ESTIMATION OF ADJUSTMENT COSTS IN A MODEL OF STATE-DEPENDENT PRICING

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Abstract

This paper provides a framework for direct analysis of the underlying price adjustment costs in an industry. A dynamic programming problem is specified for monopolistically competitive firms that face idiosyncratic costs of price adjustment. A numerical solution is calculated using value function iteration. I estimate the structural parameters of the model using data on magazine cover prices. Among the parameters estimated are the mean, variance, and persistence of the adjustment cost process. The estimated distribution of adjustment costs is nondegenerate, and the average adjustment cost paid by firms is large in comparison to other results in the literature.

JEL classification: E31, D40, and L11

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1 Introduction

The role of price stickiness in short-run economic fluctuations has been the focus of much macroeconomic research. Numerous theoretical studies of dynamic price-adjustment models have shown that the presence of a price adjustment cost (e.g. menu cost) can lead to non-neutrality of money.[1] While the implications of price adjustment costs have been studied extensively, empirical estimates of the magnitude of these costs are relatively scarce. The contribution of this paper is to estimate the structure of price-adjustment costs at the firm level. A discrete-choice dynamic-programming model is constructed, and estimates are obtained using data from the magazine industry.

In models of state-dependent pricing, adjustment costs represent more than the actual costs of physically changing the price of a product. They may include costs associated with the managerial decision-making process, information-gathering costs, and implementation costs. As stated by Ball and Mankiw (1994): "Menu costs should be viewed as a parable - a convenient formalization that captures the fact that prices are not adjusted continuously, and that they tend to adjust more quickly to large than to small shocks." Identification of the exact source, while useful, is not necessary for studying the effects of price adjustment costs in macroeconomics. The important issue is determining the general size and structure of this friction in the price adjustment problem.

In the empirical literature, researchers have looked at the implications of adjustment costs in various datasets by documenting evidence of discrete and infrequent price adjustment. Cecchetti (1986) examines newsstand prices of magazines and finds that the typical magazine allows inflation to erode its real price by about 25 percent before increasing the

[1]In early models, Barro (1972) and Sheshinski and Weiss (1977) derived optimal policies for a firm facing a fixed cost of price adjustment. In a static setting, Mankiw (1985) shows that the inclusion of second-order costs of adjusting prices may lead to first-order changes in output and welfare in response to nominal money shocks. In a dynamic equilibrium framework, Caplin and Leahy (1991) provide an example where the presence of price-adjustment costs causes monetary shocks to affect output. Dotsey, King and Wolman (1999) construct a general equilibrium model containing an independently and identically distributed (i.i.d.) fixed cost of price adjustment.

nominal price. Carlton (1986) studies transactions prices among firms buying from other firms and finds a significant degree of rigidity in many industries. Kashyap (1995) examines prices of several products sold in retail catalogs. He concludes that models with time varying costs of price adjustment are better able to explain key features of the data.

Thus far, there have been very few empirical studies of the magnitude and structure of adjustment costs. Levy, Bergen, Dutta and Venable (1997) study the costs of changing prices in supermarkets via a dataset that directly measures adjustment costs. The amount of time required at each step of the price-change process is recorded, and then wage data is used to compute the actual cost of a price change. They find that the adjustment costs comprise 0.7 percent of annual revenues, which is a nontrivial amount according to the theoretical literature.[2] Using a structural model, Slade (1998) estimates the existence, type, and magnitude of adjustment costs using weekly retail price data on saltine crackers. Her model nests both fixed and variable adjustment costs, where the fixed cost is constant over time and identical for all firms. The results of her estimation indicate that the fixed cost is the important determinant of price behavior and that the magnitude of the cost is somewhat higher than the estimate of Levy et al.[3] Aguirregabiria (1999) also estimates the magnitude of adjustment costs in the supermarket industry using a structural model. In addition to price adjustment costs, firms in this model also face a fixed cost of ordering new inventories. The estimation results are similar in magnitude to those of Slade.[4]

This research focuses directly on the structure of adjustment costs at the firm level.

[2]According to calculations from Blanchard and Kiyotaki (1987), menu costs as small as 0.08 percent of revenues may be sufficient to prevent price adjustment in response to a 5 percent change in aggregate demand.

[3]The difference between the estimates of Levy et al. and Slade point toward differences in the respective definitions of menu costs. By directly measuring the adjustment cost, Levy et al. use a strict definition of the value of labor required to enact a price change. Through structural estimation, Slade captures the cost of any rigidity in the price-setting process, of which labor costs are a subset.

[4]In addition, Agguiregabiria is able to separately identify the costs of price increases from the costs of price decreases. The fixed cost of lowering prices is found to be smaller than the cost of increasing prices, which corresponds to retailer surveys stating that wholesalers cover a portion of the cost incurred when a supermarket item is placed on sale.

Each firm is assumed to face a fixed cost of adjustment that follows an autoregressive process. This assumption encompasses the conclusions of Kashyap (the cost should be time varying) and Slade (fixed costs are important, whereas variable costs are not). The adjustment cost is embedded in a discrete-choice dynamic-programming model for a monopolistically competitive firm. The structural model is solved computationally by value function iteration. Properties of this model are illustrated using hazard rates (the probability of a price change) conditional on the given state variables. Estimates of the parameters of the adjustment cost process are obtained through an indirect inference procedure using data from the magazine industry.

The micro-panel data used in the empirical estimation consist of annual price observations of 38 magazine cover prices. This dataset was selected for several reasons. First, the price data display the characteristic properties resulting from the presence of adjustment costs: discrete and infrequent price adjustments. Second, the analysis of this data by Cecchetti is one of the most frequently cited empirical works on the subject of menu costs. Since his study is a major example of the existence of menu costs, understanding the properties of the underlying adjustment costs in this industry is important in relation to theoretical studies on the implications of menu costs. Third, as noted by Cecchetti, this is one of the few industries in which transaction prices are easily available.

Even though price-adjustment costs are not directly observed in the data, the indirect inference procedure used in the empirical analysis provides a method of estimating the parameters of the underlying structural model. This is accomplished by specifying a reduced-form regression model that characterizes the statistical properties of the data, and matching the coefficients estimated from magazine data against estimates from simulation data based upon the structural model. Two different estimates are calculated with the difference in the assumptions of the adjustment cost process. In the first estimation, the idiosyncratic adjustment cost shocks are assumed to be independently and identically distributed (i.i.d.) across firms and over time.[5] The structural parameters are identified

[5]This is the assumption used by Dotsey, King, and Wolman (1999) in their general equilibrium model of pricing decisions.

using moments based upon the firm's discrete choice concerning a price change. The second estimation relaxes the i.i.d. assumption. A persistence parameter is estimated using information from the intensive margin of the firm's pricing decision.

In the first estimation the model requires a very large variance in the adjustment cost process in order to match the magazine data. In terms of magnitude, I find that the average adjustment cost paid by firms is about 4 percent of revenues, which is large in comparison to the measured costs in Levy et al. (0.7 percent of revenues) and estimates by Slade (1.9 percent of revenues). In the second estimation, the average adjustment cost paid is 2 percent of revenues and the adjustment cost process has a high degree of persistence. In comparison to other types of adjustment costs, these estimates are two-thirds and one-third in size, respectively, of the average costs of capital adjustment in the manufacturing industry.

2 State-Dependent Pricing Model

I analyze the problem of a monopolistically competitive firm with a given initial price in a particular industry. Demand for the firm's output is determined by total demand within the respective industry and the firm's price relative to an industry price index. Firm profits are determined by firm revenues minus the cost of production.

Given the current level of industry demand and the industry price index, the firm decides whether or not to adjust its price by computing the discounted expected benefit of changing the price compared to the cost of adjustment. The benefit of price adjustment today is that the forward-looking firm can choose the optimal price based upon current demand and conditional expectations of demand in the future. The cost of price adjustment appears in the form of an idiosyncratic fixed cost. The structure of the adjustment cost process will affect both the intensive and extensive margins of the firm's decision due to the dynamic aspect of the model. If the firm decides not to change its price, then its relative price will be shifted by changes in the industry price index. For example, an increase in the industry price index would cause the firm's relative price to fall, leading to an increase in demand for the firm's output. Assuming that the firm will meet excess demand, firm profits will fall as a result of producing in excess of the optimal monopolistic output level and selling at a lower relative price.

This specification follows the standard model used in the menu cost literature with the addition of heterogeneous costs of price adjustment.[6] Formally, I assume that there are n producers who each produce a single differentiated good. The contemporaneous real profit for firm i in period t is

$$\Pi_{i,t} = \phi_{i,t}\left(\frac{P_{i,t}}{P_t}\right)Y_{i,t} - \frac{d}{\gamma}Y_{i,t}^{\gamma} \tag{1}$$

where

$$Y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\theta} Y_t \tag{2}$$

and

$$P_t = \left(\frac{1}{n}\sum_{j=1}^{n} P_{i,t}^{1-\theta}\right)^{\frac{1}{1-\theta}}. \tag{3}$$

Here $Y_{i,t}$ represents firm output, $P_{i,t}$ is the firm's price, Y_t is industry demand, P_t is the CES industry price index, $\phi_{i,t}$ is an idiosyncratic profit shock, θ is the elasticity of substitution across goods, and γ and d are parameters of the cost function.[7]

[6] See Blanchard and Kiyotaki (1987) or Ball and Romer (1990). This is the same specification used by Cecchetti and is intended to capture the primary components of the firm's profit function. Critics of this specification as it relates to the magazine industry argue that advertising revenue should be added to profits and that the decision problem should be expanded to include the subscription sales portion of the industry.

If the firm is operating close to constant returns to scale (CRS), the model can incorporate these features under certain assumptions. If advertising revenue is proportional to the firm output, then this revenue will serve to reduce the marginal cost of production. Under CRS, this is accomplished by changing the scalar on the cost function, which does not affect the estimation results. Also, if we view the single-copy market and subscription market as composed of distinct subsets of the population, then changes in production for the subscription market will not affect the marginal cost of production in the single-copy profit function.

[7] Real profits are obtained by deflating nominal profits by the aggregate price index $\left(\bar{P}_t\right)$, where ω_t

In the dynamic setting, the firm will make its pricing decision based upon the current industry price index, P, current industry demand, Y, its price at the end of the previous period, $P_{i,-1}$, the current idiosyncratic profit shock, ϕ_i, the current idiosyncratic adjustment cost that must be paid in the event of a price adjustment, ψ_i, and expectations of future realizations of these state variables, which are dependent upon the current state. If there is inflation in the economy, then the price variables will not be stationary. To frame the problem in a stationary environment, I replace the price variables with two stationary variables: the relative price at the end of the previous period $\left(p_{-1} = \frac{P_{i,-1}}{P_{-1}}\right)$and the current inflation rate (π). These two variables summarize the information needed from $P_{i,-1}$ and P because only the relative price enters the profit function. If the firm decides to leave its price fixed, then inflation causes the lagged relative price to depreciate at rate π. If the firm decides to change its price, it implicitly chooses p through its selection of P_i. Price changes are assumed to go into effect immediately.

The optimization problem is formulated using a dynamic programming approach. Based upon the current realization of the states, $S = \{p_{-1}, \pi, Y, \psi_i, \phi_i\}$, the firm will compare the value of changing its price and paying the adjustment cost, V^C, against the value of keeping its price fixed, V^{NC}. The value function is expressed as

$$V\left(p_{-1}, \pi, Y, \psi_i, \phi_i\right) = \max\left(V^C, V^{NC}\right) \tag{4}$$

where

$$\begin{aligned} V^{NC}\left(p_{-1}, \pi, Y, \psi_i, \phi_i\right) &= \Pi\left(\frac{p_{-1}}{1+\pi}, Y, \phi_i\right) + \beta E_{S'|S}\left[V\left(\frac{p_{-1}}{1+\pi}, \pi', Y', \psi_i', \phi_i'\right)\right] \\ V^{C}\left(p_{-1}, \pi, Y, \psi_i, \phi_i\right) &= \max_p \left\{\Pi\left(p, Y, \phi_i\right) - \psi_i + \beta E_{S'|S}\left[V\left(p, \pi', Y', \psi_i', \phi_i'\right)\right]\right\} \end{aligned}$$

represents the per unit cost of factor inputs. Equation (1) is obtained by rewriting the profit function as follows:

$$\Pi_{i,t} = \frac{P_{i,t}Y_{i,t}}{\bar{P}_t} - \frac{\omega_t Y_{i,t}^{\gamma}}{\bar{P}_t} = \frac{P_t}{\bar{P}_t}\left(\frac{P_{i,t}Y_{i,t}}{P_t} - \frac{\omega_t}{P_t}Y_{i,t}^{\gamma}\right)$$

where P_t is the magazine price index. The per unit cost of factor inputs relative to the magazine price index, $\frac{\omega_t}{P_t}$, is assumed to be constant over time, parametrized as $\frac{d}{\gamma}$. In addition, it is assumed that firms expect the aggregate price index and the industry price index to increase at the same rate.

Expectations are taken over the four exogenous variables, $(\pi', Y', \psi_i', \phi_i')$, using conditional distributions. I assume that industry demand and inflation follow a stationary bivariate autoregressive process independent of firm i's decision and denote the conditional distribution of this process as $\Phi_1(\pi', Y'|\pi, Y)$. The idiosyncratic profit shock is assumed to follow a stationary autoregressive process with conditional distribution $\Phi_2(\phi_i'|\phi_i)$. The adjustment cost process is modeled as an autoregressive log-normal process subject to idiosyncratic shocks:

$$\log(\psi_{i,t}) = \mu + \rho \log(\psi_{i,t-1}) + \varepsilon_{i,t} \tag{5}$$

The parameters of focus in this study are those describing the adjustment cost process: the mean, persistence, and standard deviation of the innovations to the process, $\{\mu, \rho, \sigma_\varepsilon\}$. In this model, firms will make their pricing decisions based upon not only the current realization of the adjustment cost, but also upon expectations of future realizations, where the conditional distribution for the adjustment cost process is $\Phi_3(\psi_i'|\psi_i)$. The parameters of this process will affect both the discrete choice decision as well as the optimal price decision conditional upon the firm deciding to change its price. The solution represents a partial equilibrium due to the assumption of the exogenous inflation and industry demand processes.

Proposition 1 *A solution exists to the dynamic programming problem.*

Proof. If $\beta < 1$ and all exogenous processes are stationary, then the existence of a solution to the firm's programming problem is guaranteed by Theorem 9.6 in Stokey and Lucas (1993). ■

3 Numerical analysis

Due to the discrete nature of the adjustment decision combined with serial correlation of the idiosyncratic costs, the derivation of an analytic solution to the firm's problem is not feasible. I solve the model numerically using value function iteration, which yields policy functions dependent on the state variables.[8] The implications of the solution are investigated via simulation. The numerical results are then used in the estimation procedure.

All components of the state space take values in a discrete set. The bounds of the relative price state space are set wide enough to include all optimal price decisions, and the space is divided into a grid with 0.5% increments. The bivariate autoregressive process for inflation and industry demand is transformed into a discrete-valued Markov chain following Tauchen (1986). There are seven points in the state space for these two variables, and the values used to parameterize this process will be described in the data section below. For the current analysis and estimation, the idiosyncratic profitability shock will be omitted from the problem. The adjustment cost process is specified as a first-order Markov transition matrix using the same method as for the bivariate process described above. The adjustment cost state space consists of nine discrete points bounded within two standard deviations of the mean.

I assume that the annual discount rate for the firm, β, is 0.9. The scalar on the cost function, d, affects the steady state level of output, but not the dynamic pricing decisions studied in the estimation below. As such, d is not identified given our data. The value of d is set at 0.5.

To illustrate the properties of the model, I define the optimal price, conditional on a firm deciding to change price, as

$$p^* = \arg\max_p \left\{ \Pi\left(p, Y\right) - \psi_i + \beta E_{S'|S}\left[V\left(p, \pi', Y', \psi_i'\right)\right] \right\}.^9$$

This optimal price is the solution to the maximization problem in V^C. It will be a function of the current state variables through the conditional expectations of the future value function. However, if the adjustment cost is i.i.d., then the optimal price is independent of the adjustment cost.

Property 1: If ψ is i.i.d., then p^* is independent of ψ, given $\left(p_{-1}, \pi, Y\right)$.

Next, I define the hazard rate as $H\left(p_{-1}, \pi, Y\right)$. The hazard rate represents the proba-

[8] Similar solution methods are used in Rust (1987) and Cooper, Haltiwanger and Power (1999) in the investment literature.

bility of a price change conditional on the relative price from the previous period and the current values of inflation and industry demand. Because the idiosyncratic adjustment cost is not observable to the econometrician, this variable is not conditioned upon in the hazard function. Thus, the hazard will lie in the interval $[0, 1]$.

In considering price adjustment, firms compare the current relative price if they do not adjust, $\frac{p_{-1}}{1+\pi}$, against the optimal price, p^*. As the non-adjustment price declines further below optimal price due to a decrease in p_{-1}, the firm will be more likely to adjust in order to limit the decrease in profits due to a lower relative price today and the increase in marginal cost due to higher demand.

Property 2: If $\frac{p_{-1}}{1+\pi} < p^*$, $H(p_{-1}, \pi, Y)$ is decreasing in p_{-1} given (π, Y).

Regarding the optimal price, if the inflation process exhibits persistence, firms will expect a high inflation rate today to continue into the future. In order to reduce the frequency in which the adjustment cost is paid, firms in the higher inflation state will choose a higher optimal price.

Property 3: If $\Phi_1(\pi', Y'|\pi, Y)$ is increasing in π given (p_{-1}, Y, ψ_i), then p^* is increasing in π.

Panel A of Figure 1 illustrates these first three properties. The hazards are produced by solving the model using a baseline setting of parameters which include a inflation process with persistence and an i.i.d. adjustment cost process. The figure displays the probability of price adjustment conditional on two different inflation states, holding fixed the level of industry demand at its mean value. The horizontal axis lists the relative price of the firm conditional on no price adjustment, $\frac{p_{-1}}{1+\pi}$. As described in Property 2, the hazard is decreasing in the relative price conditional on the inflation and industry demand states. The step-like shape is the result of the adjustment cost being represented by a discrete state space with nine points. As the relative price decreases, firms will be willing to pay a higher adjustment cost. The hazard function steps up when the maximum adjustment cost in terms of willingness to pay for a given relative price intersects with one of the nine discrete adjustment costs. The percentage point increase in the hazard represents the fraction of firms facing the relevant adjustment cost.

Properties 1 and 3 are illustrated by the two vertical lines. These lines represent the optimal price conditional on deciding to change prices. As a consequence of the i.i.d. adjustment cost specification, all firms choose the same optimal price. If the adjustment cost displays persistence ($\rho > 0$), then the optimal price would be dependent on the current adjustment cost through the conditional expectation function. The left vertical line represents the optimal price for the low inflation state, and the line on the right is the optimal price conditional on the high inflation state.

Similar patterns result from controlling for industry demand instead of inflation. It is more profitable for firms to change prices during periods of high demand in order to avoid large increases in production which will cause marginal revenues to fall below marginal costs.

Property 4: If $\frac{p_{-1}}{1+\pi} < p^*$, then $H\left(p_{-1}, \pi, Y\right)$ is increasing in Y given $\left(p_{-1}, \pi\right)$.

Panel B of Figure 1 presents the hazards rates conditional on two different sales states, holding inflation constant at its mean level.

4 Empirical Evidence: Magazine price data

To estimate the magnitude and persistence of price adjustment costs, I use data from the magazine industry as in Cecchetti (1986).[10] The data consist of cover prices of 38 magazines from 1959 to 1979. Annual series were constructed by recording the price of the first issue of each year. From this panel dataset, a magazine price index was created. Industry demand is represented by total single-copy sales of magazines as reported by the Magazine Publishers Association.

Table 1 presents summary statistics. Column 1 displays the number of magazines changing price in a given year. A price change for a given year is defined as an observed price differential between the first issue of the given year and the subsequent year. The second column displays the inflation rate of the magazine price index. Column 3 reports single-copy magazine sales over the time period, measured as total sales divided by the total

[10] I would like to thank Stephen Cecchetti for providing me with the magazine data.

number of magazines. The next two columns present data for firms that have adjusted prices within the specified year. These series are the average number of years since the previous change in price and the average cumulative inflation since the previous change.

From the table, it is evident that the frequency of adjustment is higher in periods of higher inflation. Correspondingly, the time between price changes is inversely related to the inflation rate. This observation supports state-dependent over time-dependent models. The average amount of inflation between price changes does not appear to be strongly correlated with the inflation rate. Representing industry demand, magazine sales are increasing through the early 1970s, and then begin to decline.

In the structural model, industry demand (sales) and inflation are assumed to follow a bivariate autoregressive process. The parameters describing this process are estimated from a VAR regression using the data series on inflation and magazine sales. The magazine sales data is normalized to mean 1, and the inflation data is parametrized as a log-normal process. The parameter estimates for the VAR are listed in Table 2 with the standard errors in parentheses. The mean inflation rate over the sample is 5 percent. The autoregressive process is then transformed into a discrete-valued Markov process.[11]

5 Estimation strategy

I use an indirect inference procedure proposed by Gourieroux, Monfort and Renault (1993) to estimate parameters of the structural model. This procedure consists of estimating auxiliary parameters from the magazine data and from simulated data from the model according to a specified criterion. In the first of two estimations, the auxiliary parameters are coefficients in a linear probability model and the criterion function is the sum of squared errors from the probability equation. Therefore, the coefficients are estimated by OLS. The structural parameters are then estimated through matching the two sets of OLS estimates (from the data and the simulation of the model) according to a minimum distance function.

[11]The state spaces for these two variables consist of seven discrete points equally distributed within two standard deviations of the mean.

The benefits of this procedure are that it provides a convenient, indirect formulation of moments relating to unobserved variables, such as the adjustment cost process in this example, and the resulting estimates have well-behaved asymptotic properties when the criterion function and the auxiliary parameters are well chosen. In the second estimation, one moment is added to the set of auxiliary parameters to identify an additional structural parameter.

The parameters to be estimated are those governing the adjustment cost process $\{\rho, \mu, \sigma_\varepsilon\}$, the elasticity of substitution across goods, θ, and the curvature parameter for the firm's cost function, γ. This paper explores two specifications: one in which the adjustment cost is i.i.d., ($\rho = 0$); and one in which the persistence parameter is included in the set of estimated structural parameters. The i.i.d. assumption in the first specification is also used in Dotsey, King, and Wolman, although a different distribution function for the adjustment cost is chosen here. Comparison of the two estimations will provide empirical evidence as to the validity of this assumption in regards to the magazine industry. The set of structural parameters to be estimated in the first specification is denoted as $\delta_1 \equiv \{\mu, \sigma_\varepsilon, \theta, \gamma\}$ and the second specification is denoted as $\delta_2 \equiv \{\mu, \sigma_\varepsilon, \rho, \theta, \gamma\}$

5.1 Auxiliary parameters and criterion function

In searching for a criterion function and set of auxiliary parameters that are closely related to the structural parameters of the model, it is natural to consider the hazard function. Ideally, the hazard function would be based upon the specification discussed above, $H(p_{-1}, \pi, Y)$. Data on magazine price inflation and magazine sales are available, but measurement of relative prices, p_{-1}, in the magazine data is problematic. Product differences across magazines, such as the amount of content and frequency of publication, lead to persistent differences in prices over time. It would be difficult to normalize each firm's relative price as is done in the model. Therefore, an alternative hazard function is specified with the claim that it captures the important aspects of the relative price. A linear specification of the hazard is chosen for convenience in estimation.

I specify a hazard function where the probability of a price change is a function of five variables: 1) the number of years between the current period (t) and the period in which firm i last changed its price $\left(\tilde{t}\right)$, $T_{i,t,\tilde{t}}$, 2) cumulative inflation since the previous change, $\pi_{i,t,\tilde{t}}$, 3) cumulative percentage change in industry demand since the previous change, $\dot{Y}_{i,t,\tilde{t}}$, 4) current inflation, π_t, and 5) current industry demand, Y_t:

$$\Pr\left(c_{i,t}=1\right)=F\left(b_0+b_1T_{i,t,\tilde{t}}+b_2\pi_{i,t,\tilde{t}}+b_3\dot{Y}_{i,t,\tilde{t}}+b_4\pi_t+b_5Y_t\right) \tag{6}$$

where $c_{i,t}$ is a dummy variable equal to 1 if the price is changed in period t for firm i.[12]

In relation to the structural dynamic-programming model presented above, this specification takes the appearance of a reduced-form hazard function.[13] Two of the state variables, inflation and industry sales, are included directly. The relative price is accounted for by a combination of several other variables. First, cumulative inflation and the cumulative change in industry sales provide information on the current level of the relative price. Since these measures are cumulative from the time of the last price change, they are linked to the change in state variables since the last time the optimal price was chosen. The measure of cumulative inflation directly captures the movement in the relative price since the last time the price was adjusted. But since this measure only indicates the fall in the relative price, information on the state variables at the time of the previous change is necessary to determine whether the relative price was previously set at a high or low level. In other words, I need additional information to infer the value of p^* at the time of the last change to combine with our knowledge of the movement in p. Together, the cumulative change in magazine sales and the current level of sales, Y, pin down the sales level at the time of the previous change, thereby providing information on p^*.

The first variable, time since previous change, is included to proxy for any omitted

[12]This reduced-form model is the same as the specification in Cecchetti (1986) with the addition of current inflation and current magazine sales.

[13]It is not essential for the matching regression to have a direct structural interpretation because of the indirect nature of the estimation procedure. In this case, the link between the regression and the model is discussed to emphasize the source of identification .

time-dependent factors in the data.[14] The estimated coefficient on this variable will provide information on the specification of the structural model, which does not include any variables growing at a constant rate. The unobservable state variable in this model is the adjustment cost.[15] Under the assumption that this adjustment cost is i.i.d., the adjustment cost is simply a missing variable that is uncorrelated with the other regressors. If there is persistence in the adjustment cost process, then the unobserved adjustment cost will be correlated with the cumulative regressors, which are functions of the firm's pricing decisions in previous periods.

One limitation of this hazard function is that it does not provide identification for the persistence parameter. The presence of serial correlation in the adjustment costs process is more likely detected in the size of the price change rather than in the frequency of changes. Over time, a firm facing a very persistent adjustment cost would be observed as making similar percentage changes in its price. In terms of the standard (s, S) model, a firm with a permanent fixed cost of adjustment will have fixed threshold bands that will be used each time the reset value is reached. Therefore, the percentage change in prices will be very similar over time. The moment included in the estimation to identify the persistence parameter is the correlation of consecutive percentage changes in price for a firm.

5.2 Indirect inference

For the first specification, the auxiliary parameters are $\alpha = \{b_1, b_2, b_3, b_4, b_5\}$. Following Gourieroux et al., the criterion is specified as $Q_T(y_T, x_T, \alpha)$, where $y_T = (y_1, ..., y_T)$ represents the endogenous discrete choice of a price change and $x_T = (x_1, ..., x_T)$ represents the exogenous sales and inflation data. The cumulative variables are endogenous functions

[14]Cecchetti includes this variable in order to control for a constant rate of technology growth.

[15]In Cecchetti's model, the unobserved term was the firm's choice of (s, S) bands. He assumed that the (s, S) bands were fixed for three-year intervals. Based upon that assumption, he estimated the model using a fixed-effects logit technique from Chamberlain (1984). Willis (2000b) illustrates the bias in his estimates, due to the presence of lagged-dependent variables, and proposes a correction using the method from Heckman and Singer (1984). The corrected results do not support Cecchetti's assumption of three-year fixed (s, S) bands.

of lagged pricing decisions and lagged exogenous variables. The criterion function in this case is the negative sum of squared errors of the linear probability model. Denote $\hat{\alpha}_T$ as the solution to the maximization of the criterion function

$$\hat{\alpha}_T = \arg\max_{\alpha} Q_T\left(y_T, x_T, \alpha\right)$$

For a given set of structural parameters, δ, I construct S simulated datasets based upon independent draws of the innovations to the exogenous processes $(\varepsilon_1^s, ...\varepsilon_T^s)$ and on initial values z_0^s, $s = 1, ...S$.

$$\left[y_t^s\left(\delta\right), x_t, t = 0, ..., T\right], s = 1, ..., S$$

For each simulation dataset, I maximize the same criterion function, replacing the observed data with the simulated data.

$$\hat{\alpha}_T^s\left(\delta\right) = \arg\max_{\alpha} Q_T\left(y_T^s\left(\delta\right), x_T, \alpha\right) \tag{7}$$

The indirect estimator of δ is defined as the solution to the following minimization problem

$$\hat{\delta} = \arg\min_{\delta}\left[\hat{\alpha}_T - \frac{1}{S}\sum_{s=1}^{S}\hat{\alpha}_T^s\left(\delta\right)\right]'\hat{\Omega}_T\left[\hat{\alpha}_T - \frac{1}{S}\sum_{s=1}^{S}\hat{\alpha}_T^s\left(\delta\right)\right]$$

where $\hat{\Omega}_T$ is a positive definite matrix that converges to a deterministic positive definite matrix Ω.[16]

The indirect estimator is asymptotically normal for fixed S:

$$\sqrt{T\left(\hat{\delta} - \delta_0\right)} \underset{T\to\infty}{\overset{d}{\to}} N\left(0, W\left(S, \Omega\right)\right)$$

where

$$W\left(S, \Omega\right) = \left(1 + \frac{1}{S}\right)\left[\frac{\partial^2 Q_\infty}{\partial\alpha\partial\delta'}\left(\frac{\partial Q_\infty}{\partial\alpha}\frac{\partial Q_\infty}{\partial\alpha}'\right)^{-1}\frac{\partial^2 Q_\infty}{\partial\alpha\partial\delta'}\right]^{-1}$$

[16]In my specification, a consistent estimator for Ω is

$$\hat{\Omega}_T = \left[T * Var\left(\hat{\alpha}_T\right)\right]^{-1}$$

The power of this procedure lies in the specification of the criterion function and the auxiliary parameters to be estimated, similar to the importance of selecting moments in GMM. The precision of the estimates, measured through the asymptotic variance above, is related to the sensitivity of the auxiliary parameters to movements in the structural parameters through $\frac{\partial^2 Q_\infty}{\partial\alpha\partial\delta'}$. If the sensitivity is low, the derivative will be near zero, indicating a high variance for the structural estimates.

Although the structural model contains no heterogeneity across firms in the first specification due to the i.i.d. assumption for the adjustment cost process, there are significant fixed effects across magazines in the data, as discussed in Chapter 1. Therefore, magazine dummy variables are included to remove the heterogeneity.

6 Results

The results of the regression using the magazine dataset are contained in column 1 of Table 3. The coefficient estimate on time since last change, $T_{i,t,\tilde{t}}$, is not significantly different from zero, indicating that there is no explicit time dependence. The probability of a price change is increasing in relation to current inflation, π_t, and cumulative inflation, $\pi_{i,t,\tilde{t}}$. In relation to magazine sales, the coefficient estimates for current sales, Y_t, and cumulative percentage change in sales since the previous change, $\dot{Y}_{i,t,\tilde{t}}$, are insignificantly negative.

6.1 Estimation of Model 1

The structural parameters are estimated using the indirect inference procedure described above where the auxiliary parameters are the five coefficients from the linear probability model. The optimal weighting matrix for the minimum distance estimator is the inverse of the variance-covariance matrix of the auxiliary parameter coefficients from the regression on the magazine data. Ten simulation datasets are constructed for each evaluation of δ_1 in the estimation procedure ($S = 10$).

One important issue in the estimation procedure is the selection of the exogenous variables. Assuming that these variables are well approximated by a Markov process, they should be simulated according to the specified process. In this case, the approximation is based upon VAR estimates from a 21-year sample of inflation and sales. Since the indirect inference procedure matches the auxiliary parameters based upon this 21-year sample, it is important that the exogenous process used in the simulation closely resembles the sample data. From the VAR estimates presented above, the fit of the inflation regression is low ($R^2 = 0.39$). The concern is that in a short time sample, if the simulated processes do not reflect those from the sample, then the estimation procedure will not produce informative results. In order to avoid this problem, the actual data for inflation and sales will be incorporated into the simulation procedure. This is accomplished by mapping the data into the corresponding discrete state space representation. The transition matrix for inflation and sales, based upon the VAR estimates, is still used in computing expectations in the firm's optimization problem.

Several steps are also taken to control for the unobserved initial condition of the cross-sectional price distribution. First, additional periods preceding the 21-year sample are simulated, based upon the actual inflation and sales values. These introductory periods mitigate the effects of the initial relative price selected for each simulated firm. The initial periods are discarded before estimating the auxiliary parameters. Second, the number of firms in the simulation is increased from 38 in the data to 100 to provide a better approximation of the cross-sectional distribution.

The structural estimates are presented in column 1 of Table 4 with the standard errors reported in parentheses.[17] The estimates of the auxiliary parameters from the simulation data are listed in column 2 of Table 3. The CES parameter estimate, $\hat{\theta}$, indicates a markup of 75 percent by the firms.[18] Based upon the estimate of the cost parameter, $\hat{\gamma}$, the

[17] Since the estimation has fewer structural parameters than auxiliary parameters, a specification test can be constructed based upon the optimal value of the objective function. The optimal value (multiplied by $\frac{TS}{1+S}$) is a chi-square statistic with $\dim \alpha - \dim \delta$ degrees of freedom. Based upon the value of the statistic, the specification of the model is rejected.

[18] The markup is $\frac{1}{\theta - 1}$. A 75 percent markup is plausible for this industry. Comparing the price of a single-copy purchase to the per issue price in a subscription contract, discounts for subscriptions are often in the range of 40-60%, indicating that the markup on single-copy price may in fact be over 100 percent.

production function is close to constant returns to scale.[19]

The estimates of the adjustment cost process are expressed in log-normal terms. The median adjustment cost faced by firms is 35.6 percent of revenues. This is not, however, the median cost paid by firms. As illustrated in Table 5, firms only adjust price when they face low adjustment costs. The first column lists the nine costs in the discrete state space. The costs are expressed as a percentage of steady state revenue. The second column displays the distribution of the adjustment costs across firms in a single simulation dataset. The third column lists the fraction of firms that adjust when faced with the respective adjustment cost. This fraction is near 1 for firms facing the lowest adjustment cost. As the adjustment cost rises, the fraction of firms adjusting falls. The highest cost paid is 35.5 percent of revenue, but only 3 percent of the firms facing that adjustment cost choose to adjust. When faced with higher adjustment costs, firms choose to wait until next period when an independently selected adjustment cost will be received. It is important to note that the parameters of the adjustment cost process are identified from the actual adjustment costs paid by firms. The upper tail of the distribution, where firms never adjust, simply represents the region above the cutoff value for adjustment and is not well identified. It does not necessarily imply that firms actually face adjustment costs as large as 3385 percent of revenues.

The mean adjustment cost paid is 4.02 percent of revenue. In terms of the existing empirical literature, this estimate is much higher than previous studies. Levy et al. find that the measurable portion of menu costs in the supermarket industry is 0.7 percent of revenues. The estimates from Slade roughly correspond to menu costs of 1.9 percent of revenue.

To evaluate the estimated magnitude of these costs in a broader context, we can compare the average price-adjustment costs to costs of capital adjustment for a typical manufacturing plant. According to estimates in Gilchrist and Himmelberg (1995), the average capital

[19]This result supports the argument for separating the single-copy and subscription pricing decisions, as discussed in footnote 5.

adjustment cost incurred by a typical large manufacturing firm is 12.5 percent of profits.[20] The corresponding estimate of the average price-adjustment cost incurred by magazine firms is 7.9 percent of profits, almost two-thirds the size of typical capital adjustment costs.

The hazard graphs for the estimated structural model, conditional on inflation and industry output, are presented in Figures 2. Properties 1-4 of the model are evident in the hazards, as discussed earlier. One difference from the previous graphs is that the probability of price adjustment is less sensitive to the current level of the industry demand (panel B of Figure 2) than before (panel B of Figure 1). This is due to the estimated value of the cost parameter, γ. In Figure 1, γ was set at 1.5 whereas the estimated value is 1.03. As γ approaches 1, the marginal cost of production is nearly constant. Therefore, monopolistically competitive firms will have less incentive to react to changes in demand than if their marginal cost curves were increasing.

I examine other implications of the structural estimates through comparison of moments in Table 6. This comparison is useful for checking the model's performance independent of the auxiliary parameters used in the estimation. The table includes one unconditional moment, the fraction of firms adjusting over the sample, two moments conditional upon price adjustment, and four correlations. The conditional moments are the average percentage change in price and average cumulative inflation since previous change. The final four moments are the correlation between the current and previous price changes, the time series correlation between inflation and the frequency of price adjustment, the correlation between inflation and the average percentage change in price, and the correlation between magazine sales and the frequency of adjustment.

Moments from the simulation of the structural model closely match the majority of

[20] This value is calculated by evaluating the cost of capital adjustment function at average values of investment rates and profit rates over the sample. The adjustment cost (c) as a percent of profits (Π) is specified as $\frac{c}{\Pi} = \frac{\zeta}{2}\left(\frac{I}{K}\right)^2\left(\frac{K}{\Pi}\right)$, where K represents capital and I represents investment. Using a sample of large manufacturing firms with bond ratings, the estimate of ζ is 2.96. The average investment rate in the full sample is 0.179 and the average profit rate $\left(\frac{\Pi}{K}\right)$ is 0.379.

moments from the magazine data listed in the table. The fraction of firms adjusting over the sample (FRAC) is almost identical in the simulation. I also find a close correspondence in the annual frequency of adjustment time series, illustrated in panel A of Figure 3. This result is related to the high correlations reported for the frequency of adjustment and inflation time series in both the data and the model. The conditional moments, the average percentage change in price and the average cumulative inflation since previous change, again are closely approximated by the simulated model.

Differences exist between the data and the model for two of the moments. First, the correlation of current and previous price changes is negative in the model as opposed to the positive correlation in the data. This difference could be due to the lack of heterogeneity in the model. As discussed in Property 1, the i.i.d. nature of the adjustment cost process causes all firms to select the same optimal price. In addition, from Table 5 we know that firms only adjust when they receive a low realization of the cost. With persistence in the adjustment cost process ($\rho > 0$), percentage change in prices might be more correlated as firms are more likely to face similar adjustment costs over time. In the extreme case, if the adjustment costs were fixed and inflation and sales remained constant, the price changes over time would be perfectly correlated.

The other moment that differs between the data and the model is the time series correlation between inflation and the average percentage change in price. This difference is illustrated in panel B of Figure 3. For most of the 1960s, the average annual percentage change in the price series for the data and the model move in opposite directions. The series from the model is highly correlated with inflation, while the series from the data is not. One other time series is plotted for additional comparison. Panel C of Figure 3 graphs the average annual cumulative inflation since the previous price change for adjusting firms. These series also do not appear to be as closely related. The differences apparent in panel B and C could again be due to heterogeneity across firms in the data.

6.2 Estimation of Model 2

The second estimation includes the persistence parameter of the adjustment cost process into the set of structural parameters to be estimated. This estimation is more general than the first since the i.i.d. assumption ($\rho = 0$) is nested in the second estimation. This parameter is not well identified by the current set of regression coefficients used in the indirect inference procedure, so the correlation of sequential price changes is added to the set of auxiliary parameters. The optimal weighting matrix must now include weights relating to correlation of prices changes. These weights are calculated by measuring the variance of the correlation in multiple simulations of the model using the estimated parameters from a first stage estimation, where an identity matrix is used for the weighting. As in the previous estimation, ten simulation datasets are constructed for each evaluation of δ_2 in the estimation procedure ($S = 10$).

The structural estimates are presented in column 2 of Table 4 with the standard errors reported in parentheses. The estimates of the auxiliary parameters from the simulation data are listed in column 3 of Table 3.[21] The CES parameter estimate, $\hat{\theta}$, indicates a markup of 152 percent by the firms, double the estimate of Model 1. The estimate of the cost parameter, $\hat{\gamma}$, is almost identical to the earlier estimate.

The estimates of the adjustment cost parameters are much different than before. The persistence parameter of the adjustment cost process is estimated as 0.68, significantly different than the i.i.d. assumption used in Model 1. This higher degree of persistence results in a lower median adjustment cost faced by firms: 2.9 percent of revenues, down from 35 percent of revenue in Model 1. Table 7 displays the adjustment frequency of firms facing each of the adjustment costs in the state space. In the earlier estimation, nearly

[21] As mentioned earlier, correlation in the adjustment cost process, ($\rho > 0$), will cause the error term to be correlated with the lagged dependent variables. The resulting regression coefficients will be biased. This bias, however, does not necessary lead to bias in the estimates of the structural parameters. Under the assumption that the model and the data come from the same data generating process, matching biased moments from the simulated data to biased moments from the magazine data will still produce consistent estimates.

all firms receiving the lowest adjustment cost choose to adjust because they know that they will get an independent draw from the cost process next period. Here, however, only slightly more than 50 percent of the firms choose to adjust when faced with the low costs. The lower adjustment percentage is due to the fact that firms with the lowest cost know that there is a higher probability of receiving the low cost next period. Therefore, more firms will delay adjustment in order to reduce the number of times they have to incur the cost.

The mean adjustment cost paid is 2 percent of revenue, half of the mean cost paid in the previous model. This estimate is much more similar to that found in the supermarket industry, but this amount still represents an economically significant cost to the firms. In terms of profits, these costs represent 3.3 percent of profits.

The third column of Table 6 lists the previously described additional moments produced by the estimates for Model 2. The moments are all similar to those from Model 1 with the exception of the change in the correlation of percentage changes in prices, which now closely matches the magazine data statistic. In panel A of Figure 3, the frequency of price adjustment from the simulation of Model 2 is a better approximation of the magazine data than Model 1. In terms of the average percentage change in price and average cumulative inflation for adjusting firms, the time series simulation from Model 2 is similar to that of Model 1. Both series are highly correlated with inflation, as opposed to the low correlation between the magazine data and inflation.

7 Conclusion

The objective of this paper is to estimate the structure of price adjustment costs in a particular industry. A dynamic-programming model for a monopolistically competitive firm facing a fixed cost of adjustment is specified and solved numerically. The parameters of the unobserved adjustment cost process are estimated through indirect inference using data on magazine cover prices.

In comparison to the other empirical results, the estimated adjustment costs are large.

The estimated costs are higher than those measured in the supermarket industry, where there is clearly a sizable cost associated with physically changing prices on the large assortment of goods in stock. According to the simulated results, the mean adjustment cost paid by firms is 3.3 or 7.9 percent of profits depending on the model, which is one-third to two-thirds as large as costs of capital adjustment in the manufacturing industry.

The large difference in the estimates of the standard deviation of the adjustment cost process is linked to the i.i.d. assumption. To match the linear probability regression from the data, both models require long periods of inactivity between price adjustments. With an i.i.d. process, this is accomplished by having extremely large costs mixed in with small costs, causing firms to postpone adjustment until a low cost is received. With a higher degree of persistence, as identified in the estimate of Model 2, a lower standard deviation is required. Firms now face on average a lower, but persistent costs.

To further explore the structural models, several other moments were calculated in order to compare implications of the models with results from the magazine dataset. The models closely match the majority of moments as well as the time series on frequency of adjustment in the data. Model 1 has difficulty, however, in replicating the time series behavior of two conditional moments: average cumulative inflation since the previous price change and the average percentage change in price. Another difference lies in the correlation of a firm's current and previous percentage change in price. The estimate of Model 2 addresses the difference in the correlation of price changes, using this information from the firm's intensive margin decision to identify the persistence parameter of the adjustment cost process. The resulting estimate indicates a high degree of persistence, which could potentially be one explanation for the heterogeneity observed in the magazine data.

Future research will explore a second possible explanation for heterogeneity through inclusion of the profitability shocks, which were removed from the analysis above. These shocks will have different effects on the results because they enter the firm's profit function regardless of the pricing decision, whereas the adjustment costs are only present when a firm decides to change its price.

In other work, Willis (2000a) focuses on the equilibrium of this model. The current estimation procedure does not include an equilibrium condition requiring that the pricing decisions of firms aggregate to match the magazine price index. In addition, the model assumes that industry demand is exogenous. By solving a general equilibrium version of this model, the macroeconomic consequences of adjustment costs can be explored.

References

Aguirregabiria, Victor, "The Dynamics of Markups and Inventories in Retailing Firms," *Review of Economics Studies*, April 1999, *66* (2), 275–308.

Ball, Laurence and David Romer, "Real Rigidities and the Non-Neutrality of Money," *The Review of Economic Studies*, April 1990, *57* (2), 183–204.

___ **and N. Gregory Mankiw**, "A Sticky-Price Manifesto," *Carnegie-Rochester Conference Series on Public Policy*, 1994, *41*, 127–151.

Barro, Robert, "A Theory of Monopolistic Price Adjustment," *Review of Economics Studies*, 1972, *34*, 17–26.

Blanchard, Olivier and Nobuhiro Kiyotaki, "Monopolistic Competition and the Effects of Aggregate Demand," *American Economic Review*, September 1987, *77*, 647–666.

Caplin, Andrew and John Leahy, "State-Dependent Pricing and the Dynamics of Money and Output," *Quarterly Journal of Economics*, August 1991, *106* (3), 683–710.

Carlton, Dennis, "The Rigidity of Prices," *American Economic Review*, 1986, *76*, 255–274.

Cecchetti, Stephen, "The Frequency of Price Adjustment: A Study of the Newsstand Prices of Magazines," *Journal of Econometrics*, August 1986, *31*, 255–274.

Chamberlain, Gary, "Panel Data," *Handbook of Econometrics, Vol. 2*, 1984, pp. 1247–1318. A. Griliches and M.D. Intriligator, eds.

Cooper, Russell, John Haltiwanger, and Laura Power, "Machine Replacement and the Business Cycle: Lumps and Bumps," *American Economics Review*, September 1999, *89* (4), 921–946.

Dotsey, Michael, Robert King, and Alexander Wolman, "State-Dependent Pricing and the General Equilibrium Dynamics of Money and Output," *Quarterly Journal of Economics*, May 1999, *114*, 655–690.

Gilchrist, Simon and Charles Himmelberg, "Evidence on the Role of Cash Flow for Investment," *Journal of Monetary Economics*, 1995, *36*, 541–572.

Gourieroux, Christian, Alain Monfort, and Eric Renault, "Indirect Inference," *Journal of Applied Econometrics*, 1993, *8*, S85–S118.

Heckman, James and Burton Singer, "A Method for Minimizing the Impact of Distributional Assumptions in Econometric Models for Duration Data," *Econometrica*, March 1984, *52* (2), 271–320.

Kashyap, Anil, "Sticky Prices: New Evidence from Retail Catalogs," *Quarterly Journal of Economics*, February 1995, *110*, 245–274.

Levy, Daniel, Mark Bergen, Shantanu Dutta, and Robert Venable, "The Magnitude of Menu Costs: Direct Evidence from Large U.S. Supermarket Chains," *Quarterly Journal of Economics*, 1997, *113*, 791–825.

Mankiw, Gregory, "Small Menu Costs and Large Business Cycles: A Macroeconomic Model of Monopoly," *Quarterly Journal of Economics*, May 1985, *100*, 529–539.

Rust, John, "Optimal Replacement of GMC Bus Engines: An Empirical Model of Harold Zurcher," *Econometrica*, September 1987, *55*, 999–1033.

Sheshinski, Eytan and Yoram Weiss, "Inflation and Costs of Adjustment," *Review of Economics Studies*, 1977, *44*, 281–303.

Slade, Margaret, "Optimal Pricing with Costly Adjustment: Evidence from Retail-Grocery Prices," *Review of Economic Studies*, January 1998, *65*, 87–107.

Stokey, Nancy and Robert Lucas, *Recursive Methods in Economic Dynamics*, Cambridge, MA: Harvard University Press 1993.

Tauchen, George, "Finite State Markov-Chain Approximations to Univariate and Vector Autoregressions," *Economics Letters*, 1986, *20*, 177–181.

Willis, Jonathan, "General Equilibrium of a Monetary Model with State-Dependent Pricing," mimeo, Boston University, 2000.

——, "Magazine Prices Revisited," mimeo, Boston University, 2000.

Table 1: Magazine Price Data

	Fraction of magazines changing price (percent)	Magazine industry inflation (percent)	Total single-copy sales (thousands)	Avg. number of years since last price change (years)	Average magazine inflation since last change (percent)
1959	5.26	1.18	227.32	3.00	10.79
1960	2.63	0.48	225.90	13.00	27.98
1961	7.89	2.05	219.00	3.33	4.41
1962	13.16	3.80	217.30	10.00	19.60
1963	31.58	7.12	225.47	7.83	22.93
1964	18.42	3.01	226.38	6.00	17.90
1965	13.16	3.45	237.20	7.40	25.16
1966	23.68	4.13	243.60	5.44	19.65
1967	28.95	8.05	248.81	4.64	21.44
1968	18.42	5.64	246.66	7.29	31.17
1969	23.68	5.11	232.83	5.22	24.03
1970	18.42	4.28	234.10	5.57	28.24
1971	10.53	3.32	246.40	6.75	33.47
1972	13.16	3.42	255.77	8.40	33.21
1973	21.05	5.70	270.17	5.88	26.83
1974	50.00	14.57	269.48	4.84	31.77
1975	28.95	7.24	256.68	3.45	25.33
1976	44.74	11.05	266.46	2.88	25.29
1977	34.21	8.94	243.39	3.46	30.98
1978	36.84	8.95	251.53	1.93	17.43
1979	31.58	6.02	225.69	3.08	25.37

Table 2: Coefficient Estimates for VAR of Inflation and Sales

	constant	$\log(\pi_{t-1})$	Y_{t-1}	R^2
$\log(\pi_t)$	-1.28	0.61	0.03	0.39
	(2.21)	(0.15)	(2.06)	
Y_t	0.19	-0.003	0.79	0.59
	(0.14)	(0.01)	(0.13)	

Table 3: Coefficient Estimates of Auxiliary Parameters

	Data	Model 1	Model 2
	(1)	(2)	(3)
$T_{i,t,\tilde{t}}$	-0.013	0.004	-0.0034
	(0.010)		
$\pi_{i,t,\tilde{t}}$	1.35	0.95	1.09
	(0.25)		
$\dot{Y}_{i,t,\tilde{t}}$	-0.26	-0.09	0.075
	(0.25)		
π_t	2.14	2.40	1.78
	(0.63)		
Y_t	-0.02	0.05	-0.02
	(0.37)		
Corr($\%\Delta P_t, \%\Delta P_{t-1}$)	0.26	–	0.21
R^2	0.15	0.05	
Obs.	807		

NOTE: Dummy variables were included in the regression to control for differences across magazines. The dummy coefficients were jointly significant. The coefficient estimates are not reported.

Table 4: Estimates of Structural Parameters

	Model 1	Model 2
σ_{ε}	3.04	1.94
	(0.42)	(0.51)
μ	-1.03	-3.54
	(1.29)	(0.80)
θ	2.33	1.66
	(1.90)	(0.31)
γ	1.03	1.02
	(0.41)	(0.11)
ρ		0.68
		(0.10)
χ^2 (1)	26.8	6.2

Table 5: Distribution of Adjustment Costs in Model 1

adjustment cost (% of "steady state" revenue)	realizations	fraction adjusting
0.08	79	0.96
0.37	136	0.82
1.71	255	0.65
7.79	335	0.32
35.55	461	0.03
162.34	356	0
741.27	241	0
3385	145	0
15456	92	0
mean adjust cost paid = 4.02 %		

Table 6: Additional Moments

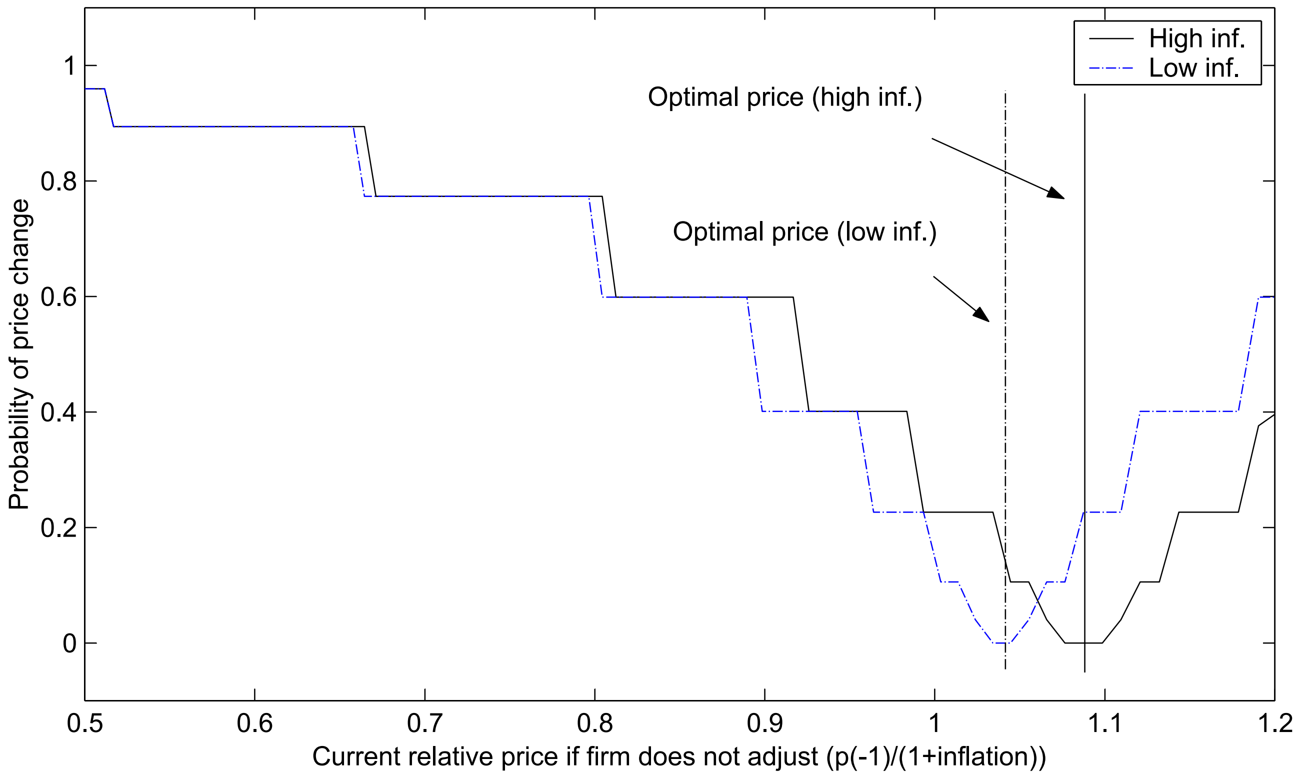
Moment	Data	Model 1	Model 2
Unconditional moments			
Fraction of firms adjusting (FRAC)	0.22	0.23	0.24
Conditional moments			
Average $\%\Delta P_i$	23.5%	23.5%	21.7%
Average $\pi_{i,t,\tilde{t}}$	24.0%	22.8%	21.4%
Correlations			
Corr($\%\Delta P_{i,t}$, $\%\Delta P_{i,\tilde{t}}$)	0.20	-0.064	0.21
Corr(π_t,FRAC$_t$)	0.96	0.91	0.94
Corr(π_t,Avg($\%\Delta P_i$))	0.18	0.81	0.76
Corr(Y_t,FRAC$_t$)	0.56	0.55	0.54

Table 7: Distribution of Adjustment Costs in Model 2

adjustment cost (% of "steady state" revenue)	realizations	fraction adjusting
0.06	74	0.54
0.16	130	0.56
0.42	235	0.51
1.10	349	0.36
2.90	415	0.22
7.63	391	0.13
20.04	275	0.03
52.64	147	0
138.31	84	0
mean adjust cost paid = 2.00 %		

Figure 1

Panel A: Hazard rates controlling for inflation



Panel B: Hazard rates controlling for industry output

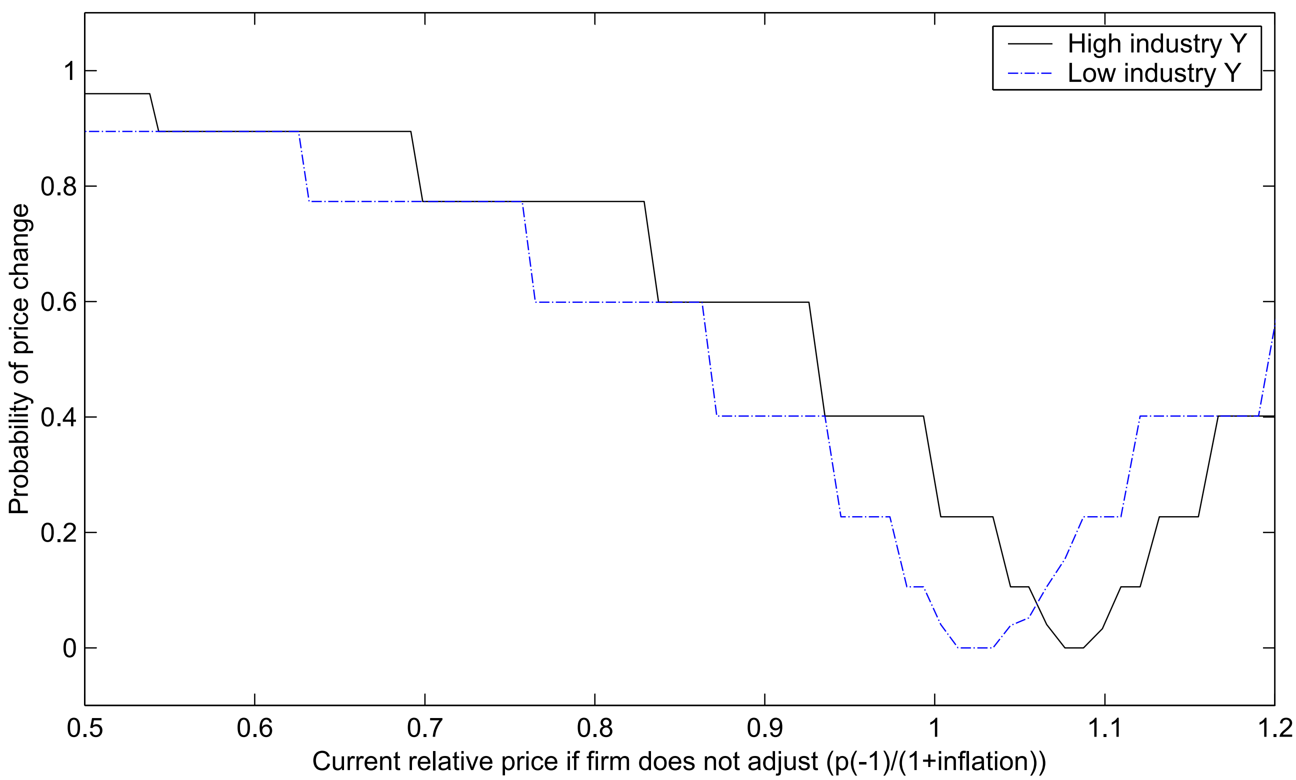
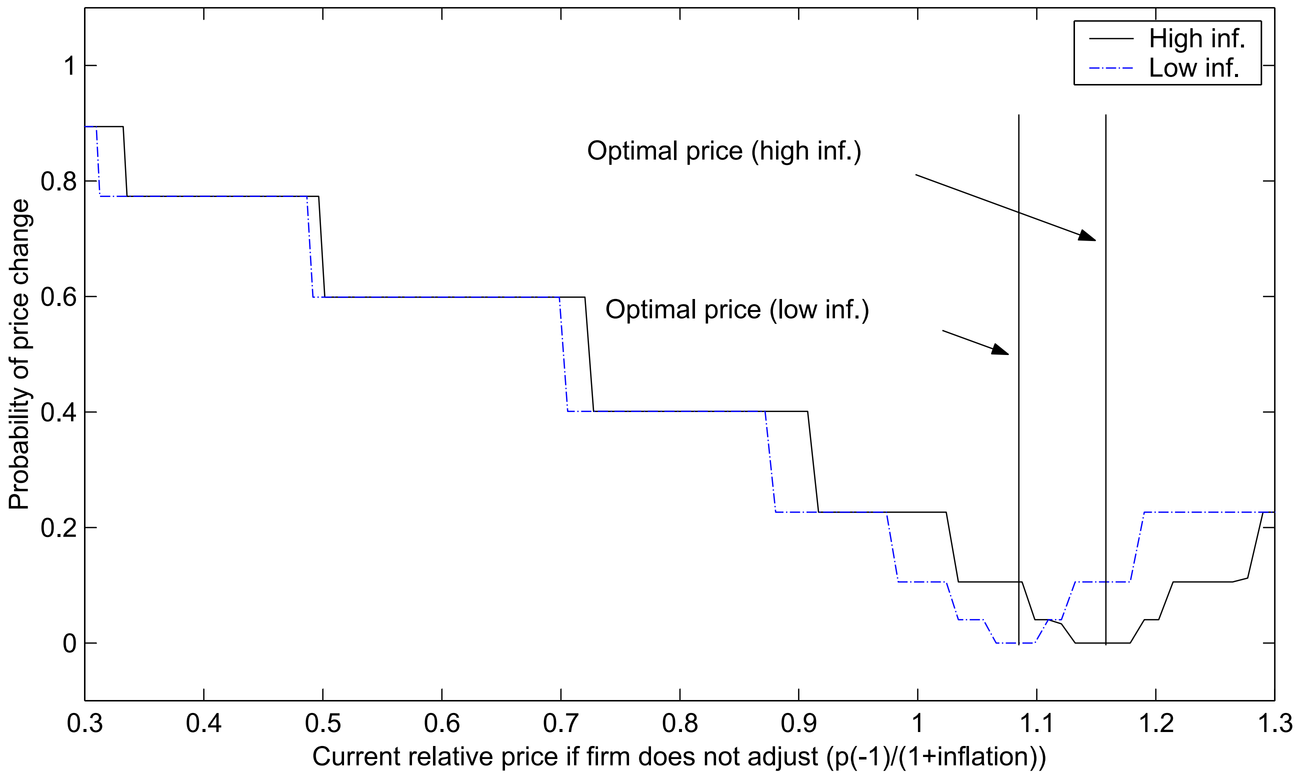


Figure 2

Panel A: Hazard rates controlling for inflation



Panel B: Hazard rates controlling for industry output

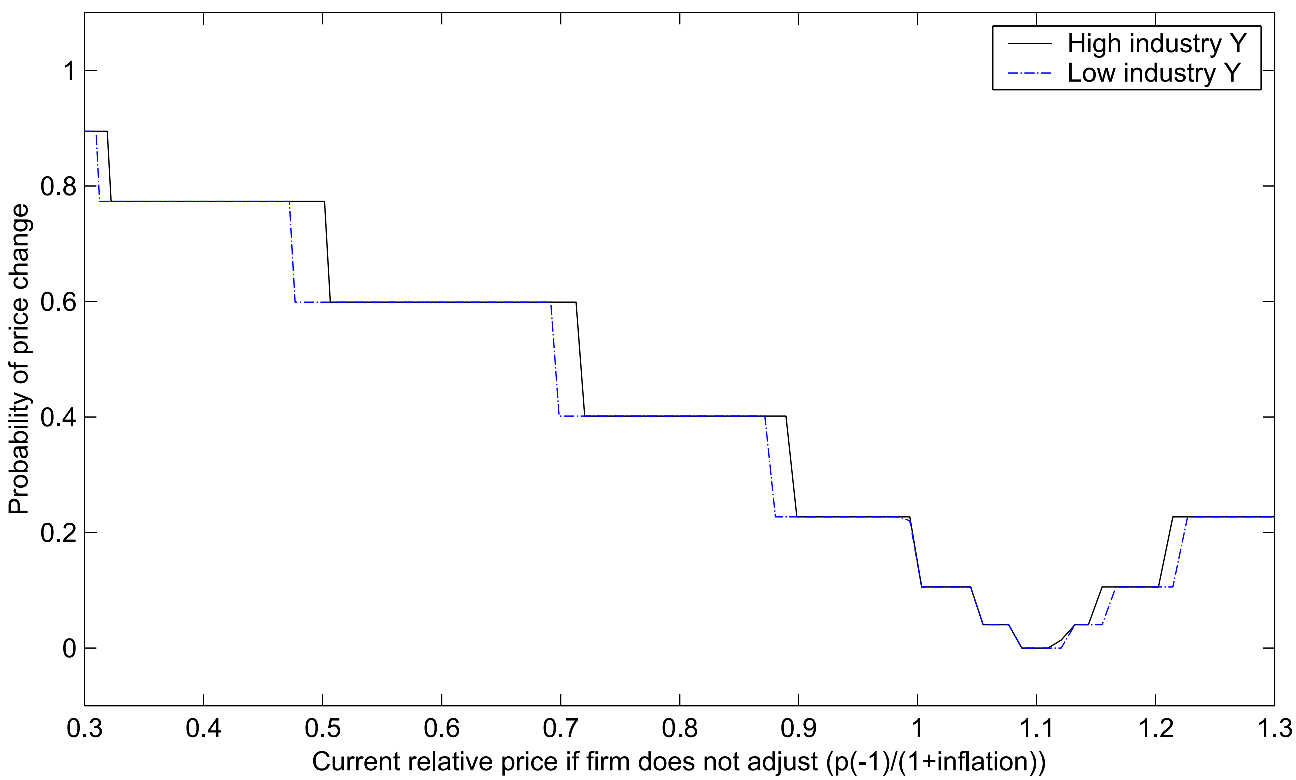
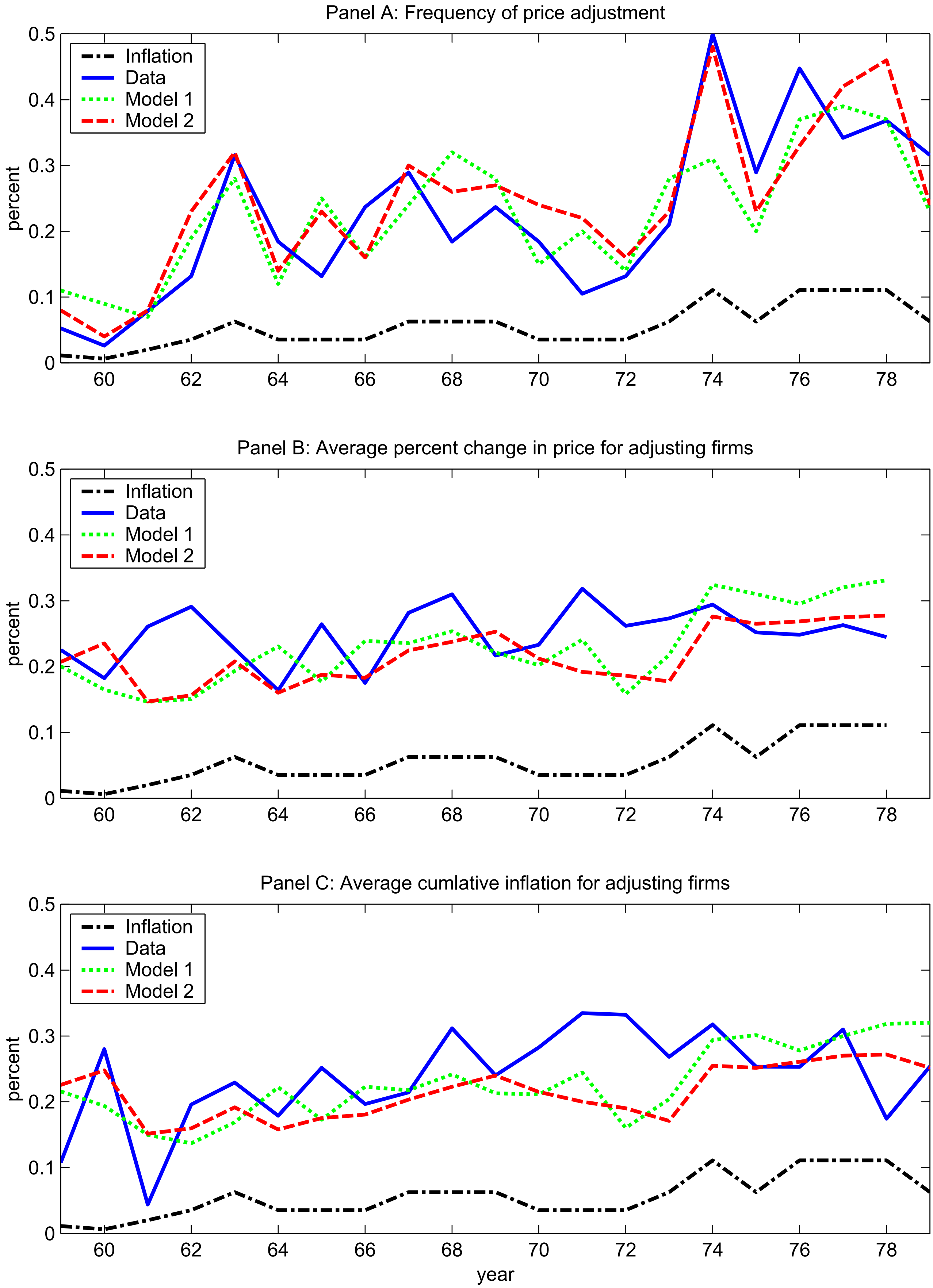


Figure 3


Panel A: Frequency of price adjustment
Inflation
Data
Model 1
Model 2
percent
0
0.1
0.2
0.3
0.4
0.5
60
62
64
66
68
70
72
74
76
78
Panel B: Average percent change in price for adjusting firms
Inflation
Data
Model 1
Model 2
percent
0
0.1
0.2
0.3
0.4
0.5
60
62
64
66
68
70
72
74
76
78
Panel C: Average cumlative inflation for adjusting firms
Inflation
Data
Model 1
Model 2
percent
0
0.1
0.2
0.3
0.4
0.5
60
62
64
66
68
70
72
74
76
78
year