State-Dependent Pricing and the Non-neutrality of Money

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Abstract

Golosov and Lucas (2007) have challenged the view that infrequent price adjustments by firms explain why money has aggregate real output effects. The basis of their challenge is the 'selection effect' – re-setting firms are not selected at random, they are those firms whose prices are furthest from the optimal reset price. Because of this the aggregate price level is sufficiently flexible for monetary neutrality. In this paper I add price review costs to an otherwise standard Golosov and Lucas model. This weakens the selection effect and restores monetary non-neutrality to a level comparable to that of the Calvo (1983) pricing model.
1. Introduction

In Golosov and Lucas (GL 2007) money is neutral even when firms, facing menu costs, adjust their prices intermittently. They attribute this to a ‘selection effect’ – the firms that are resetting are those with prices furthest from the optimal reset price. In this paper I develop a discrete-time version of the GL model in which money is non-neutral. This is due to one very natural extension to the GL model: I allow price review costs and the direct costs of changing prices to play distinct roles in the pricing decision. The former are incurred when information is gathered and processed and when decisions are made; the latter (‘menu costs’), are incurred only when prices are changed. The distinction is important because there is substantial evidence that firms change their prices less frequently than they review them. The effect of review costs on the firm’s pricing strategy has been analyzed in an expanding number of recent papers (reviewed below). My aim in this paper is to embed both review costs and menu costs in an otherwise standard menu-cost model and examine the effect this has on the strength of the selection effect. I find that this extension to the standard model sufficiently weakens the selection effect to give a degree of money non-neutrality similar to that of a model with Calvo (1983) pricing.

Money is non-neutral when the aggregate price level is slow to adjust. Such price-level stickiness has been attributed to costs associated with changing prices. The presence of such costs provided new-Keynesians with just the micro-foundation that earlier Keynesian models lacked. And yet the new-Keynesian analysis of monetary policy is usually based on the simplifying
assumption of Calvo: firms choose how much to change prices but not when.\footnote{Clarida, Gali and Gertler (1999) is a comprehensive survey of the new-Keynesian analysis of monetary policy based on the Calvo approach.} Their timing is random. New-Keynesians are left with the hope that the Calvo approach is close enough an approximation to a fully-specified menu-cost model to justify its use for the analysis of monetary policy. Unfortunately the standard menu-cost model, appropriately calibrated to match the micro-data, behaves rather unlike the Calvo model and the micro-foundations of Keynesian monetary policy would seem to be far from established.

In Caplin and Spulber’s (1987) early menu-cost model, money is completely neutral because of the selection effect.\footnote{Golosov and Lucas (2007) first coined the phrase ‘selection effect’. Caballero and Engel (2007) argue that the key distinction is that between the ‘extensive’ and ‘intensive’ margins. In the former a money shock raises the price level through its effect on the fraction of firms making price adjustments. The intensive margin is the additional price increases of those firms that were going to adjust anyway. Only the intensive margin is active in the Calvo model, while in menu-cost models both margins are strictly positive.} Firms that are re-setting are not drawn randomly – they are those with prices furthest from the optimal reset price. Consider the effects of a positive monetary shock. Those firms with initial prices well below their equilibrium will reset and, when they do so, make large adjustments (to catch up). Firms with prices nearer their equilibrium values or even some way above them are unlikely to reset. The aggregate price level is an average of the large price adjustments of the re-setters and the zero adjustments of others. In Caplin and Spulber’s model the average price level exactly keeps pace with the monetary shock, neutralising any aggregate real output effects. They show that while there may be firm-level stickiness in prices, the aggregate price level is not and, because of this, money is neutral.

GL find that the selection effect is also present in a fully-specified menu-cost model with idiosyncratic productivity. Calibrating their model to match
observed patterns of price setting (as described in Bils and Klenow (2004) and Klenow and Kryvtsov (2008)), they find that the selection effect blunts the real effects of money – not completely, but substantially so. Acknowledging that the menu cost model can explain price stickiness at the firm level, GL argue that it does not offer new-Keynesians the micro foundation they seek. And they find that the Calvo model, widely used in new-Keynesian analysis, is not a ‘serviceable approximation to behaviour under menu costs.’

The standard menu-cost model can be challenged along two related lines. First it is simply not consistent with observed patterns of price changes in the micro data. And secondly, its description of the price-setting process and its associated costs is seriously incomplete. The first weakness concerns the failure of the standard model to account for the wide dispersion of price changes observed in the data. According to Klenow and Kryvtsov (2008), the average absolute change in those prices being re-set is around 10% and yet they find that 44% of price changes are less than 5% in absolute value. Since, in the standard menu-cost model, prices only adjust when they are some way from their equilibrium values, small price adjustments are only made if menu-costs are small – too small for the model to remain consistent with other features of the data.

Recent menu-cost models have been more successful in explaining the wide dispersion of price changes in the micro-data. Several introduce some form of heterogeneity in menu costs. Dotsey, King and Wolman (1999) assume that menu costs are stochastic so that those firms with small menu costs will adjust prices even when current prices are close to the equilibrium. Dotsey, King and Wolman (2006) add idiosyncratic shocks to their earlier
model, generating the large price changes observed in the data. Klenow and Kryvtsov (2008) assume fixed but different menu costs specific to 67 sectors. Small price adjustments will be made by firms in sectors with low menu costs. Similarly, Nakamura and Steinsson (2008) develop a multi-sector model in which menu-costs (and therefore price-resetting frequencies and their size) vary by sector. Midrigan (2010) adds two extensions to the standard model: idiosyncratic productivity shocks are assumed to have fat-tailed distributions; and output is produced by multi-product firms so that there are ‘economies of scope’ in adjusting prices. 3 Firms re-set all prices when optimisation requires re-setting only one. 4 With the combination of fat-tailed productivity shocks and economies of scope, Midrigan explains both the large mean of absolute price changes and the frequency of small ones. This sufficiently weakens the selection effect to generate real effects of money similar to those in models with Calvo pricing. Finally Gertler and Leahy (2008) have developed a model with Poisson arrival of uniformly-distributed idiosyncratic productivity shocks and small menu costs, so that many price changes are small.

These ‘second generation’ menu-cost models (to borrow Klenow and Kryvtsov’s term for them) have successfully modified the standard model to account for the mean size and wide dispersion of price changes in the data. And in doing so, they find that the selection effect is weak enough for money

3 Midrigan also seeks to explain the difference between ‘regular’ and ‘posted’ prices and the interesting observation that 90% of temporary nominal prices return to their original values. Although temporary price adjustments by firms may reduce the real effects of money, Midrigan finds this to be relatively unimportant.

4 To support his use of scope economies, Midrigan cites Lach and Tsiddon (2007) who present evidence that economies of scope in price setting may account for the fact that some price changes are small.
to have real effects comparable to those of the Calvo model.\textsuperscript{5} Collectively they suggest that the new-Keynesian analysis of monetary policy, based as it is on the Calvo pricing model, may yet have sound micro foundations.

The second weakness of the standard menu-cost model concerns its characterisation of the price-setting process and its associated costs. This is the focus of this paper. Standard menu-cost models typically assume that firms costlessly and continuously review their prices and change them only if the menu costs are justified. They largely ignore the costs of gathering and processing the relevant information and the costs of the pricing decision itself – collectively price review costs.\textsuperscript{6} Firm surveys find two features which challenge the standard model. First, firms review their prices intermittently, not continuously, adjusting them less frequently than reviewing. Secondly review costs are substantially higher than the direct costs of physically changing prices.

In analyzing the impact of review costs and menu costs in an otherwise standard menu-cost model, the distinction between state- and time-dependent pricing becomes blurred. When reviewing their prices (and possibly changing them), firms are assumed to set the date of the next review. This date is chosen optimally given the current state variables. Although the firm’s pricing behaviour is purely state-dependent, one of its choice variables is the date of the next review. Time- and state-dependency are interwoven. In Midrigan

\textsuperscript{5} Indeed Gertler and Leahy obtain a closed-form solution that is identical to that of the new-Keynesian model based on Calvo pricing, though obviously the parameters have a different interpretation in their case.

\textsuperscript{6} Alvarez \textit{et al} (2010), Woodford (2009) and others refer to these costs as ‘information’ costs. My preference is for the wider term ‘review costs’ to stress the fact that it covers information gathering, information processing, decision-making – the costs of all activities involved in pricing decisions.
(2010) he asks: ‘Is firm pricing state- or time-dependent?’ My answer is ‘both’.  

Price reviews and price adjustments are both costly exercises and will, for that reason, occur infrequently. The evidence suggests that reviews are more frequent than adjustments – not all reviews lead to a change in price. Hall et al (2000) find that the median firm in their UK survey changed prices twice a year but reviewed prices every month (only 17% of reviews change prices). Using Euro-area data, Fabiani et al (2006) find that ‘the modal number of price reviews ranges in most countries between one and three times per year, while the median firm in nearly all countries changes its price only once a year’. Alvarez et al (2010) review the survey evidence across a number of European and North American countries. They conclude: ‘The median firm in the Euro area reviews its price a bit less than three times a year, but changes its price only about once a year, and similar for UK and US.’ More precisely the median US firm reviews its price twice a year and changes it 1.4 times, suggesting that 30% of reviews do not lead to a change in price. Because of likely measurement errors associated with the median, Alvarez et al focus on the mass of US firms reviewing or changing their prices more than four times.

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7 Midrigan’s own answer is state-dependent, at least in US manufacturing. Yet he also makes clear that ‘the terms time- and state-dependent pricing are somewhat obscured by the richness, in recent work, of models with nominal rigidities that employ elements of both of these price setting mechanisms.’

8 The fact that state- and time-dependency are closely interconnected may explain why firms have responded differently when asked directly about their pricing strategies. Fabiani et al (2006) investigate the pricing behaviour of more than 11,000 firms in the euro area on the basis of surveys conducted by nine Eurosystem national central banks. They find that ‘around one-third of the respondents indicate that they follow mainly time-dependent rules, while two-thirds use rules with state-dependent elements’. In their analysis of 654 UK companies in a Bank of England survey, Hall et al (2000) report that ‘time-dependent pricing was more common than state-dependent pricing, with 79% of the respondents reporting that they reviewed their prices at a specific frequency’. Analysing similar data for the US, Blinder et al (1998) observe that 60% of their respondents said that they had ‘periodic price reviews’ (which they interpret as a time-dependent pricing strategy).

9 It is possible for price adjustments to be more frequent than reviews. This would be the case if prices were indexed. It would also be the case if, following a review, a time-schedule of prices was set in place, as analysed by Burstein (2006).
a year. Only 37% of these reviews led to price changes. There is, then, substantial variation across countries and firms in the proportion of reviews that lead to price changes, but reviews are always more frequent than changes.

**Related Literature**

Information and decision costs play a more central role (than menu costs) in recent models of price stickiness. Reis (2006) has shown that a producer who faces costs of acquiring, absorbing and processing information will be rationally ‘inattentive to news, only sporadically updating his or her information.’ Reis suggests that since the costs of processing information are likely to exceed the cost of the information itself, the firm will still review intermittently even if free information is available.\(^{10}\) I follow Reis in explaining inattention (periodic price reviews) as a result of information costs and I embed this feature in a general equilibrium model which also allows menu costs to influence the firm’s pricing decision.

Alvarez et al (2010) obtain interesting analytical results from a model that allows the firm’s pricing strategy to be influenced by both review costs and menu-costs. They argue that the observed micro evidence on price-setting (including the frequencies of price reviews and price changes) can potentially be explained using the level and relative magnitudes of review and menu costs. The model in this paper is similar in spirit to theirs but my analysis of the two costs is set in a general equilibrium framework designed to analyse the aggregate real effects of monetary shocks.

\(^{10}\) Mankiw and Reis (2007) argue that inattention can be justified either by information costs or by appealing to epidemiology (Carroll (2006)).
Information costs also play an important role in Woodford’s (2009) model which is also similar in spirit to that developed in this paper. Firms pay for a noisy signal (of current market conditions) and, using this signal, they decide whether or not to review their price. When the signal leads to a review, the firm gathers the complete set of information that is required to set a new price, a price which stays in effect until the next review. Although price-setting is purely state-dependent, the model’s macroeconomic implications are similar to those of a Calvo model. The timing of price reviews in Woodford’s model relies on a low-cost signal. In the model I develop in this paper, the date of the next review is set endogenously as part of the current review. Woodford’s model fails to explain why the frequency of price reviews in the data exceeds that of price adjustments since, in his analysis, prices are always adjusted when a review takes place. There are no direct costs of changing prices, just information costs. And if (as Reis (2006) has hinted) review costs are dominated by decision costs, the role of the information signal is less clear.

In Costain and Nákov (2011) the probability of price adjustment is a smooth function of the value of making that adjustment. This function is parameterised such that Calvo and GL price adjustments emerge as special cases. Calibrating their model to match the AC Nielsen dataset (documented by Midrigan (forthcoming)), they find that the behaviour of their ‘estimated model is much closer to that of a Calvo model’. In the model developed here, the value of making the price adjustment is not known without incurring a review cost. Costain and Nákov find support for a Calvo pricing mechanism precisely because, in the data used to calibrate the model, time must play a role. The underlying reasons for this feature are this focus of the model developed here.
Recognizing that state-dependency creates a selection effect that time-dependent schemes do not, Knotek (2010) develops a model in which the firm is assumed to review its prices intermittently and change them only if menu-costs suggest a change to be worthwhile. But price reviews occur randomly with a probability that is independent of the date of the last review. In the model developed here the date of the next review is set optimally as part of the current review. Gorodnichenko (2008) explains infrequent reviews through information externalities – firms acquire information from price changes of others. The information externality and menu costs reinforce each other in delaying price adjustments and this leads to sticky aggregate prices.

Bonomo and Carvalho (2004, 2010) also focus on information costs in a model that treats the price contract length as endogenous. As in the model developed here, they stress the importance of the costs of information gathering, decision-making and internal-communication. And at each (infrequent) review date, the firm decides on the next review date – an assumption I also adopt. They show that the interval between reviews is increasing in the real costs of gathering and processing information and/or adjusting its prices. My focus in this paper is the strength of the selection effect when review costs add a time dimension to firms’ pricing. To do this I analyse the separate roles played by review costs and menu costs, the latter only incurred when prices are actually changed. Bonomo and Carvalho (in both papers) assume that review costs and menu costs are always incurred together.

Bonomo, Carvalho and Garcia (2010) allow review costs and menu costs to play separate roles in pricing behaviour. Firms have the option to
adjust or not following a review, menu costs being incurred only if an adjustment takes place. They also allow price adjustments to take place without any review (uninformed adjustment), so that firms only incur menu costs. The possibility of uninformed price changes (even in the presence of menu costs) is an interesting extension to the standard approach. I apply the central ideas of the Bonono, Carvalho and Garcia model to analyse the strength (or otherwise) of the selection effect when time plays a role in price-setting behaviour.

The rest of the paper is organised as follows. In the following section I identify seven key features of the micro data, features which the review-cost model should explain. In section 3 I extend GL’s model to allow review and menu costs to exert separate influences on the firm’s pricing decision. The main results are presented and discussed in section 4 and a final section offers a summary and conclusion.

2 The Micro Evidence

Three recent papers have analysed datasets on firms’ pricing behaviour. Midrigan (2010) – henceforth M – uses a dataset of scanner price data, maintained by the Kilts Center for Marketing, at the University of Chicago Graduate School of Business. The prices are those set by one retail company, Dominick’s Finer Foods, covering 9,000 products in 86 stores in the Chicago area. Klenow and Kryvtsov (2008) and Nakamura and Steinsson

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11 Midrigan focuses on the distinction between posted and regular prices. I calibrate using the moments of regular price changes only. Midrigan and Kehoe (2010) show that 72% of all price changes are temporary in nature, and half of these return to the level set before the temporary change. So while the overall frequency of price changes is large (22% of all prices change each month), the frequency of regular price changes is much smaller (7% per month). They find that temporary price changes cannot offset monetary shocks well, whereas regular changes can. The fact that temporary prices quickly return to their original levels suggests that in calibrating models of the sort I develop in this paper, it is the frequency and size of regular price changes that is relevant for calibration.
(2008) – henceforth *KK* and *NS* respectively – analyse price data collected by the U.S. Bureau of Labor Statistics for the Consumer Price Index. There are many technical issues that lead *M*, *KK*, and *NS* to arrive at (slightly) different conclusions but the main features of their data can be conveniently summarised in the following seven observations.

1. Price changes are more frequent than once imagined. *KK* find that prices are changed every 4–7 months depending on the treatment of temporary price changes; *NS* find median durations of between 8 and 12 months for ‘regular’ prices. Taking *KK*’s higher figure and *NS*’s lower one, the calibration target I use in the next section is that 14% of prices are reset each month.\(^\text{12}\)

2. Many of the price changes that do occur are large in absolute value. *KK* report that the mean absolute change in regular prices is around 10%; *NS* find this to be a little lower at 8.5%.

3. Notwithstanding (2), *KK* and *M* find that a significant number of price changes are small. *KK* report that 44% are less than 5% in absolute value, *M* reporting a lower figure of 25%. *M* estimates the standard deviation of regular (absolute) price changes to be 8%, 25% of changes are less than half the mean and 8% are less than a quarter of the mean. There is, then, considerable dispersion in the distribution of price changes.

\(^{12}\) *NS* highlight the substantial heterogeneity in re-setting frequency across sectors, from over 90% per month in some sectors to less than 5% in others. *GL* calibrate using a re-set frequency of 21.9%.
4. Even for individual items, price durations vary considerably over time.\textsuperscript{13}

KK report that the standard deviation of completed ‘contract lengths’ is 7 months within ‘ELIs’ and 5.2 months within ‘quote lines’.\textsuperscript{14}

5. KK find that the size of absolute price changes is not related to the interval of time since they were last re-set. I report (below) the correlation between the absolute change in reset prices and the time since they were last reset as $\rho_1$. The data suggests this should be small.

6. KK report that the intensive margin (the size of price changes) rather than the extensive margin (the fraction of items with price changes) dominates variations in inflation. They report the correlation ($\rho_2$) between inflation and the fraction of prices being re-set to be 0.25 and the correlation ($\rho_3$) between inflation and average change in reset prices to be 0.99.

7. The last feature of the price data concerns the relative frequencies of price reviews and price adjustments: not all reviews lead to adjustments. As we have seen, Alvarez \textit{et al} (2010) report substantial survey variation in the fraction of reviews that are followed by price adjustments. However, the qualitative evidence is clear - there are always more reviews than there are adjustments.

\textit{KK} demonstrate that standard state- and time-dependent pricing models fail to explain one or more of these features of the micro data. Second generation state-dependent models have been more successful, but none

\textsuperscript{13} Dixon and Kara (2010) develop a ‘Generalized Taylor’ model in which contract periods vary across firms but not over time. Their model thus fails to explain the fourth feature of the micro data.

\textsuperscript{14} ELIs are entry-level items, and quote lines are particular items within the ELIs.
explain why price reviews are intermittent and more frequent than price
adjustments. The extended GL model I develop in the next section does just
that.

3. A Model with Review Costs and Menu Costs

In this section I add review costs into an otherwise standard GL menu-cost
model. I begin with a description of a discrete-time (monthly) version of their
model.

The Standard Menu-Cost Model

Households consume a continuum of differentiated products, of unit measure,
indexed \( z \). The Spence-Dixit-Stiglitz composite consumption good takes the
now-familiar form,

\[
c_t = \left[ 1 \int_0^{C_t(z)} \frac{\epsilon^{-1}}{\epsilon} \, dz \right]^{\epsilon} \quad (1)
\]

\( C_t(z) \) is the household consumption of good \( z \) at date \( t \) and \( \epsilon \) is the elasticity
of substitution between the differentiated goods.

GL derive the demand function facing the firm producing good \( z \) as,

\[
C_t(z) = c_t^{1-\gamma} \left( \frac{\alpha p_t(z)}{w_t} \right)^{-\epsilon} \quad (2)
\]
where $p_t(z)$ is the firm’s price, $w_t$ is the economy-wide wage rate at which all firms are assumed to hire labour, $\alpha$ is the disutility of labour; $\gamma$ is the degree of risk aversion. Equation (1) may then be written,

$$c_t = \left[ \int_0^1 \left( \frac{\alpha p_t(z)}{w_t} \right)^{1-\varepsilon} \frac{dz}{\varepsilon} \right]^{-1/[\gamma(\varepsilon-1)]} \tag{3}$$

The presence of $c_t$ in (2) means that, strictly, it should be treated as a state-variable but its behaviour (from (3)) depends on the entire distribution of all firms’ prices. GL conjecture that if wage inflation were constant, (3) would be a time-invariant constant at some level $\bar{c}$. They find that the constant-$\bar{c}$ assumption is a good approximation in their case, even for a model with stochastic wage inflation. Stopping at the mean may be an approximation too far given the extensions I add to the GL model and for this reason I allow $c_t$ to vary (as I explain below).

The firm’s profit function is,

$$\Pi_t(z) = C_t(z) \left( p_t(z) - \frac{w_t}{v_t(z)} \right) - I_t(z) k w_t$$

where $I_t(z)$ is an indicator variable that takes the value 1 if the firm changes its price in period $t$ and zero otherwise; $k$ is the real menu cost – the hours of labour needed to change price; and $v_t(z)$ is labour productivity in firm $z$. The firm’s output is a function of labour alone.

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15 In the GL model the process for the log of the economy-wide wage rate is also that of the log of the money supply. Hence wage inflation and money-supply growth are identical.

16 The firm’s output is a function of labour alone.
\[
\pi_t(z) = c_t^{1-\eta'} (\alpha x_t(z))^{-\varepsilon} \left( x_t(z) - \frac{1}{v_t(z)} \right) - I_t(z) \kappa \tag{4} \]

where \( \pi_t(z) = \Pi_t(z) / w_t \) and \( x_t(z) = p_t(z) / w_t \) is the relative price (inverse of the real product wage) of good \( z \).

The wage rate \( (w_t) \) and idiosyncratic productivity \( (v_t(z)) \) are assumed to follow,

\[
\log(w_t) = \mu + \log(w_{t-1}) + \nu_t, \quad \nu_t \sim N(0, \sigma^2_{\nu})
\]

\[
\log(v_t(z)) = \rho \log(v_{t-1}(z)) + \omega_t(z), \quad \omega_t(z) \sim N(0, \sigma^2_{\omega})
\]

Following Krusell and Smith (1998) I make the firm’s problem tractable by assuming that they perceive \( c_t \) to be a function of a small number of its moments (not just its mean as in GL). In particular I assume,

\[
\log(c_t) = \lambda_0 + \lambda_1 \log(c_{t-1}) + \lambda_2 \nu_t + \epsilon_t \tag{5}
\]

I explain the derivation of the \( \lambda \) coefficients below. The firm maximizes profits discounted at a constant rate \( \beta \) so that the real value \( (V) \) function of the firm is given by the solution to the Bellman equation,

\[
V \left( \frac{p_{t-1}(z)}{w_t}, v_t(z), c_t \right) = \max_{p_t(z)} \left[ \pi_t(z) + \beta E_t V \left( \frac{p_t(z)}{w_{t+1}}, v_{t+1}(z), c_{t+1} \right) \right] \tag{6}
\]

There are three state variables, \( p_{t-1}(z) / w_t, v_t(z) \) and \( c_t \). This is because profits are a function only of these three variables and the choice variable \( p_t(z) \); and the future values of \( p_{t-1}(z) / w_t, v_t(z) \) and \( c_t \) depend only on their current values, the choice variable and the future shocks. I solve
the firm’s problem (6) by value function iteration on a grid, and approximate
the processes for \(v_t(z)\) and \(c_t\) using a method suggested by Tauchen
(1986).\(^\text{17}\)

The parameters in equation (5) are obtained numerically. Step 1: I
generate simulated values for \(w_t\), and \(v_t(z)\) for 2,000 months and over 5,000
firms. Step 2: I initially assume that \(c_t\) is constant for all \(t\); Step 3: I solve
equation (6) conditional on the assumed process for \(c_t\). Step 4: I obtain
solutions for all firms’ real prices \(x_t(z)\) and, I find the values of \(c_t\) (for each
month) by numerically solving the fixed point problem,\(^\text{18}\)

\[
c_t = \left( c_t^{1-\gamma} \alpha^{-\gamma} \right) \left[ \int_0^1 x_t(z)^{1-\gamma} \, dz \right]^{\varepsilon^{-1}}
\]  

(3a)

Step 5: Using the updated \(c_t\), I obtain revised estimates of the \(\lambda\) coefficients
and repeat steps 3 through 5 until the \(\lambda\) coefficients have converged.\(^\text{19}\)

The implied assumption of GL’s profit function (4) is that price-reviews
are continuous and costless. Each month, in the discrete-time version of the
model, the firm costlessly determines the equilibrium price and incurs a menu-
cost only if the price is actually adjusted. There are no costs associated with
information gathering, information processing and the pricing decision itself.

\(^{17}\) The solution method used is similar to that adopted by NS. They helpfully provided the
Matlab programmes they used in their paper. My own Matlab codes are available on request.
\(^{18}\) Equation (3a) is solved by a simple iterative procedure. First guess a value for \(c_0\), solve
firms’ real prices given this value, update \(c_t\) from (3a) and continue until convergence.
\(^{19}\) More precisely, convergence is achieved when the values of \(\lambda_0\), \(\lambda_1\), and the standard
deviation of \((\lambda_2 v_t + e_t)\) assumed in step 3 are unchanged in step 5. These solutions, including
the nested solutions for (3a) for each of 2,000 periods, were computationally expensive, even
when running Matlab on a Sun Fire x4140, with Quad-Core AMD Opteron(tm) Processor
2356, core speed 2300MHz and 32GB of memory.
A Menu-Cost Model with Review Costs

Now consider the case where price reviews are costly. I re-write the profit function as,

$$\pi_t(z) = c_t^{1-\gamma} (\alpha x_t(z))^{-\delta} \left( x_t(z) - \frac{1}{v_t(z)} \right) - l_t(z) k - J_t(z) \eta k$$ \hspace{1cm} (7)

$J_t(z)$ is an indicator variable that takes the value one if prices are reviewed that month and zero otherwise; $\eta$ is the ratio of the price review cost to the menu cost.\(^\text{20}\) I assume that price changes can only occur when reviews take place: $l_t(z) = 0$ if $J_t(z) = 0$. When a review does take place ($J_t(z) = 1$), $l_t(z)$ can be zero or one.

Price reviews are now likely to be intermittent, the more so with higher values for $\eta$. In Woodford (2009) firms always change prices when a full review is suggested by the signal of market conditions. If no such signal were available (or available at infinite cost), how should the firm behave? Consider a firm that makes three decisions in every price review: (i) should it change its price? (ii) what price to set if (i) is affirmative; and (iii) when next to review. Dropping the firm index for notational convenience, the real value function of the firm can then be written as,

$$V\left( \frac{p_{t-1}}{w_t}, v_t, c_t \right) = \max_{\rho_t, T_t} \left[ \sum_{i=0}^{T-1} \beta^i \pi_t + \beta^T V\left( \frac{p_{t-1}}{w_{T_t}}, v_{T_t}, c_T \right) \right]$$ \hspace{1cm} (8)

\(^\text{20}\) We know that there is, in the data, considerable heterogeneity in review intervals, suggesting that $\eta$ might also vary across firms. In this paper I limit myself to constant menu costs and review costs. Allowing both some measure of heterogeneity will further strengthen the model’s ability to capture features of the micro-data.
There are now two choice variables: the firm’s price and the time interval $(T)$ to the next review. The optimal interval is allowed to vary with time-$t$ state variables $(p_{t-1}/w_t,v_t,c_f)$ and hence it carries a time subscript.\(^{21}\) The GL model is obtained as special case by simply setting $\eta$ to zero. In this case $T_t = 1$ for all $t$. The state-dependent component of the firm’s pricing decision becomes less important as review costs get larger and menu costs smaller. In the extreme, when the frequency of reviews equals the frequency of price changes, the model collapses to discrete version of Reis (2006). In this sense the model developed here has GL and Reis models as polar cases, GL by assuming zero review costs and Reis by assuming zero menu costs. In the interval between reviews, the firm’s relative price will be expected to decline by the anticipated rate of wage inflation.

Like Woodford, I do not allow for price indexation or the possibility of ‘uninformed price adjustments’ (as in Bonono, Carvalho and Garcia (2010)).\(^{22}\) Nominal prices remain unchanged between reviews. Also like Woodford I make the implicit assumption that no costless information is available. The arrival of such information may well lead firms to bring forward the date of the planned review\(^{23}\). If review costs were dominated by processing and decision costs, the assumption of a pre-set review interval is less objectionable.\(^{24}\) I assume that the firm cannot change the date of its next review – the costs of

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\(^{21}\) Bonomo and Carvalho (2004, 2010) assume the time interval is constant for any given monetary policy regime and analyze its change over time when a regime switch occurs.

\(^{22}\) One can sensibly interpret uninformed price adjustments in terms of Midrigan and Kehoe’s (2010) temporary price changes. Since I calibrate on the moments of regular price changes (as Midrigan and Kehoe recommend), such uninformed price changes can be ignored.

\(^{23}\) Bonono, Carvalho and Garcia consider the more realistic case of partial information between full reviews. Freely available information about the aggregate price level may lead firms to index their own prices but the authors admit that this is only a ‘realistic representation of price and wage setting rules during periods of very high inflation.’

\(^{24}\) This is why Reis (2006) argued that firms will still review intermittently even if free information were available.
doing so always exceed the benefits. I also ignore the possibility that reviews may decide to change price but not in the same month. Ideally the decision to change prices in the month the review takes place and to keep them fixed between reviews is one that should be based on the firm’s optimising behaviour, rather than exogenously imposed. In this paper I focus on only one extension to the standard menu-cost approach: that of review costs and their effect on monetary non-neutrality. Other extension will doubtless follow.

Review intervals are assumed to be whole months and in the range 1-12 months. Optimal review intervals are always within this range for all cases considered. When the review takes place, prices are not always adjusted, so the frequency of reviews will always exceed the frequency of price changes, as it does in the micro-data.

The presence of review costs weakens the selection effect. This is because as review costs rise, menu-costs must be lowered to match the target reset frequency. When menu-costs play no role, the firms that are resetting are not those with prices furthest from the optimal reset price and the selection effect disappears (as in Reis (2006) and Mankiw and Reis (2002)).25 And price changes will occur at preset intervals, as in Taylor (1980). Although there is some endogenous time variation in the length of these intervals, it is likely to be small, especially for higher values for $\eta$. When menu-costs play some role in pricing decisions, the selection effect will be weaker than in the GL model with monthly reviews. My aim is to evaluate how much weaker.

Integrating (2) defines aggregate real output,

\[\text{Integrating (2) defines aggregate real output,}\]

25 Knotek (2010) describes the weaker selection effect in these terms: ‘Infrequent information updating in a state-dependent pricing model mitigates this selection effect, since firms do not always know exactly how their price compares with their optimal price’ (pp1544-5)
\[ y_t = \frac{1}{c_1 y_t} \left( \frac{\alpha p_t(z)}{w_t} \right)^{-\varepsilon} dz \]

In an economy with no review or menu costs, profit-maximizing prices are given by,

\[ \tilde{p}_t(z) = \left( \frac{\varepsilon}{\varepsilon - 1} \right) \left( \frac{w}{v(z)} \right)_t \]

And the aggregate output of such an economy would be,

\[ \tilde{y}_t = \frac{1}{c_1 y_t} \left( \frac{\alpha \tilde{p}_t(z)}{w_t} \right)^{-\varepsilon} dz \]

I define the output gap \((g)\) as,

\[ g_t = \log(y_t) - \log(\tilde{y}_t) \]

and the (monthly) inflation rate as \( \int_0^1 (\log(p_t(z)) - \log(p_{t-1}(z)))dz \).

**Model Calibration**

I follow GL in the choice of many of the parameters of the model: the risk aversion parameter, \(\gamma = 2\); the elasticity of substitution, \(\varepsilon = 7\); the disutility of work, \(\alpha = 6\). GL give their reasons for the values selected. And I follow NS in my choice of (monthly) discount rate, \(\beta = 0.9966\) and in the parameters of the wage (equivalently, money) process, \(\mu = 0.0021\) and \(\sigma_v = 0.0032\), implying an average annual wage-money growth rate of around 3%. According to Franco

\(^{26}\) An alternative definition of the aggregate output gap would be to take the mean over all firms’ gaps. The time average of this measure would be zero. The mean of \(g\) over time is typically negative since (by Jensen’s inequality), the difference in means is not equal to the mean of differences.
and Philippon (2007), idiosyncratic productivity shocks are highly persistent and they account for a substantial proportion of the variance of overall productivity. Compared with other menu-cost models, I assume a higher degree of persistence of the productivity shock and set $\rho = 0.9$.\(^{27}\)

A key parameter is clearly $\eta$, implicitly zero in GL. Zbaracki et al (2004) report that ‘managerial costs are more than 6 times … the physical costs associated with changing prices’ (p. 515), so $\eta = 6$ can be considered an appropriate benchmark. For completeness I also report results for $\eta = 2$ and $\eta = 20$.\(^{28}\) Alvarez et al (2010) identify two ‘observable statistics’ that provide direct evidence about $\eta$. The first is the ratio of adjustment to review frequencies, but, as we have seen, the survey evidence on this ratio shows too much variation to pin down a calibration target for $\eta$. Alvarez et al also show that the ratio of the mode to the mean size of price change is a monotone function of $\eta$.\(^{29}\) KK report only the mean and median price changes. Given the Alvarez et al analysis, I investigate whether variations in the ratio of mean to median can assist in model selection. The remaining two parameters $(k, \sigma_\omega)$ were chosen to match the first two micro-data regularities of the seven outlined in section 2:

- The frequency of price changes is around 14%.
- The absolute values of price changes that do occur are typically in the range 8.5% - 10%.

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\(^{27}\) In their monthly model NS set $\rho = 0.66$.

\(^{28}\) Gertler and Leahy (2008) assume that firms incur a ‘decision cost’ just large enough to prevent them from changing prices in the absence of idiosyncratic productivity shocks which follow a Poisson process. Although they require a small decision cost ‘for technical reasons’, they acknowledge that the evidence suggests that such costs are substantially higher than those incurred when changing prices.

\(^{29}\) The distribution of price changes is normal for their model with review costs only, and binomial for the menu cost model.
I then compare each model’s performance in matching the remaining five features described in section 2.

4. Results

The results are set out in Tables 1 and 2, the first covering pricing behaviour and the second the macroeconomic implications. Consider first the standard menu-cost model, the results of which are given in the column headed ‘GL’. In this model $\eta = 0$, so price reviews take place costlessly each month, the firm incurring menu-costs only when prices are actually changed. Because the model is calibrated to mimic re-set frequencies and their size, these closely match the data (the shaded rows in Table 1). Setting $k$ to 0.014 and $\sigma_\omega$ to 0.04, the price reset frequency is 13.8%, and the mean absolute change of reset prices is 9.4%, both sufficiently close to the calibration targets. The model also succeeds in capturing the observed variation in price contract lengths: the standard deviation of contracts is 6.5 months compared with the 5–7 month range reported by KK. And the correlation between the absolute change in reset prices and the time since they were last reset ($\rho_1$ in Table 1) is weak, as it is in the data.

Predictably the standard menu-cost model fails to account for the substantial dispersion in price changes. The standard deviation of price changes is 2% compared with 8% in the data. And the percentages of small price adjustments are well short of those in the data: in the GL model only 0.05% of price changes are less 5% compared with 25% in M’s data.

From Table 2 $\log(c_t)$ follows an AR(1) process with the current innovation influenced to some degree by the money-wage shock. The $R^2$ statistic suggests that the assumed process for the Spence-Dixit-Stiglitz
aggregate offers a good approximation to its behaviour over time. Both extensive ($\rho_2$) and intensive ($\rho_3$) margins are positive, the former less than the latter. The extensive margin is, however, too strong – 0.6 compared with 0.25 reported by KK. The GL model generates a very weak business cycle and money is close to being neutral. The former is reflected in the low standard deviation of the output gap, $\sigma_g$. In a fashion similar to GL, I analyse the impact of money on aggregate real output through a regression of the simulated output gap on its lag and the current growth rate of the money supply (or equivalently, nominal wages). The coefficient on the money wage shock is 0.157 (0.003) using monthly simulations.\(^{30}\)

To summarize: in the monthly discrete-time version of GL’s standard menu-cost model, money is close to being neutral through the selection effect, but the model fails to capture the substantial dispersion in price changes observed in the data.

Three versions of the review-cost model are presented, with three values for $\eta$: 2, 6 (the benchmark) and 20. To achieve simulated values sufficiently close to the target price reset incidence, mean review frequencies are 20.5, 17.4% and 16.7% for the three cases respectively. And the variance of the idiosyncratic shocks is adjusted to replicate the mean size of absolute price changes. There is relatively little variation in the (endogenous) review intervals: they are in the range 4-5 months when $\eta = 2$ and 5-6 months when $\eta = 6$ and $\eta = 20$. The mean review intervals range from 4.87 months ($\eta = 2$)

\(^{30}\) GL regress quarterly output on wage inflation alone and obtain a coefficient of 0.05. I derive quarterly time aggregations of the monthly simulations and in a regression of the quarterly output gap on wage inflation alone I obtain a coefficient of 0.07.
to nearly 6 months ($\eta = 20$).\textsuperscript{31} When $\eta = 2$ and reviews are more frequent, 64\% of them lead to price changes. This rises to 85\% for the case of the most expensive and less frequent reviews. Both cases struggle to capture the dispersion in price durations, the standard deviations of reset intervals being short of $KK$’s range, 5-7\%, though that for $\eta = 2$ is close. As review costs become more important, there is less dispersion in the reset interval over firms as the latter is affected more by review incidence, and this varies little over states. $KK$ find that the ratio of mean to median (absolute) price change is 1.165: the ratios for $\eta = 2$ and $\eta = 6$ lie either side of this. This is broadly consistent with the direct evidence for $\eta$ reported in Zbaracki et al (2004).

The review-cost model does explain the wide dispersion of price adjustments and it is this that is crucial in reducing the selection effect as Midrigan (2010) has recently demonstrated. He argues that the ‘strength of the selection effect depends on the measure of the marginal firms whose desired price changes lie in the neighbourhood of the adjustment thresholds’. When this is relatively large, as in $GL$, the distribution of price changes is bimodal, showing little dispersion. The kernel density function\textsuperscript{32} for non-zero price changes shown in Figure 1 clearly shows this is the case for the $GL$ model. The bimodal densities are steeply peaked close to the re-set thresholds. When the measure of marginal firms is small, most firms are dispersed away from their adjustment thresholds, price changes are more widely dispersed and the selection effect is weaker. That price changes are

\textsuperscript{31}Because $k$ is adjusted to achieve the target reset frequency, review costs do not change a great deal as $\eta$ is varied. When $\eta = 2$, the review cost is 0.02 (i.e. $2k$); when $\eta = 6$ it is 0.036 ($6k$) and when $\eta = 20$, the review cost is only slightly higher at 0.052 ($20k$). The marginal difference in review intervals reflects this. The model generates little time-variation in review intervals. A model with some heterogeneity in $\eta$ across firms would obviously raise the variance of review intervals. This is something for future work.

\textsuperscript{32}I used the Gaussian kernel density function in STATA version 11.
more widely dispersed in the case of the review cost model is again clear from Figure 1 (shown for the case of $\eta = 6$), though the distribution of prices in the review-cost model is still bimodal, unlike that of prices in the Dominick’s data analysed by Midrigan.

Across all review-cost models, there is little correlation between the size of the price change and the time it was last re-set ($\rho_1$). As $\eta$ gets larger review intervals lengthen but this does not raise the correlation between price change and reset interval. Although the review intervals are allowed to be state-dependent, I find that it is generally constant over time. And as $\eta$ rises, the required (lower) menu cost increases the fraction of reviews that lead to price changes. Because there is little variation in the reset intervals, $\rho_1$ becomes less informative.

The key macroeconomic implications of review costs are set out in Table 2. Compared with the GL model, there is more serial correlation in the behaviour of $\log(c_t)$ and it is more sensitive to innovations to the money wage.⁴³ All versions of the model are more successful than the GL model in explaining the roles of the intensive and extensive margins of inflation. The standard deviation of the output gap is over 3 times that of the GL model.⁴⁴ To further appreciate the role played by infrequent reviews, I consider an identical economy where firms review monthly and re-set conventionally, taking into account only the costs of changing prices. The results are given in the row labelled ‘monthly review’ in Table 2. The standard deviation of the output gap of an economy populated by such firms is between 7% and 19% that of an

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⁴³ The high $R^2$ statistics for all models suggests that the assumed AR(1) process for the Spence-Dixit-Stiglitz aggregate is a good approximation to its behaviour over time.

⁴⁴ The standard deviation of the output gap is 0.305% for $n = 6$, close to Midrigan’s (2010) consumption standard deviation of 0.29% for his benchmark case.
economy populated by firms reviewing infrequently. And the persistence of the output gap and inflation rate of an economy of monthly reviewers is substantially below that of an economy of infrequent reviewers. The review-cost model sufficiently weakens the selection effect to restore monetary non-neutrality, as the two regressions illustrate. In the case of the quarterly regressions, the coefficient on wage inflation is four times that of the GL model.

Figure 2 plots impulse-responses implied by the output gap regressions reported in Table 2. The persistence of the output gap following a unit shock to the money supply (or nominal wage) is substantially higher for all variants of the review-cost model and they are not too dissimilar from that of the Calvo model. The last column of both tables presents the results of a Calvo model, where the firms review randomly with a probability of just over 0.14. Some price reviews leave the nominal price unchanged; 96% of them lead to a price change. The standard deviations of price durations and changes are very close to those observed in the data. The Calvo model predictably fails in two areas. First it implies an overly-strong correlation between the size of the price change and the time it was last re-set ($\rho_1$). And secondly (from Table 2) the correlation of inflation with the fraction of firms resetting is well below that in the data – predictably the extensive margin is absent in the Calvo model. In other respects the Calvo model and the review-cost model look very similar.

In their different ways and for their own reasons, Midrigan (2010), Nakamura and Steinsson (2008), Woodford (2009) and Gertler and Leahy (2008) all find that the Calvo model offers a reasonable approximation to their

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35 As a small number of reviews will not change prices, a review incidence of above 0.14 is required to achieve the 14% reset frequency target.
own ‘second generation’ menu-cost model. I reach the same conclusion for the review-cost model without invoking any heterogeneity in menu costs, kurtosis in productivity shocks or scope economies in re-pricing. Each of these may also be important additional reasons for a weak selection effect to generate monetary non-neutrality. But even in their absence, monetary policy may also matter in a world where it is costly both to review prices and to change them.

5. Summary and Conclusions
Golosov and Lucas (2007) have challenged the view that infrequent price adjustment by firms explains why money has aggregate real output effects. The basis of their challenge is the ‘selection effect’ – re-setting firms are not selected at random, they are those firms whose prices are furthest from their equilibrium levels and who therefore make substantial adjustments when their prices are changed. Like Caplin and Spulber (1987), Golosov and Lucas show how the aggregate price can be sufficiently flexible to neutralize the real effects of money even when firms change their prices infrequently because of menu costs.

The Golosov and Lucas critique is an important one. New-Keynesians have justified their assumption of price rigidity by an appeal to the costs of changing them. The presence of a strong selection effect in menu-cost models implies that the new-Keynesian analysis of monetary policy still lacks a convincing micro-foundation. Unfortunately Golosov and Lucas base their argument on a menu-cost model that fails to explain the wide dispersion of price adjustments observed in the micro data and recently analysed in Klenow and Kryvtsov (2008), Nakamura and Steinsson (2008) and Midrigan (2010).
For example Klenow and Kryvtsov find that the mean absolute price change is around 10% but 44% of prices changes are less than 5% in absolute value. In the Golosov and Lucas model, small price changes simply do not occur.

A number of papers have extended the standard model to explain the wide dispersion in price changes, and when they do so the selection effect is sufficiently weakened to restore the non-neutrality of money. Midrigan (2010), for example, assumes that productivity shocks have pronounced kurtosis and firms enjoy economies of scope, taking the opportunity to change all their prices when strict menu-cost considerations justify re-setting only one. These two extensions to the standard model weaken the selection effect and restore the real effects of money to a level close to that of the Calvo model.

In this paper I incorporate Reis’s (2006) notion of rational inattentiveness into a standard menu-cost model and investigate the effects this has on monetary neutrality. I do this by assuming that price-setting involves two distinct costs: review costs (information gathering, processing, decision-taking) and menu costs (the direct costs of physically changing prices). The standard menu-cost model (implicitly) assumes that reviews are continuous and costless – it is only costly to change prices. The micro data suggests otherwise. Price reviews are intermittent and far more costly than price adjustments. And they do not always lead firms to change their prices. Alvarez et al (2010) find that ‘the median firm in the Euro area reviews its price a bit less than three times a year, but changes its price only about once a year’. A similar pattern holds in US data. In my modified menu-cost model, when the firm reviews its price it (i) decides whether or not to change it and by how much; and (ii) sets the date of the next review. Both decisions are state-
dependent, i.e. influenced by the firm’s inherited price, its current productivity and the state of the macro-economy. The selection effect in the modified model is sufficiently weak for the non-neutrality of money to be similar to that of a model with the Calvo pricing. The Golosov and Lucas critique evaporates with one obvious modification to the assumed price-setting process.
Table 1: Pricing Behaviour

<table>
<thead>
<tr>
<th></th>
<th>GL Data</th>
<th>Review Cost Model</th>
<th>Calvo Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( \eta = 2 )</td>
<td>( \eta = 6 )</td>
</tr>
<tr>
<td>( k )</td>
<td>-</td>
<td>0.0140</td>
<td>0.010</td>
</tr>
<tr>
<td>( \sigma_{\epsilon} )</td>
<td>-</td>
<td>0.040</td>
<td>0.055</td>
</tr>
<tr>
<td>Review Frequency (%)</td>
<td>-</td>
<td>100</td>
<td>20.5</td>
</tr>
<tr>
<td>Mean Review Interval (months)</td>
<td>-</td>
<td>1</td>
<td>4.87</td>
</tr>
<tr>
<td>Max-Min Review Interval (months)</td>
<td>-</td>
<td>1-1</td>
<td>5-4</td>
</tr>
<tr>
<td>Reset Frequency (%)</td>
<td>14</td>
<td>13.77</td>
<td>13.23</td>
</tr>
<tr>
<td>Reviews that change price (%)</td>
<td>-</td>
<td>100</td>
<td>64.47</td>
</tr>
<tr>
<td>Std Deviation of Reset Intervals (months)</td>
<td>5.2 - 7.0</td>
<td>6.36</td>
<td>4.78</td>
</tr>
<tr>
<td>Percent of labour reviewing</td>
<td>-</td>
<td>7.88</td>
<td>14.85</td>
</tr>
<tr>
<td>Percent of labour re-setting</td>
<td>4.82</td>
<td>3.94</td>
<td>2.47</td>
</tr>
</tbody>
</table>

**Absolute Price Changes**

<table>
<thead>
<tr>
<th>Mean (%)</th>
<th>NS 8.5</th>
<th>KK 11.0</th>
<th>9.43</th>
<th>10.42</th>
<th>10.46</th>
<th>10.45</th>
<th>10.16</th>
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</thead>
<tbody>
<tr>
<td>Median (%)</td>
<td>KK 9.7</td>
<td>8.91</td>
<td>8.98</td>
<td>8.91</td>
<td>8.69</td>
<td>8.46</td>
<td></td>
</tr>
<tr>
<td>Ratio mean to median</td>
<td>KK: 1.165</td>
<td>1.058</td>
<td>1.160</td>
<td>1.174</td>
<td>1.203</td>
<td>1.201</td>
<td></td>
</tr>
<tr>
<td>Standard Deviation (%)</td>
<td>8</td>
<td>1.99</td>
<td>4.98</td>
<td>5.79</td>
<td>6.48</td>
<td>8.14</td>
<td></td>
</tr>
<tr>
<td>Kurtosis</td>
<td>4</td>
<td>4.59</td>
<td>4.15</td>
<td>4.08</td>
<td>4.02</td>
<td>5.67</td>
<td></td>
</tr>
<tr>
<td>Percent &lt; 5%</td>
<td>KK 44</td>
<td>0.05</td>
<td>12.36</td>
<td>16.12</td>
<td>24.65</td>
<td>31.42</td>
<td></td>
</tr>
<tr>
<td>Percent &lt; quarter of the mean</td>
<td>8</td>
<td>0</td>
<td>0.19</td>
<td>0.24</td>
<td>3.36</td>
<td>10.98</td>
<td></td>
</tr>
</tbody>
</table>

\( \rho_1 \) | - | 0.0797 | 0.0036 | -0.0159 | -0.0144 | 0.3083 |

*Notes:* The results reported in this table are based on the simulated pricing behaviour of 5,000 firms over 2,000 months. \( \rho_1 \) is the correlation between the absolute size of price change and the time since last set. The two shaded rows are those used in model calibration through the choice of \( k \) and \( \sigma_{\epsilon} \).
Table 2: Aggregate Implications

<table>
<thead>
<tr>
<th>GL</th>
<th>Review Cost Model</th>
<th>Calvo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \eta = 2 )</td>
<td>( \eta = 6 )</td>
</tr>
<tr>
<td>( k )</td>
<td>0.0140</td>
<td>0.0100</td>
</tr>
<tr>
<td>( \sigma_{\omega} )</td>
<td>0.040</td>
<td>0.055</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spence-Dixit-Stiglitz Aggregate (log( c_t ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda_0 )</td>
</tr>
<tr>
<td>(0.008)</td>
</tr>
<tr>
<td>( \lambda_1 )</td>
</tr>
<tr>
<td>(0.008)</td>
</tr>
<tr>
<td>( \lambda_2 )</td>
</tr>
<tr>
<td>(0.002)</td>
</tr>
<tr>
<td>( \sigma_e )</td>
</tr>
<tr>
<td>( R^2 )</td>
</tr>
<tr>
<td>( \rho_2 \ (KK = 0.25) )</td>
</tr>
<tr>
<td>( \rho_3 \ (KK = 0.99) )</td>
</tr>
<tr>
<td>( \sigma_g ) Periodic Review (%)</td>
</tr>
<tr>
<td>( \sigma_g ) Monthly Review (%)</td>
</tr>
</tbody>
</table>

Persistence: Periodic Review

| Output gap | - | 0.560 | 0.623 | 0.674 | 0.689 |
| Inflation | - | 0.726 | 0.753 | 0.721 | 0.586 |

Persistence: Monthly Review

| Output gap | 0.261 | 0.096 | 0.199 | 0.155 | - |
| Inflation | 0.401 | 0.292 | 0.223 | 0.146 | - |

Output Gap Regression

| \( g_{t-1} \) | 0.270 | 0.564 | 0.627 | 0.670 | 0.697 |
| (0.013) | (0.013) | (0.013) | (0.013) | (0.016) |
| \( d\log(w_t) \) | 0.157 | 0.392 | 0.410 | 0.417 | 0.449 |
| (0.003) | (0.008) | (0.010) | (0.012) | (0.036) |

Notes: The results reported in the table are based on simulated aggregations over 5,000 firms for 2,000 months. \( \rho_2 \) is the correlation between the inflation rate and the fraction of prices being reset. \( \rho_3 \) is the correlation between the inflation rate and the mean change in those prices which are being reset. \( \sigma_g \) is the standard deviation of the output gap. Persistence is the simple correlation coefficient of the variable with its one-month lagged value.
Figure 1: Distributions of Non-zero Price Changes

Figure 2: Output Gap Impulse Responses
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Dixon, Hugh, and Engin Kara. (2010) “Can we explain inflation persistence in a way that is consistent with the micro-evidence on nominal rigidity?” Journal of Money, Credit and Banking 42:151-170.


