

# Understanding and Modelling Reset Price Inflation

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## Abstract

Bils, Klenow and Malin (forthcoming) (BKM) constructed a measure of reset price inflation (i.e. the rate of change of all "desired" prices) for the US. They argue that the existing pricing models cannot explain the observed reset inflation and aggregate inflation. In this paper, I show that a model that can account for the heterogeneity in contract lengths we observe in the data matches the data on both series. I also show that the BKM measure of reset inflation is a flawed measure of the concept they wish to measure and can be quite misleading.

Keywords: DSGE models, reset inflation, GTE, Calvo, price-level targeting.

JEL: E32, E52, E58.

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# 1 Introduction

Reset price inflation is the rate of change of all desired prices. This measure of inflation is unobservable in the data. Recent work by Bils et al. (forthcoming) (BKM) attempt to construct an empirical index of reset prices between 1990 and 2009, using the micro data on prices collected by the US Bureau of Labour Statistics for the CPI. The dataset covers about 70% of the CPI. This is the same database as Klenow and Kryvtsov (2008) used, only updated by more recent years. They then evaluated whether the existing Dynamic Stochastic General Equilibrium (DSGE) models can explain the constructed reset price inflation. This measure of inflation allows us to evaluate how far the existing models are consistent with the firm-level data. The issue is important since, as shown by Levin, López-Salido, Nelson and Yun (2008) and Kara (2010), micro-evidence on firm behaviour can significantly affect policy conclusions that arise from a model.

To construct this measure, the authors, for each month, divide items into two categories: those that change price and those that do not. For those that change price, the reset price is simply the current price. For those that do not change price, the reset price is updated according to the rate of reset inflation among price changers in the current period. The updated prices are the reset prices for those that do not change price. The reset price in the economy is the weighted average of all reset prices. This inflation index is similar to the inflation index constructed by Shiller (1991) for house prices.

This measure might be best understood with an example, which is similar to the example provided by the authors. Consider an economy with two goods, each with an equal share: A and B. Assume that Good A's price increases by 20% in period  $t$ , whereas Good B's price remains unchanged. Assume further that both goods have changed price in period  $t - 1$ . The reset inflation for Good A in period  $t$  is simply 20%. Aggregate inflation in the economy is 10%. Now consider the case in which in period  $t + 1$  Good B's price increases by 20%, whereas Good A's price remain unchanged. The reset inflation for Good B is zero, since the increase in Good A's price in period  $t$  also increases the base price for calculating reset inflation for Good B by 20%. Thus, reset inflation for both Goods A and B in period  $t + 1$  is zero, whereas aggregate inflation is again 10%.

BKM employ a version of the popular Smets and Wouters (2007) model to examine whether or not the model is consistent with the data on reset inflation. Specifically, BKM assume that firms set their prices according the Calvo process, in which prices are set for a random duration<sup>1</sup>. They find that this model cannot explain the observed reset price inflation. Reset price inflation is more persistent than the data suggest. Based on this finding, they conclude that DSGE models are inconsistent with the data on reset inflation.

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<sup>1</sup>Smets and Wouters (2007) assume the Calvo model with indexation (IC). In this model, the initial price is set according to the Calvo model but the price is updated with recent inflation. In this model, even though there is a price plan or a contract, the price changes each period during the contract length. This implication of the model is inconsistent with the micro-evidence provided by Klenow and Kryvtsov (2008) and Nakamura and Steinsson (2008). Given this concern, BKM remove the indexation and consider the Calvo model.

This paper presents a DSGE model that explains the data on reset price inflation perfectly well. This is true even though the model exhibits substantial strategic complementarity. I employ a model that has a more realistic contract structure than the Calvo model employed by the BKM. Specifically, I employ a Generalized Taylor Economy (GTE), in which there are many sectors, each with a Taylor-style contract, as in Dixon and Kara (2010a), Dixon and Kara (2010b) and Kara (2010). The model can account for the heterogeneity in contract lengths we have observed in the data (see e.g. Bils and Klenow (2004) and Klenow and Kryvtsov (2008)). The Calvo and GTE models differ in their price setting and in their underlying distribution of contracts. The price setting in the GTE is more myopic than in the Calvo model. Also, the Calvo model underestimates the share of flexible prices.

I also compare the BKM measure of reset inflation in the models with the theoretical ideal. I find that in the GTE, the constructed reset inflation shows a very similar pattern to the theoretical ideal. However, this is not true in the Calvo model. In sharp contrast to the findings reported in BKM, the Calvo model itself does not necessarily suggest that reset inflation should adjust sluggishly. The theoretical reset inflation in the model is similar to that in the GTE. This finding suggests that the BKM measure is not a robust measure of the change in desired prices.

The remainder of the paper is organised as follows. Section 2 presents the model. Section 3 presents evidence on reset price inflation. Section 4 presents the results. Section 5 concludes the paper.

## 2 The Model

The model is the GTE framework of Dixon and Kara (2010a). In this otherwise standard DSGE model, there can be many sectors, each with a different contract length. When all the contracts have the same duration in the economy, the model reduces to a standard Taylor model. An advantage of the GTE approach is that it is general enough to represent any distribution of contract lengths, including those generated by the Calvo model. The Calvo model is different from the GTE because the price setters do not know how long the contract will last: each period a fraction  $\omega$  of firms/households chosen randomly starts a new contract. However, the Calvo process can be described in deterministic terms at the *aggregate* level because the firm-level randomness washes out. As shown in Dixon and Kara (2006), the distribution of contract lengths across firms is given by  $\alpha_i = \omega^2 i (1-\omega)^{i-1} : i = 1 \dots \infty$ , with mean contract length  $T = 2\omega^{-1} - 1$ . The model here differs from the one in Dixon and Kara (2010a), which assumes that wages are sticky whereas goods prices are flexible. Herein I assume that wages are flexible whereas goods prices are sticky.

### 2.1 Structure of the Economy

As in a standard DSGE model, in the model economy, there is a continuum of firms  $f \in [0, 1]$ . Corresponding to the continuum of firms  $f$ , there is a unit interval of household-unions ( $h \in [0, 1]$ ). Each firm is then matched with

a firm-specific union ( $f = h$ )<sup>2</sup>. The unit interval is divided into  $N$  sectors, indexed by  $i = 1 \dots N$ . The share of each sector is given by  $\alpha_i$  with  $\sum_{i=1}^N \alpha_i = 1$ . Within each sector  $i$ , there is a Taylor process. Thus, there are  $i$  equally sized cohorts  $j = 1 \dots i$  of unions and firms. Each cohort sets the price which lasts for  $T_i$  periods: one cohort moves each period. The share of each cohort  $j$  within the sector  $i$  is given by  $\lambda_{ij} = \frac{1}{T_i}$  where  $\sum_{j=1}^{T_i} \lambda_{ij} = 1$ . The longest contracts in the economy are  $N$  periods.

A typical firm produces a single differentiated good and operates a technology that transforms labour into output subject to productivity shocks. The final consumption good is a constant elasticity of substitution (CES) aggregate over the differentiated intermediate goods. Note that the assumption of CES technology means that the demand for a firm's output ( $y_{ft}$ ) depends on the general of price ( $p_t$ ), its own price ( $p_{ft}$ ) and the output level ( $y_{ft}$ ):  $y_{ft} = \theta(p_t - p_{ft}) + y_t$ , where  $\theta$  measures the elasticity of substitution between goods. Thus, the only commonality within a sector is that all firms in the same sector have the same contract length. The other elements of the model are standard New Keynesian. The representative household derives utility from consumption and leisure. The government conducts monetary policy according to a Taylor rule.

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<sup>2</sup>This assumption means that there is a firm-specific labour market. The implications of this assumption for inflation dynamics are well known (see, for example Edge (2002) and Woodford (2003)).

## 2.2 Log-linearized Economy

In this section, I will simply present the log-linearized macroeconomic framework.<sup>3</sup> Before defining the optimal price setting rule in the GTE, it is useful to define the optimal price that would occur if price were perfectly flexible ( $\bar{p}_{it}$ ) (i.e. "the optimal flex price"). The log-linearized version of the optimal flex price in each sector is given by

$$\bar{p}_{it} = p_t + \gamma y_t - \delta a_t \quad (1)$$

with the coefficients  $\gamma$  and  $\delta$  being:

$$\gamma = \frac{\eta_{cc} + \eta_{LL}}{1 + \theta \eta_{LL}} \text{ and } \delta = \frac{1 + \eta_{LL}}{1 + \theta \eta_{LL}} \quad (2)$$

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 labor elasticity and  $\theta$  is the sectoral elasticity.  $a_t$  denotes productivity shocks, which follows an  $AR(1)$  process:  $a_t = \rho a_{t-1} + \varepsilon_t$ , where  $\varepsilon_t$  is an  $idd(0, \sigma_a^2)$ . The optimal flex prices will, in general, differ across sectors, since the sectors are hit by different shocks.

We can represent the price-setting behaviour in the *GTE* in terms of three general equations: one for the optimal price in sector  $i$  ( $x_{it}$ ), one for the average price in sector  $i$  ( $p_{it}$ ) and one for the average price in the economy

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<sup>3</sup>A technical appendix at the end of the paper provide a detailed discussion of the underlying assumptions of the model and the derivation of the structural equations.



$(p_t)$ . These are:

$$x_{it} = \sum_{j=1}^{T_i} \lambda_{ij} \bar{p}_{it+j-1} \quad (3)$$

$$p_{it} = \sum_{j=1}^{T_i} \lambda_{ij} x_{it-(j-1)} \quad (4)$$

$$p_t = \sum_{i=1}^N \alpha_i p_{it} \quad (5)$$

where  $\lambda_{ij} = \frac{1}{i}$ . The optimal price (3) in sector  $i$  is simply the average (expected) optimal flex price over the contract length (the nominal price is constant over the contract length). The optimal prices will, in general, differ across sectors, since they take the average over a different time horizon. The average price in sector  $i$  (4) is related to the past optimal prices in that sector. The average price in the economy (5) is simply the weighted average of all ongoing sectoral prices.

These equations (3 - 5) can represent the Calvo economy. To obtain the simple Calvo economy from (3), the summation is made with  $T_i = \infty$  and  $\lambda_{ij} = \omega(1 - \omega)^{j-1} : j = 1 \dots \infty$ , where  $\omega$  is the Calvo hazard rate.

The output level in the economy is given by the standard Euler condition:

$$y_t = E_t y_{t+1} - \eta_{cc}^{-1} (r_t - E_t \pi_{t+1}) \quad (6)$$

where  $\pi_t = p_t - p_{t-1}$  is the inflation rate and  $r_t$  is the nominal interest rate.

Following Taylor and Wieland (2008), the central bank follows a Taylor style rule under which the short term interest rate is adjusted to respond to the inflation rate and the current and lagged output levels:

$$r_t = \phi_\pi \pi_t + \phi_y (y_t - y_{t-1}) + \xi_t \quad (7)$$

where  $\xi_t$  is a monetary policy shock and follows a white noise process with zero mean and a finite variance.

The average reset inflation for price changers ( $\tilde{\pi}_t$ ) at period  $t$  is given by

$$\tilde{\pi}_t = \sum_{i=1}^N \sum_{j=1}^{T_i} \alpha_i \lambda_{ij} (x_{it} - x_{it-1}) \quad (8)$$

$\tilde{\pi}_t$  is the theoretical reset price inflation and is different from the BKM measure of reset inflation. When constructing their empirical measure of reset inflation, BKM assume that firms that do not change price in the current period update their reset prices according to the average reset inflation for price changers. Thus, the constructed reset price in sector  $i$  ( $p_{it}^*$ ) is given by

$$p_{it}^* = \sum_{j=1}^{T_i} \lambda_{ij} \left( x_{it-(j-1)} + \sum_{k=0}^{j-2} \tilde{\pi}_{t-k} \right) \quad (9)$$

If we define aggregate constructed reset inflation as  $\pi_t^* = p_t^* - p_{t-1}^*$ , we have:

$$\pi_t^* = \sum_{i=1}^N \alpha_i \pi_{it}^* \quad (10)$$

where  $\pi_{it}^* = p_{it}^* - p_{it-1}^*$  is the sectoral constructed reset inflation.

### 2.3 Choice of Parameters

The time period of calibration is bi-monthly. I use the KK dataset to calibrate a GTE. The data are derived from the US Consumer Price Index data collected by the Bureau of Labor Statistics. The period covered is 1988-2005, and about 300 categories account for about 70% of the CPI. The dataset provides the average proportion of prices changing per month for each category. I interpret these statistics as Calvo reset probabilities. I then generate the distribution of durations for that category using the formula put forward by Dixon and Kara (2006). I sum all sectors using the category weights. The distribution in terms of months is plotted in Figure 1. The mean contract length is around 15 months. There is a long tail. However, the most common contract duration is one month. I then aggregate monthly data to a bimonthly level. For computational purposes, the distribution is truncated at  $N = 30$ , with the 30-period contracts absorbing all of the weights from the longer contracts. Following the literature, (e.g. Dixon and Kara (2010a), Walsh (2005) and Woodford (2003)), I set  $\eta_{LL} = 4.5$ ,  $\eta_{CC} = 1$  and  $\theta = 6$ . I set  $\rho = 0.8$  and  $\sigma_a = 4.10\%$ , in line with BKM<sup>4</sup>. I set  $\phi_\pi = 0.75$ ,  $\phi_\pi = 1.1$  and  $\phi_y = 0.5$ , in line with Taylor (1999). Following BKM, I set the standard deviation of monetary policy shocks to 0.48%. In the Calvo model, I set

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<sup>4</sup>In the working paper version of the paper see Bils, Klenow and Malin (2009)), BKM calibrate the standard deviations of idiosyncratic productivity shocks in their menu cost model at around 5%.

$\omega$  to  $\omega = 0.25$  so that the mean contract length in the two models are the same.

### 3 Evidence on Reset Price Inflation

Table 1 reports summary statistics on BKM’s empirical measure of reset inflation as well aggregate inflation. The first row of Table 1 reports the persistence of reset inflation. The persistence of these series is measured by the first-order autocorrelation. As the table shows, there is no persistence in reset inflation. The serial correlation is almost zero. Aggregate inflation is more persistent than reset inflation. The third row of Table 1 reports the persistence of aggregate inflation. The serial correlation of aggregate inflation is around 0.27. The table further indicates that aggregate inflation is less volatile than reset inflation. The standard deviation of reset inflation is around 0.69%, whereas the standard deviation of aggregate inflation is 0.52%. These numbers imply that the ration between the standard deviations of reset inflation and the standard deviations of inflation is around 1.3.

All goods	
Standard deviation of $\pi^*$ ( $\sigma_{\pi^*}$ )	0.69%
Serial correlation of $\pi^*$	-0.03
Standard deviation of $\pi$ ( $\sigma_{\pi^*}$ )	0.52%
Serial correlation of $\pi$	0.27
$\sigma_{\pi^*}/\sigma_{\pi}$	1.32

Table 1: Summary Statistics for monthly Reset and Aggregate Price Inflation (source: BKM)

Note that, in addition to aggregate statistics, BKM also report statistics for two subgroups: flexible goods and sticky goods. However, this categorization is misleading, since the flexible goods group does not consist only of goods that adjust their prices every period. BKM report that the mean frequency of price changes in this group is 0.33. If within each group there is a Calvo process, then in the flexible group there are plenty of contracts longer than 1-period. Recall the distribution of contracts in the Calvo model is given by the following formula:  $\alpha_i = \omega^2 i (1 - \omega)^{i-1} : i = 1 \dots \infty$ , where  $\alpha_i$  is the share of  $i$ -period contract in the economy. Therefore, the statistics for the subgroups reported in BKM have limited value. I do not report and discuss those statistics here.

## 4 Results

Having reviewed the stylised features we can ask the following question: can a DSGE model that accounts for the heterogeneity in contracts lengths explain these features? Table 3 provides an answer to this question. There, I report summary statistics for the GTE based on the Klenow and Kryvtsov (2008) dataset (hereafter, KK-GTE) <sup>5</sup>.

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<sup>5</sup>All calculations are performed using Dynare version 4.2 (see Juillard (1996)).

All goods	
Standard deviation of $\pi^*$ ( $\sigma_{\pi^*}$ )	0.69%
Serial correlation of $\pi^*$	-0.03
Standard deviation of $\pi$ ( $\sigma_{\pi^*}$ )	0.41%
Serial correlation of $\pi$	0.29
Standard deviation of $\tilde{\pi}$	0.4%
Serial correlation of $\tilde{\pi}$	-0.04
$\sigma_{\pi^*}/\sigma_{\pi}$	1.68

Table 2: Summary Statistics for bi-monthly Reset and Aggregate Price Inflation

As the table shows, the standard deviation and serial correlation of reset inflation match the empirical statistics. The model also closely aligns with aggregate inflation data. The serial correlation of aggregate inflation in the model is 0.29%, whereas it is 0.27% in the data. The standard deviation of aggregate inflation in the model is 0.41%, whereas it is 0.52% in the data. At around 1.68, the ratio of the standard deviations for reset versus actual inflation is in-line with what the data suggests. In the data, this ratio is 1.32.

Figure 2 plots the impulse response functions (IRFs) for reset price and aggregate inflation to the productivity shock in the model<sup>6</sup>. The initial responses are normalized to one. The model IRFs are in line with the empirical IRF reported in BKM. Prices adjust gradually and go back to the initial steady state after some time of the shock. Aggregate price is more persistent than reset price because it includes many prices that are fixed.

<sup>6</sup>The standard deviations of monetary policy shocks are small relative to the standard deviations of productivity shocks. Thus, the presence of monetary policy shocks in the model does not significantly affect conclusions. This is true for all the experiments reported in the paper.

These results suggest that the model does a remarkable job of accounting for the observed persistence and volatility of both reset inflation and aggregate inflation. It is important to note that the model exhibits strategic complementarity among firms. BKM argue that a model with strong strategic complementarities cannot match the data. In this model,  $\gamma$  is a measure of the degree of strategic complementarity of firm pricing decisions (see equation 2). If  $\gamma < 1$ , then the model exhibits strategic complementarities. If  $\gamma > 1$ , then in the model firm decisions are strategic substitutes. My calibrated value of  $\gamma = 0.2$  implies a large degree of strategic complementarity.

The table also reports the standard deviation and the persistence of  $\tilde{\pi}_t$ .  $\tilde{\pi}_t$  is the theoretical reset price inflation. It is unobservable in the data but is observable in the model. It is important to examine to see if  $\tilde{\pi}_t$  follows a similar pattern as  $\pi_t^*$ .  $\pi_t^*$  may not be a good measure of  $\tilde{\pi}_t$ . Given that the KK-GTE fits many of the facts in BKM aim to match, I can safely use it to compare  $\tilde{\pi}_t$  and  $\pi_t^*$ . As the table shows, the statistics for  $\tilde{\pi}_t$  are similar to those for  $\pi_t^*$ . Figure 3 plots the impulse response functions (IRFs) for the constructed reset price inflation and the theoretical one to the productivity shock<sup>7</sup>. In the KK-GTE,  $\tilde{\pi}_t$ , indeed, follows a similar pattern as  $\pi_t^*$ .

What is the mechanism at work here? This is best illustrated by focusing on the theoretical reset price inflation. First, recall that following Taylor

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<sup>7</sup>The standard deviations of monetary policy shocks are small relative to the standard deviations of productivity shocks. Thus, the presence of monetary policy shocks in the model does not significantly affect conclusions. This is true for all the experiments reported in this paper.

and Wieland (2008), I assume that the central bank follows a Taylor style rule under which the interest rate responds to changes in inflation rate and in the growth rate of the output. As discussed in Woodford (2003, p. 522-527), such a policy is closely related to the price-level targeting (PLT), under which the central bank reacts to changes in prices and output, as the Taylor and Wieland (2008) rule is the first difference of PLT. This policy closely approximates the outcome under PLT. In fact, Gorodnichenko and Shapiro (2007) argue that the Greenspan FED did price level targeting. Under such a policy, the central bank aims to offset the impact of the shock on the price level. Consider a positive productivity shock that hits the economy at time  $t$ . The productivity shock would lead to a decrease in reset price inflation. The central bank would try to push inflation up, not only to its target but, temporarily above its target. A period of below-target inflation would have to be matched by a period of above-target inflation to get the price level back on its targeting path. Figure 3 confirms this intuition. As the figure shows, reset price inflation falls when the shock hits the economy. It becomes positive after the second period. Hence, the persistence of it is almost zero. Figure 4 plots the IRFs for aggregate inflation to the productivity shock. Aggregate inflation is more persistent than reset price inflation.

So, why do BKM argue that the general equilibrium models cannot fit the empirical estimates reported in Table 1? To understand the difference between our conclusions, I repeat the same experiments as in Table 2 but replace the GTE assumption with the Calvo process, as in BKM. All the



parameters are held at their baseline values. Table 3 reports the summary statistics of reset inflation and aggregate inflation for BKM’s Calvo economy. As the table shows and as BKM find, the constructed reset inflation in the BKM model is more persistent than in the data. The serial correlation of reset inflation in the model is  $-0.48$ , whereas it is  $-0.03$  in the data. The serial correlation of aggregate inflation in the model is  $0.68$ , whereas it is  $0.27$  in the data. Related to this result, aggregate inflation is considerably less volatile than in the data. The standard deviations of aggregate inflation is about one fourth of what it is in the data. The standard deviation of reset price inflation in the model is higher than in the data. It is  $0.82\%$  in the model, whereas it is  $0.69\%$  in the data. Given these numbers, the model fails the ratio of the standard deviations for reset versus actual inflation test. This ratio is  $3.8$  in the model, whereas it is only  $1.32$  in the data. These findings are all in line with the findings reported in BKM.

	All goods
Standard deviation of $\pi^*$ ( $\sigma_{\pi^*}$ )	$0.82\%$
Serial correlation of $\pi^*$	$-0.48$
Standard deviation of $\pi$ ( $\sigma_{\pi}$ )	$0.21\%$
Serial correlation of $\pi$	$0.68$
Standard deviation of $\tilde{\pi}$	$0.21$
Serial correlation of $\tilde{\pi}$	$-0.04$
$\sigma_{\pi^*}/\sigma_{\pi}$	$3.84$

Table 3: Summary Statistics for monthly Reset and Aggregate Price Inflation from BKM’s 2-sector Calvo Model

If we focus on the statistics for  $\tilde{\pi}$ , we see that, in contrast to the case

with the GTE, in the Calvo model  $\tilde{\pi}_t$  is quite different from  $\pi_t^*$ . The serial correlation of  $\tilde{\pi}_t$  is -0.04, whereas it is -0.51 for  $\pi_t^*$ . There is also difference in standard deviations, although the difference is not as great as in serial correlations. The standard deviation of  $\tilde{\pi}_t$  is  $-0.68\%$ , whereas it is  $-0.82\%$  for  $\pi_t^*$ . Figure 4 plots the IRFs for constructed reset inflation and theoretical inflation for a productivity shock. Figure 4 confirms that the difference between the two measures of reset inflation. It is interesting to note that  $\tilde{\pi}_t$  in the Calvo model is similar to than in the KK-GTE. Thus, the Calvo model itself does not suggest that the reset inflation should adjust sluggishly.

Therefore, the conclusion that the Calvo model generates too much reset price inflation arises due to the way BKM measure reset inflation. This suggests that the BKM measure of reset inflation is not a good measure of the concept they want to measure and can be misleading.

A question arises: why  $\tilde{\pi}$  is very different from  $\pi_t^*$  in the Calvo model. To understand the reason for this result, first note that the KK-GTE differs from the Calvo in two respects. First, the price setting in the GTE is more myopic than in the Calvo model. Second, the underlying distribution of contracts are different. The first difference arises because of the fact that the Calvo firms do not know how long their contract will last, whereas in the GTE they do. As a consequence, Calvo firms have a probability distribution over contract lengths. Since there is a positive probability of any duration occurring, firms when setting their prices need to look at far into the future. The GTE firms, on the other hand, since they know in which sector they

belong and, therefore, how long is their contract, they only need look at things that happen during the contract length. Thus, Calvo-firms are more forward-looking than the GTE firms<sup>8</sup>. The Calvo firms that adjust their prices in period  $t$  react more to the shock than the corresponding firms in the GTE. As a consequence, the Calvo economy experiences higher deflation than the GTE at time  $t$  when the productivity shock hit the economy. To bring the current price level back to its starting point, the Calvo economy will need to experience higher inflation than the GTE in future periods.

Perhaps the importance of the difference in price-setting on reset prices can be clearly shown by comparing the Calvo model with a special GTE that has exactly the same distribution of contract lengths as the Calvo model (i.e a Calvo-GTE). The distribution of contracts with the chosen parameter value  $\omega = 0.25$  is plotted in Figure 5. Thus, the sole difference between the two models is the price setting. Figure 6 plots the impulse response function of theoretical reset inflation to a positive productivity shock in the Calvo model and in the Calvo-GTE. As the figure shows, in the Calvo firms react more to the shocks than the Calvo-GTE firms and set a lower price than the GTE firms. As a consequence, the Calvo economy experiences higher inflation than the corresponding GTE.

When constructing their measure of reset price inflation, BKM assume that those firms that do not reset price update their prices according to the rate of reset inflation among price changers in the current period. This can

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<sup>8</sup>This point is made in Dixon and Kara (2010a) and is emphasised in Dixon (2006).

be clearly seen by considering the constructed reset price inflation in the Calvo model, given by

$$\pi_t^* = \omega \tilde{\pi}_t + (1 - \omega) (\pi_{t-1} + (\tilde{\pi}_t - \tilde{\pi}_{t-1})) \quad (11)$$

As this equation makes clear, the large change in  $(\tilde{\pi}_t - \tilde{\pi}_{t-1})$  in the initial period in the model leads to large discrepancy between the constructed reset inflation and the theoretical ideal.

However, as noted BKM, the Calvo model generates too much persistence in aggregate inflation. Furthermore, the Calvo model significantly underestimates the share of flexible contracts. The reason for this can be understood by comparing Figures 1 and 4. In the KK-GTE, just as we observe in the data, there is a high proportion of flexible prices. The share of 1-month contract is around 25% in the KK-GTE, where it is only 6% in the Calvo model.

Finally, it is important to note that BKM focus on the period between 1990-2009. They note that when they consider longer samples, they find that aggregate inflation is more persistent. They suggest that the high degree of persistence over longer samples might be due to monetary policy. The KK-GTE confirms this suggestion. In Dixon and Kara (2010b), one finds that, with a different monetary policy, the GTE can generate a very persistent inflation response, peaking at the 8th quarter and beyond. Thus, as in the data, in the GTE the high persistence is not a structural feature of the

economy and can change if monetary policy changes.

## 5 Conclusions

I have examined whether a GTE model that accounts for the heterogeneity in contracts length can explain the data on both aggregate inflation and constructed reset inflation. In this otherwise standard DSGE model, there are many sectors, each with a Taylor style contract. I have shown that a GTE calibrated based on the Klenow and Kryvtsov (2008) dataset explain both. The model incorporates strong complementarities.

These results contrast with the findings reported by BKM. These authors argue that DSGE models with strong complementarities have trouble in explaining their measure reset price inflation and aggregate inflation. BKM employ the popular Calvo model. They argue the model generates too much persistence in reset price inflation and aggregate inflation. I show that the conclusion that the Calvo model generates a degree of persistence stems from the way BKM measure reset inflation. In the Calvo model the theoretical reset price inflation is slightly more persistent than in the KK-GTE. The reason for this difference is that the price setting in the Calvo model is more forward-looking than in GTE. BKM's constructed reset inflation is updated according to the growth theoretical reset price inflation. Increased persistence in reset inflation in the Calvo model leads to a large difference between the constructed reset inflation and the theoretical ideal. Moreover, using the

GTE approach, I am able to understand why the Calvo model generates too much persistence in aggregate inflation. The reason for this is that the Calvo model underestimates the share of flexible prices.

These findings clearly show the existing models strong complementarities can readily account for the observed reset price inflation. Reset price may turn out to be a useful concept for monetary policy. I leave this issue as a matter for future research

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## 6 Appendix: The Model

### 6.1 Firms

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

$$Y_{ft} = A_t L_{ft} \quad (12)$$

where  $a_t = \log A_t$  is a productivity shock and follows an  $AR(1)$  process:  $a_t = \rho a_{t-1} + \varepsilon_t$ .  $f \in [0, 1]$  is firm specific index. Differentiated goods  $Y_t(f)$  are combined to produce a final consumption good  $Y_t$ . The production function here is  $CES$  and corresponding unit cost function  $P_t$

$$Y_t = \left[ \int_0^1 Y_{ft}^{\frac{\theta-1}{\theta}} df \right]^{\frac{\theta}{\theta-1}}, P_t = \left[ \int_0^1 P_{ft}^{1-\theta} df \right]^{\frac{1}{1-\theta}} \quad (13)$$

The demand for the output of firm  $f$  is given by

$$Y_{ft} = \left( \frac{P_{ft}}{P_t} \right)^{-\theta} Y_t \quad (14)$$

The firm chooses  $\{P_{ft}, Y_{ft}, L_{ft}\}$  to maximize profits subject to (12, 14), yields the following solutions for price, output and employment at the firm level given  $\{Y_t, W_{ft}, P_t\}$ .

$$P_{ft} = \frac{\theta}{\theta - 1} \frac{W_{ft}}{A_t} \quad (15)$$

$$Y_{ft} = \left( \frac{\theta}{\theta - 1} \right)^{-\theta} \left( \frac{W_{ft}}{A_t P_t} \right)^{-\theta} Y_t \quad (16)$$

$$L_{ft} = \left( \frac{\theta}{\theta - 1} \right)^{-\theta} \left( \frac{1}{A_t} \right) \left( \frac{W_{ft}}{A_t P_t} \right)^{-\theta} Y_t \quad (17)$$

Price is a markup over marginal cost, which depends on the wage rate ( $W_{ft}$ ) and the sector specific productivity shocks.

## 6.2 Household-Unions

The representative household  $h$  has a utility function given by

$$U_h = E_t \left[ \sum_{t=0}^{\infty} \beta^t [U(C_{ht}) + V(1 - H_{ht})] \right] \quad (18)$$

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

The household's budget constraint is given by

$$P_t C_{ht} + \sum_{s^{t+1}} Q(s^{t+1} | s^t) B_h(s^{t+1}) \leq B_{ht} + W_{ht} H_{ht} + \Pi_{ht} - T_{ht} \quad (19)$$

where  $B_h(s^{t+1})$  is a one-period nominal bond that costs  $Q(s^{t+1} | s^t)$  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,  $\Pi_{ht}$  is the profits distributed by firms and  $W_{ht}H_{ht}$  is the labour income. Finally,  $T_t$  is a lump-sum tax.

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

$$u_{ct} = \beta R_t E_t \left( \frac{P_t}{P_{t+1}} u_{ct+1} \right) \quad (20)$$

$$\sum_{s^{t+1}} Q(s^{t+1} | s^t) = \beta E_t \frac{u_{ct+1} P_t}{u_{ct} P_{t+1}} = \frac{1}{R_t} \quad (21)$$

$$X_{it} = \frac{\theta}{\theta - 1} \frac{V_L (1 - H_{it+s})}{\left[ \frac{u_c(C_{t+s})}{P_{t+s}} \right]} \quad (22)$$

Equation (20) is the Euler equation. Equation (21) gives the gross nominal interest rate. Equation (22) shows that the optimal wage in sector  $i$  ( $X_{it}$ ) is a constant "mark-up" over the ratio of marginal utilities of leisure and marginal utility from consumption. Note that the index  $h$  is dropped in equations (20) and (22), which reflects our assumption of complete contingent claims markets for consumption and implies that consumption is identical across all households in every period ( $C_{ht} = C_t$ ).

Using (15), aggregating for firm  $f$  in sector  $i$ , substituting out for  $W_{it}$  in the resulting equation using the optimal labour supply condition (22), using

the labour demand function (17) to substitute out for  $L_{it}$  and log-linearizing the resulting equation, I obtain the price level when prices are full flexible

$$p_{it}^* = p_t + \frac{(\eta_{cc} + \eta_{LL})}{(1 + \theta\eta_{LL})}y_t - \frac{(1 + \eta_{LL})}{(1 + \theta\eta_{LL})}a_t \quad (23)$$

Note that the optimal flex price in each sector is the same.

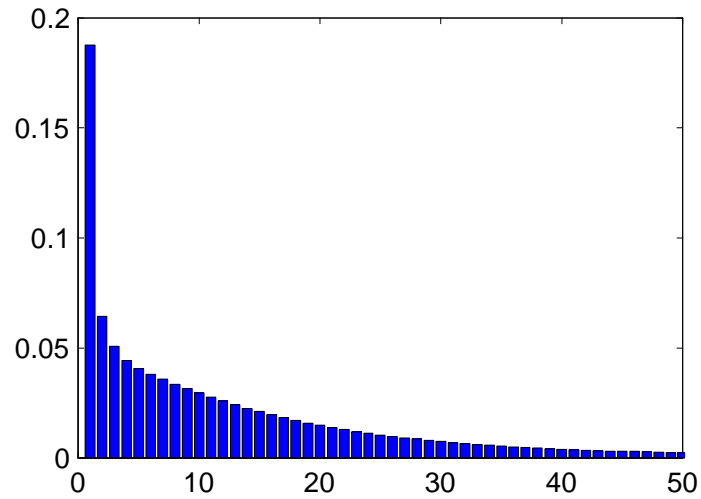


Figure 1: KK-distribution: the distribution of completed contract lengths (in months)

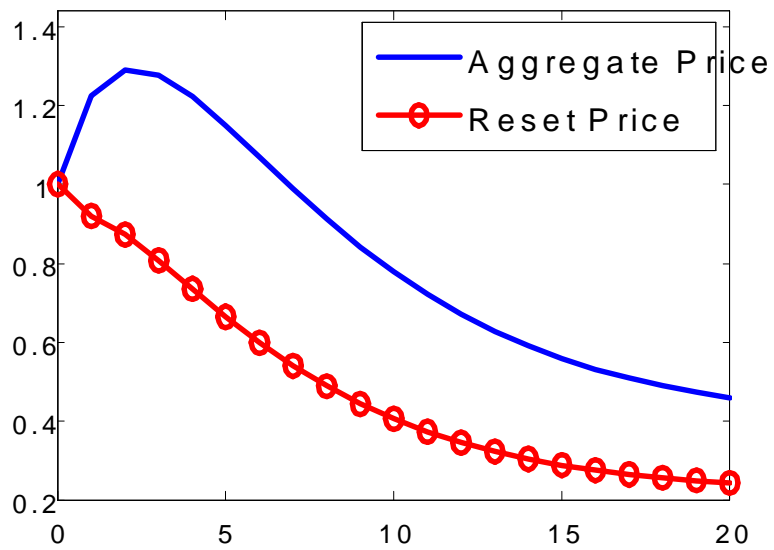


Figure 2: Response of constructed Reset Price to a productivity shock in the KK-GTE (percent deviation from the steady state)

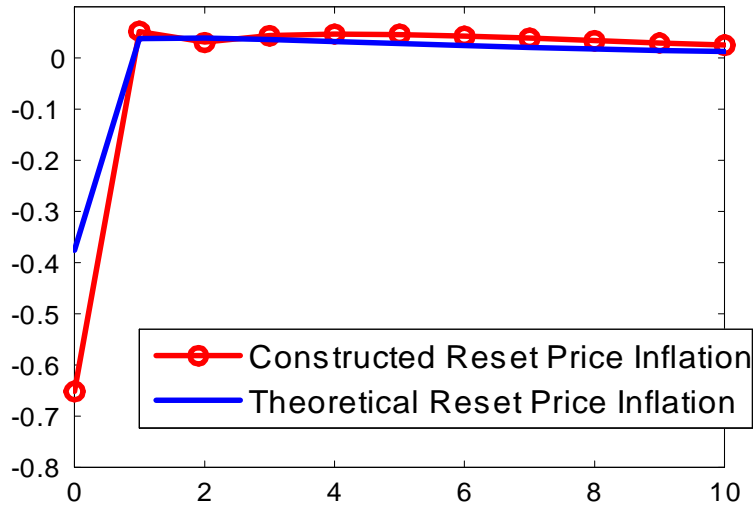


Figure 3: Responses of Constructed Reset Price Inflation and theoretical Reset Price inflation to a productivity shock in the KK-GTE (percent deviation from the steady state)

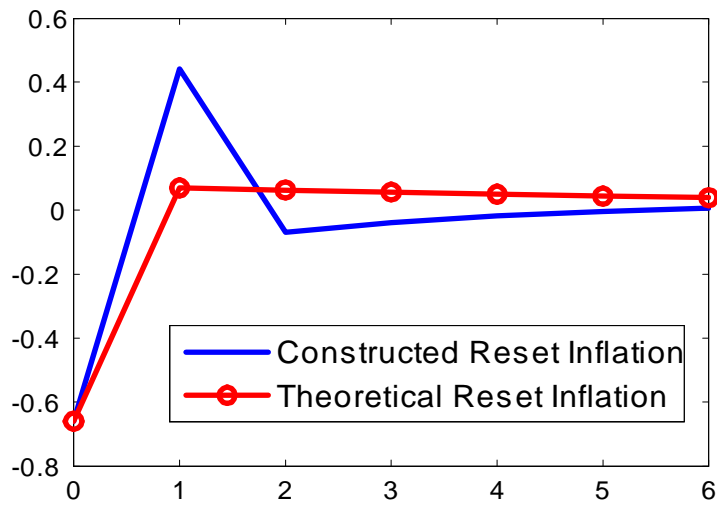


Figure 4: Responses of Constructed Reset Price Inflation and theoretical Reset Price inflation to a productivity shock in the Calvo model (percent deviation from the steady state)

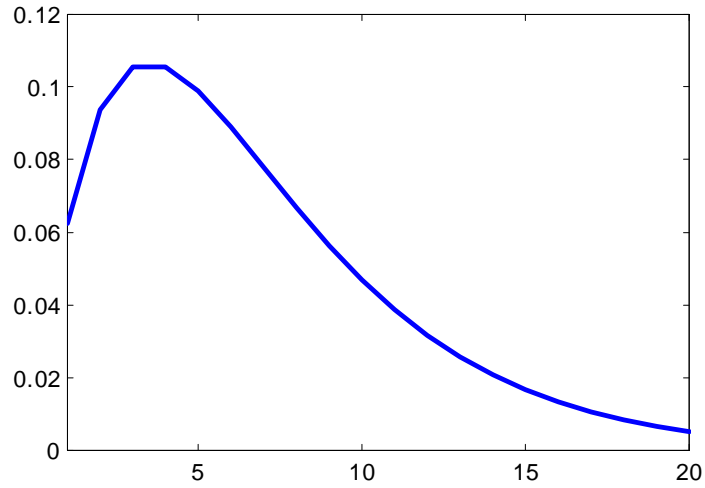


Figure 5: Distributiun of Completed Contract Lengths in the Calvo model (in months)

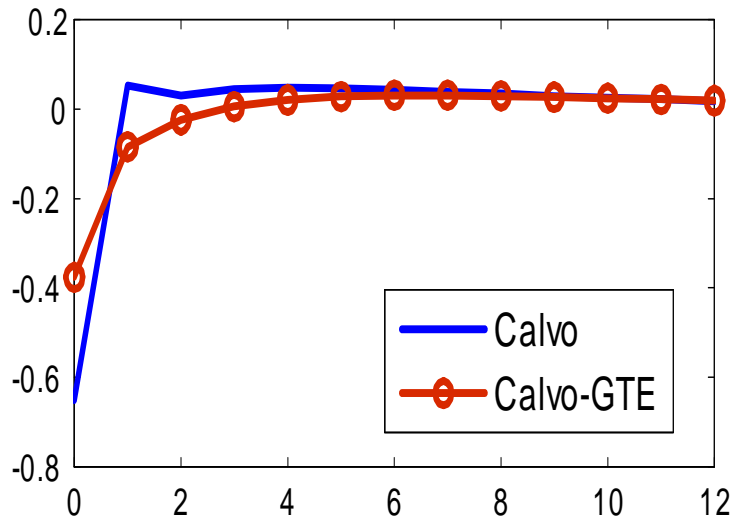


Figure 6: Responses of Theoretical Reset Inflation to a productivity shock in the Calvo model and In the Calvo-GTE (percent deviation from the steady state)