WHAT DO MICRO PRICE DATA TELL US ON THE VALIDITY OF THE NEW KEYNESIAN PHILLIPS CURVE?

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Abstract

The New Keynesian Phillips Curve (NKPC) is now the dominant model of inflation dynamics. In recent years, a large body of empirical research has documented price-setting behaviour at the individual level, allowing the assessment of the micro-foundations of pricing models. This paper analyses the implications of 25 theoretical models in terms of individual behaviour and finds that they considerably differ in their ability to match the key micro stylised facts. However, none is available to account for all of them, suggesting the need to develop more realistic micro-founded price setting models.

Keywords: Pricing models, micro data, Phillips Curve, hazard rate.

JEL: E31, D40.

1 Introduction

In recent years, there have been considerable advances in the theoretical modelling of inflation. A new generation of models has emerged, characterised by pricing equations derived from the optimising behaviour of forward looking firms, in a framework of nominal rigidities and imperfect competition. Aggregation over individual decisions leads to relations linking inflation to some measure of real activity, in the spirit of the traditional Phillips Curve, although with firm micro-foundations. This New Keynesian Phillips Curve (NKPC) is now the dominant approach to price modelling and variants of it are routinely used as the supply block of dynamic stochastic general equilibrium (DSGE) models, which are increasingly popular in academic macroeconomics and policy making institutions.

There is also growing recognition that the understanding of price stickiness can be improved by examining pricing behaviour at the micro level, where pricing decisions are actually made. Individual information on price setting allows determining to which extent the assumptions used in deriving theoretical models are actually realistic, which helps discriminate among competing models. Micro evidence is also an aid in solving problems of observational equivalence that are sometimes present in the analysis of aggregate time-series data. For instance, as is well known, the popular Calvo (1983) pricing model can be distinguished from the quadratic adjustment model of Rotemberg (1982) on the basis of micro data.

Empirical evidence on pricing policies at the microeconomic level had remained quite limited until recent years. Indeed, most quantitative studies with individual price data were quite partial and focussed on very specific products. Fortunately, a large and growing body of empirical research aimed at improving the understanding of the characteristics of the inflation process is now available. Following Bils and Klenow (2004), numerous authors have analysed datasets of the individual prices that are used to compute consumer price indices (CPIs) and producer price indices (PPIs), mostly within the context of the Eurosystem Inflation Persistence Network (IPN). Following Blinder (1991), a significant number of central banks have conducted surveys on price setting behaviour, including those participating in the IPN.

The aim of this paper is to survey recent work on micro price data, focussing on those aspects related to the conformity of assumptions used in pricing models put forward in the literature[1]. After this introduction, the remainder of this paper is organised as follows. Section 2 discusses the main features of micro CPI and PPI datasets, as well as survey data. Section 3 presents the main micro implications of 25 pricing models. Sections 4 and 5 refer to the analysis of frequencies and hazard rates of price adjustment and section 6 to heterogeneity in the frequency of price change. Sections 7 and 8 are devoted to assessing the relevance of time dependent and forward looking behaviour and section 9 presents available evidence on imperfect competition. The paper ends with a section of concluding remarks.

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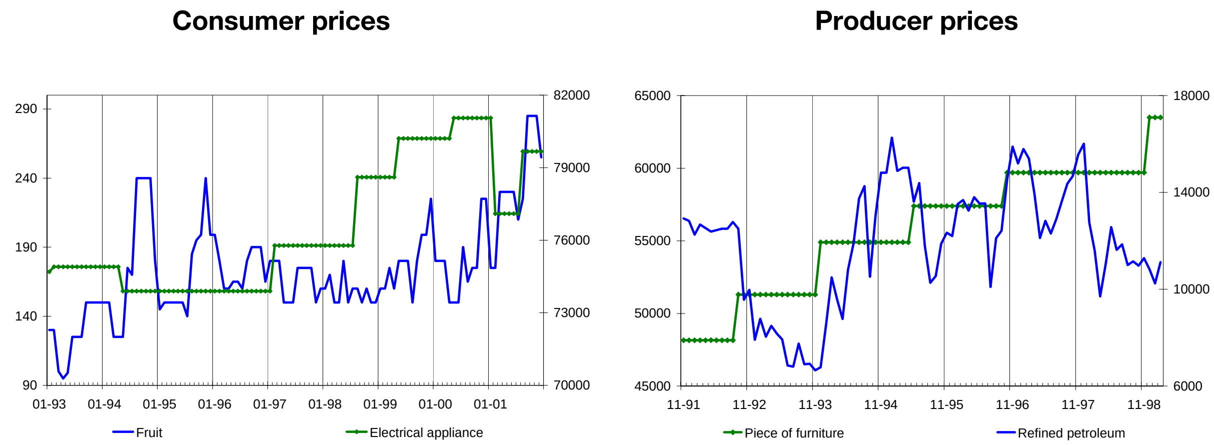
1. For an overview of IPN results on micro data, see Álvarez et al. (2006). More detailed IPN summaries on individual consumer prices are provided in Dhyne et al. (2006) and Sabbatini et al. (2007), which also consider producer price data. Vermeulen et al. (2007) summarises producer price data, whereas Fabiani et al. (2006) and the book by Fabiani et al. (2007) give an overview of results on survey data in the euro area and Lünnemann and Mathä (2007) compare survey results in the euro area with those in other countries. Angeloni et al. (2006) and Gaspar et al. (2007) discuss the implications of micro IPN findings for macroeconomic modelling and the design of monetary policy.

2 Data sources

The evidence considered in this paper refers to quantitative datasets made up of the individual transaction prices that are compiled by national statistical offices to compute CPIs and PPIs and qualitative one-off surveys on pricing behaviour, mostly carried out by central banks. These quantitative datasets have the clear advantage that they are representative[2] of consumer expenditure and industrial production, in contrast with earlier evidence[3] that had a narrow focus, in terms of products, types of outlets and cities considered. Moreover, datasets contain a huge number of monthly price quotes, which may add up to several millions, and extend for several years.

Figure 1

Examples of individual price trajectories



Source: Álvarez and Hernando (2006) for consumer prices and Álvarez *et al.* (2008) for producer prices. Prices in pesetas.

Figure 1 displays some paths of actual price series corresponding to consumer and producer prices in Spain, similar to those found in other countries. [See e.g. Baumgartner *et al.* (2005)]. There are three features worth highlighting. First, most individual prices remain unchanged for several months. Second, prices are not typically reset with a fixed periodicity and, third, there is marked heterogeneity across products in the frequency of price change.

A complementary approach to analyse price setting practices is to survey firms directly. Surveys offer unique information on some aspects of pricing policies, such as the information set used or the reasons that justify delays in price adjustments. The approach may be considered controversial, since firms could lack incentives to respond truthfully. However, questionnaires used [See e.g. Fabiani *et al.* (2007) for the precise questionnaires of euro area countries] have avoided problematic questions that could lead firms to conceal the

2. Data confidentiality reasons have prevented full coverage in some countries. See references in table 2 for the precise goods and services covered in each study.

3. Prominent examples include Cecchetti (1986) on newsstand prices of magazines, Carlton (1986) on producer prices of intermediate products used in manufacturing and Lach and Tsiddon (1992) on retail food product prices.

truth[4]. Moreover, response rates were not low, so selectivity biases probably played a minor role. Finally, answers could be sensitive to the precise wording of questions, the order in which they appear, and the setting in which the questions were answered. Nonetheless, the fact that questionnaires in different countries differ in these aspects[5] but produce similar results suggests that the quantitative importance of these concerns is likely to be small.

4. In some cases, firms may be secretive about prices of their business to business transactions, to avoid tipping off the competition. Moreover, illegal collusive behaviour cannot be expected to be reported in a survey.

5. Cross country methodological differences also exist in quantitative micro data analyses, although their importance seems to be minor. Indeed, Dhyne et al. (2006) use a common 50 product basket for euro area countries and the US and find that quantitative differences with the respective full samples are quite small.

3 Predictions of pricing models

The aim of this section is to briefly review the implications of 25 pricing models, so as to check them against micro data in the rest of the paper. We focus on the following 4 dimensions: the frequency of price adjustment, the hazard rate (i.e. the probability that a price (p_t) will change after k periods, conditional on having remained constant during the previous k-1 periods) $h(k) = Pr\{p_{t+k} \neq p_{t+k-1} \mid p_{t+k-1} = p_{t+k-2} = ... = p_t\}$), the consideration of heterogeneous behaviour in the frequency of price change, and the possibility of allowing for non-rational behaviour. To the extent possible, we also present the Phillips curves implied by these models.

3.1 Sticky contract or information models

Sticky contract or information models [Lucas (1972), Fischer (1977), Mankiw and Reis (2002), Carvalho (2005), Reis (2006) and Maćkowiack and Wiederholt (2007)] imply continuous price adjustment, so that the hazard rate is zero for prices aged more than one period and there is no heterogeneity across firms in the frequency of price change. This is also the case for the heterogeneous Mankiw and Reis (2002) model proposed by Carvalho (2005), since heterogeneity refers to the frequency of updating the information set. Further, in these models firms set prices optimally, subject to informational constraints, so there is no room for irrational behaviour.

In Lucas (1973) islands model firms have imperfect knowledge of the price level and rationally estimate it on the basis of the price of its good, solving a signal extraction problem. The Phillips curve is given by

$$\pi_t = {}_{t-1}E\,\pi_t + \gamma(y_t - \overline{y})$$

where π_t is the inflation rate, ${}_{t-1}E\,\pi_t$ is the expectation of π_t, conditional on the information set up to t-1, y_t is output and $\overline{y}$ is trend output. In this model, inflation is driven by its past expectation and the output gap.

Fischer (1977) introduces price rigidity by assuming that prices are predetermined, but not fixed. That is, contracts set prices for several periods, specifying a different price for each period. Mankiw and Reis (2002) reintroduce the idea that prices are predetermined. Opportunities to adopt new price paths do not arise deterministically, as in Fischer (1977), but stochastically. Each period, a given fraction λ of price setters obtains new information about the state of the economy and computes a new path of optimal prices. The equation for the inflation rate is given by

$$\pi_t = \left[\frac{\alpha\lambda}{1-\lambda}\right] y_t + \lambda \sum_{j=0}^{\infty} (1-\lambda)^j \;{}_{t-1-j}E\,(\pi_t + \alpha\,\Delta\, y_t)$$

where the relevant expectations are past expectations of current economic conditions. Reis (2006) inattentiveness model adds to the standard profit-maximisation problem the constraint that agents must pay a cost to acquire, absorb and process information in forming expectations. The model provides a micro-foundation for Mankiw and Reis (2002) and inflation follows a continuous time version of Mankiw and Reis (2002) expression. In these models, prices react with equal speed to all disturbances. In contrast, in Maćkowiack

Table 1

Predictions of pricing models

	Frequency (f) of price change	Hazard rate	Heterogeneity in f	Non optimality of price setters
Sticky information				
Carvalho (2005)	$f = 1$	$h(k) = \begin{cases} 1 & if \quad k = 1 \\ 0 & if \quad k \neq 1 \end{cases}$	No	Not allowed
Fischer (1977)	$f = 1$	$h(k) = \begin{cases} 1 & if \quad k = 1 \\ 0 & if \quad k \neq 1 \end{cases}$	No	Not allowed
Lucas (1972)	$f = 1$	$h(k) = \begin{cases} 1 & if \quad k = 1 \\ 0 & if \quad k \neq 1 \end{cases}$	No	Not allowed
Maćkowiak and Wiederholt (2007)	$f = 1$	$h(k) = \begin{cases} 1 & if \quad k = 1 \\ 0 & if \quad k \neq 1 \end{cases}$	No	Not allowed
Mankiw and Reis (2002)	$f = 1$	$h(k) = \begin{cases} 1 & if \quad k = 1 \\ 0 & if \quad k \neq 1 \end{cases}$	No	Not allowed
Reis (2006)	$f = 1$	$h(k) = \begin{cases} 1 & if \quad k = 1 \\ 0 & if \quad k \neq 1 \end{cases}$	No	Not allowed
Menu costs				
Danziger (1999)	$0 < f \leq 1$	$h(k) = \theta \quad \forall\ k$	No	Not allowed
Dotsey *et al.* (1999) [1]	$0 < f \leq 1$	$\Delta h(k) = \begin{cases} > 0 & if \quad k < v^* \\ 1 & if \quad k = v^* \\ 0 & if \quad k > v^* \end{cases}$	No	Not allowed
Nakamura and Steinsson (2007) [1]	$0 < f \leq 1$	$h(k)$ increasing or increasing and then non-increasing	No	Not allowed
Sheshinski and Weiss (1977)	$0 < f \leq 1$	$h(k) = \begin{cases} 1 & if \quad k = d^* \\ 0 & if \quad k \neq d^* \end{cases}$	No	Not allowed
Time dependent				
Álvarez *et al.* (2005)	$0 < f \leq 1$	$h(k) = \sum \beta_i(k)\theta_i + \beta_{n+1}(k)\theta I_{12}$ $\beta_i(k) = \omega_i \theta_i^{k-1} / (\sum \omega_i \theta_i^{k-1} + \omega_{n+1}\theta^{\text{int}(k-1/12)})$ $\beta_{n+1}(k) = \omega_{n+1}\theta^{\text{int}(k-1/12)} / (\sum \omega_i \theta_i^{k-1} + \omega_{n+1}\theta^{\text{int}(k-1/12)})$	Yes	Not allowed
Aoki (2001)	$0 < f \leq 1$	$h(k) = \begin{cases} \omega + \theta(1-\omega) & if \quad k = 1 \\ \theta & if \quad k \neq 1 \end{cases}$	Yes	Not allowed
Bonomo and Carvalho (2004)	$0 < f \leq 1$	$h(k) = \begin{cases} 1 & if \quad k = d^* \\ 0 & if \quad k \neq d^* \end{cases}$	No	Not allowed
Calvo (1983)	$0 < f \leq 1$	$h(k) = \theta \quad \forall\ k$	No	Not allowed
Carvalho (2006)	$0 < f \leq 1$	$h(k) = \sum \beta_i(k)\theta_i$ $\beta_i(k) = \omega_i \theta_i^{k-1} / \sum \omega_i \theta_i^{k-1}$	Yes	Not allowed
Gali and Gertler (1999)	$0 < f \leq 1$	$h(k) = \begin{cases} \omega + \theta(1-\omega) & if \quad k = 1 \\ \theta & if \quad k \neq 1 \end{cases}$	Yes	Allowed
Sheedy (2005) [2]	$0 < f \leq 1$	Unrestricted	No	Not allowed
Taylor (1980)	$0 < f \leq 1$	$h(k) = \begin{cases} 1 & if \quad k = d^* \\ 0 & if \quad k \neq d^* \end{cases}$	No	Not allowed
Taylor (1993) [3]	$0 < f \leq 1$	$h(k) = \begin{cases} 1/(N-k) & if\ k \leq N \\ 0 & if\ k > N \end{cases}$	Yes	Not allowed
Wolman (1999)	$0 < f \leq 1$	$h(k) = \begin{cases} \theta & if \quad k < d^* \\ 1 & if \quad k = d^* \\ 0 & if \quad k > d^* \end{cases}$	No	Not allowed
Generalised indexation				
Christiano *et al.* (2005) [4]	$f = 1$	$h(k) = \begin{cases} 1 & if \quad k = 1 \\ 0 & if \quad k \neq 1 \end{cases}$	No	Allowed
Smets and Wouters (2003) [4]	$f = 1$	$h(k) = \begin{cases} 1 & if \quad k = 1 \\ 0 & if \quad k \neq 1 \end{cases}$	No	Allowed
Convex costs of adjustment				
Kozicki and Tinsley (2002)	$f = 1$	$h(k) = \begin{cases} 1 & if \quad k = 1 \\ 0 & if \quad k \neq 1 \end{cases}$	No	Not allowed
Rotemberg (1982)	$f = 1$	$h(k) = \begin{cases} 1 & if \quad k = 1 \\ 0 & if \quad k \neq 1 \end{cases}$	No	Not allowed
Consumer anger				
Rotemberg (2005) [1], [5]	$0 < f \leq 1$	$h(k) = \theta \quad \forall\ k$	No	Not allowed

Notes: [1] No closed form of the hazard rate available [2] The hazard rate cannot be zero at any period and f<1 [3] Assuming that the distribution of contracts is uniform over [1,N] [4] All agents behave non optimally with a given frequency [5] Hazard rate for non-time varying distributions and Wiederholt (2007) model, firms decide optimally what to observe. When idiosyncratic conditions are more relevant than aggregate conditions firms pay more attention to idiosyncratic conditions. Another extension of Mankiw and Reis (2002) model is given by Carvalho (2005), who introduces heterogeneity in firm behaviour. Specifically, each group of firms updates its information set with a different frequency. This does not change the implication of the model in terms of continuous price adjustment or hazard rates, although, interestingly, leads monetary shocks to have substantially larger and persistent real effects.

3.2 Menu costs models

In menu costs models, firms must incur a fixed cost to change nominal prices. As a consequence, firms do not adjust prices continuously, but rather when they find it profitable to do so. In the models we consider [Sheshinski and Weiss (1977), Danziger (1999), Dotsey *et al.* (1999) and Nakamura and Steinsson (2007)] all firms are assumed identical, so there is no heterogeneity in the frequency of price change. Further, firms set prices optimally. Implications for the hazard function differ from model to model.

In Sheshinski and Weiss (1977) firms face a constant rate of inflation and find it optimal to adopt a one sided Ss policy. Nominal prices are fixed over intervals of constant duration (d*), which is (ambiguously) affected by inflation. Consequently, the hazard rate, as in Taylor (1980) and Bonomo and Carvahlo (2004), is one for prices aged d* periods and zero for the rest. Within a general equilibrium framework, Danziger (1999) studies a model with menu costs, where each firm's productivity is exposed to aggregate and idiosyncratic shocks. Prices are determined by a two-sided Ss markup strategy. In the model, the probability that a firm's price changes is endogenously determined and is independent of the last price adjustment occurred. Consequently, the hazard rate is constant, as in Calvo (1983). In Danziger (1999), the expected duration of a price is higher the higher are menu costs and the discount rate and lower the more uncertain are idiosyncratic shocks and the higher the trend in the money supply. In Dotsey *et al.* (1999), each firm faces a different menu cost, which is drawn independently over time from a continuous distribution. Within each period, some firms adjust their price, which is identical for all adjusting firms. Positive average inflation ensures that the benefit to changing prices becomes arbitrarily large over time, which makes the number of vintages (v*) of firms in the economy finite. The hazard rate is increasing up to v*, where it is one and then zero. v* is lower the higher is trend inflation. More recent menu cost models, like Nakamura and Steinsson (2007), also consider idiosyncratic productivity shocks. No analytical expression is available for the hazard rate, although it is shown that, as the variance of idiosyncratic shocks rises relative to the rate of inflation, the hazard function flattens out at longer durations, although it remains steeply upward sloping in the first few periods.

3.3 Time dependent models

Time dependent models allow for infrequent price adjustment. Heterogeneity in the frequency of price change is allowed for in some models [Taylor (1993), Galí and Gertler (1999), Aoki (2001), Álvarez *et al.* (2005) and Carvalho (2006)]. Non rational behaviour is allowed for only in Galí and Gertler (1999). Models generally differ in their predictions for hazard rates.

The most common time dependent pricing specifications in the literature are those by Taylor (1980) and Calvo (1983). In Taylor's model, prices are set by multiperiod contracts and remain fixed for the duration of the contract, as in Sheshinski and Weiss (1977) and Bonomo and Carvalho (2004). In this case, the hazard rate is zero, except in the period (d*) in which the end of the contract occurs, when the hazard is one. In the Calvo model, there is a constant probability that a given price setter will change its price at any instant, so the hazard rate is constant, as in Danziger (1999). As shown by Roberts (1995), the implied New Keynesian Phillips curve of these two models and that of Rotemberg (1982) is the same

$$\pi_t = \beta E_t \pi_{t+1} + \lambda \hat{s}_t = \beta E_t \pi_{t+1} + \delta (y_t - \overline{y})$$

where $\hat{s}_t$ is the deviation of log real marginal cost from its steady-state value. The NKPC relates inflation to anticipated future inflation and real marginal cost. This contrasts, for instance, with Mankiw and Reis (2002).

Similarly, Wolman (1999) considers a truncated Calvo model, which allows for a constant hazard up to a given horizon d*, in which all firms must adjust, so that the hazard rate is one. The model rules out the possibility of price durations of arbitrarily long length by assuming a zero hazard rate for horizons greater than d*. This model is able to account for inflation inertia, in the sense that lagged inflation appears in the New Keynesian Phillips Curve. Specifically,

$$\pi_t = \sum_{i=1}^{\infty} \varphi_i \pi_{t-i} + \sum_{j=1}^{J} \mu_j E_t \pi_{t+j} + \sum_{j=0}^{J} \kappa_j \hat{s}_{t+j}$$

so that current inflation depends of lagged inflation, future expected inflation and real marginal costs. More recently, Sheedy (2005) has obtained the NK Phillips Curve for a general distribution of price durations. In particular, if the hazard rate is increasing, there is structural persistence, in contrast with the Calvo (1983) model. The expression of the Phillips in the general case is

$$\pi_t = \sum_{i=1}^{n-1} \varphi_i \pi_{t-i} + \sum_{j=1}^{n} \mu_j E_t \pi_{t+j} + \kappa \hat{s}_t$$

Thus, current inflation depends on n-1 lags of past inflation, n expected future inflation rates, and current real marginal cost. Further, if the hazard function has a positive slope then all lags of inflation have positive coefficients.

Taylor (1993) allows for heterogeneity in the frequency of price adjustment, by considering the case where the duration of the price contracts varies across different groups of firms. Considering that the distribution of firms is uniform over durations in [1,N] the hazard rate is monotonically increasing. In turn, Álvarez *et al.* (2005) introduce an annual Calvo model, whereby the hazard rate is constant every 12, 24, 36 , … periods[6] and incorporate it in a mixture of Calvo agents. The hazard rate of the finite mixture is monotonically decreasing with spikes every 12, 24, 36… periods.

Aoki (2001) introduced a heterogenous economy with a flexible sector —in which prices change continuously— and a sticky sector —in which prices are set as in Calvo (1983). The hazard rate of this model is constant after the second period, as in Galí and Gertler (1999). Carvalho (2006) has generalised this model allowing for n sectors and not imposing the existence of a fully flexible sector. The hazard rate corresponds to a mixture

6. Specifically, $h(k) = \theta I_{12}$ and $I_{12} = \begin{cases} 1 & if \quad k/12 = int(k/12) \\ 0 & elsewhere \end{cases}$

of Calvo price setters and is monotonically decreasing, converging to the hazard rate of the stickiest sector. [Álvarez *et al.* (2005)]. The generalized NKPC that accounts explicitly for heterogeneity in price stickiness is:

$$\pi_t = \beta\, E_t \pi_{t+1} + \varphi\,(y_t - \bar{y}) + \psi\, g_t$$

Heterogeneity introduces a new, endogenous shift term (g_t) in the Phillips Curve that can be written as a weighted average of sectoral output gaps, with weights related to the sectoral frequencies of price adjustment. Moreover, the coefficient on the aggregate output gap in the Phillips curve also depends on the sectoral distribution of price stickiness. The standard NKPC obtains as a special case when the frequency of price changes is the same across all sectors. Interestingly, monetary shocks in this model have considerably larger and more persistent real effects than in identical-firms economies with a similar degree of rigidities.

The above models rely on forward looking price setters. Galí and Gertler (1999) propose a model that allows for departures from this assumption. Specifically, they assume that a fraction of firms (ω) set prices according to a backward looking rule of thumb. These firms index on last period's optimal price, rather than on last period's aggregate price index. This implies that this fraction of firms changes prices continuously, whereas the rest do in with a constant conditional probability. The hazard rate is constant after the second period, as in Aoki (2001). This leads to a NKPC of the form

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f\, E_t \pi_{t+1} + \psi\, \hat{s}_t$$

where all the coefficients are explicit functions of the structural parameters (the degree of price stickiness, the share of rule of thumb price setters and the discount factor).

Bonomo and Carvalho (2004) consider an endogenous time-dependent pricing model, in which the frequency of price changes is chosen optimally by firms, but firms do not react to shocks in between pricing decisions. The hazard rate is prices is one for the optimally chosen duration of the contract and zero elsewhere, as in Sheshinski and Weiss (1977) and Taylor (1980).

3.3.1 GENERALISED INDEXATION

Another explanation for inflation inertia, which is often used in DGSE models, is some sort of automatic and generalised indexation mechanism. For instance, in the Christiano *et al.* (2005) model, lagged inflation enters the NKPC because firms are assumed to index their prices using lagged inflation rates in the periods where prices are not adjusted optimally, according to the Calvo model, thus implying that prices change continuously. In this class of models, all firms behave non optimally a fraction of their time and the hazard rate is only nonzero for prices aged 1 period. In Smets and Wouters (2003), firms partially index to the aggregate price index. These models lead to a generalisation of the NKPC of the form

$$\pi_t - \rho\, \pi_{t-1} = \beta\, E_t\left[\pi_{t+1} - \rho\, \pi_t\right] + \xi\, \hat{s}_t$$

where ρ is the indexation parameter, which is equal to one in the Christiano *et al.* (2005) model and is left unrestricted in Smets and Wouters (2003).

3.4 Convex costs of adjustment

In Rotemberg (1982) firms set prices so as to minimise deviations from the optimal price subject to quadratic frictions of price adjustment. The solution implies that all firms must adjust prices continuously, so there is no heterogeneity in the frequency of price adjustment and the hazard rate is only non-zero for the first period. As is well known, this model is observationally equivalent at the aggregate level to the Calvo model. Kozicki and Tinsley (2002) have generalised this model, by assuming that frictions of price adjustment are captured by a polynomial. Micro implications of this generalisation are the same, but it provides a rationalisation of the appearance of lagged inflation terms in the Phillips Curve. Specifically, the implied equation is

$$\pi_t = \sum_{i=1}^{m} \left(\sum_{j=1}^{m} \beta^j \delta_j \right) E_t \, \pi_{t+i} - \sum_{i=2}^{m} \sum_{j=1}^{m} \delta_j \, \pi_{t-i+1} + \gamma \left(y_t - \bar{y} \right)$$

where coefficients are functions of the friction polynomial of order m+1.

3.5 Customer anger

Rotemberg (2005) explains price rigidity in a model in which consumers react negatively to price increases when they become convinced that prices are unfair. Firms are reluctant to change prices since this will lead consumers to re-think the fairness of prices and could lead to adverse reactions. In general, as the information set of consumers varies, their resistance to price increases will also vary. Firms will optimally keep prices unchanged with a time-varying probability, that depends on the evolution of consumers beliefs on fair pricing. If these are constant, the model is equivalent to Calvo (1983). In this model, the frequency of price adjustment can depend on economy-wide variables observed by consumers. This frequency is common for all firms, since there is no assumption of heterogeneity. The implied hazard rate depends on the time-varying distribution of consumer beliefs and no closed form is available. In this model, consumers are irrational in the sense that they are maximising something different from their utility function. Rather, they also wish to harm firms that use unfair pricing strategies.

4 Frequency of price adjustment

Table 2 presents available estimates of the monthly frequency of price change obtained in studies that employ individual CPI and PPI data. The data clearly confirm the impression from figure 1 that price adjustment is infrequent[7]. Indeed, the (unweighted) median estimate of price change is 18.1% for consumer prices and 22.5% for producer prices. Unsurprisingly, the frequencies of price adjustment are higher in countries like Sierra Leone and Slovakia, where aggregate inflation has been higher than in the rest of countries. Note that the highest frequencies are 25% for producer prices and 51% for consumer prices. Excluding Sierra Leone and Slovakia, the maximum frequency of consumer price change is 26%.

Table 3 presents the distribution of the number of price changes reported by firms in surveys. In most countries, the majority of companies state that they adjust prices once or less than once a year (median country: 68.5% of firms) and only a small fraction report that they change prices once a quarter or more often (median country: 14.0% of firms). The mean duration of price changes is generally around one year (median country: 11.8 months). Thus, survey data confirm that there is substantial price stickiness[8].

The low frequency of price adjustment that is observed in every country and with different data sources is clear evidence against some models proposed in the literature (see table 12), which predict that prices should change continuously (i.e. frequency: 100%). For instance, sticky contract or information models, such as Lucas (1972), Fischer (1977), Mankiw and Reis (2002), Carvalho (2005), Reis (2006) or Maćkowiack and Wiederholt (2007) imply continuous price adjustment. This is also the case for models with convex costs of adjustment, such as Rotemberg (1982) or Kozicki and Tinsley (2002). Other models that rely on some sort of widespread and automatic indexation mechanism, such as Christiano *et al.* (2005) or Smets and Wouters (2003), also imply that prices change every period. As stressed by Woodford (2007) and Angeloni *et al.* (2006), indexation models contradict[9] the empirical regularity that price changes are not frequent.

In contrast, other models, such as those in the menu cost tradition, such as Sheshinski and Weiss (1977), Danziger (1999), Dotsey *et al.* (1999) or Nakamura and Steinsson (2007) allow for lumpy price adjustment. This is also the case for time dependent models, such as Taylor (1980), Calvo (1983), Taylor (1993), Wolman (1999), Galí and Gertler (1999), Aoki (2001), Bonomo and Carvalho (2004), Álvarez *et al.* (2005), Sheedy (2005) or Carvalho (2006), which do not restrict the frequency of price change and so are able to account for infrequent price adjustment. Finally, the consumer anger model of Rotemberg (2005) also allows for infrequent price adjustment.

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7. Gopinath and Rigobon (2006) also find that price adjustment is infrequent with import and export micro price data.

8. Precise comparisons of quantitative data and qualitative data sources are not easy. Business to business transactions are covered in surveys and PPIs but, logically, not in CPIs. Surveys consider services, but PPIs do not. Further, Jensen's inequality renders the inverse of the mean frequency a downward biased estimate of average duration if there is heterogeneity [see e.g. Baudry et al. (2007)].

9. In addition, the evidence on the size of price adjustments reported by e.g. Dhyne et al. (2006) or Stahl (2006) shows that price changes of the size of aggregate inflation are rare, casting additional doubt on the generalised indexation hypothesis.

Table 2

Monthly frequency of price changes (%). Quantitative micro data

Consumer prices				Producer prices			
Country	Paper	Sample period	Frequency	Country	Paper	Sample period	Frequency
Austria	Baumgartner *et al.* (2005)	1996:1- 2003:12	15.1				
Belgium	Aucremanne and Dhyne (2004)	1989:1- 2001:1	16.9	Belgium	Cornille and Dossche (2006)	2001:1- 2005:1	24
Denmark	Hansen and Hansen (2006)	1997:1- 2005:12	17.3				
Euro area	Dhyne *et al.* (2006)	1996:1- 2001:1	15.1	Euro area	Vermuelen *et al.* (2007)		21
Finland	Vilmunen and Laakkonen (2005)	1997:1- 2003:12	16.5				
France	Baudry *et al.* (2007)	1994:7 - 2003:2	18.9	France	Gautier (2006)	1994:1-2005:6	25
Germany	Hoffmann and Kurz-Kim (2006)	1998:2 - 2004:1	11.3	Germany	Stahl (2006)	1997:1-2003:9	22
Hungary	Gábriel and Reiff (2007)	2002:1-2006:5	19.9				
Italy	Veronese *et al.* (2006)	1996:1 - 2003:12	10.0	Italy	Sabbatini *et al.* (2006)	1997:1- 2002:12	15
Japan	Saita *et al.* (2006)	1999:1-2003:12	23.1				
Luxembourg	Lünnemann and Mathä (2005)	1999:1 - 2004:12	17.0				
Mexico	Gagnon (2006)	1994.1-2004:12	22.6 (32.5)				
Netherlands	Jonker *et al.* (2004)	1998:11 - 2003:4	16.5				
Portugal	Dias *et al.* (2004)	1992:1 - 2001:1	22.2	Portugal	Dias *et al.* (2004)	1995:1- 2001:1	23
Sierra Leone	Kovanen (2006)	1999:11-2003:4	51.5				
Slovakia	Coricelli and Horváth (2006)	1997:1-2001:12	34.0				
Spain	Álvarez and Hernando (2006)	1993:1 - 2001:12	15.0	Spain	Álvarez *et al.* (2008)	1991:1-1999:2	21
United States	Bils and Klenow (2004)	1995:1-1997:12	26.1				
United States	Klenow and Kryvtsov (2005)	1988:2-2003:12	23.3 (29)				
United States	Nakamura and Steinsson (2007)	1988:1-2005:12	21.1 (26.5)	United States	Nakamura and Steinsson (2007)	1988:1-2005:12	24.7

For German CPI, frequencies refer to the sample considering item replacements and non quality adjusted data
For Mexican CPI, figures refer to the low inflation 2002-2003 period, whereas those in brackets refer to the high inflation 1995-1997 period
For Spanish CPI, the sample excludes energy products, which biases downwards aggregate frequency
For Italian PPI, figures exclude energy products, which biases downwards aggregate frequency
For French PPI, the reported figure does not include business services
Figures from Klenow and Kryvtsov (2005) correpond to regular prices, whereas those in brackets refer to all prices
Figures from Nakamura and Steinsson (2006) correspond to the 1998-2005 period. CPI frequencies refer to regular prices, wheras figures in brackets correspond to all prices. PPI figures correspond to finished goods

Table 3

Number of price changes per year (%). Survey data

Country	Paper	<1	1	2– 3	≥ 4	Median	Mean (in months)
Austria	Kwapil *et al.* (2005)	24	51	15	11	1	12.7
Belgium	Aucremanne and Collin (2005)	18	55	18	8	1	11.9
Canada	Amirault *et al.* (2006)	8	27	23	44	2-3	6.8
Estonia	Dabušinskas and Randveer (2006)	14	43	25	18	1	10.0
Euro area	Fabiani *et al.* (2006)	27	39	20	14	1	12.3
France	Loupias and Ricart (2004)	21	46	24	9	1	11.8
Germany	Stahl (2005)	44	14	21	21	1	13.5
Italy	Fabiani *et al.* (2007)	20	50	19	11	1	11.9
Japan	Nakagawa *et al.* (2000)	23	52	11	14	1	12.5
Luxembourg	Lünnemann and Mathä (2006)	15	31	27	27	2-3	9.0
Netherlands	Hoeberichts and Stokman (2006)	10	60	19	11	1	10.7
Portugal	Martins (2005)	24	51	14	12	1	12.7
Spain	Álvarez and Hernando (2007a)	14	57	15	14	1	11.1
Sweden	Apel *et al.* (2005)	29	43	6	20	1	12.7
United Kingdom	Hall *et al.* (2000)	6	37	44	14	2-3	8.2
United States	Blinder *et al.* (1998)	10	39	29	22	1	8.8

Figures for United Kingdom and Sweden taken from Mash (2004)
Figures for Germany taken from Fabiani *et al.* (2006)
Figures for Japan correspond to less than 1, 1-2, 3-4 and over 5, changes per year, respectively.

Mean implicit durations obtained from the interval-grouped data. The following assumptions have been made: for firms declaring “at least four price changes per year" 8 price changes are considered (i.e. mean duration of 1.33 months); for those declaring “two or three changes per year” 2.5 price changes (i.e. mean duration: 4.8 months); for those declaring “one change per year” a duration of 12 months; and for those declaring “less than one price change per year”, a change every two years is considered (mean duration of 24 months)

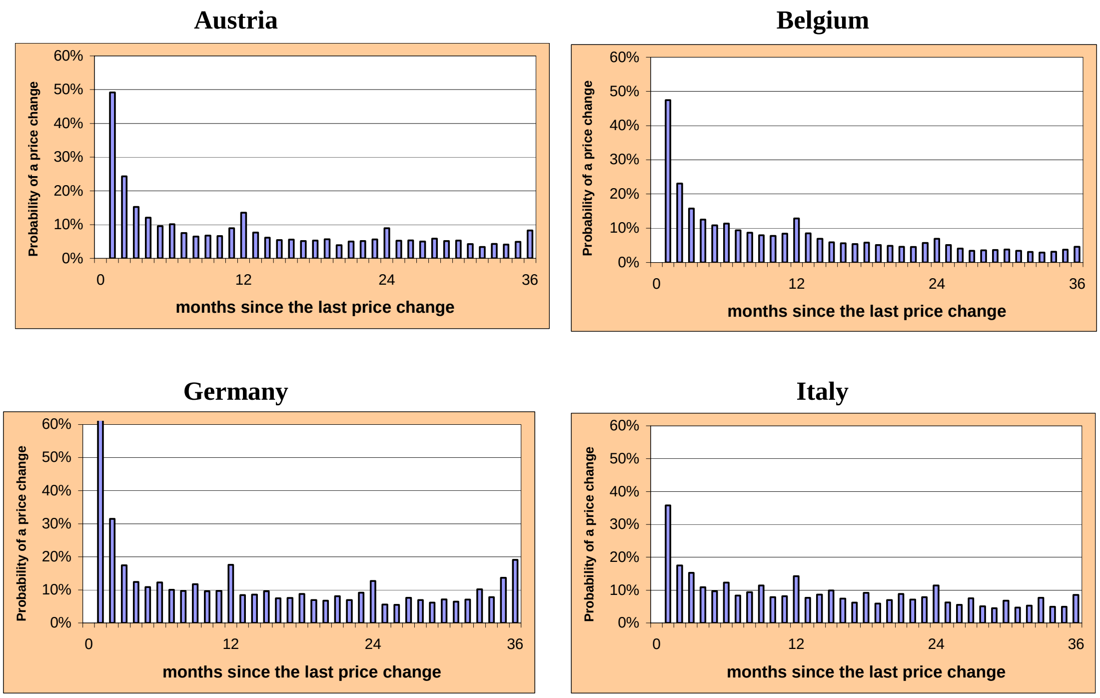
5 The hazard function of price changes

The literature on pricing models has mainly concentrated on matching the average frequency of price adjustment. This focus on the first moment of the distribution of price durations entails discarding useful information that allows discriminating among competing models. In contrast, the hazard function of price changes $h(k)$ contains the same information as the cumulative distribution function of price durations, so fully characterises its distribution, with the added advantage that it is readily interpreted in the light of many pricing models. Moreover, many models which are observationally equivalent on the basis of the frequency of price change, present sharply different hazard rates (see Table 1 and the figures in Appendix 1).

The validity of the different theoretical models can be assessed on the basis of estimates of hazard functions using consumer price micro data [see e.g. Fougère *et al.* (2007), Hansen and Hansen (2006) or Saita *et al.* (2006)]. Figure 2 presents estimates of this function for Austria [Baumgartner *et al.* (2005)], Belgium [Aucremanne and Dhyne (2004)], Germany [Hoffmann and Kurz-Kim (2006)] and Italy [Veronese *et al.* (2006)]. There are three common findings that are observed in all countries. First, hazard rates of price changes are not zero in any period, even for long horizons. Second, hazard functions are downward sloping and third, an important number of firms adjust prices every 12, 24, 36 ... months. These stylised facts are also found with producer price data, as shown by Álvarez *et al.* (2008) or Nakamura and Steinssson (2007).

Figure 2

Hazard functions for consumer price changes



The fact that hazard rates are not zero for any period is clearly at odds with some theoretical models. All models that predict continuous price adjustment imply that $h(k)=0 \; for \; k>1$. This includes models based on sticky contracts or information [Lucas (1972), Fischer (1977), Mankiw and Reis (2002), Carvalho (2005), Reis (2006) and Maćkowiack and Wiederholt (2007)], convex costs of adjustment [Rotemberg (1982) and Kozicki and Tinsley (2002)] and widespread indexation [Christiano *et al.* (2005) and Smets and Wouters (2003)]. It also contradicts Sheshinski and Weiss (1977), Taylor (1980) and Bonomo and Carvalho (2004), where all prices are reset with a fixed periodicity, determined by the length (d*) of the contract, which implies that all prices have the same duration. The truncated Calvo model of Wolman (1999) and the menu cost model of Dotsey *et al.* (1999), imply that $h(k)=0 \; for \; k>v^*$, so that all firms necessarily adjust prices after a certain number of periods. In contrast, non zero hazard rates are accommodated by many time dependent models [Calvo (1983), Taylor (1993), Galí and Gertler (1999), Aoki (2001), Álvarez *et al.* (2005), Sheedy (2005) and Carvalho (2006)] and also Danziger (1999), Nakamura and Steinsson (2007) and Rotemberg (2005).

The downward slope of the empirical hazard rate cannot be explained by most of the considered theoretical models (see Table 1 and Appendix 1). Only the models by Álvarez *et al.* (2005), Rotemberg (2005), Sheedy (2005) and Carvalho (2006) are able to account for this stylised fact. The downward slope of the hazard function, taken at face value, means that a firm will have a lower probability of changing its price the longer it has kept it unchanged, a possibility that is allowed in the models of Rotemberg (2005) and Sheedy (2005). An alternative explanation is that it simply reflects the aggregation of heterogeneous price setters. Indeed, it is well known in the failure literature that a mixture of distributions with non-increasing failure rates has a decreasing failure rate [see Proschan (1963)]. The intuition is as follows. By definition, firms with sticky pricing strategies have a lower probability of adjusting prices than firms with flexible pricing rules. The aggregate hazard function considers price changes for all firms and the share of price changes by firms with flexible pricing strategies decreases with the age of the price, that is, with the amount of time since the price was last changed. For high ages, only price changes of sticky firms are observed. In fact, it is straightforward to show [e.g. Álvarez *et al.* (2005)] that the hazard rate of a mixture of two components with hazard rates $h^1(k)$ and $h^2(k)$ and survival functions $S^1(k)$ and $S^2(k)$ is given by

$$h(k)=\beta(k)\,h^1(k)+(1-\beta(k))\,h^2(k)$$

$$\beta(k)=\frac{S^1(k)}{S(k)}$$

The expression shows that the hazard rate of an aggregate is a convex linear combination of its components, with (survival-based) weights that vary with the horizon. Furthermore, the change in the hazard rate is given by

$$\frac{\Delta h(k)}{\Delta k}=\frac{\Delta h^1(k)}{\Delta k}\beta(k)+\frac{\Delta h^2(k)}{\Delta k}\left[1-\beta(k)\right]+H(k)$$

where $H(k)=-\beta(k)\left[1-\beta(k)\right]\left[h^1(k)-h^2(k)\right]^2\varepsilon(k)$, and

$$\varepsilon(k) = \left\{ \frac{1 + \left[h^1(k) - h^2(k) \right]^{-1} \left[\frac{\Delta h^1(k)}{\Delta k} - \frac{\Delta h^2(k)}{\Delta k} \right] \Delta k}{1 - h(k) \Delta k} \right\}$$

The expression shows that the change of the hazard rate of an aggregate is a convex linear combination of the changes of the hazards of its components plus a heterogeneity effect. It is important to stress that the mixture of non-increasing hazard function is always non-increasing, but the converse is not necessarily note. A mixture of distributions with increasing hazard rates need not be constant or decreasing [Block *et al.* (2003)].

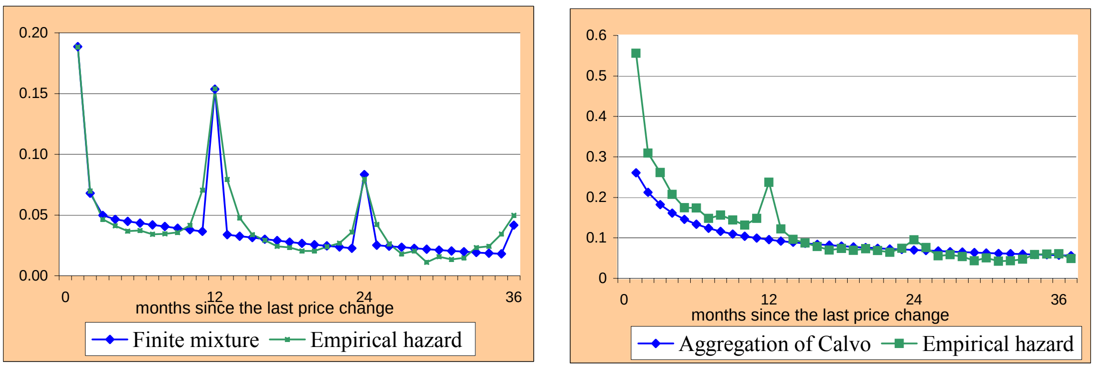
The existence of spikes in the hazard function every 12, 24, 36 ... months can be explained by the coexistence of different Taylor agents with contracts of those durations or by the annual Calvo model of Álvarez *et al.* (2005), but not with the rest of models considered in table 1. Note that the presence of these spikes is a reflection of the seasonality that is present in every quantitative micro data study [See e.g. Sabbatini *et al.* (2007) for the evidence in euro area countries].

To account for the three stylised facts on hazard rates, Álvarez *et al.* (2005) propose a parsimonious model made up of several Calvo agents and an annual Calvo agent. As can be seen in the left panel of figure 3, this provides a very accurate representation of individual data. Another possibility, as in Carvalho (2006) would be to consider that economies are made up of numerous sectors and that each of them follows a different Calvo pricing rule. This could be seen as producing a more accurate representation of the data. However, the results in the right panel of figure 3 point to some problems of this alternative hypothesis. Indeed, the aggregation of Calvo price setters misses some features of the hazard function of price changes. First, even considering a high number of sectors, within sector heterogeneity is likely to be present. In general, there will be some price setters who are more flexible than the average of the most flexible group and others that follow stickier pricing policies than the average of the stickiest group. Second, by construction, the hazard of the aggregate does not show annual spikes that are present in the data.

Figure 3

Hazard functions for price changes

Spanish producer prices | **United States consumer prices**



Introducing heterogeneity in pricing models leads to precise implications in terms of the hazard of the aggregate. In some cases, such as Taylor (1993), Álvarez *et al.* (2005) or Carvalho (2006), it generates a decreasing hazard rate. Generalising some other models could also lead to decreasing hazards. For instance, generalising Galí and Gertler (1999) to include several types of Calvo agents plus a fraction of rule of thumb price setters leads to a monotonically decreasing hazard rate and the same could be obtained introducing heterogeneity in Aoki (2001), Sheedy (2005) and Rotemberg (2005) models for certain parameter values. However, this will not necessarily happen. The aggregation of models that imply continuous price adjustment [sticky contract or information models, such as Lucas (1972), Fischer (1977), Mankiw and Reis (2002), Carvalho (2005), Reis (2006), Maćkowiack and Wiederholt (2007), models with convex costs of adjustment, such as Rotemberg (1982) or Kozicki and Tinsley (2002), or models with widespread and automatic indexation mechanism, such as Christiano *et al.* (2005) or Smets and Wouters (2003)] cannot generate a decreasing hazard rate. It is also relevant to note that the mixture of hazard rates which are zero for some horizons is also zero for those horizons[10]. This is a problem for models such as Wolman (1999) or Dotsey *et al.* (1999).

10. Note that if $h^1(j) = h^2(j) = 0$ for some j, then $h(j) = 0$.

6 Heterogeneity

As seen in the previous section, one possible explanation for the downward slope of hazard functions is that there is heterogeneity in pricing behaviour. However, most pricing models assume that all firms are identical. If differences in pricing behaviour exist but are not taken into account this will lead to misspecificied models.

Table 4

Heterogeneity in pricing behaviour

Monthly frequency of price changes (%).

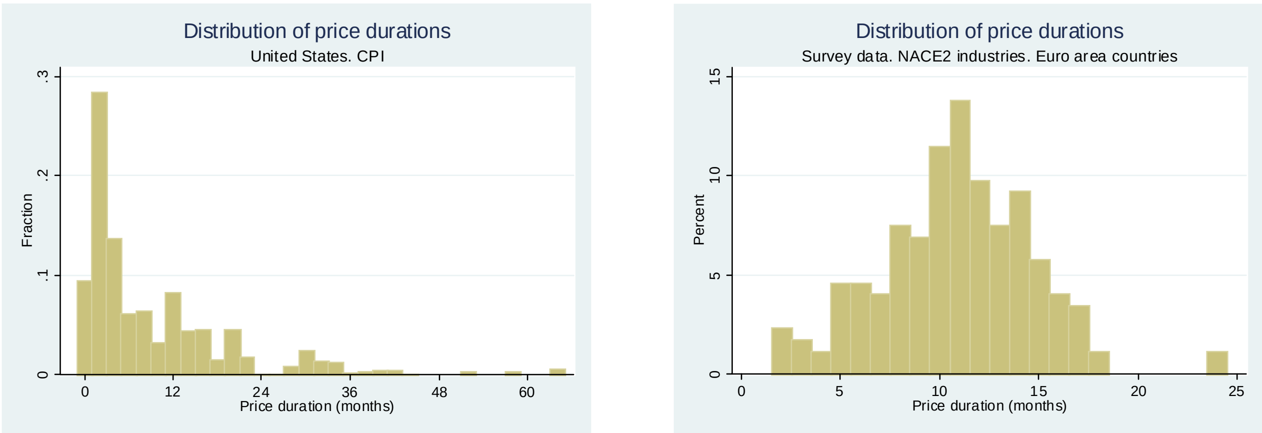
1. Consumer prices	Unprocessed food	Processed food	Energy	Non energy industrial goods	Services
Austria	37.5	15.5	72.3	8.4	7.1
Belgium	31.5	19.1	81.6	5.9	3
Denmark	57.5	17.6	94.6	8.3	7.3
Euro area	28.3	13.7	78	9.2	5.6
Finland	52.7	12.8	89.3	18.1	11.6
France	24.7	20.3	76.9	18	7.4
Germany	25.2	8.9	91.4	5.4	4.3
Italy	19.3	9.4	61.6	5.8	4.6
Japan	71.8	30.8	50.9	22.7	3.9
Luxembourg	54.6	10.5	73.9	14.5	4.8
Mexico	26.4	12.5	54.9	18.7	6.1
Netherlands	30.8	17.3	72.6	14.2	7.9
Portugal	55.3	24.5	15.9	14.3	13.6
Spain	50.9	17.7	n.a.	6.1	4.6
United States	47.7	27.1	74.1	22.4	15

2. Producer prices	Food	Durable products	Energy	Non-durable non-food	Intermediate products	Capital goods
Belgium	20	14	50	11	28	13
Euro area	27	10	72	11	22	9
France	32	13	66	10	23	12
Germany	26	10	94	14	23	10
Italy	27	7	n.a	10	18	5
Portugal	21	18	66	5	12	n.a
Spain	24	10	38	10	28	8

Source: Consumer prices: For euro area countries and United States, Dhyne *et al.* (2006); for Denmark, Hansen and Hansen (2006); for Japan, Saita *et al.* (2006) and for Mexico, Gagnon (2006). Figures for Mexico refer to the period 2003-2004. For producer prices, Vermeulen *et al.* (2007)

The recent micro evidence consistently finds that price adjustment is heterogeneous across firms. Indeed, as can be seen in table 4, sectors in which companies change prices frequently coexist with others in which firms frequently keep prices unchanged for relatively long periods. Some interesting findings arise. Specifically, CPI price adjustments are particularly frequent for energy and unprocessed food products, whereas services prices tend to remain constant for long periods. In turn, processed food products and non-energy industrial goods tend to occupy an intermediate ranking. Survey data also show that prices of food and energy are changed more frequently than for other goods or services [see Álvarez and Hernando (2007a) for Spain]. Within sector heterogeneity is still highly relevant, as can be seen in figure 4. The left panel presents the histogram of price durations in the Nakamura and Steinsson (2007) dataset of United States consumer price data. The right panel presents the histogram of price durations based on survey data of NACE 2 euro area industries used in Álvarez and Hernando (2007b). Available evidence [e.g. Jonker *et al.* (2004) for the Netherlands or Veronese *et al.* (2005) for Italy] also points out the impact of the type of outlet on the frequency of price adjustment. Indeed, the frequency of price changes is significantly higher in supermarkets and hypermarkets than in traditional shops, suggesting that the structure of the retail sector plays a role in explaining differences in the degree of price adjustment. Analysis of producer prices also finds that energy and food products are also characterised by more frequent price adjustment, whereas capital goods and durables are the stickiest components.

Figure 4



Heterogeneity in price adjustment is certainly a feature that needs to be considered in pricing models. Indeed, of the 25 models considered in Table 1 only 5 allow for heterogeneity of price changes and Galí and Gertler (1999) and Aoki (2001) only allow for a limited degree of heterogeneity, since a fraction of price setters adjust prices continuously, whereas the rest do it with an unrestricted and constant frequency. In turn, 3 models allow for quite general heterogeneity: Taylor (1993), Álvarez *et al.* (2005) and Carvalho (2006).

Interestingly, heterogeneity is found to be related to differences in industry characteristics[11] such as costs and market competition. For instance, the frequency of consumer price change depends on the variability of input prices [Hoffmann and Kurz-Kim (2006)] and differences in the cost structure help explain differences in the degree of producer price flexibility [Álvarez *et al.* (2008) and Cornille and Dossche (2006)], a result also found with survey data [Álvarez and Hernando (2007a and 2007b)]. Specifically, the share of labour costs in variable costs negatively affects the frequency of price change —given that wages do not change often—, whereas the share of costs of intermediate goods in variable costs has a positive impact. Regarding market competition, survey evidence shows that higher competition leads to more frequent price changes [Álvarez and Hernando (2007a and 2007b)], a result also found with consumer prices [Lünnemann and Mathä (2005)].

11. Some theoretical models, such as Danziger (1999) and Bonomo and Carvalho (2004), predict a positive relationship between the frequency of price change and the variance of idiosyncratic shocks.

7 Time dependent behaviour

Some estimators have been suggested in the literature to measure the relative importance of time-dependent price setters. The one most commonly used was introduced by Klenow and Kryvtsov (2005). Their measure[12] is given by $\alpha_{KK} = \frac{fr^2 \ Var(S_t)}{Var(\pi_t)}$, where fr and fr_t refer to the mean frequency of price change and frequency at time t, respectively, and $Var\,(S_t)$ and $Var\,(\pi_t)$ refer to the variance of the size of price change and inflation, respectively. Klenow and Kryvtsov (2005) define the numerator of the above expression as the time dependent component of the inflation variance, because that would be the value of $Var\,(\pi_t)$ if the frequency of price adjustment were constant. As stressed by Dias *et al.* (2007), it is important to notice that the type of staggering that implies $Var(\pi_t) = fr^2 \ Var(S_t)$ is uniform staggering, for which $fr_t = fr$. Models with continuous price adjustment and time dependent models predict a constant frequency of adjustment, so $\alpha_{KK} = 1$. As an alternative measure of time dependent behaviour, Dias *et al.* (2006) show that the complement of the Fisher and Konieczny (2000) index[13] (FK) can be seen as an estimator of the share of firms with uniformly staggered pricing behaviour.

Table 5 presents the results of these measures. In general, both measures point to the relevance of time dependent behaviour for countries with low and moderate inflation and are in line with the stability over time of the frequency of price change reported in the different micro studies. Interestingly, the Klenow and Kryvstov measure points to a very low share of time dependent price setters for Sierra Leone and Mexico, which is to be expected given the high inflation rates in those countries in the period under analysis.

Quantitative studies also find some specific elements of state dependence. For instance, inflation is associated with higher frequencies of price increases and lower frequencies of price decreases [see e.g. Veronese *et al.* (2005) for Italian CPI or Stahl (2006a) for German PPI evidence], although the magnitude of the effects is moderate. Indirect tax changes are also found to have an impact on the frequency of price adjustment [see e.g. Aucremanne and Dhyne (2004) for Belgian CPI or Álvarez *et al.* (2008) for Spanish PPI], although the share of firms that adjust prices following an indirect tax rate change is relatively small.

Survey data provide an alternative way of determining the relevance of time dependent behaviour (table 6). Firms have been asked for the strategy they follow when reviewing their prices. In the typical survey, they were offered the following options: "At specific time intervals", which can be interpreted as evidence of time dependence, "In response to specific events", which is in line with state dependent models, and "Mainly at specific time intervals, but also in response to specific events", which reflects a mixed strategy. In general, results show the coexistence of time and state dependent elements in pricing behaviour at the individual level.

12. If $Cov(\,fr\,S_t\,,(\,fr - fr_t\,)S_t \neq 0$ the Klenow and Kryvtsov (2005) measure may not be in the [0,1] interval. In practice, this term is typically small. See Dias et al. (2007) for a detailed discussion.

13. $FK = \sqrt{\frac{Var(\,fr_t\,)}{fr(1-fr)}}$

Table 5

Importance of time dependent behaviour. Quantitative micro data

	Consumer prices			Producer prices	
Country	Dias *et al.* measure	Paper	Klenow Kryvstov measure	Paper	Klenow Kryvstov measure
Austria	79				
Belgium	82			Cornille and Dossche (2006)	86 (36)
Finland	64	Kurri (2007)	98		
France	81	Baudry *et al.* (2007)	83	Gautier (2006)	92.2 (97.9)
Germany	87				
Italy	76				
Luxembourg	52				
Netherlands	73				
Portugal	83	Dias *et al.* (2006)	74 (69)	Dias *et al.* (2006)	92
Spain	85				
Euro area	82				
United States		Klenov and Kryvtsov (2005)	97(91)		
Mexico		Gagnon (2006)	34.6 (82.7)		
Sierra Leone		Kovanen (2006)	3.1		

Notes: Dias *et al.* (2005) measures computed as the complement of the median synchronisation ratio presented in Dhyne *et al.* (2005). Klenow-Kryvstov measures: For Portuguese CPI, figures refer to 1993-1997 and those in brackets to 1998-2000. For French PPI, figures in brackets control for seasonality, VAT rate changes and euro cash-changeover. For Belgian PPI, figures exclude the months of January and December, whereas those in brackets do not. For Mexican CPI figures refer to the high inflation 1995-1999 period, whereas those in brackets refer to the low inflation 1999-2002 period. For US CPI, figures in brackets refer to regular prices including substitutions

The evidence on country studies summarised in Fabiani *et al.* (2006) generally shows that the share of firms following mainly time-dependent rules is generally higher for other services than in trade, which, in turn, is higher than in manufacturing. Larger companies also tend to use time dependent rules slightly more often. To shed more light on the relationship between use of time dependent pricing strategies and industry characteristics, table 7 presents the results of a multinomial logit model with Spanish survey data. The following results are worth highlighting: First: time dependent rules tend to be used more the higher is the labour intensity of production processes, reflecting a higher stability of marginal costs in those industries. Second: the higher is the degree of perceived competition the lower is the fraction of firms using purely time-dependent rules. This result is consistent with the idea that prices of firms operating in more competitive markets are more likely to react to changes in their environment. Third, small sized firms tend to rely less on time dependent pricing strategies.

Overall, there seems to be a need to develop more realistic theoretical state dependent models, though, since implications of the most widespread models are at odds with micro data. For instance, menu cost models, assume that firms evaluate their pricing policy every period and set a new price if they find it convenient. However, in practice, firms do not continuously evaluate their pricing plans. Fabiani *et al.* (2006) and Lünnemann and Mathä (2007) show that firms review prices infrequently. Indeed, for the euro area as a whole, Fabiani *et al.* (2006) find that 57% of firms review prices not more than three times a year and only 12% review more than once a month. The modal firm reviews prices once a year, a result also found for non euro area countries [Lünnemann and Mathä (2007)]. These results are in line with the predictions of Reis (2006) inattentiveness model, which rationalises infrequent price reviewing. Unfortunately, this model also predicts that firms must change prices continuously.

Table 6

Importance of time dependent behaviour. Survey data
Share of firms (%)

Country	Paper	Time-dependent	Time and state dependent
Austria	Kwapil *et al.* (2005)	41	32
Belgium	Aucremanne and Collin (2005)	26	40
Canada	Amirault *et al.* (2006)	66	-
Estonia	Dabušinskas and Randveer (2006)	27	50
Euro area	Fabiani *et al.* (2006)	34	46
France	Loupias and Ricart (2004)	39	55
Germany	Stahl (2005)	26	55
Italy	Fabiani *et al.* (2007)	40	46
Luxembourg	Lünnemann and Mathä (2006)	18	32
Netherlands	Hoeberichts and Stokman (2006)	36	18
Portugal	Martins (2005)	35	19
Spain	Álvarez and Hernando (2007a)	33	28
United Kingdom	Hall *et al.* (2000)	79	10
United States	Blinder *et al.* (1998)	60	10

For US: time and state dependent considers periodic price reviews for some products but not for others. For France, the figure corresponds to the one reported in Fabiani *et al.* (2006)

An additional problem for menu costs models is that they are typically among the least recognised theories by firms[14], despite their prevalence in theoretical research. Fabiani *et al.* (2006) report that menu costs rank eight out of ten theories for the euro area and similar results are reported by Lünnemann and Mathä (2007) for other countries. Theories in which information is costly are even ranked lower [Fabiani *et al.* (2006)]

14. Only 10.9% and 7.6% of Spanish firms state that menu costs and information costs, respectively, are important or very important reasons for deferring price changes. The corresponding figures for implict contracts, coordination failure and explicit contracts are 57.8%, 43.1% and 39.2%, respectively [Álvarez and Hernando (2007a)].

Table 7

Multinomial logit regression. Price review

Vatiable	Time dependent			Time and state dependent		
	Coefficient	Standard error	z	Coefficient	Standard error	z
Labour	3.15	0.55	5.7	2.16	0.58	3.7
Competition	-0.12	0.06	-2.1	0.06	0.06	1.1
Demand conditions	0.04	0.03	1.3	0.07	0.03	2.1
Small sized firm	-0.48	0.12	-3.9	-0.68	0.13	-5.4
Food	-0.61	0.41	-1.5	0.41	0.47	0.9
Consumer non food	-0.29	0.38	-0.8	0.54	0.45	1.2
Intermediate	-1.52	0.37	-4.1	-0.37	0.44	-0.8
Capital goods	-1.34	0.38	-3.5	-0.11	0.45	-0.3
Food trade	-0.18	0.41	-0.4	0.23	0.48	0.5
Energy trade	0.05	0.75	0.1	0.23	0.91	0.3
Other trade	0.02	0.37	0.1	0.63	0.44	1.4
Hotels and travel agents	0.27	0.44	0.6	1.09	0.52	2.1
Bars and restaurants	-0.56	0.39	-1.4	0.59	0.46	1.3
Transport	-0.07	0.37	-0.2	0.66	0.46	1.5
Communications	-0.67	0.47	-1.4	-0.21	0.58	-0.4
Constant	-0.24	0.38	-0.6	-1.40	0.45	-3.1

Number of observations	1847
Wald chi2 (30)	213.08
Log likelihood	-1881.63
AIC	3768.71
BIC	3945.39
Pseudo R2	0.07

Reference group: State dependent. Reference sector: Energy
Robust standard errors

8 Forward looking behaviour

Survey evidence allows determining to which extent pricing policies of firms are forward looking, as typically assumed in theoretical models. Table 8 presents evidence on forward looking pricing behaviour in the surveys of the United States and Canada. The evidence shows substantial departures from the hypothesis of forward looking price setters. In particular, a significant fraction of firms is not affected by changes in the outlook for the national economy. The impact of future inflation is generally more important, although less so than anticipated firm specific costs[15]. However, only 45% of US firms and 40% of Canadian firms state that they will raise prices in the face of anticipated costs increases. When asked about the reasons for not changing prices in this context, firms give especial attention to coordination failure and implicit and explicit contract explanations. These are also the theories that tend to receive the broadest support in surveys carried out in other countries [Fabiani *et al.* (2006) for euro area countries].

Table 8

Forward looking price behaviour. American surveys

Share of firms (%)

United States

1. Do forecasts about the future outlook for the national economy ever directly affect the prices you set?

Never	70.5
Ocassionally	15.0
Often	14.5

2.Do forecasts of future economy-wide inflation rates ever directly affect the prices you set?

Never	51.8
Ocassionally	19.9
Often	28.3

3. When you see cost or wage increase coming, do you raise your prices in anticipation?

Yes or often	44.4
No or rarely	55.6

4. Why do not firms raise their prices in the face of anticipated cost increases?

We worry competing firms won't raise their prices	26.4
It would antagonize or cause difficulty for our customers	25.6
Once costs rise, we can raise our prices promptly	14.9
We lack confidence in our cost forecasts	8.3
Contracts or regulation prohibit anticipatory price hikes	6.6
Other	18.2

Canada

If you foresee an increase in your future costs (such as raw materials), do you raise your own prices in anticipation?

Yes	40
Other	60

Source: For the United States, Blinder *et al.* (1998). Question 3 only asked to firms that do not consider cost totally unimportant. Question 4 only asked to firms that do not rise prices in anticipation of cost increases. For Canada, Amirault *et al.* (2006)

15. In Maćkowiak and Wiederholt (2007) firms pay more attention to idiosyncratic shocks than to aggregate conditions if idiosyncratic shocks are more variable than economy-wide ones.

Table 9 presents the evidence of European surveys. Again, the existence of a significant share of firms deviating from full forward looking behaviour is found. Interestingly, some surveys have asked firms whether they follow some simple rule of thumb when setting prices (for instance, changing prices by a fixed percentage) or whether they consider a wide set of indicators that relate to the current environment (backward looking firms) or include expectations on the future economic environment (forward looking firms). It is found that around one third of firms employ some simple rule of thumb when setting prices, in line with Galí and Gertler (1999), a prediction which is not shared by any other theoretical model. However, Álvarez and Hernando (2007a) find that the fact that a firm applies a rule of thumb has a significative negative impact on the frequency of price change, so firms which use simple rule sof thumb change prices less frequently than the rest. In contrast, in Galí and Gertler model (1999) rule of thumb price setters change prices continuously and the rest of companies adjust prices less often. Probably, a rule of thumb whereby firms change prices once a year, in line with aggregate yearly past inflation, would capture inflation dynamics more realistically and would also capture seasonal behaviour.

Table 9

Forward looking price behaviour. European surveys

Share of firms (%)

Country	Rule of thumb	Backward looking	Forward looking
Belgium	37	29	34
Estonia	n.a.	59	41
Luxembourg	32	34	34
Portugal	25	33	42
Spain	33	39	28
	Past information	Past information and forecasts	Forecasts
Austria	37	51	12
	Past information	Contemporary information	Expectations
Germany	23	55	15
	Past information	Current and future information	
Italy	32	68	

Note: For Germany, rescaled figures from Stahl (2006b) on firms stating that the corresponding information vintage is very important.

To analyse the relationship between the information set that a firm uses and industry characteristics, Table 10 presents the results of a multinomial logit model with Spanish survey data. Some interesting results are obtained: First, a higher sectoral labour share is associated with a greater reliance on rule of thumb behaviour, reflecting lower uncertainty in total costs developments. Second, the higher is the degree of market competition, the higher is forward looking behaviour. Third, the more relevant are demand conditions the higher is the use of forward looking strategies. Fourth, small sized firms are more likely to adopt some simple rule of thumb.

Table 10

Multinomial logit regression. Information set

	Backward looking			Forward looking		
	Coefficient	Standard error	z	Coefficient	Standard error	z
Labour	-2.16	0.54	-4.0	-1.92	0.61	-3.1
Competition	0.21	0.05	4.0	0.21	0.06	3.4
Demand conditions	0.09	0.03	3.0	0.13	0.04	3.6
Small sized firm	-0.22	0.12	-1.9	-1.13	0.14	-8.0
Food	0.44	0.40	1.1	0.32	0.43	0.7
Consumer non food	0.35	0.38	0.9	0.30	0.39	0.8
Intermediate	0.65	0.37	1.8	0.51	0.37	1.4
Capital goods	0.26	0.38	0.7	0.04	0.38	0.1
Food trade	0.07	0.41	0.2	-1.05	0.46	-2.3
Energy trade	1.25	0.93	1.3	0.95	1.08	0.9
Other trade	0.14	0.37	0.4	-0.32	0.39	-0.8
Hotels and travel agents	0.70	0.41	1.7	0.99	0.42	2.4
Bars and restaurants	0.29	0.38	0.8	-0.47	0.43	-1.1
Transport	-0.13	0.37	-0.4	-0.35	0.39	-0.9
Communications	-0.50	0.54	-0.9	0.39	0.45	0.9
Constant	-0.35	0.38	-0.9	-0.49	0.40	-1.2
Number of observations	1847					
Wald chi2 (30)	253.33					
Log likelihood	-1852.35					
AIC	3768.71					
BIC	3945.39					
Pseudo R2	0.07					

Reference group: Rule of thumb. Reference sector: Energy

Robust standard errors

9 Imperfect competition

One defining characteristic of New Keynesian price setting models is some element of imperfect competition, which provides a price formation story: prices arise from the profit-maximizing decisions of individual firms. Imperfect competition also makes it feasible for some firms not to adjust their price in a given period, in contrast with a perfect competition environment.

The various surveys address the issue of how firms set prices using slightly different formulations. Nevertheless, the results of the national surveys can be compared by grouping the answers into three alternatives: “markup over costs”, “price set according to competitors’ prices” and “other”. For the euro area as a whole, a significant share of firms (54%) set their prices as a markup over marginal costs, suggesting that they enjoy a non negligible degree of market power. The fraction of companies setting prices according to those of their competitors is 27%. Finally, around 19% of the companies state that they do not have autonomous price setting policies. For these firms, the final decision on the price charged is taken by a different economic agent, and this may be the public sector, the parent company, the main customers or the suppliers. Country results, as reported in table 11, provide a similar picture. Overall, survey evidence provides strong support for the view that imperfect competition characterizes most product markets. Imperfect competition, though, seems to be of a more complex kind than implied by the monopolistic competition model, since there is evidence of e.g. price discrimination.

Table 11

Price setting rules

	Markup	Variable mark-up	Competitors' price	Other
Belgium	46	33	36	18
Estonia	53		46	2
Euro area	54		27	18
France	40		38	22
Germany	73	69	17	10
Italy	42		32	26
Netherlands	56	30	22	21
Portugal	65		13	23
Spain	52		27	21

Notes: 1. Rescaled figures excluding non-responses. 2. For Belgium, variable markup corresponds to firms adopting a markup rule and responding “important” or “very important” to at least one of the theories concerning countercyclical markups. 3. For Portugal, the question was not addressed directly. The information reported in the table has been estimated on the basis of the answers to other questions. 4. For Estonia, firms were asked to assess the relevance of different price setting rules – the results in the table refer to the most relevant rule chosen.
Source: For euro area countries, Fabiani *et al.* (2006). For Estonia, Dabušinskas and Randveer (2006)

10 Concluding remarks

This paper finds that theoretical models considerably differ in their ability to match the main micro stylised facts (table 12), but none is available to account for all of them, suggesting the need to develop more realistic micro-founded price setting models. Surprisingly, an important number of theoretical models is unable to account for any of the main micro stylised facts.

Three aspects that need to be incorporated in most theoretical models are the existence of heterogeneity in the frequency of price adjustment —which probably lies behind the downward sloping hazard rate—, non optimal price setters, and seasonality —which is reflected in annual spikes in the hazard rate. Incorporating heterogeneity is particularly important since in multi-sector economies monetary shocks have considerably larger and more persistent real effects than in identical-firms economies with similar degrees of rigidities [Aoki (2001), Carvalho (2006)]. However, not all models can be generalised to generate sectoral differences in the frequency of price adjustment. This is case for all models that imply continuous price adjustment, such as Carvalho (2005) heterogeneous version of Mankiw and Reis (2002).

A non negigible fraction of firms seem to follow non optimal behaviour when setting prices, but only Galí and Gertler (1999) this non optimal feature in terms of rule of thumb price setters[16]. This suggests the need to include this feature in other theoretical models and derive its implications for monetary policy. However, available evidence suggests that firms which use simple rules of thumb change prices less frequently than the rest, instead of continuously, as in Galí and Gertler (1999). Models in which rule of thumb firms change prices once a year, in line with annual inflation, are likely to capture inflation dynamics more realistically. This would also help capture existing seasonality. Only the models by Taylor (1993) and Álvarez *et al.* (2005) account for seasonality.

Survey evidence also suggests that elements of state dependence should play a role. However, there seems to be a need to develop more realistic theoretical state dependent models, since implications of the most widespread models are at odds with micro data. For instance, menu costs models, assume that firms evaluate their pricing policy every period and set a new price if they find it convenient. However, in practice, firms do not continuously evaluate their pricing plans and models that rationalise infrequent price reviewing, like Reis (2006) inattentiveness model, unfortunately also predict that firms must change prices continuously. An additional problem for menu costs models is that they are typically among the least ranked theories by firms. This is also the case for theories that stress that information is costly. According to surveys, particularly relevant are models that emphasize implicit contracts, as in Rotemberg (2005), or the existence of some sort of coordination failure.

16. In Christiano et al. (2005) and Smets and Wouters (2003) all firms behave non optimally a fraction of their time.

Table 12

Conformity of pricing models with micro data stilised facts						
	Infrequent adjustment	Hazard rate			Heterogeneity in adjustment	Non optimality of price setters
		Always non-zero	Decreasing	Annual spikes		
Sticky information						
Carvalho (2005)	No	No	No	No	No	No
Fischer (1977)	No	No	No	No	No	No
Lucas (1972)	No	No	No	No	No	No
Maćkowiak and Wiederholt (2007)	No	No	No	No	No	No
Mankiw and Reis (2002)	No	No	No	No	No	No
Reis (2006)	No	No	No	No	No	No
Menu costs						
Danziger (1999)	Yes	Yes	No	No	No	No
Dotsey *et al.* (1999) (2)	Yes	No	No	No	No	No
Nakamura and Steinsson (2007)	Yes	Yes	No	No	No	No
Sheshinski and Weiss (1977)	Yes	No	No	No	No	No
Time dependent						
Álvarez *et al.* (2005)	Yes	Yes	Yes	Yes	Yes	No
Aoki (2001)	Yes	Yes	No	No	Yes	No
Bonomo and Carvalho (2004)	Yes	No	No	No	No	No
Calvo (1983)	Yes	Yes	No	No	No	No
Carvalho (2006)	Yes	Yes	Yes	No	Yes	No
Gali and Gertler (1999)	Yes	Yes	No	No	Yes	Yes
Sheedy (2005)	Yes	Yes	Yes	No	No	No
Taylor (1980)	Yes	No	No	No	No	No
Taylor (1993)	Yes	Yes	No	Yes	Yes	No
Wolman (1999)	Yes	No	No	No	No	No
Generalised indexation						
Christiano *et al.* (2005)	No	No	No	No	No	Yes
Smets and Wouters (2003)	No	No	No	No	No	Yes
Convex costs of adjustment						
Kozicki and Tinsley (2002)	No	No	No	No	No	No
Rotemberg (1982)	No	No	No	No	No	No
Consumer anger						
Rotemberg (2005)	Yes	Yes	Yes	No	No	No

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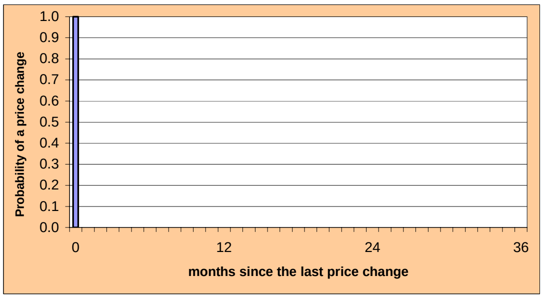
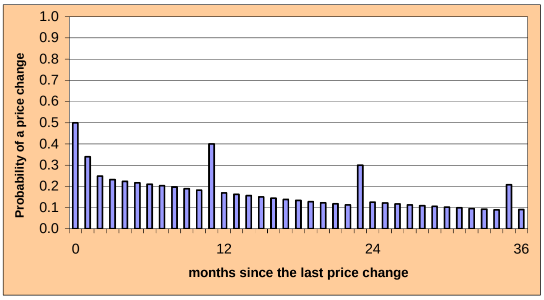
Appendix 1a

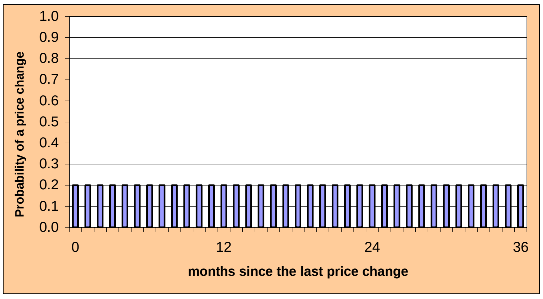
Continous price adjustment [1]



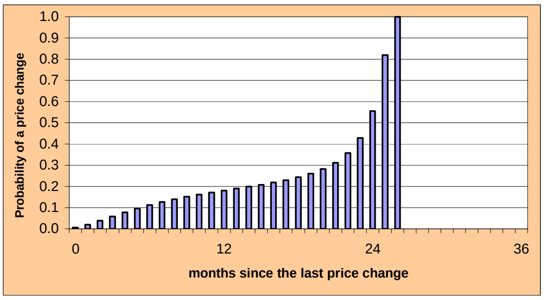
Stylised facts



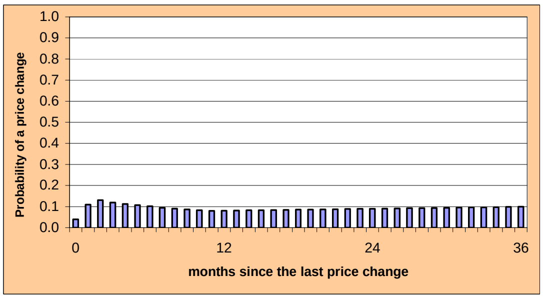
Calvo (1983), Danziger (1999) and Rotemberg (2005) [2]



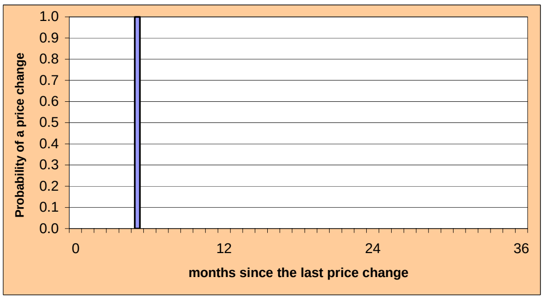
Dotsey *et al.* (1999)



Nakamura and Steinsson (2007)



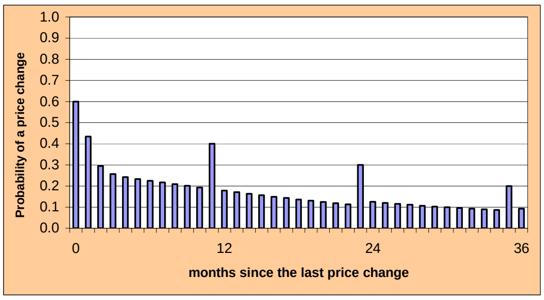
Sheshinski and Weiss (1977), Taylor (1980), Bonomo and Carvalho (2004)



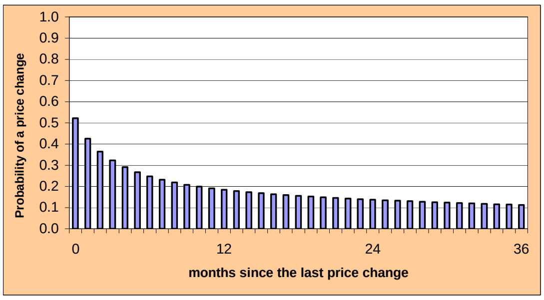
Notes: [1] Lucas (1972), Fischer (1977), Mankiw and Reis (2002), Carvalho (2005), Reis (2006), Maćkowiack and Wiederholt (2007), Christiano et al. (2005), Smets and Wouters (2003), Rotemberg (1982) and Kozicki and Tinsley (2002) [2] Rotemberg (2005): particular case

Appendix 1b

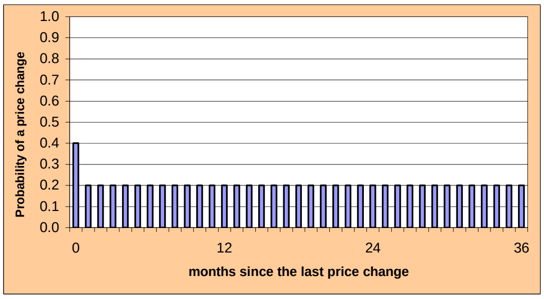
Álvarez *et al.* (2005)



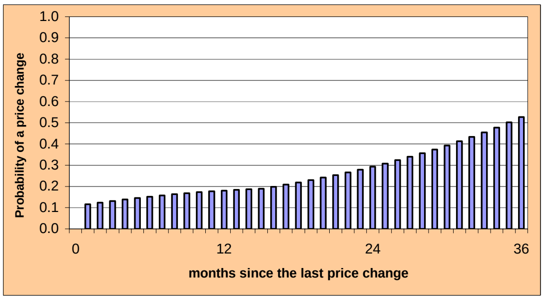
Carvalho (2006)



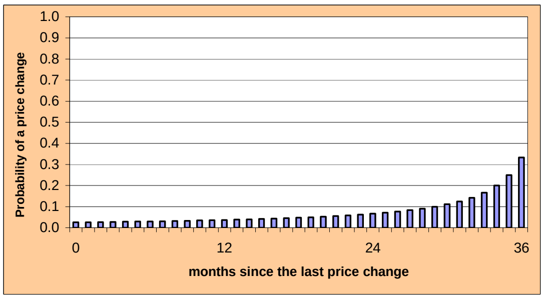
Gali and Gertler (1999) and Aoki (2001)



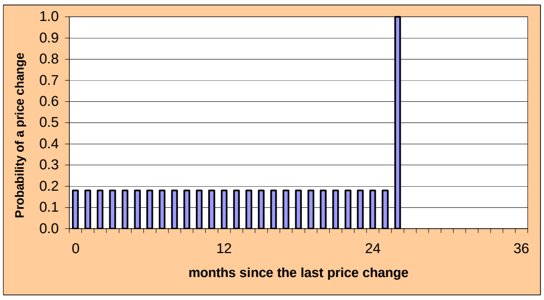
Sheedy (2005)



Taylor (1993) [3]



Wolman (1999)



[3] Assuming that the distribution of contracts is uniform over [1, 40]

Appendix 2

Data definitions for variables used in multinomial logit models

Variable	Source	Comment
Labour	Industrial, Trade and Services surveys. Instituto Nacional de Estadíitica	Labor costs as a percentage of labour and intermediate inputs costs. NACE 3 digit level
Compettition	Álvarez and Hernando (2007a)	Importance of competitors' prices to explain price decreases.
Demand conditions	Álvarez and Hernando (2007a)	Importance attached by firms to demand conditions in explaining price changes.
Small sized firm	Álvarez and Hernando (2007a)	Employment of firms with less than 50 employees.

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