, 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 are two alternatives to these models, namely, the model by Gali and Gertler (1999) (GG) and the Generalized Taylor Economy (GTE) (Dixon and Kara (2010a), Dixon and Kara (2010b), Kara (2010))[5]. These models can explain inflation persistence in a way that is consistent with the micro-data on prices. The GG model assumes that a proportion of firms set their prices according to a "rule-of-thumb". The remainder set their prices according to the Calvo process. The inflation equation in this model is in the same form as in the inflation equation in the IC model. In the GG, the coefficients on past and expected inflation rates on the share of the rule-of thumb price-setters, whereas in the IC, the coefficients depend on the degree of indexation to the past inflation.

The GTE generalizes the simple Taylor model to allow for sectoral heterogeneity with contract lengths suggested by the micro-data. Dixon and Kara (2010b) show that the GTE with an empirically relevant distribution of contract lenghts can potentially explain inflation persistence. Figure 1 plots the distribution of contracts lengths for the US economy based on Bils and Klenow (2004) (see Dixon and Kara (2010b) for a detailed discussion). There is a very long tail, indicating some very long contracts: over 3% of weighted categories have less than 5% of prices changing per month, implying average contract lengths of over 40 months. The European data and the Nakamura and Steinsson (2008) findings are very similar in broad outline. Several paper have appeared recently which emphasise the importance of

[5] This is not to ignore the recent model proposed by Cogley and Sbordone (2008). These authors also note that the IC model is inconsistent with the micro-evidence on prices. They see inflation persistence in terms of varying inflation targets that cause trend inflation to change. The GG and the GTE differ from theirs in that these models seek to explain inflation persistence as an intrinsic consequence of the dynamic pricing process and not as a result of changes in monetary policy. This paper focuses on models that explain inflation persistence as an intrinsic consequence of the dynamic pricing process. See also the model by Dennis (2006).

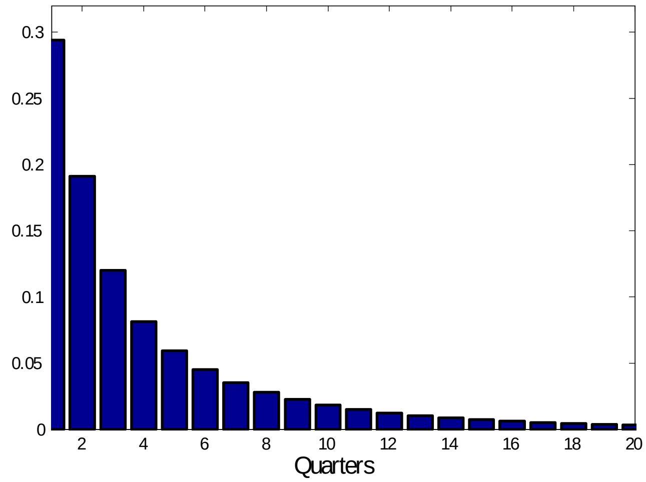

Figure 1: $BK-$Distribution

heterogeneity on aggregate dynamics[6]. An important example is the paper by Coenen, Christoffel and Levin (2007) which considers a multi-sector models with Taylor-style contracts. These studies show the emprical promise of such a model. However, it is important to note that there is a limitation to studies like this, as these studies consider models that have contract lengths of up to 4 periods. Clearly, as Figure 1 suggests, generating a more realistic case requires to go beyond the cases these papers consider[7]. A unique feature of the GTE framework is that it is sufficiently general that it can be used to model any distribution of contract lengths, including the one generated by the Calvo model (see Dixon and Kara (2010a)). Indeed, recent work by Kara (2010) shows, that by using the GTE, that a failure to use a model that has a distribution that accounts for hetereogenity in the contract lengths that we observe in the data, significantly affect policy conclusions.

In this paper, I use the GTE and the GG models 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 the micro-evidence. I then evaluate the welfare costs of ignoring the micro-data. To do so, I

[6]See Dixon and Kara (2010a) for a complete list.

[7]The same arguments apply to the case studied by Carvalho and Dam (2008). These authors consider contract lengths of up to 8 periods.

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 either the GTE or the GG.

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 GTE and the GG have very similar policy recommendations and policy rules that are optimal from the perspective of the IC and SI models can lead to welfare losses. Calculations reported in the paper suggest welfare losses of around $0.01\% - 0.02\%$ of consumption.

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 presents the results. Section 6 reviews the related studies in the literature. Section 7 concludes the paper.

2 The Model

The framework presented here is based on Dixon and Kara (2010b). 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. I 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[8]. 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 $(f = h)$[9]. 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.

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[10], $i = 1...N$, 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. The SI model is a special case of the GFE.

In the GTE framework, while the unit interval are divided into segments corresponding to sectors and cohorts within sectors, this need not reflect any objective factor in terms of sector or cohort specific aspects of technology or preferences. Sectors are composed of firms that have the same contract length. In this sense, there is no sense of location. This is an important property, that allows it to be demonstrated that a Calvo economy can be represented by a GTE (see Dixon and Kara(2010a) for a full discussion). The 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

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

[9] 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 (2010a) and Edge (2002)).

[10] N can be infinite.

in deterministic terms at the aggregate level because firm-level randomness washes out. As shown in Dixon and Kara (2006), 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. I will also describe the Gali and Gertler model and how it is related to the IC model.

The model here differs from the one in Dixon and Kara (2010b) in that in Dixon and Kara (2010b) we 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. This is simply beacuse of the assumption that each household h is twinned with firm f. Thus, in Dixon and Kara (2010b), 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. Note that Huang and Liu (2002) claim that price setting cannot generate as much persistence as wage setting. Edge disagrees with this conclusion. Edge (2002) shows that price setting can generate as much persistence as the wage setting, if one assumes a firm-specific labour market, rather than a common labour market, as Huang and Liu do (see Woodford (2003, Chapeter 3) for a detailed dicussion). The result reported in this paper suggest that Edge's conclusion carries over to a setting in which there are many sectors, each with a different contract length.

2.2 Log-linearized Economy

In this section I will simply present the log-linearized macroeconomic framework[11]. 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):

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

[11] 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 (2010a) for a more detailed discussion.

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 (24) from the representative household's consumption is given by

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

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^N, π_{ft}^N and y_t^N 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[12] 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[13]:

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

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

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 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

[12] 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.

[13] 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.

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 the 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).

As is well known (see Woodfford (2003, p. 213-218), under these assumptions, the inflation dynamics in the IC model can be expressed as:

$$\pi_t = \zeta_b E_t \pi_{t-1} + \zeta_f \pi_{t+1} + \frac{1}{1+a}\frac{\omega^2}{1-\omega}\left(\gamma \tilde{y}_t + \frac{\tilde{\tau}_t}{(1+\theta\eta_{LL})}\right) \tag{11}$$

where $\zeta_b = \frac{a}{1+a}$, $\zeta_f = \frac{1}{1+a}$ and $\zeta_y = \frac{1}{1+a}\frac{\omega^2}{1-\omega}$.

In the GG model, as Steinsson (2003) shows, the inflation equation is in the same form as in (11), expect that the coefficients are different. In deriving this equation, Gali and Gertler assume that a fraction χ of firms set their prices according to a "rule-of-thumb". The rest of the firms set their prices according to the Calvo process[14]. More specifically, the price set by the rule-of-thumb firms at time t are the price level a Calvo price-setter sets in $t-1$ plus an adjustment for inflation, which is based on lagged inflation. In the GG model, the coefficients are as follows:

$$\zeta_b = \frac{\chi}{\chi + (1-\omega)} \tag{12}$$

$$\zeta_f = \frac{(1-\omega)}{\chi + (1-\omega)} \tag{13}$$

$$\zeta_y = \frac{\omega^2(1-\chi)}{\chi + (1-\omega)} \tag{14}$$

In a GFE, the trajectory of prices is set at the outset of the contract.

[14] The model can be thought of a two-sector economy in which in one sector firm set their prices according to a rule of thumb and in the other firms set their prices according to the Calvo model.

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

$$p_{it} = \sum_{j=1}^{i} \lambda_{ij} E_{t-j+1} p^*_t \tag{15}$$

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.

$$r_t = \phi_r r_{t-1} + \phi_\pi \pi_t + \phi_y \tilde{y}_t \tag{16}$$

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[15].

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

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)

$$W_t = -\frac{U_c(C)C}{2} L_t + t.i.p \tag{17}$$

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

$$L_t = (\eta_{cc} + \eta_{LL})\tilde{y}_t^2 + \theta \left(1 + \eta_{LL}\theta\right) \sum_{i=1}^{N} \sum_{j=1}^{i} \alpha_i \lambda_{ij} \left(p_{ijt} - p_t\right)^2 \tag{18}$$

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 dispersion can be summarised in terms of variability of current and lagged inflation rates[16]. Thus, the loss function can be rewritten as

$$L_t = \left[(\eta_{cc} + \eta_{LL})\tilde{y}_t^2 + \left(1 + \eta_{LL}\theta\right) \kappa^{-1} \left(\pi_t - a\pi_{t-1}\right)^2\right] \tag{19}$$

where $\kappa = \frac{\omega^2}{1-\omega}$.

[16] 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.

In the case of the Gali and Gerler model, as Steinsson (2003) shows, the loss function is given by

$$L_t = \left[(\eta_{cc} + \eta_{LL})\tilde{y}_t^2 + (1 + \eta_{LL}\theta)\left(\kappa^{-1}\pi_t^2 + \kappa_r^{-1}(\pi_t - \pi_{t-1})^2\right)\right] \qquad (20)$$

where $\kappa_r^{-1} = \omega^2 \frac{(1-\chi)}{\chi}$. The loss function in this model penalize fluctuations not only in the output gap and in inflation, as in the Calvo model but also in $(\pi_t - \pi_{t-1})$. Thus, the degree of price dispersion in the GG model is higher than that in the Calvo model owing to the presence of backward-looking rule-of-thumb price-setters in the GG. Increased degree of price dispersion in the GG means that price stability in this model is more important than that in the Calvo model.

The loss function gives the loss function in the sticky information model, as in Ball, Mankiw and Reis (2005) (p. 13), when $\lambda_{ij} = \omega(1-\omega)^{j-1}$: $j = 1..\infty$, $p_{ijt} = p_{jt}$,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

$$\sum_{j=1}^{i} \lambda_j (p_{jt} - p_t)^2 = \sum_{j=1}^{i} \eta_j (p_t - E_{t-j}p_t)^2 \qquad (21)$$

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[17]. The discussions in Bils and

[17] The Calvo-GTE is one of the two GTEs which Dixon and Kara (2010b) consider. The Calvo-GTE is a special GTE because it has exactly the same contract structures, as in the standard Calvo model. However, the model captures inflation dynamics better than the Calvo model. As discussed in detail in Dixon and Kara (2010b), the Calvo-GTE is able to generate a hump-shaped inflation response, whereas the Calvo-model cannot. The two models differ in their pricing rules. In the GTE, firms know which sector they belong to and therefore they do not need to look beyond the contract duration when setting their

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 $\omega = 0.25$[18]. There is no indexation ($a = 0$).

The other models are calibrated according to the macro-estimates. 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 $0.66 - 0.84$. Given these numbers, I follow Rabanal and Rubio-Ramirez (2005) and Smets and Wouters(2005) to set $a = 0.76$[19]. Thus, the implied values of ς_b and ς_f are $\varsigma_b = 0.43$ and $\varsigma_f = 0.57$. As in the case of the Calvo-GTE, I set $\omega = 0.25$ and $\gamma = 0.2$.

prices. In the Calvo model, firms do not know which sector they sector they belong to. Thus, when setting their prices, they have a probability distribution over the contract lengths. This makes the price setting behaviour myopic in the GTE. This myopia goes a long way towards explaining the output and inflation dynamics we observe in the empirical data.

[18]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 Dixon and Kara (2010b)). 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.

[19]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.

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

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

In the Gali and Gertler model, as in the case of the Calvo-GTE, I set $\omega = 0.22$ and set $\gamma = 0.2$. χ denotes the fraction of firms that set the prices according to a rule-of-thumb. The value of χ can be backed out from the value calibrated for ς_b in the IC model.Given the values of ω, $\varsigma_b = 0.43$ implies $\chi = 0.57$.

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. Coibion reports that the model's empirical performance deteriorates significantly with a lower value of ω and a higher value of γ. Mankiw and Reis estimate that $\theta = 34.1$ and $\omega = 0.7$[20]. 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 $\theta = 34.1$ and $\omega = 0.7$[21].There is no indexation. This calibration is also similar to the calibration in Reis (2008), which studies the optimal monetary policy implication of the SI model. However, I will also report results with a lower value of ω and a

[20] 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.

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

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 Results

This section aims 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 either the GG or the GTE? To answer this question, I first assume that the true is the GG and then consider the case in which the central bank uses the IC model when formulating its monetary policy. This case is of particular interest, since the IC model is many central banks' favorite model and, as we have seen earlier, inflation dynamics in the two models are almost exactly the same. 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 as a result of such a policy in the true economy (i.e. using the GG model). 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. I then perform the same experiments for the case in which the central bank uses the Calvo$-GTE$ model when formulating its policy instead of the GG model. Before carrying out this experiment, it is essential to establish that the optimised *three−* parameter 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_cC. Welfare levels under optimal policy corresponds to those discussed in Section 2.4.

5.1 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%[22].

		Policy rule coefficients		
	(Relative) welfare loss	ϕ_r	ϕ_π	ϕ_y
IC	1.04	1.2	0.67	0.04
SI	1.00	2.53	10.77	0.19
Calvo$-GTE$	1.07	1.11	1.06	0.02
GG	1.08	1.09	1.41	0.02

Table 2: Optimal Taylor rule

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 that $\phi_\pi = 1.24$. 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

[22]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))

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 0.67. The Calvo-GTE suggests a value of $\phi_\pi = 1.1$. The value of ϕ_π suggested by the GG is very similar to the value of ϕ_π suggested by the Calvo-$GTE : \phi_\pi = 1.4$.

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 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 them 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 length 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 strongly to inflation is costly. As a consequences, the coefficient of inflation in the policy rule is not large, with a value of around 1.

Now consider the IC model. The finding that the central bank should not react strongly to inflation in this model is in line with the findings reported in 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.

	Standard deviations (%)			(Relative) welfare loss
	$(\pi_t - a\pi_{t-1})$	π_t	$\tilde{y}_t$	
IC; $\phi_\pi = 0.67$	0.03	0.07	1.01	1.04
IC; $\phi_\pi = 1.06$	0.01	0.02	1.23	1.07

Table 3: The relative welfare losses in the IC under different policies

Next consider the GG. The policy that this model suggests is very similar to the policy suggested by the Calvo-GTE. It is important to note that the GG suggests the need to react to inflation slightly more strongly than is suggested by the Calvo$-GTE$. The GG suggests a value of $\phi_\pi = 1.4$, whereas the Calvo$-GTE$ suggests that ϕ_π should be $\phi_\pi = 1.1$. The reason for this difference is that price stability is harder to control in the GG, due to the presence of backward-looking-rule-of-thumb price-setters. As discussed earlier, the loss functions in this model clearly shows that price dispersion in the GG increases as the proportion of the rule of thumb firms increases. Thus, the higher the proportion of rule of thumb firms in this model, the harder it becomes to control inflation. Indeed, as Figure 2 shows, the higher the fraction of the rule-of-thumb firms, the more aggressive the central bank should be in its response to inflation.

Finally, we can look at the SI. The question here is why this model favours a policy that strongly reacts to inflation. 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 the contract. In this model, the length of the contract does not affect the 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 the 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 length 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

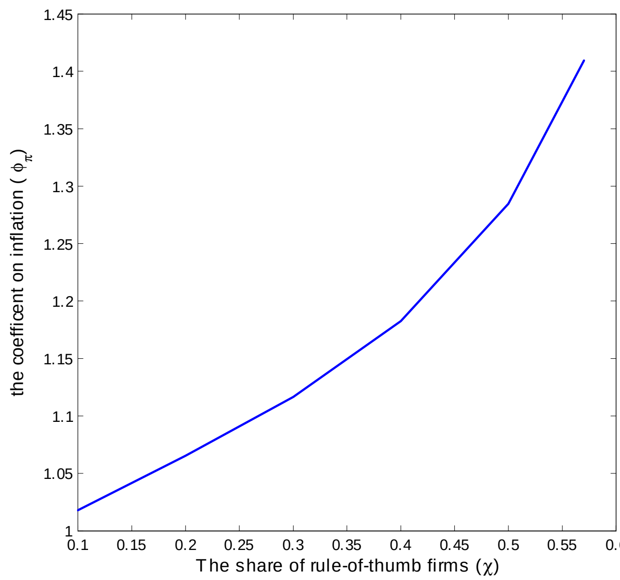

Figure 2: The coefficent on inflation in the optimal Taylor rule (ϕ_π) in the GG model, as the shavre of rule-of-thumb firms (χ) varies from 0.1 to 0.6.

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 demonstrated 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 similar 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, would 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 loss is 7%. 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 loss is only 2%. Again, the GG agrees with the Calvo-GTE's assessment. The more general conclusion from this experiment is that the IC and SI models can potentially provide a misleading assessment of outcomes under alternative policy rules.

	IC	SI	Calvo$-GTE$	GG
Welfare losses	1.07	1.00	1.02	1.04

Table 4: Welfare loss under an extreme inflation-targeting policy relative to that under an optimal Taylor rule

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.

5.2 Welfare Costs of Ignoring Micro-data on Prices

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?

	True Model			Policy generating models	
		(1)	(2)	(3)	(4)
		GG	Calvo$-GTE$	IC; $a = 0.76$	SI
(1)	GG	1.08	–	1.51	1.15
(2)	Calvo$-GTE$	–	1.07	1.34	1.29

Table 5: Performance of policy rules that are optimal in the IC and SI when the true model is either the Calvo-GTE or the GG

I first assume that the true economy is represented by the GG model. I then consider the case in which the central bank formulates its policy by employing the IC model. Row 1 column 3 of Table 5 reports the welfare loss in the GG under the rule that is optimal from the perspective of the IC model. As is evident from Table 5, employing a rule that is optimal from the perspective of the IC model can lead to a poor outcome in the GG. The relative loss in this case is as high as 50%. Turning to the SI, row 1 column 4 Table 6 shows the results of the same exercise as in Row 1 column 3 of Table 5 but assumes that the policy generating model is the SI. When the SI is assumed, the relative loss is around 20%. Thus, the GG suggests that it is very costly to ignore the micro-evidence on prices. The GG model further suggests that it would be less costly to implement a policy that arises from the SI model, compared to a policy that arises from the IC model.

Turning to the case in which the true economy is the Calvo-GTE, row 2 of Table 5 repeats the same exercises as in row 1 of Table 5 but assumes that the true situation is represented by the Calvo-GTE. The results reported there indicate that the conclusion in the previous experiment carries over to a setting in which the true situation is represented by the Calvo-GTE: it is costly to ignore the micro-evidence on prices. According to the Calvo-GTE, the loss is around 30%.

In light of the discussion in the previous section, the source of the large welfare losses in the Calvo-GTE and the GG 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 and the GG 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 and the GG.

It appears that the scale of the welfare costs of ignoring the micro-data is model dependent. To understand the differences in magnitudes, first recall from the pervious section that price stability is harder to control in the GG than in the Calvo-GTE and, therefore, the central bank using the GG needs to react more aggressively to inflation to achieve the same level of stabilization inflation as when using the Calvo-GTE. Thus, even if ϕ_π is the same in both models, inflation in the GG would not change as much as it does in the Calvo-GTE[23]. As a consequence, under the SI policy the change in the output gap in the GG would not be as large as in the Calvo-GTE. Therefore, the relative loss in the GG due to implementing the SI-policy is smaller than the relative loss in the Calvo-GTE. It also interesting to note that if a policy fails to stabilize fluctuations in inflation sufficiently, such a policy would be more costly in the GG than in the Calvo-GTE. The reason is also easy to understand. The rule-of-thumb price price-setters in the GG model update their prices according to the past inflation rate. Thus, the higher initial inflation rate under the IC policy in the GG model further reinforces inflationary pressures in this model and this lead to higher welfare losses.

I have thus far expressed welfare losses in terms of the ratio between the welfare loss in the true model under a policy that is suggested by a model that ignores the mciro-data and the welfare loss under the optimal policy in the true model. It would also be instructive to express welfare losses in terms of consumption (i.e. the difference between the welfare loss in the true

[23]To confirm this suggestion, I calculate the value of ϕ_π in the SI policy that achieves the same level of inflation stabilization in the GG, as in the Calvo-GTE. All the other conditions are the same as before. The value of ϕ_π that achieves this is $\phi_\pi = 20$. When $\phi_\pi = 20$, the proportional change in the welfare cost of price dispersion and in the output gap variability in the GG is very similar to those of in the Calvo-GTE. Thus, the relative losses in each model are very similar.

model under a policy that is suggested by a model that ignores the mciro-data and the welfare loss under optimal policy in the true model). Consider, for example, the case in which the true model is represented by the GG one and the policy formulation model is the IC model. In this case, the welfare loss is 0.01% of consumption. If I consider the case in which the standard deviations of shocks to productivity are doubled, then the loss goes up 0.02% of consumption. The Calvo-GTE suggests a similar level of welfare loss.

The general conclusion from these experiments is that it is costly to employ models to monetary policy analysis that are inconsistent with the micro-data on prices.

6 Relation to the Literature

This section reviews the literature on this topic. Levin, López-Salido, Nelson and Yun (2008) have recently also emphasised the importance of micro-evidence on optimal monetary design. They suggest that microeconomic datasets are one promising tool to discriminate between models when models are very similar (or are observationally equivalent) at the aggregate level but differ in their policy recommendations. More specifically, for example, in one of the cases these authors study, which is relevant to the cases I have considered, they assume that firms set their prices according to the Calvo process and then consider two types of real rigidity which lower firms' inclination to increase prices in the face of an increase in nominal aggregate demand . One specification is firm-specific inputs, as in Woodford (2003), and the other is a kinked demand structure, as in Kimball (1995). They then calibrate the two specifications in a way that the two specifications are identical in their implications for loglinear dynamics. Indeed, even though the two models are exactly the same at the aggregate level, the authors show that the specifications differ in their loss functions and, therefore, in their policy recommendations. However, the discussion in Levin et al. suggest that there is not enough micro evidence to reject any of the two specifications. In fact, it may well be the case that both specifications are empirically relevant. My analysis differs substantially from theirs. I compare models of pricing that are consistent with the micro evidence on prices to those that are not. However, the conclusions reported in this paper can be seen as complementary to those of Levin et al. (2008)., further strengthening their conclusions.

This paper is also related to that of Levin and Williams (2003). Levin and Williams consider optimal monetary policy design in different models. Some of the models these authors consider, however, do not have explicit microfoundatiions (e.g. a Fuhrer and Moore model with habit persistence in consumption, as in Fuhrer (2000) and an empirical VAR model). They also employ an ad-hoc loss function for the central bank. However, recent work by Walsh (2005) shows that policy conclusions based on the standard exogenous objectives can be misleading. This paper considers models that have microfoundations and derives a loss function for each model by taking a second-order approximation of the representative households utility function. Thus, this paper extends the Levin and Williams (2003) analysis to the case in which the objectives of monetary policy are endogenous.

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 have used two models. The first model is the model suggested by Gali and Gertler (1999) and the second model is the Generalized Taylor Economy (GTE). The GG model assumes that a fraction of firms set their prices according to a rule-of-thumb. The rest of the firms set their prices according to the Calvo process. 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 models. Both models are consistent with the micro-data and can potentially explain the persistence of inflation.

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 the 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 welfare losses when using models that are consistent with micro-data. The models that are consistent with micro-data lead to very similar policy recommendations.

I conclude, therefore, that the models that are inconsistent with the micro data should not be used for monetary policy analysis. The more general lesson is that it is a mistake to put all emphasis to the macro-data and to overlook the micro-data, as has been the case in the past. A failure to recognise the importance of micro-evidence on optimal monetary design can mislead policymakers about the trade-offs they face and, therefore, can lead to the design of policies that are not be appropriate for implementation.

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Appendix:

A The Model

A.1 Households

The representative household h has a utility function given by

$$U_h = E_t \left[\sum_{t=0}^{\infty} \beta^t \left[U(C_{ht}) + V\left(1 - H_{ht}\right) \right] \right] \tag{22}$$

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

$$P_t C_{ht} + \sum_{s^{t+1}} Q(s^{t+1} \mid s^t) B_h(s^{t+1}) \leq B_{ht} + \left(1 - \tau_t\right) W_{ht} H_{ht} + \Pi_{ht} + T_{ht} \tag{23}$$

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:

$$u_{ct} = \beta R_t E_t \left(\frac{P_t}{P_{t+1}} u_{ct+1} \right) \tag{24}$$

$$\sum_{s_{t+1}} Q(s^{t+1} \mid s^t) = \beta E_t \frac{u_{ct+1} P_t}{u_{ct} P_{t+1}} = \frac{1}{R_t} \tag{25}$$

[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.

$$W_{it} = \frac{\theta}{\theta - 1} \frac{1}{(1 - \tau_t)} \frac{V_L (1 - H_{it})}{\frac{u_c(C_t)}{P_t}} \tag{26}$$

Equation (24) is the Euler equation. Equation (25) gives the gross nominal interest rate. Equation (26) shows that the optimal wage. The index h is dropped in equations (24) and (26), 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

$$Y_{ft} = Z_t L_{ft} \tag{27}$$

$f \in [0, 1]$ 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

$$Y_t = \left[\int_0^1 Y_{ft}^{\frac{\theta-1}{\theta}} df \right]^{\frac{\theta}{\theta-1}}, \tag{28}$$

$$P_t = \left[\int_0^1 P_{ft}^{1-\theta} df \right]^{\frac{1}{1-\theta}} \tag{29}$$

The demand for the output of firm f is given by

$$Y_{ft} = \left(\frac{P_{ft}}{P_t} \right)^{-\theta} Y_t \tag{30}$$

The firm chooses $\{P_{ft,} Y_{ft}, L_{ft}\}$ to maximize profits subject to (27, 30), yields the following solutions for price, output and employment at the firm level given $\{Y_t, W_{ft}, P_t\}$.

$$P_{ft} = \frac{\theta}{\theta - 1}\frac{W_{ft}}{Z_t} \tag{31}$$

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

$$L_{ft} = \left(\frac{\theta}{\theta - 1}\right)^{-\theta}\left(\frac{W_{ft}}{Z_t P_t}\right)^{-\theta}\left(\frac{Y_t}{Z_t}\right) \tag{33}$$

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 (31), aggregating for firm f in sector i, substituting out for W_{it} in the resulting equation using the optimal labour supply condition (26), using the labour demand function (33) to substitute out for L_{it} and log-linearizing the resulting equation, I obtain the price level when prices are full flexible (7)[25]

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

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.

$$y_t^* = \frac{(1 + \eta_{LL})}{(\eta_{cc} + \eta_{LL})} z_t + \frac{\tilde{\tau}_t}{(\eta_{cc} + \eta_{LL})} \tag{35}$$

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

$$y_t^N = \frac{(1 + \eta_{LL})}{(\eta_{cc} + \eta_{LL})} z_t \tag{36}$$

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

This equation implies that the natural level output varies with the productivity shocks.

B Derivation of the welfare function[26]

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

$$U_t(C) = U_C(C)C(c_t + \frac{1-\eta_{cc}}{2}c_t^2) + t.i.p, \tag{37}$$

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 $\hat{y}_t = y_t - \bar{y}_t$, (37) can be expressed in terms of the output gap

$$U_t(C) = U_C C\left(\hat{y}_t + \frac{1-\eta_{cc}}{2}\hat{y}_t^2 + (1-\eta_{cc})\hat{y}_t\bar{y}_t\right) + t.i.p + O(\|a\|)^3 \tag{38}$$

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

$$\int V(1-L_{ft}) = -V_L(1-L)L\int\left(\hat{l}_{ft} + \frac{(1+\eta_{ll})}{2}\hat{l}_{ft}^2 + (1+\eta_{ll})\hat{l}_{ft}\bar{l}_t\right) + t.i.p, \tag{39}$$

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

[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)).

$$\begin{aligned}\int V(1-L_{ft}) &= -V_L(1-L_{ft})L\int\left(\hat{y}_{ft}+\frac{(1+\eta_{ll})}{2}\left(\hat{y}_{ft}^2-2\hat{y}_{ft}\hat{z}_t\right)+(1+\eta_{ll})\hat{y}_{ft}\bar{l}_t\right)+t.i.p\\ &= -V_L(1-L_t)L(E_f(\hat{y}_{ft})+\frac{(1+\eta_{ll})}{2}E_f\left(\hat{y}_{ft}^2\right) \qquad (40)\\ &\quad -(1+\eta_{ll})\left(E_f(\hat{y}_{ft})\hat{z}_t-E_f(\hat{y}_{ft})\bar{l}_t\right))+t.i.p \qquad (41)\end{aligned}$$

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 (29) and using the resulting expression to substitute for $E_f(\hat{y}_{ft})$,I obtain

$$\int V(1-L_{ft})=-V_L(1-L)L\begin{pmatrix}\hat{y}_t+\frac{(1+\eta_{ll})}{2}\hat{y}_t^2+\frac{(\theta^{-1}+\eta_{ll})}{2}Var_f(\hat{y}_{ft})\\ -(1+\eta_{ll})\left(\hat{y}_t\hat{z}_t-\hat{y}_t\bar{l}_t\right)\end{pmatrix}+t.i.p \qquad (42)$$

Summing (38) with (42), 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 (30) to replace $Var_f(y_{ft})$, I obtain equation (17) in the text.