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Microeconomic rigidities and aggregate price dynamics*

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This paper is an attempt to enrich the characterization of the sluggish behavior of the aggregate price level. Our contribution to this vast literature is to explicitly consider microeconomic heterogeneity and its interaction with nonlinear microeconomic price adjustment policies. The model we propose outperforms the constant-probability-of-adjustment/partial-adjustment model in describing the path of postwar U.S. inflation. Using only aggregate data, we infer that the probability that a firm adjusts its price depends on the sign *and* the magnitude of the deviation of the price from its target level. At the aggregate level we find that the aggregate price level responds less to negative shocks than to positive shocks, that the size of this asymmetry increases with the size of the shock, and that the number of firms changing their prices – and therefore the flexibility of the price level to aggregate shocks – varies endogenously over time in response to changes in economic conditions.

1. Introduction

There is substantial evidence on the stickiness of the aggregate price level: researchers have estimated a variety of partial-adjustment-like equations substantiating a lack of instantaneous adjustment. This conclusion is reached almost regardless of the way the target price level is defined. For example, it does not seem to depend on the nature of expectations, as it holds in the standard partial adjustment model where the target is the 'static-frictionless' price [e.g., Eckstein and Fromm (1968), de Ménil (1974) and Gordon (1981, 1984)] as well as in rational expectations equilibrium models [Rotemberg (1982)]. Furthermore, this conclusion also does not depend on the place where nominal rigidities are looked for, as it holds in models where the

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precise source of rigidity is unspecified and broad [e.g., Gordon (1981, 1984)],[1] as well as in models where the price rigidity is measured conditional on factor prices and productivity [Blanchard (1987)].

The standard formalization of the dynamic aspects of the partial adjustment setup is obtained by introducing quadratic adjustment costs of changing prices (or wages) at the firm level [Rotemberg (1982)], which leads to continuous but slow price adjustments at the firm level. Since this model conveys linear microeconomic policies, the aggregate simply replicates the microeconomic partial adjustment equation.[2] The lack of realism of the microeconomic behavior in the preceding description led researchers to an alternative interpretation where, instead of having all firms adjust partially, a fraction of firms adjusts fully. Rotemberg (1987) shows that this probabilisitic interpretation of the partial adjustment model is observationally equivalent to the standard interpretation, as long as the probability of adjusting is *independent* of the deviation between firms' prices and their corresponding targets [as in Calvo (1983)].

Although elegant and simple, the aforementioned independence assumption is not as innocuous as may seem at first glance. At the microeconomic level, it rules out realistic considerations, such as the influence of the magnitude of the deviation between actual and target prices on the likelihood of a price adjustment, and possible asymmetries in this likelihood with respect to the sign of this deviation. At the aggregate level, it implies that the number of firms adjusting their prices, and price elasticity with respect to aggregate shocks, do not change over time. It also implies that the response of the price level to shocks above and below their mean is symmetric.

In this paper we relax the independence assumption. Using aggregate data and a tight stochastic structure, we follow a methodology developed in Caballero and Engel (1992a) and estimate flexible functions describing the probability of individual price adjustment as a function of the magnitude of the deviation, which we call *adjustment hazard* functions. For postwar U.S. data, we reject the independence assumption in favor of an adjustment hazard function that is increasing with respect to the magnitude of the deviation between firms' prices and their respective target levels. We also find that – still at the microeconomic level – there is more downward than upward rigidity.

The hazard function we estimate implies a non-linear behavior of the aggregate price level with history dependent impulse responses. The extent to which prices adjust and the asymmetry between the price level's response to shocks that are above and below average depend on the current cross-section

[1]In these models the lack of response of the GNP deflator to aggregate demand shocks may be due to prices *or* wages [Fischer (1977) and Taylor (1980)].

[2]This assumes that structural parameters are the same across firms.

distribution of price deviations. We construct an index of aggregate price flexibility which captures the response of the price level to aggregate shocks at a given instant in time. We find that this index varies significantly during the time period considered (1955–1989): it increases from 53% in 1968 to 73% in 1975. In contrast, this index is constant and equal to the adjustment probability in the case of the partial adjustment model.

We also define an index that measures the degree of asymmetry in the aggregate response to positive and negative aggregate innovations; this index remains constant and equal to zero for partial adjustment models. The model we estimate implies that the price level is more sensitive to shocks that are larger than average than to shocks that are smaller than average. Furthermore, this asymmetry increases with the size of the shocks. The largest degree of asymmetry over the period considered, which is attained in 1976, is equal to 5% for small shocks (one standard deviation from their mean) and increases to 16% when large shocks (three standard deviations from their mean) are considered. The qualitative features of these results remain valid even when we impose symmetry in the microeconomic policy. In this case the largest degree of aggregate asymmetry is still attained in 1976, and is equal to 4% for small shocks and 12% for large shocks.

The paper has four sections in addition to this introduction. Section 2 reviews the partial adjustment model and the observationally equivalent constant hazard model. Section 3 describes the non-constant hazard models and discusses the measures of stickiness and aggregate asymmetries considered. Section 4 presents the estimation methodology and the results. Section 5 concludes.

2. The partial adjustment model

Because of its simplicity and ability to capture the substantial serial correlation of inflation, the partial adjustment model (PAM) has played a central role in discussions of aggregate price stickiness. In this section we describe this model in detail, since it defines the benchmark for the more general case discussed later in the paper.

Letting $p_{i,t}$ and $\tilde{p}_{i,t}$ denote firm i's (logarithm of) actual and target price at time t, respectively, we can write the partial adjustment equation as

$$\Delta p_{i,t+1} = \lambda(\tilde{p}_{i,t+1} - p_{i,t}),$$

where $\Delta x_t \equiv x_t - x_{t-1}$. Straightforward algebraic steps lead to

$$\Delta p_{i,t+1} = \lambda \Delta \tilde{p}_{i,t+1} + (1-\lambda)\Delta p_{i,t},$$

which, after aggregating across firms under the assumption that all firms have the same partial adjustment coefficient, yields the equation

$$\Delta p_{t+1} = \lambda \Delta \tilde{p}_{t+1} + (1-\lambda)\Delta p_t, \tag{1}$$

where the notation without the subindex i indicates the aggregate.

This derivation assumes that each individual firm adjusts continuously. An alternative way of deriving eq. (1) – due to Rotemberg (1987) based on Calvo's (1983) model – is to assume that individual firms adjust infrequently, but that when they do so, they adjust fully. The equivalence is obtained when a firm's adjustment within any given period occurs with probability λ. For realism and comparability with our discussion later in the paper, in what follows we favor this discontinuous adjustment/probabilistic interpretation of eq. (1).

In order to complete the characterization of prices one must determine the target price, $\tilde{p}$. In the standard partial adjustment model this typically corresponds to some 'frictionless' price, p^*, where frictionless may refer to the economy as a whole or to a more basic partial equilibrium concept where the price of factors of production and intermediate inputs as well as exogenous productivity are taken as given. This procedure is consistent with rational expectations (up to a constant) if the increments in p^* are independent. If the latter does not hold, forward looking firms will consider the signal contained in currently available data about future changes in their 'frictionless' prices, for prices set today are expected to persist for $1/\lambda > 1$ periods.[3]

In order to compute $\tilde{p}_{it}$, consider the situation of a firm that has already chosen (or been given) a probability of adjusting its price within a period (equal to λ). Also assume that the firm has discount rate δ and that the flow loss from a deviation between actual and frictionless prices is proportional to the square deviation. The target price is now easily computed by obtaining the first-order condition of the problem

$$\min_{\tilde{p}_{i,t}} \mathrm{E}_t\left[\sum_{s=t}^{\infty}\left(\frac{1-\lambda}{1+\delta}\right)^{s-t}(\tilde{p}_{i,t}-p^*_{i,s})^2\right],$$

where E_t denotes the expectation conditional on all information available at time t, and the realizations of $\{p^*_{i,s}\}_{s\geq t}$ are exogenous to the firm.

This yields the solution

$$\tilde{p}_{i,t} = p^*_{i,t} + \sum_{s=t}^{\infty}\left(\frac{1-\lambda}{1+\delta}\right)^{s+1-t}\mathrm{E}_t[\Delta p^*_{i,s+1}].$$

Aggregating across individual firms yields

[3]In a sense, pre-rational expectations papers recognized these issues and partially incorporated them by expanding the partial adjustment equations to incorporate additional lags of frictionless prices on the right-hand side.

$$\tilde{p}_t = p_t^* + \sum_{s=t}^{\infty} \left(\frac{1-\lambda}{1+\delta}\right)^{s+1-t} \mathrm{E}_t[\Delta p_{s+1}^*]. \tag{2}$$

To complete our specification of the partial adjustment model, we must specify how we measure p_t^* and how we model its dynamic behavior. As mentioned above, one possibility is to define it as the price level that would yield an equilibrium output level equal to the long-run/potential one [e.g. Gordon (1981)]. An alternative, which is the one we follow here, is to start from the microeconomic units and describe frictionless prices *given* the actual value of variables affecting the firm's desired price but that also can be sluggish (e.g., wages and price of materials), as in Blanchard (1987). The former approach captures overall nominal rigidities, including prices and wages, while the latter reflects only conditional price rigidities.[4]

In the spirit of the latter approach, let us construct the frictionless price from a simple constant markup equation:

$$p_{i,t}^* = \mu + \sum_j \alpha_j p_{j,i,t}^{\mathrm{m}} + \left(1 - \sum_j \alpha_j\right) w_{it}, \tag{3}$$

where μ is the desired markup, the p_j^{m}'s are prices of materials, and w is the (nominal) unit labor cost (i.e., it takes into account wages and productivity fluctuations).[5] The coefficients α_j are later estimated using cointegration procedures and are assumed to be the same across firms. Thus after aggregating over all firms we obtain

$$p_t^* = \mu + \sum_j \alpha_j p_{j,t}^{\mathrm{m}} + \left(1 - \sum_j \alpha_j\right) w_t. \tag{4}$$

Next, we obtain the expected increments in p^* from its univariate representation.[6] Using this, together with eqs. (1) and (2), the partial adjustment model is fully characterized.

It is important to notice that if the discount factor is not too large, the forward looking nature of $\tilde{p}$ removes part of the difference between measures of conditional (on wages and material prices) and unconditional stickiness. Except for discounting, $\tilde{p}$ accounts for future changes in wages and material prices that are due to current shocks.

[4]One cannot conclude from this that the latter is a lower bound for the sluggishness of the former.

[5]Under (short-run) constant returns to labor, productivity fluctuations are entirely exogenous to the firm. Otherwise, they are determined partly by the firm's actual price and one should not interpret $p_{i,t}^*$ as the price the firm would charge if it didn't face adjustment costs; it still can be used for our purposes, however. Also note that unit labor cost captures average, not marginal productivity; the former is a 'reasonable' proxy of the latter nonetheless [see de Ménil (1974, p. 132)].

[6]Feedbacks can also be considered by using the bivariate representation of p^* and p.

3. Heterogeneity and non-constant adjustment hazards

The probabilistic interpretation of the partial adjustment framework reveals the unpleasant microeconomic underpinnings of such a model. In particular, it seems highly unrealistic that the probability that a firm adjusts its price is independent of the magnitude of the deviation of the price from its target level. A more reasonable conjecture is that this probability *increases* with the magnitide of the deviation.

Also, if there is sufficient symmetry in the underlying loss and adjustment cost functions, we expect the probability of adjusting upward to be larger than that of adjusting downward (for a given absolute deviation) if core inflation is positive. Furthermore, at the aggregate level it seems unlikely that the number of firms adjusting should be constant as implied by the partial adjustment model. Again, a more reasonable conjecture is that large shocks lead more firms to change their prices than small shocks.

The main purpose of this paper – and this section in particular – is to study the implications of relaxing the independence or *constant hazard* assumption in the directions suggested by the previous two paragraphs for *aggregate* price equations.

3.1. The adjustment hazard approach

The first obstacle that arises when relaxing the constant hazard assumption is that doing so necessarily implies that heterogeneity must be incorporated explicitly into the model. If a firm's probability of adjusting depends on the difference between its actual and target prices, a difference we denote by z_{it}, understanding aggregate price dynamics requires keeping track of the evolution of the cross-section of price deviations at all points in time [Caballero and Engel (1991)]. We summarize these deviations in terms of a cross-section distribution, $F_t(z)$. Different cross-section distributions $F_t(z)$ generally lead to different average probability of adjusting, and therefore a different number of units that actually adjust, even when the mean deviation is the same. The only case where all the relevant information is summarized in the first moment of the cross-section distribution is when the adjustment hazard is constant;[7] once this assumption is relaxed, higher (and usually unobserved) moments of the cross-section distribution of price deviations necessarily matter.

Let us represent a firm's probability of adjusting in a given time period by a hazard function, $\Lambda(z)$. Thus the probability that a firm adjusts its price in any given time period depends on the value of the deviation from its target price.[8] The z_{it}'s change over time because of several reasons: First,

[7]This can be seen by rewriting eq. (1) as $\Delta p_{t+1} = \lambda(\Delta \tilde{p}_{t+1} - \bar{z}_t)$, where $\bar{z}_t \equiv \int_{-\infty}^{\infty} z \, \mathrm{d}F_t(z)$.
[8]We could also allow for the possibility of time-varying hazards.

aggregate shocks shift the average $\tilde{p}_{i,t}$. Second, occasionally firms adjust their prices. And third, there are idiosyncratic shocks to the factors determining frictionless and, therefore, target prices; like productivity and individual demand shocks. This last factor, i.e. idiosyncratic shocks, which is totally irrelevant for aggregate dynamics in the partial adjustment framework since it only affects higher moments, plays an important role once the adjustment hazard is non-constant. Throughout we assume that idiosyncratic shocks are generated by independent random walks with standard deviation of their increments equal to σ_I.

As a matter of convention, we let the realization of idiosyncratic shocks occur at the beginning of period t, and let $F_t(z)$ represent the cross-section distribution of deviations just after these shocks have been realized. Idiosyncratic shocks are followed by the aggregate shock, $\Delta\tilde{p}_{t+1}$, that shifts firms from z to their respective $z-\Delta\tilde{p}_{t+1}$ location in state space. At this point a fraction $\Lambda(z-\Delta\tilde{p}_{t+1})$ of the firms at each location $z-\Delta\tilde{p}_{t+1}$ adjust their prices, and they do so by an amount equal to $\Delta\tilde{p}_{t+1}-z$. A straightforward calculation [see Caballero and Engel (1992a)] then leads to the following expression for inflation during the time interval $[t, t+1)$:[9]

$$\Delta p_{t+1} = \int_{-\infty}^{\infty} (\Delta\tilde{p}_{t+1}-z)\Lambda(z-\Delta\tilde{p}_{t+1})\,\mathrm{d}F_t(z). \tag{5}$$

The aggregate shock $\Delta\tilde{p}_{t+1}$, together with actual price changes at the firm level, $\Delta\tilde{p}_{i,t+1}$, and the realization of new idiosyncratic shocks yields a new cross-section distribution, $F_{t+1}(z)$, starting from $F_t(z)$. The unfolding of this sequence of events fully determines the evolution of the aggregate price level. We return to this in the empirical section.

3.2. Heterogeneity and non-constant hazards: An example

In the empirical section we look for departures from partial adjustment/constant probability models that seem realistic at the *microeconomic* level. However, we judge the success of the results by their ability to explain the dynamic behavior of the *aggregate* price level. In particular, we study whether allowing the (microeconomic) hazard to be (i) increasing with respect to the distance from the current price to its target and, (ii) asymmetric with respect to upward and downward price adjustments, improves the aggregate fit. In this subsection we highlight potential consequences of these generalizations.

Consider a simple hazard function capturing (i) and (ii):

[9]The determination of $\tilde{p}$ when increments in $\tilde{p}$ are not independent is extremely cumbersome when the adjustment hazard is non-constant. For this reason in the empirical section we approximate $\tilde{p}$ by its partial adjustment counterpart.

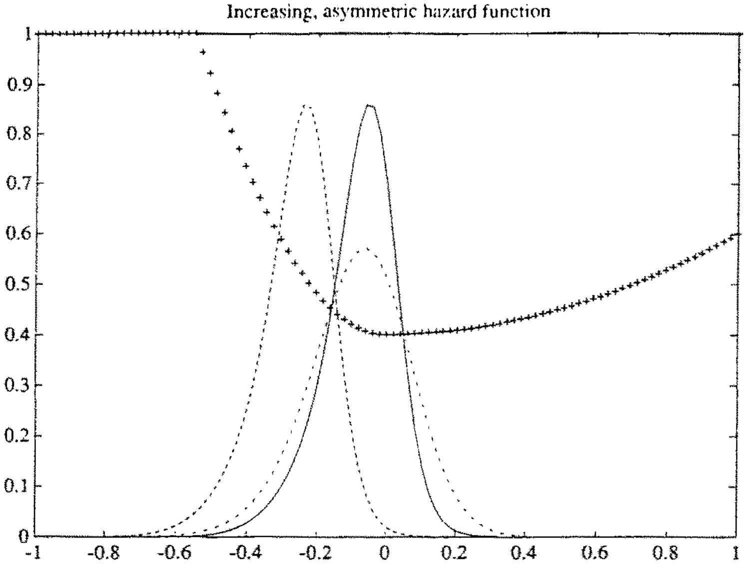

Fig. 1. Cross-section distributions and an increasing/asymmetric hazard.

$$\Lambda(z)=\lambda_0+\begin{cases}\lambda^+z^2 & \text{for} \quad z>0,\\ \lambda^-z^2 & \text{for} \quad z<0.\end{cases}$$

Fig. 1 provides an example of this hazard (line with + signs) with its corresponding ergodic density (solid line) and two other cross-section densities: One is just a spread out version of the ergodic density while the other one is shifted to the left. In both cases the *average* hazard is larger than in the ergodic one, thus the number of units changing their prices will be larger than in the ergodic one. It is precisely the endogenous dynamic interplay between the adjustment hazard function and the cross-section distribution, and the implication of such interaction over the number of units adjusting prices, that provides aggregate realism to these models. In particular, increasing hazard models tend to exacerbate the impact of large shocks by bunching units adjustments [Caballero and Engel (1992a, c)].

On the other hand, the asymmetry at the microeconomic level tends to be undone by the shape of the cross-section distribution; it is more likely that large shocks can bring to light the impact of these asymmetries on the aggregate [Caballero (1992)].

3.3. Indices of aggregate rigidity and asymmetries

As hinted above, the endogenous evolution of the cross-section distribution of price deviations has the potential of interacting in complex ways with the adjustment hazard function. In particular, there is a non-linear mapping from microeconomic policies to aggregate outcomes. In this subsection we propose indices of aggregate price stickiness and asymmetry which will be used later in the empirical section.

The history dependence present in discontinuous-adjustment/non-representative-agent models is reflected on the degree of stickiness and asymmetries present at any point in time. These features depend on past events through the impact of these events on the current cross-section distribution of firms' price deviations.

Given an economy with adjustment hazard $\Lambda(z)$ and firm specific idiosyncratic shocks (beyond the hazard shock) that are normal with standard deviation σ_I, we define the index of price-flexibility at time t as

$$F_{k,t} \equiv \frac{1}{2}\left\{\frac{\Delta p_{k,t}^{+} - \bar{\Delta} p}{\Delta \tilde{p}_k^{+} - \bar{\Delta}\tilde{p}} + \frac{\bar{\Delta} p - \Delta p_{k,t}^{-}}{\bar{\Delta}\tilde{p} - \Delta \tilde{p}_k^{-}}\right\},$$

where a bar denotes the long-run average, $\Delta\tilde{p}^{\pm} = \bar{\Delta}\tilde{p} \pm k\sigma_{\Delta\tilde{p}}$ (where $\sigma_{\Delta\tilde{p}}$ denotes the standard deviation of $\Delta\tilde{p}$), and $\Delta p_{k,t}^{\pm}$ is equal to the change in the price level after the cross-section distribution of prices at time t is disturbed by a sequence of (i) an aggregate shock of size $\Delta\tilde{p}_k^{\pm}$, (ii) a normal idiosyncratic shock with standard deviation σ_I, and (iii) the hazard shock determined by $\Lambda(z)$. This index approaches one as prices become fully flexible and zero as they become unresponsive to aggregate shocks. It depends on time exclusively because of the effect of the interplay between the cross-section distribution of deviations and the non-constant hazard function, which determines the number of firms adjusting prices at any given time.

Accordingly, the index of asymmetry at time t is defined as

$$A_{k,t} \equiv \frac{\Delta p_{k,t}^{+} - \bar{\Delta} p}{\Delta \tilde{p}_k^{+} - \bar{\Delta}\tilde{p}} - \frac{\bar{\Delta} p - \Delta p_{k,t}^{-}}{\bar{\Delta} p - \Delta \tilde{p}_k^{-}}.$$

Simple algebra together with the constraint $\bar{\Delta}\tilde{p} = \bar{\Delta} p$, shows that in the partial adjustment model the price-flexibility and asymmetry statistics are constant and equal to the adjustment probability λ, and 0, respectively. We use these as a benchmark when we present the statistics implied by our estimates below.

4. Empirical evidence

In this section we apply our model to annual U.S. data for the period 1955–1989. Our measure of final prices is the finished goods producer price index. We use two inputs categories: (i) intermediate materials, supplies, and components, and (ii) crude materials for further processing. The wage/productivity measure corresponds to the (nominal) unit labor cost of the business sector (source: Bureau of Labor Statistics).

We start by constructing p^*. We exploit the stationarity of the deviation between p^* and p to estimate a cointegrating regression between p (instead of p^*) and the price of materials and unit labor cost to recover the function p^*.[10] We obtained coefficients for the price of intermediate materials, the price of crude materials and unit labor cost, of 0.43, 0.22 and 0.35, respectively.

Using these estimates we constructed a series for Δp^*, whose univariate representation is an AR(3) process with coefficients 1.05, -0.59 and 0.27, for the first, second and third lags, respectively. Finally, we constructed a series of $\Delta\tilde{p}$ by fixing $\delta=0.1$ and using the value of λ estimated for the partial adjustment model in eq. (2).[11]

4.1. Estimation

Estimating the best hazard model within a particular parameteric family requires choosing a criterion by which the performance of different adjustment hazards can be compared. A natural candidate is to calculate the series of price changes determined by a particular set of parameters, and then look at the sum of the corresponding squared residuals. This is the criterion we use. We consider the family of hazard functions mentioned in section 2.2 (weakly increasing piecewise quadratic with a discontinuity in the second derivative at the origin and bounded between 0 and 1), since it contains a rich variety of hazard functions that are increasing and asymmetric. It also contains the partial adjustment model as a particular case.

We work in discrete space and time. Firms' deviations are allowed to take one of 99 equally spaced values between -1.0 and 1.0. We generate the sequence of cross-section densities as follows: The cross-section density at time $t+1$ is obtained from that at time t by first shifting the latter by an amount equal to (the negative of) the current change in $\tilde{p}$, then applying an

[10]The cointegration equation implements a Stock and Watson (1990) correction with two leads and two lags of the first difference of each of the right-hand side variables. See Caballero (1991) for a more detailed discussion of the virtues of this procedure when estimating the coefficients of p^* in small samples. Also, the sum of the coefficients on input and unit labor cost coefficients was 0.96. We renormalized them so they add up to one. Finally, and most importantly, we cannot be sure that we have really obtained a proxy for p^* rather than $\tilde{p}$ directly, or any other convex combination of these, since $\tilde{p}$ is also cointegrated with p. However, this can be shown to be more important for the estimate of p^* (which is never used directly) than for $\tilde{p}$ (which is what we use in the final stage) since the forward looking term in the expression for $\tilde{p}$ tends to compensate for any error in the estimate of p^*.

[11]When estimating adjustment hazards we allowed for a fixed fraction α of agents that adjust prices fully in every period. Assuming that these agents may vary from one period to another we have that the relevant estimate for λ in (2) is equal to $\alpha+(1-\alpha)\lambda$.

Table 1

Estimated hazards.[a]

	Constant hazard	Non-const. hazard: Micro. constr.	Non-const. hazard: Unconstrained
λ_0	0.33 (0.17)	0.19 (0.28)	0.03 (0.02)
λ^-	–	–	1.21 (0.08)
λ^+	–	1.14 (0.43)	0.00 (0.15)
SSR × 100	0.262	0.227	0.225

[a]Standard errors are in parentheses. SSR: sum of squared residuals, $\sigma_I = 0.05$.

idiosyncratic shock that is normal with zero mean and standard deviation σ_I,[12] and finally applying the hazard shock [so that the probability density at a point $z \neq 0$ decreases by a fraction $\Lambda(z) \cdot \mathrm{d}t = \Lambda(z)$].[13,14]

4.2. Results

Table 1 presents the basic estimates. Column 1 shows the estimates for the partial adjustment model, while columns 2 and 3 present the results for a non-constant hazard model of the form

$$\Lambda(z) = \lambda_0 + \begin{cases} \lambda^+ z^2 & \text{for} \quad z > 0, \\ \lambda^- z^2 & \text{for} \quad z < 0. \end{cases}$$

Column 2 presents the case where λ^+ and λ^- are constrained to be equal; column 3 relaxes this constraint. We also allow for a fraction α of firms that adjusts fully to the aggregate price shock in every period.[15] The constant hazard model has a sum of squared residuals 15% larger than that of the non-constant hazard model with microeconomic symmetry imposed, and 18% larger than the unconstrained non-constant hazard model. The estimates of the non-constant component corresponding to price increases in the

[12]Since the length of available data limits the number of parameters we can estimate, we fixed $\sigma_I = 0.05$.

[13]We assume that there is only one shock per year, which implies that $\Lambda(z) \leq 1$.

[14]The initial cross-section density is assumed to be equal to the ergodic density that would exist if aggregate shocks followed a random walk with drift equal to that of the aggregate shock process and (instantaneous) variance equal to the sum of the idiosyncratic variance and the variance of the series of aggregate shocks; this is the best choice of initial density in a precise sense [see Caballero and Engel (1992b)]. To account for the error this introduces we disregard the first six observations when evaluating the sum of squared residuals.

[15]The estimated value of α is 0.56.

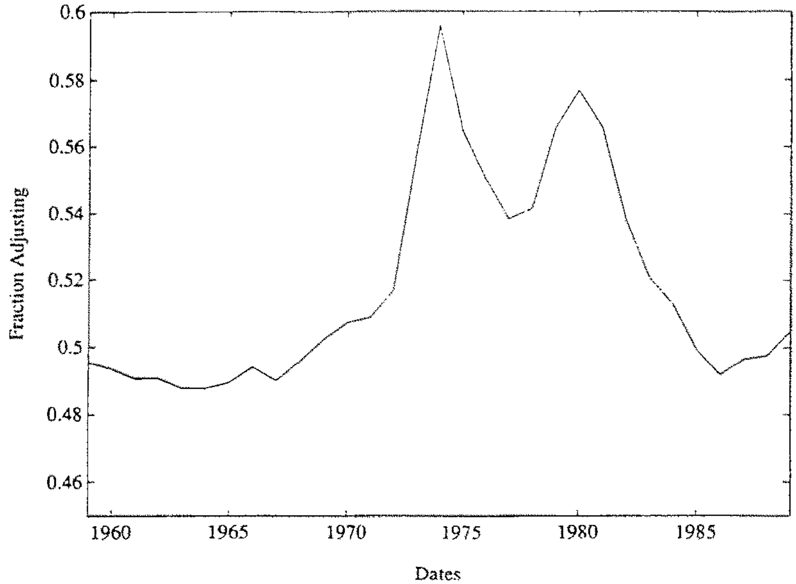

Fig. 2. Number of firms adjusting their prices.

latter (λ^-) is different from zero at reasonable significance level. The asymmetry in the hazard is also quite apparent; conditional on the magnitude of firms' price deviations, firms are more likely to increase their prices than to decrease them.

Fig. 2 illustrates the implied path of the number of firms adjusting their prices for the unrestricted model (column 3 in table 1). In sharp contrast with the constant hazard model, the estimated non-constant hazard model conveys large fluctuations in the fraction of firms that adjust their prices. This realistic flexibility of the non-constant hazard model is what gives it additional explanatory power at the aggregate level.

Another way to capture the richness of the non-constant hazard model is through the implied path of the price-flexibility and asymmetry indices, which in the partial adjustment model are constant and equal to λ and 0, respectively. Fig. 3 depicts the evolution over time of the index of aggregate price flexibility for shocks of one standard deviation, $F_{1,t}$, for the non-constant hazard cases. These suggest that immediately after the price shock of 1974 the economy became more vulnerable to new shocks: the cross-section distribution of agents was concentrated toward the left after this shock (negative values of z). Thus, subsequent price shocks found firms in a region where the adjustment probability was untypically high.

Fig. 4 presents the asymmetry indices corresponding to shocks of one and

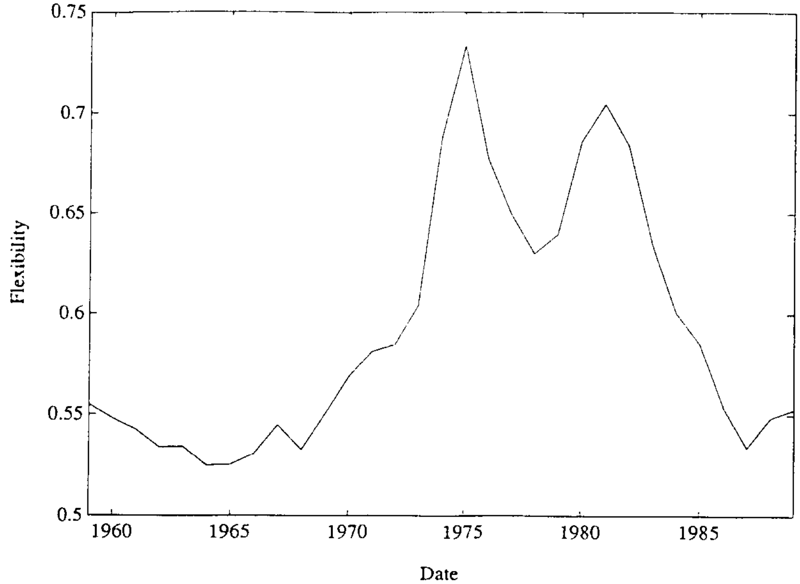

Fig. 3. Flexibility index.

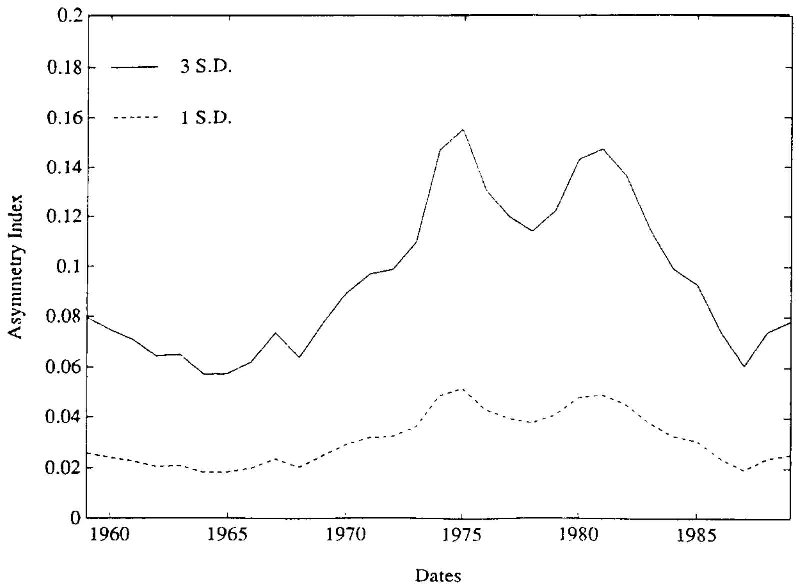

Fig. 4. Asymmetry index.

Table 2

Flexibility and asymmetry indices.

		Non-const. hazard	
	Constant hazard	Micro. constr.	Unconstrained
Max $F_{1,t}$	0.70	0.73	0.73
Min $F_{1,t}$	0.70	0.59	0.53
Mean $F_{1,t}$	0.70	0.63	0.59
Max $A_{1,t}$	0.00	0.04	0.05
Min $A_{1,t}$	0.00	0.01	0.02
Mean $A_{1,t}$	0.00	0.02	0.03
Max $A_{3,t}$	0.00	0.12	0.16
Min $A_{3,t}$	0.00	0.02	0.06
Mean $A_{3,t}$	0.00	0.06	0.10

three standard deviations for the non-constant hazard models. This figure shows that the re-positioning of the cross-section distribution also determines that the degree of asymmetry increases after a large price shock. It is interesting to notice that the asymmetry index grows dramatically when larger shocks are considered, and that the aggregate asymmetry prevails even when the microeconomic policies are restricted to be symmetric.

Table 2 summarizes the main insights of figs. 3 and 4 and the previous discussion. It is interesting to point out that the behavior of flexibility and asymmetry indices of the most flexible specification prevails even when the microeconomic policy is constrained to be symmetric. At the aggregate level, only the increasing feature of the hazard seems to matter.

5. Conclusion

Individuals firms are continuously hit by aggregate and idiosyncratic shocks which, when combined with price stickiness, generate a cross-section distribution of deviations from optimal prices. Except for the very extreme case where the probability of adjustment is independent of the magnitude and sign of these deviations, the dynamic behavior of aggregate prices is shaped in non-trivial ways by the interaction between the adjustment rule and the endogenous evolution of the cross-section distribution of deviations.

Instead of imposing independence between adjustment and deviations, in this paper we have estimated the nature of this relationship. Our results reject the independence assumption in favor of a positive relation between the probability of adjustment and the magnitude of the price deviation. We also find that the increase in the probability of adjustment is larger for negative than for positive deviations: i.e. there seems to be more (microeconomic) downward than upward rigidity.

The main aggregate implications of these findings is that (i) the degree of flexibility of the aggregate price level varies significantly over time and (ii) prices respond more to positive than to negative shocks, this asymmetry increases with the size of shocks and it prevails even when the microeconomic asymmetry is removed.

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