



Demery, D. (2012). State-dependent pricing and the non-neutrality of money. *Journal of Macroeconomics*, 34(4), 933–944.
<https://doi.org/10.1016/j.jmacro.2012.05.003>

Peer reviewed version

License (if available):
CC BY-NC-ND

Link to published version (if available):
[10.1016/j.jmacro.2012.05.003](https://doi.org/10.1016/j.jmacro.2012.05.003)

[Link to publication record in Explore Bristol Research](#)
PDF-document

This is the author accepted manuscript (AAM). The final published version (version of record) is available online via Elsevier at <http://www.sciencedirect.com/science/article/pii/S0164070412000547>. Please refer to any applicable terms of use of the publisher.

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available: <http://www.bristol.ac.uk/pure/user-guides/explore-bristol-research/ebr-terms/>

State-Dependent Pricing and the Non-Neutrality of Money

David Demery

April 2012

JEL codes: E30 E31

Key Words: menu-cost, information costs, non-neutrality of money, state-dependent pricing, time-dependent pricing, inattention.

I would like to thank Nigel Duck and this Journal's referee for very helpful comments. Remaining errors are my own.

David Demery is *Senior Research Fellow in Economics, University of Bristol* (E-mail: david.demery@bris.ac.uk).

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.

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 review their prices intermittently and the change them 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 Reis’s (2006) ‘inattentiveness’ model.

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 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 (1983): firms choose how much to change prices but not when.¹ 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.² 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 their fully-specified menu-cost model with idiosyncratic productivity. Calibrating their model to

¹ Clarida, Galí and Gertler (1999) is a comprehensive survey of the new-Keynesian analysis of monetary policy based on the Calvo approach.

² 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.

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 explain stickiness of the aggregate price level.

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 survey 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 (2010) develop a multi-sector model in which menu-costs (and therefore price-resetting frequencies and their size) vary by sector. Midrigan (2011) 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 to have real effects comparable to those of the Calvo model.⁵ Collectively they suggest that the new-Keynesian analysis of monetary policy, based as it is on

³ Midrigan also seeks to explain the difference between ‘regular’ and ‘posted’ prices and the interesting observation that 86% 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.

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.

Calvo pricing, may yet be a reasonable approximation to an analysis with sounder 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.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.⁷

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. In the model developed in this paper, firms are assumed to set the date of the next review when reviewing their prices (and possibly changing them). 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-

⁶ Alvarez *et al* (2011), 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.

⁷ In motivating his inattentiveness model, Reis (2006) went so far as to claim that 'with the exception of magazine prices and restaurant menus, for most products it is difficult to identify any significant fixed physical costs of changing prices' (p.793).

dependency are interwoven. In Midrigan (2010) he asks: 'Is firm pricing state- or time-dependent?'⁸ My answer is both.⁹

Price reviews and price adjustments are both costly exercises and will, for that reason, occur infrequently. The standard menu-cost model and its second-generation extensions assume that review costs and price adjustment costs are always incurred together. The evidence suggests otherwise. Price reviews are more frequent than adjustments - not all reviews lead to a change in price.¹⁰ 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* (2011) 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

⁸ 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.'

⁹ 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).

¹⁰ 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).

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 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.

Allowing review costs and menu costs to play distinctive roles in price setting helps to solve two puzzles: why so many price changes are small and why firms only review their prices intermittently. Reviews are infrequent because they are costly. The cost of actually changing price is substantially lower and, because of this, firms will find it profitable to change price following a review even when only marginal adjustments are called for.

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 were available.¹¹ 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. The *GL* menu-cost and

¹¹ Mankiw and Reis (2007) argue that inattention can be justified either by information costs or by appealing to epidemiology (Carroll (2006)).

Reis inattentiveness models are nested as special cases within my more general model.

Alvarez *et al* (2011) 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.

Information costs also play an important role in Woodford's (2009) model which is 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 (described in Midrigan (2011)), 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 the 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 Bonomo, Carvalho and Garcia model to analyse the quantitative, general equilibrium 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 (2011) – 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.¹² The prices are those set by one retail company, Dominick's Finer Foods, covering 9,000 products in 86 stores in the Chicago area. *M*'s data are weekly. Klenow and Kryvtsov (2008) and Nakamura and Steinsson (2008) – henceforth *KK* and *NS* respectively – analyse monthly 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 consumer 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' (non-sale) prices. For model calibration I use a reset frequency target of 8.7% per month - the figure

¹² 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.

reported by *NS* for prices excluding sales and substitutions for the period 1998-2005.¹³

2. Many of the price changes that do occur are large in absolute value. *KK* report that the median absolute change in regular prices is around 10%; *NS* find the median absolute change in prices to be a little lower at 8.5%, which is the target I use in model calibration. *NS* find that median fraction of regular price changes that are increases is 64.8%, a feature I also use in model calibration.¹⁴
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 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.
4. Even for individual items, price durations vary considerably over time.¹⁵ *KK* report that the standard deviation of completed 'contract lengths' is 7 months within 'ELIs' and 5.2 months within 'quote lines'.¹⁶
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

¹³ See *NS* Table II. This table also highlights the substantial heterogeneity in re-setting frequency across sectors, from close to 90% per month in vehicle fuels to only 3.6% in clothing. Because of this the mean reset frequency is substantially higher than the median.

¹⁴ See *NS* Table II (incidence of price increases) and VIII (median absolute price change). *KK* find that 57% are increases. The difference is that *KK* report the mean fraction, whereas *NS* report the median.

¹⁵ 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.

¹⁶ ELIs are entry-level items, and quote lines are particular items within the ELIs.

since they were last reset as ρ_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 (ρ_2) between inflation and the fraction of prices being re-set to be 0.25 and the correlation (ρ_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 *et al* (2011) 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.

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 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,

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

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

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

$$C_t(z) = c_t^{1-\varepsilon\gamma} \left(\frac{\alpha p_t(z)}{w_t} \right)^{-\varepsilon} \quad (2)$$

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,¹⁷ α is the disutility of labour; γ is the degree of risk aversion. Equation (1) may then be written,

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

¹⁷ 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.

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 .¹⁸

Expressed in units of the money wage, using equation (2),

$$\pi_t(z) = c_t^{1-\varepsilon\gamma} (\alpha x_t(z))^{-\varepsilon} \left(x_t(z) - \frac{1}{v_t(z)} \right) - I_t(z) k \quad (4)$$

where $\pi_t(z) \equiv \Pi_t(z) / w_t$ and $x_t(z) \equiv p_t(z) / w_t$ 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,

¹⁸ The firm's output is a function of labour alone.

$$\log(w_t) = \mu + \log(w_{t-1}) + v_t, \quad v_t \sim N(0, \sigma_v^2)$$

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

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,

$$\log(c_t) = \lambda_0 + \lambda_1 \log(c_{t-1}) + \lambda_2 v_t + e_t \quad (5)$$

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

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

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).¹⁹

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

¹⁹ 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.

firms. Step 2: I guess an initial set of parameters for equation (5). 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,²⁰

$$c_t = \left(c_t^{1-\varepsilon\gamma} \alpha^{-\varepsilon} \right) \left[\int_0^1 x_t(z)^{1-\varepsilon} dz \right]^{\frac{\varepsilon}{\varepsilon-1}} \quad (3a)$$

Step 5: Using the updated c_t , I obtain revised estimates of the parameters of equation (5) and repeat steps 3 through 5 until the λ coefficients have converged.²¹

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 their 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.

A Menu-Cost Model with Review Costs

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

$$\pi_t(z) = c_t^{1-\varepsilon\gamma} (\alpha x_t(z))^{-\varepsilon} \left(x_t(z) - \frac{1}{v_t(z)} \right) - l_t(z)k - J_t(z)q \quad (7)$$

²⁰ Equation (3a) is solved by a simple iterative procedure. First guess a value for c_t , solve firms' real prices given this value, update c_t from (3a) and continue until convergence.

²¹ More precisely, convergence is achieved when the values of λ_0, λ_1 and the standard deviation of $(\lambda_2 v_t + e_t)$ assumed in step 3 are unchanged in step 5.

$J_t(z)$ is an indicator variable that takes the value one if prices are *reviewed* that month and zero otherwise; $q = \eta k$ is the review cost and η is the ratio of the price review cost to the menu cost.²² I assume that price changes can only occur when reviews take place: $I_t(z) = 0$ if $J_t(z) = 0$. When a review does take place ($J_t(z) = 1$), $I_t(z)$ can be zero or one.

Price reviews are now likely to be intermittent, the more so with higher values for η . 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,

$$V\left(\frac{p_{t-1}}{w_t}, v_t, c_t\right) = \max_{p, T_t} E_t \left[\sum_{i=0}^{T_t-1} \beta^i \pi_{t+i} + \beta^{T_t} V\left(\frac{p_t}{w_{T_t}}, v_{T_t}, c_{T_t}\right) \right] \quad (8)$$

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 $(p_{t-1}/w_t, v_t, c_t)$ and hence it carries a time subscript.²³ The *GL* model is obtained as special case by simply setting η to zero. In this case $T_t = 1$ for all t . Setting $k = 0$ and $q > 0$, the model collapses to a discrete-time

²² We know that there is, in the data, considerable heterogeneity in review intervals, suggesting that η 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.

²³ 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.

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 Bonomo, Carvalho and Garcia (2010)).²⁴ Alvarez *et al* (2011) show that 'price plans' are not optimal when the inflation rate is low (as it is in the model calibrated below). Hence it is reasonable to assume that nominal prices remain unchanged between reviews.²⁵ Also like Woodford I make the implicit assumption that no costless information is available.²⁶ The arrival of such information (whether idiosyncratic or aggregate) may well lead firms to bring forward the date of the planned review. So it might seem natural to allow firms the opportunity to re-schedule review dates following the arrival of free new information. Re-scheduled reviews are very likely to be followed by price adjustments as their timing is triggered by new information. A model that allows for re-scheduling thus collapses to a menu-cost model in which price reviews and price adjustments are coincident. It might be possible to imagine firms re-scheduling following big informational surprises but this would complicate the model without much in return. In common with other recent contributions, I therefore assume that

²⁴ 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.

²⁵ The Alvarez *et al* result suggests that the model developed here would not be appropriate for analysing the effects of inflation.

²⁶ For example Bonomo, Carvalho and Garcia (2010) analyse the case where freely-available information about the aggregate price level may lead firms to index their own prices. The authors admit that this is only a 'realistic representation of price and wage setting rules during periods of very high inflation.'

the costs of re-scheduling review dates are prohibitive.²⁷ I also ignore the possibility that reviews may lead to a change in 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 extensions will doubtless follow.

Review intervals are assumed to be whole months. 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 survey data.

The presence of review costs weakens the selection effect. This is because as review costs rise, menu-costs must be lower to match the target reset frequency. When menu-costs play no role (the inattention model), the firms that are re-setting are *not* those with prices furthest from the optimal reset price and the selection effect disappears (as in Calvo (1983), Reis (2006) and Mankiw and Reis (2002)).²⁸ And price changes will occur at preset but state-dependent intervals. 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,

²⁷ Reis (2006) has also argued that firms will still review intermittently even if free information were available. This would be the case if review costs were dominated by processing and decision costs, rather than the cost of information itself.

²⁸ 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)

$$y_t = \int_0^1 c_t^{1-\varepsilon\gamma} \left(\frac{\alpha p_t(z)}{w_t} \right)^{-\varepsilon} dz$$

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,

$$\tilde{y}_t = \int_0^1 c_t^{1-\varepsilon\gamma} \left(\frac{\alpha \tilde{p}_t(z)}{w_t} \right)^{-\varepsilon} dz$$

I define the output gap (g) as,²⁹

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

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%.

²⁹ 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.

A key parameter is clearly η , implicitly zero in *GL*. Alvarez *et al* (2011) identify two ‘observable statistics’ that provide direct evidence about η . 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 η . Alvarez *et al* also show that the ratio of the mode to the mean size of price change is a monotone function of η .³⁰ I find that the ratio of the mean to the median price change also varies with η . *KK* report that this ratio is 1.165 in their micro-data and I therefore calibrate η to match it.

I follow *NS* in the calibration of the remaining three parameters (k , ρ and σ_ω). They were chosen to match the following micro-data features reported by *NS* and outlined in section 2:

- The frequency of price changes is 8.7% per month.
- The average absolute price changes that do occur is 8.5%
- 64.8% of price changes were increases.³¹

I then compare each model’s performance in matching the remaining features described in section 2.³²

4. Results

The calibration parameters and targets of five models are given in Table 1, the *GL* model and four review-cost variants, including the Reis ‘inattention’ polar case. Tables 2 and 3 report the simulation results, the first covering pricing behaviour and the second the macroeconomic implications. Consider first the

³⁰ In Alvarez *et al* the ratio of the mode to mean absolute price change is an increasing monotone function of the ratio of menu-costs to the ‘observation’ cost. In my model this implies that the ratio of mean to median price changes might rise with η , as it does.

³¹ The percentage of price increases in all models was close enough to target by setting ρ to 0.72.

³² *GL* calibrate the same three parameters on the frequency of price changes, the mean size of absolute price change and standard deviation of prices that change. They target a re-set frequency of 21.9% without distinguishing regular and sale prices.

standard menu-cost model (*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. Predictably the standard menu-cost model fails to account for the substantial dispersion in price changes (Table 2). The percentage of small price changes is well short of that found in the data: only 0.1% of price changes are less 5% compared with 25% in *M*'s data.

From Table 3 $\log(c_t)$ follows an AR(1) process with the current innovation influenced to some degree by the money-wage shock.³³ Both extensive (ρ_2) and intensive (ρ_3) margins are positive, the former less than the latter. The extensive margin is, however, too strong – 0.62 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, σ_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 0.263 (0.002) using monthly simulated data.³⁴

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.

³³ *GL* allow for no time variation in the Spence-Dixit-Stiglitz aggregate (i.e. $R^2 = 0$). Although equation (5) is an obvious improvement on *GL*'s constant-*c* approach, the accuracy gain is marginal since, as *GL* argue, aggregate shocks play a relatively minor role in the firm's pricing decision compared with idiosyncratic shocks.

³⁴ *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 0.17.

Four variants of the review-cost model are presented. In the first three menu costs are positive with the following values for η : 0.5, 1 and 7. In the fourth case menu costs are zero and review costs positive (corresponding to Reis's inattentiveness case). As the ratio of review costs to menu costs rises, the mean review interval lengthens: from 4 months when $\eta = 0.5$ to over 8 months when $\eta = 7$ (Table 2). When firms incur no menu costs the mean review interval is close to one year. And the standard deviation of review intervals rises from 0.15 months when $\eta = 0.5$, to 0.77 months when $\eta = 7$ and 3.4 months when menu-costs are zero. When $\eta = 0.5$ and reviews are most frequent, only 35% of them lead to price changes. This rises to 72% when $\eta = 7$ and close to 100% in the inattentiveness case.³⁵ Across all review-cost models, the correlation between the size of the price change and the time it was last re-set (ρ_1) is negative but weak.³⁶

The ratio of mean to median absolute price change rises with η and when $\eta = 7$ this ratio matches that in the data (Table 1). This benchmark case is broadly consistent with the direct evidence reported in Zbaracki *et al* (2004).³⁷ And, from the results presented in Table 2, the benchmark model alone succeeds in capturing the distribution of reset intervals, with a standard deviation of 6.6 months lying within the range found in the data (5-7 months). The benchmark model also explains the wide dispersion of price adjustments and it is this that is crucial in reducing the selection effect as Midrigan (2011) has recently demonstrated. He argues that the 'strength of the selection effect depends on the measure of the marginal firms whose desired price changes

³⁵ In the inattentive case firms will always adjust as they incur no cost in doing so. On a small number of occasions the adjustment required is zero.

³⁶ The correlation is weak and positive in *KK*'s data.

³⁷ Zbaracki *et al* (2004) report that 'managerial costs are more than 6 times ... the physical costs associated with changing prices' (p. 515).

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 function³⁸ 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 more widely dispersed in the case of the review cost model is again clear from Figure 1 (shown for the case of $\eta = 7$), 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.

The key macroeconomic implications of review costs are set out in Table 3. Compared with the *GL* model, there is more serial correlation in the behaviour of $\log(c_t)$ and it is more responsive to innovations in the money wage. The R^2 of the approximation for $\log(c_t)$ is 0.986 for the benchmark case ($\eta = 7$). In *GL*'s original model an R^2 of zero was argued to be sufficient since variations in c_t in their case were small and had a minor effect on the firm's pricing behaviour. Nakamura and Steinsson (2010) and Midrigan (2011) also apply the Krussel and Smith approach and they report R^2 s of 0.98. The R^2 s in Table 3 are similar to theirs.

The benchmark model alone succeeds in capturing the roles of the extensive (ρ_2) and intensive (ρ_3) margins of inflation. The standard deviation of the output gap for the benchmark model is over 3 times that of the *GL*

³⁸ I used the Gaussian kernel density function in STATA version 11.

model.³⁹ The review-cost model sufficiently weakens the selection effect to strengthen monetary non-neutrality, as the output-gap regressions illustrate. As review costs become increasingly important, the impact of money on the output gap increases, though persistence following the shock eventually declines with higher values of η .⁴⁰ Even when the review cost is only half the size of the menu cost, monetary non-neutrality is significantly more pronounced than in the standard menu-cost case.

Figure 2 plots impulse-responses implied by the output gap regressions reported in Table 3. The benchmark model and Reis's inattentiveness model have very similar implications for monetary non-neutrality. The figure also plots the response of a Calvo model calibrated to match the frequency of price changes but one that shares the same idiosyncratic and monetary shocks as the benchmark model. The contemporaneous impact of a monetary shock on the output gap is similar for all review-cost models and the Calvo model, but the effects are far more persistent in the latter.⁴¹ Although the impact of money on the output gap is similar in the benchmark and Calvo models, the models are likely to have very different wider policy implications. For example the effect of a doubling of the variance of the money shock is likely to be very different in the benchmark model, where firms have the option to adjust the timing of their next review. In the Calvo model firms do have this option.⁴²

³⁹ The standard deviation of the output gap is 0.34% for $\eta = 7$, close to Midrigan's (2011) consumption standard deviation of 0.29% for his benchmark case.

⁴⁰ Results not reported suggest that persistence is greatest when $\eta = 2$.

⁴¹ In the Calvo model's output gap regression, the coefficient on the monetary shock is 0.495 (0.017) and that on lagged output is 0.848 (0.010). The Calvo model predictably implies an overly strong positive correlation between the size of the price change and the time it was last reset. And the extensive margin of aggregate prices is completely absent.

⁴² Paciello and Wiederholt (2011) analyse in more detail the policy implications of making the timing of reviews endogenous.

In their different ways, Midrigan (2011), Nakamura and Steinsson (2008), Woodford (2009) and Gertler and Leahy (2008) all find that monetary non-neutrality is a feature of models based on sound micro-foundations for price stickiness. I reach the same conclusion 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 will 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 level 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 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 (2011). 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 (2011), 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* (2011) 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 Calvo pricing. The Golosov and Lucas critique evaporates with one reasonable modification to the assumed price-setting process.

Table 1: Model Calibration

	Data	GL	Review Cost Model			
		$\eta = 0$	$\eta = 0.5$	$\eta = 1$	$\eta = 7$	Inattention
<i>Parameters common to all models</i>		$\alpha = 6; \gamma = 2; \varepsilon = 7; \beta = 0.9966; \mu = 0.0021; \sigma_v = 0.0032$				
<u>Calibration Parameters</u>						
k		0.0170	0.01740	0.01726	0.00842	0
q		0	0.00870	0.01726	0.05894	0.0930
ρ		0.72	0.72	0.72	0.72	0.72
σ_ω		0.04	0.0547	0.0635	0.095	0.1170
<u>Calibration Targets</u>						
Reset Frequency (%)	8.7	8.7	8.7	8.7	8.7	8.7
Mean absolute price change (%)	8.5	8.5	8.5	8.5	8.5	8.5
Price increases (% share)	64.8	66.9	65.4	64.7	62.7	64.6
Ratio of mean to median	1.165	1.030	1.098	1.120	1.164	1.264

Notes: Parameters that are common to all models are based on those adopted by Golosov and Lucas (2007) and Nakamura and Steinsson (2008). The three (independent) calibration parameters in the first column (k , ρ and σ_ω) were chosen to match the price re-set frequency, mean absolute size of price change and the percentage of price changes that are increases. $\eta = 7$ matches the ratio of the mean to median of absolute price changes and this is the benchmark model.

Table 2: Pricing Behaviour

	Data	GL	Review Cost Model			
		$\eta = 0$	$\eta = 0.5$	$\eta = 1$	$\eta = 7$	Inattention
<u>Review and Re-set Intervals</u>						
Mean Review Interval (months)	-	1	3.977	4.995	8.25	11.55
Max-Min Review Interval (months)	-	1-1	4-3	5-4	9-4	14-3
Standard Deviation of Review Intervals (months)	-	-	0.151	0.071	0.77	3.71
Reviews that change price (%)	-	100	34.7	43.3	71.7	97.7
Standard Deviation of Reset Intervals (months)	5.2 - 7.0	10.3	9.5	8.5	6.6	4.38
<u>Absolute Price Changes</u>						
Percent < 5%	<i>KK</i> 44 <i>M</i> 25	0.10	2.10	5.13	23.36	36.81
ρ_1	-	-0.232	-0.165	-0.109	-0.132	-0.385

Notes: The results reported in this table are based on the simulated pricing behaviour of 5,000 firms over 2,000 months. ρ_1 is the correlation between the absolute size of price change and the time since last set.

Table 3: Aggregate Implications

	GL		Review Cost Model		
	$\eta = 0$	$\eta = 0.5$	$\eta = 1$	$\eta = 7$	Inattention
<u>Spence-Dixit-Stiglitz Aggregate</u>					
$(\log c_t)$					
λ_0	-0.340 (0.003)	-0.306 (0.003)	-0.282 (0.004)	-0.191 (0.003)	-0.150 (0.003)
λ_1	0.650 (0.004)	0.685 (0.003)	0.711 (0.004)	0.805 (0.003)	0.847 (0.003)
λ_2	0.298 (0.001)	0.394 (0.002)	0.407 (0.002)	0.433 (0.002)	0.441 (0.002)
σ_e	0.0002	0.0003	0.0003	0.0003	0.0003
R^2	0.975	0.980	0.972	0.986	0.986
ρ_2 ($KK = 0.25$)	0.617	0.541	0.421	0.276	0.039
ρ_3 ($KK = 0.99$)	0.992	0.994	0.957	0.994	0.992
σ_g (%)	0.107	0.181	0.219	0.343	0.466
<u>Output Gap Regression</u>					
g_{t-1}	0.530 (0.007)	0.599 (0.009)	0.641 (0.010)	0.575 (0.015)	0.448 (0.019)
$d\log(w_t)$	0.263 (0.002)	0.386 (0.005)	0.406 (0.007)	0.443 (0.020)	0.459 (0.025)

Notes: The results reported in the table are based on simulated aggregations over 5,000 firms for 2,000 months. ρ_2 is the correlation between the inflation rate and the fraction of prices being reset. ρ_3 is the correlation between the inflation rate and the mean change in those prices which are being reset. σ_g is the standard deviation of the output gap.

Figure 1: Distributions of Non-zero Price Changes

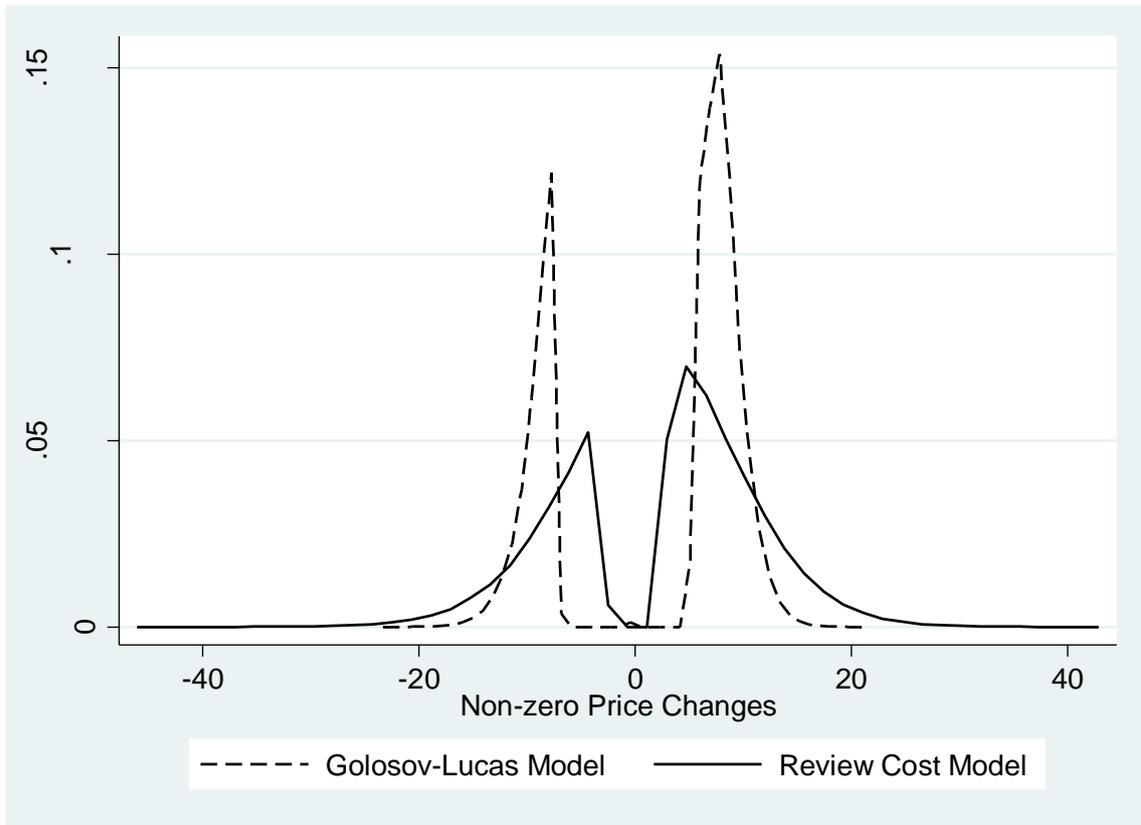
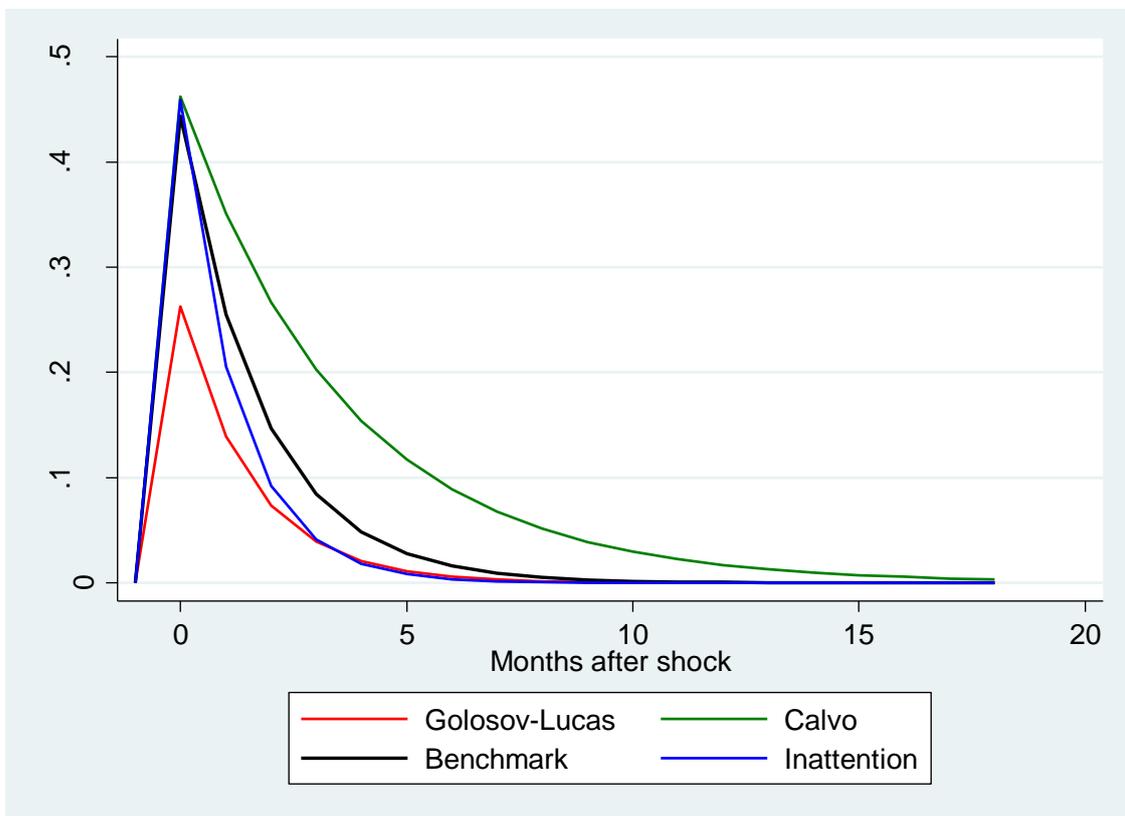


Figure 2: Output Gap Impulse Responses



REFERENCES

- Alvarez, Fernando E, Francesco Lippi, and Luigi Paciello. (2011) "Optimal price setting with observation and menu costs." *Quarterly Journal of Economics*, 126:1909-1960.
- Bils, Mark, and Peter J. Klenow. (2004) "Some evidence on the importance of sticky prices." *Journal of Political Economy*, 112:947-985.
- Blinder, Alan. S., Elie Canetti, David E. Lebow, and Jeremy. B. Rudd. (1998) *Asking About Prices: A New Approach to Understanding Price Stickiness*. New York: Russell Sage Foundation.
- Bonomo, Marco, and Carlos Carvalho. (2004) "Endogenous time-dependent rules and inflation inertia." *Journal of Money, Credit and Banking* 36:1015-1041.
- Bonomo, Marco, and Carlos Carvalho. (2010) "Imperfectly credible disinflation under endogenous time-dependent pricing." Federal Reserve Bank of New York, Staff Report 355.
- Bonomo, Marco, Carlos Carvalho and René Garcia. (2010) "State-dependent pricing under infrequent information: a unified framework" Federal Reserve Bank of New York, Staff Report 455.
- Burstein, Ariel. (2006) "Inflation and Output Dynamics with State Dependent Pricing Decisions" *Journal of Monetary Economics*, 53:1235-1257.
- Caballero, Ricardo and Eduardo Engel. (2007) "Price stickiness in Ss models: new interpretations of old results." *Journal of Monetary Economics* 54:S100-121.
- Calvo, Guillermo A. (1983) "Staggered prices in a utility-maximizing framework." *Journal of Monetary Economics* 12:383-398.
- Caplin, Andrew S., and Daniel F. Spulber. (1987) "Menu costs and the neutrality of money," *The Quarterly Journal of Economics* 102:703-725.
- Carroll, Christopher D. (2006) "The epidemiology of macroeconomic expectations." In Larry Blume and Steven Durlauf, editors, *The Economy as an Evolving Complex System, III*. Oxford University Press
- Costain, James and Antón Nákov. (2011) "Price adjustments in a general model of state-dependent pricing." *Journal of Money, Credit and Banking* 43.
- Clarida, Richard, Jordi Galí, and Mark Gertler. (1999) "The science of monetary policy: a new-Keynesian perspective", *Journal of Economic Literature* 37:1661-1707.
- 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.
- Dotsey, Michael, Robert King, and Alexander Wolman. (1999) "State-dependent pricing and the general equilibrium dynamics of money and output." *Quarterly Journal of Economics*, 114:655-690.

- Dotsey, Michael, Robert King, and Alexander Wolman. (2006) "Inflation and real activity with firm-level productivity shocks: a quantitative framework." Unpublished paper, Federal Reserve Bank of Richmond.
- Fabiani, Silvia, Martine Druant, Ignacio Hernando, Claudia Kwapil, Bettina Landau, Claire Loupiau, Fernando Martins, Thomas Matha, Roberto Sabbatini, Harald Stahl, and Ad Stokman. (2006) "What firms' surveys tell us about price-setting behavior in the Euro Area." *International Journal of Central Banking* 2:3-47.
- Franco, Francesco, and Thomas Philippon. (2007) "Firms and aggregate dynamics." *Review of Economics and Statistics* 89:587-600,
- Gertler, Mark, and John Leahy. (2008) "A Phillips curve with an Ss foundation." *Journal of Political Economy* 116:533-572.
- Golosov, Mikhail, and Robert E. Lucas Jr. (2007) "Menu costs and Phillips curves" *Journal of Political Economy* 122:171-199.
- Gorodnichenko, Yuriy. (2008) "Endogenous information, menu costs and inflation persistence." National Bureau of Economic Research Working Paper 14184.
- Hall, Simon, Mark Walsh and Anthony Yates. (2000) "Are UK companies' prices sticky?" *Oxford Economic Papers* 52:425-446.
- Klenow, Peter J., and Oleksiy Kryvtsov. (2008) "State-dependent or time-dependent pricing: does it matter for recent U.S. inflation?" *The Quarterly Journal of Economics* 123:863-904.
- Knotek, Edward S. (2010) "A tale of two rigidities: sticky prices in a sticky information environment." *Journal of Money Credit and Banking* 42:1543-64.
- Krusell, Per and Anthony A. Smith. (1998) "Income and wealth heterogeneity in the macro-economy." *Journal of Political Economy* 106:867-896.
- Lach, Saul, and Daniel Tsiddon. (2007) "Small price changes and menu costs." *Managerial and Decision Economics*, 28:649-656.
- Mankiw, N. Gregory and Ricardo Reis. (2002) "Sticky information versus sticky prices: a proposal to replace the new Keynesian Phillips curve." *Quarterly Journal of Economics*, 117:1295-1328.
- Mankiw, N. Gregory, and Ricardo Reis. (2007) "Sticky information in general equilibrium." *Journal of the European Economic Association*, 2:603-613.
- Midrigan, Virgiliu. (2010) "Is firm pricing state or time-dependent? Evidence from US manufacturing." *Review of Economics and Statistics* 92:643-656.
- Midrigan, Virgiliu. (2011) "Menu costs, multi-product firms and aggregate fluctuations." *Econometrica* 79:1139-1180.
- Midrigan, Virgiliu, and Patrick J. Kehoe. (2010) "Prices are sticky after all." Federal Reserve Bank of Minneapolis, Research Department Staff Report 413.

- Nakamura, Emi, and Jón Steinsson. (2008) "Five facts about prices: a reevaluation of menu cost models." *Quarterly Journal of Economics*, 123:1415-1464.
- Nakamura, Emi, and Jón Steinsson. (2010) "Monetary Non-Neutrality in a Multisector Menu Cost Model." *Quarterly Journal of Economics*, 125:961-1013.
- Paciello, Luigi and Mirko Wiederholt. (2011) "Exogenous information, endogenous information and optimal monetary policy." Mimeo.
- Reis, Ricardo. (2006) "Inattentive producers." *Review of Economic Studies* 73:793-821.
- Woodford, Michael. (2009) "Information-constrained state-dependent pricing." *Journal of Monetary Economics*. 56(S):100-124.
- Zbaracki, Mark, Mark Ritson, Daniel Levy, Shantanu Dutta, and Mark Bergen. (2004) "Managerial and customer costs of price adjustment: direct evidence from industrial markets," *Review of Economics and Statistics*. 86:514-533.