Some Evidence on the Importance of Sticky Prices

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Abstract

We examine the frequency of price changes for 350 categories of goods and services covering more than 70 percent of consumer spending, based on unpublished data from the BLS for 1995 to 1997. Compared with previous studies we find much more frequent price changes, with half of prices lasting less than 4.3 months. The frequency of price changes differs dramatically across goods. We exploit this variability to ask whether monthly time series for prices and consumption of goods with frequent price changes (flexible-price goods) differ markedly compared to time series for goods displaying infrequent price changes (sticky-price goods). Compared to the predictions of time-dependent sticky price models, actual inflation rates are far more volatile and transient, particularly for sticky-price goods.

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1. Introduction

The importance of price stickiness remains a central question in economics. After a ten-year period of relative quiet, sticky-price models are again at, or near, the center of analysis of business cycle fluctuations and monetary policy. Goodfriend and King (1997), Rotemberg and Woodford (1997), Clarida, Gali, and Gertler (1999), Erceg, Henderson, and Levin (2000), Chari, Kehoe, and McGrattan (2000), Christiano, Eichenbaum, and Evans (2001), and Dotsey and King (2001) are examples of recent work built on the assumption that firms adjust prices infrequently and satisfy all demand at those posted prices.

Each of these papers employs a time-dependent rule for price changes, that is, prices are set and maintained for a set number of periods or each period a fraction of firms have an opportunity to adjust prices to new information (as in Calvo, 1983).[1] This time-dependent pricing yields very tractable results. It also provides a setting in which monetary policy can influence economic activity for some period of time. By contrast, Caplin and Spulber (1987) illustrate that state-dependent models of price changes generate less clear predictions for the impact of monetary policy on real activity. As we discuss at length, models with time-dependent pricing also clearly imply that inflation rates become much more persistent and much less volatile if price changes are relatively infrequent.

The speed with which sticky-price models were first jettisoned then retrieved partly reflects the lack of conclusive evidence on the extent and importance of sticky prices. Several papers have shown that certain wholesale and retail prices often go unchanged for many months (Carlton, 1986, Cecchetti, 1986, Kashyap, 1995, Levy, Bergen, Dutta and Venable, 1997, Blinder, Canetti, Lebow and Rudd, 1998, MacDonald and Aaronson, 2001, and Kackmeister, 2001). Compared to these studies, we obtain broader evidence on the extent of retail price rigidities and their consequences for the behavior of inflation. We employ unpublished data from the U.S. Bureau of Labor Statistics (BLS) for 1995 to 1997 on the

[1] Dotsey and King allow some endogeneity in how many firms choose to adjust their prices.

monthly frequency of price changes for 350 detailed categories of consumer goods and services. We find that many prices seldom change. Prices of newspapers, men's haircuts, and taxi fares change in only 2 or 3 percent of monthly observations. By contrast, many prices change very frequently. The prices of gasoline, tomatoes, and airfares change monthly about 70 percent of the time. We exploit this diversity. We classify goods by how frequently they display monthly price changes in the 1995-1997 data, then ask how the behavior of inflation differs between goods with frequent versus infrequent price changes.

In the next section (section 2) we present the disaggregate data on the frequency of price changes for 1995 to 1997. We contrast our findings to the existing literature. We find much more frequent price changes, with half of prices lasting for 4.3 months or less. We also present a number of characteristics that predict whether a good will display a flexible price. We find that variables capturing the volatility of market supply and demand can account for most of the variation in price flexibility across categories. For example, goods that exhibit frequent model changes also typically exhibit flexible pricing.

In section 3 we briefly sketch a general equilibrium sticky-price model that follows work in Chari, Kehoe and McGrattan (2000, 2001). They model monopolistically competitive firms with staggered price setting of a fixed duration. The wrinkle we add is multiple consumer goods with prices fixed for different durations across the goods. We simulate this model to illustrate how flexible-price goods and sticky-price goods can differ in their responses to shocks.[2]

In section 4 we analyze monthly time series on prices and consumption for 123 goods of varying price stickiness. The workhorse Calvo and staggered pricing models imply that price stickiness dampens the initial inflation impact of a shock, stretching out the inflation impact over time as successive cohorts of firms adjust their prices. That is, in these models sticky prices should dramatically reduce the innovation volatility of a good's inflation rate

[2] Several papers have incorporated sticky-price and flexible-price sectors into model economies. Examples include Ohanian, Stockman, and Kilian (1995), Aoki (2001), and Benigno (2001).

while, at the same time, dramatically raising the persistence of that good's inflation. We do not see this in the data. The data on goods' inflation rates present both a volatility and persistence problem for time-dependent models of sticky price. Conditional on prices that change every 4 or 5 months, as we see in the BLS data, we find that inflation rates are in general far too volatile and far too transient. This discrepancy cannot be resolved by adding plausible measurement error or idiosyncratic shocks. In sum, the time-series on goods' inflation rates suggest larger and more transient inflation movements than implied by popular time-dependent pricing models.

The final section (section 5) summarizes and discusses directions for further work.

2. BLS Data on the Frequency of Price Changes

For calculating the CPI, the BLS collects prices for about 71,000 non-housing goods and services per month.[3] These are collected from around 22,000 outlets across 44 geographic areas. The BLS divides non-housing consumption into roughly 350 categories called "entry-level items" (ELIs). The outlets are sampled probabilistically based on household point-of-purchase surveys, and the items within each ELI are sampled according to estimates of their relative sales in the outlet.

The BLS *Commodities and Services Substitution Rate Table* gives, for each ELI, the percentage of quotes with price changes. For example, the 1997 *Table* indicates that 6,493 price quotes were collected on bananas in 1997, and that 37.8% of these quotes differed from the quote on the same type of bananas at the same outlet in the preceding month. (The *Table* does not contain information on the magnitude of price changes, just what share of price quotes involved *some* change in price.) The field agents who collect price quotes use a detailed checklist of item attributes to try to make sure they are pricing the same item in

[3] The sources used for this section, unless otherwise noted, were *The Boskin Commission Report* (1986) and the *BLS Handbook of Methods* (U.S. Department of Labor, 1997, Chapter 17).

consecutive months. When they cannot find an item, they substitute the price of a closely-related item at the outlet. These "item substitutions" are the focus of the BLS *Table*, and we discuss them in detail later in this section. Item substitutions happen to be rare for bananas (only 1 in 1997) compared to other categories (3.1% of non-housing price quotes in 1997).

The BLS has provided us with the unpublished *Commodities and Services Substitution Rate Table* for the years 1995 through 1999. The BLS revised the ELI structure in 1998, so frequencies cannot be readily compared before and after 1998. For the 168 ELI definitions which remained unchanged, however, the frequencies are quite stable on either side of the revision. The correlations for any pair of years lie between 0.96 and 0.98. In order to maximize the number of ELIs for which there is a price index before 1998, we use the 1995-1997 data and its ELI structure (350 ELIs).

In Table 1 we list, for each ELI, the 1995-1997 average *monthly* frequency of price changes. For food and energy ELIs, in which items are priced monthly, this is the simple average of the frequencies in the 1995, 1996, and 1997 BLS *Tables*. For the other ELIs, the frequencies in the BLS *Tables* are a mixture of one-month price change frequencies and two-month price change frequencies. In the five largest areas — New York City and suburbs, Chicago, Los Angeles and suburbs, San Francisco / Oakland / San Jose, and Philadelphia — the BLS collects quotes monthly for all goods and services. For the other 39 geographic areas, the BLS collects quotes monthly only for food and energy, and bimonthly for all other goods and services. According to the *BLS Handbook of Methods* (U.S. Department of Labor, 1997, CPI Appendix 3), the top five areas represent 25.7% of the goods and services priced in the CPI. Because goods and services are priced monthly in the top five areas, compared to bimonthly in other areas, monthly quotes represent 40.8% of the price quotes collected each month in each ELI outside food and energy.[4] Thus, in the BLS *Tables*, the frequency of price

[4] If 25.7% of the items within an ELI are priced monthly and 74.3% are priced bi-monthly, then monthly quotes represent 25.7/(25.7 + 0.5*74.3) = .408, or 40.8%, of all price quotes in a given month.

changes in ELIs outside food and energy is an average of monthly (weight 40.8%) and bimonthly (weight 59.2%) price change frequencies.

If the monthly probability of a price change is constant for items within an ELI (the same across areas and the same from month to month), then we can identify the monthly frequency of price changes from the mixed frequency the BLS reports and the fraction of quotes which are monthly versus bimonthly.[5] Let y = the mixture of monthly and bimonthly frequencies (data from the BLS *Tables*), λ = the constant monthly frequency of price changes (not directly observed), and z = the fraction of quotes which are monthly (40.8% according to the BLS). Then $y = z*\lambda + (1-z)*(\lambda + (1-\lambda)*\lambda)$. Since $z \in (0, 1)$ and $\lambda \in [0,1]$, the solution for λ is the negative root of this quadratic in λ.

Table 1 reports estimated monthly frequencies (λ's) for each of the 350 ELIs. They are simple averages of the estimated monthly frequencies for 1995, 1996 and 1997 for each ELI. The ELIs are in order of increasing frequency of price changes. They range from 0.9% for vehicle inspection to 71% for fresh tomatoes. Figure 1 gives the histogram of frequencies for the 350 ELIs. Not all ELIs are equally important, however, as their weights in the December 1997 CPI range from 0.001% for playground equipment to 3.84% for new cars. Table 1 provides the weight of each ELI and the resulting percentile of the ELI in the cumulative distribution of frequencies. Weighting the ELIs by their relative importance, the monthly frequency of price changes averages 25.1% with a standard deviation of 17.6%. The weighted median is 20.8%. For the (weighted) median category, the mean time between price changes

[5] To do so, we assume that the probability of a price changing from p_a to p_b one month, then changing *back* to p_a the next month, is zero. Based on scanner data for select seasonal goods at certain Chicago-area supermarkets, Chevalier, Kashyap and Rossi (2000) find that such temporary sales are actually quite common. To the extent they occur, our estimated monthly frequencies understate the true monthly frequencies. Since Chevalier et al. find that temporary sales typically last one week or less, even monthly price quotes (as for the top five areas and for food and energy) understate the true frequency of price changes. As we discuss later in this section, however, one could argue that regularly-scheduled sales mask the stickiness of "baseline" prices.

is 4.3 months.[6] Thus for items comprising one half of consumption, prices change less frequently than every 4.3 months.

The 350 ELIs in Table 1 cover 71.2% of the December 1997 CPI. The categories not covered are owner's equivalent rent and household insurance (20.3% weight), residential rent (5.8%), used cars (1.2%), and various unpriced items (collectively 1.5%). One question that arises is whether scanner data, which are becoming increasingly available to economists (e.g., Chevalier et al., 2000), might dominate the BLS average frequency data. Scanner data could afford weekly data on prices and quantities for thousands of consumer items. At present, however, scanner data cannot match the category coverage of the BLS data. Hawkes and Piotrowski (2000, Table 1) report that, as of December 1999, only 10.2% of consumer expenditures are scannable through AC Nielsen data for supermarkets, drugstores, and mass merchandisers.[7] As noted, the 350 categories in the BLS *Table* cover 71.2% of the CPI.

Comparison to Other Empirical Studies of Price Stickiness

The BLS data suggests much more frequent price adjustment than has been found in other studies.[8] Blinder et al. (1998) surveyed 200 firms on their price setting. The median firm reported adjusting prices about once a year.[9] In contrast, the median consumer item in the BLS *Table* changes prices every 4.3 months. And 85% of consumption falls in categories whose prices change more frequently than once a year. One possible source of this difference

[6] In calculating the mean number of months between price changes we are assuming a constant over time (and equal across items within an ELI) instantaneous probability of a price changing. If λ = the monthly frequency of price changes, then the implied instantaneous probability is $-\ln(1-\lambda)$ and the implied mean time between price changes is $-1/\ln(1-\lambda)$ months. This is the formula we used to calculate the Mo. column from the Freq. column in Table 1. If we instead assume that prices change on a discrete monthly basis, then the mean duration is simply $1/\lambda$, or about half a month longer.

[7] Categories of consumption not currently scanned include rent, utilities, restaurant meals (which make up about 40% of spending on food), medical care, transportation, insurance, banking, and education, and the vast majority of home furnishings (including appliances), apparel, and entertainment.

[8] The BLS data also suggest more frequent price adjustment than has typically been employed in calibrated macro models. Chari et al. (2000), for instance, consider a benchmark case in which prices are set for one year.

[9] Hall, Walsh and Yates (2000) surveyed 654 British companies and obtained similar results: 58% changing prices once a year or more, vs. 51% in Blinder et al.'s survey.

in findings is that firms in the Blinder et al. survey sell mostly intermediate goods and services (79% of their sales) rather than consumer goods and services.

Even compared to other studies of *consumer* prices, the BLS data imply considerably more frequent price changes. Cecchetti (1986) studied newsstand prices of 38 American magazines over 1953 to 1979. He found the average number of years since the last price change ranged from 1.8 years to 14 years, depending on the period. In our Table 1, magazines (including subscription as well as newsstand prices) exhibit price changes 5.5% of months, implying adjustment every 1.5 years on average. More importantly, magazines are at the sticky end of the spectrum in Table 1: prices change more frequently than for magazines for 93.5% of non-housing consumption.[10]

Kashyap (1995) studied the monthly prices of 12 mail-order catalog goods for periods as long as 1953 to 1987. Across goods and time, he found an average of 14.7 months between price changes. This contrasts with the 4.3 month median in the BLS data. Based on Table 1, prices change more frequently than every 14.7 months for 88% of non-housing consumption. The 12 Kashyap goods consist mostly of apparel. In the BLS data, prices actually change more frequently for clothing: the monthly hazard is 30.0% for apparel items, versus 25.1% for all items. So prices for the goods in Kashyap's sample are far stickier than the typical BLS item, apparel or otherwise. Mail-order prices may tend to be stickier than prices in retail outlets. Another factor could be that Kashyap selected "well-established, popular-selling items that have undergone minimal quality changes" (Kashyap, 1995, p. 248). As we discuss below, changing product features appear to play a role in price changes.

MacDonald and Aaronson (2001) examine restaurant pricing (more exactly, pricing for food consumed on premises) for the years 1995 to 1997 using BLS data. They find that restaurant prices do not change very frequently, with prices displaying a median duration of about 10 months. These are close to the durations we report for breakfast (11.5 months),

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[10] Cecchetti (1986, p. 256) explicitly states that he is interested in studying a good with greater than typical price stickiness in order to test alternative models of price rigidity.

lunch (10.6), and dinner (10.4) prices in Table 1. This consistency is not surprising given we are using the same underlying data source. Note, however, that prices change less frequently at restaurants than for the typical good in the CPI bundle. Prices change more frequently than for restaurant foods for about 75% of non-housing consumption.

Kackmeister (2001) analyzes data on the price levels of up to 49 consumer products (depending on the period) in Los Angeles, Chicago, New York and Newark in 1889-1891, 1911-1913, and 1997-1999. The goods are at the ELI level or slightly higher, and include 27 food items, 14 household goods, and 8 clothing items. He finds that the frequency, size, and variability of price changes are higher in the last period than in the first period. For 1997-1999 he finds that 31% of goods change price each month. This is higher than the mean frequency of 25% in our data, and some of the difference may owe to the composition of goods (food and apparel exhibit more frequent price changes than the median category in our data).

With data on price levels, Kackmeister is able to investigate how often prices are temporarily marked down from a "baseline price" that is itself much stickier. He finds that 22% of prices change each month *excluding* price reductions that reverse themselves one month later. If the same fraction (9/31) of price changes arose from temporary sales in our data, then our mean frequency net of temporary sales would be 18%. The median time between changes in *baseline* prices would be 6.2 months, compared to 4.3 months between price changes. Even 6.2 months is considerably shorter than the 12 months or more found by previous studies. Moreover, one could argue that temporary sales represent a true form of price flexibility that should not be filtered out, say because the magnitude and duration of temporary sales responds to shocks.

Differences in Price Stickiness Across Broad Consumption Categories

Table 2 provides price change frequencies for selected broad categories of consumption. The first row shows that the (weighted) mean frequency is 25% for all items.

The next three rows provide (weighted) mean frequencies for durable goods, nondurable goods, and services, respectively, based on U.S. National Income and Product Account (NIPA) classifications. Price changes are modestly more frequent for durable goods (32%) than for nondurable goods (28%), and are notably less frequent for services (20%). The lower frequency of price changes for services could reflect the lower volatility of consumer demand for them.

The next six rows in Table 2 provide frequencies for each of the six CPI Expenditure Classes defined by the BLS. At the flexible end are transportation prices (e.g., new cars, airfares), 36% of which change monthly. At the sticky extreme are medical care (drugs, physicians' services) and entertainment (admission prices, newspapers, magazines, and books), 9% and 12% of whose prices change monthly.

In the final two rows of Table 2 we distinguish goods with relatively little value added beyond a primary input, for instance gasoline or fresh fruits and vegetables. Such goods are presumably subject to more volatile cost shocks. These "raw" goods are a subset of the food and energy items goods excluded by the BLS in its core rate of CPI inflation.[11] As expected, products closely linked with primary inputs (raw products) display more frequent price changes, with the frequency averaging 50.7%. The remaining goods (processed goods) display an average frequency of 20.1%. So, even excluding the raw goods, frequency of price change remains considerably higher than values typically cited in the literature based on narrower sets of goods.

Menu-cost models of price adjustment (e.g., Barro, 1972, or Caplin and Spulber, 1987) predict that price changes are more frequent in markets with high trend inflation (or high trend deflation). Related to this, Ball, Mankiw, and Romer (1988) exploit the prediction that the frequency of price changes should be greater in an economy with high average inflation. We

[11] The set of raw goods consists of gasoline, motor oil, fuel oils, natural gas, electricity, meats, fresh fruits, fresh vegetables, and fresh milk and cream. Unlike the BLS food and energy categories, it does not include meals purchased in restaurants or foods the BLS classifies as processed goods.

examined whether the frequency of price changes (as always, based on the 1995 to 1997 panel of observations) is greater for goods that display a higher absolute level of price inflation. The average rate of inflation is based on the good's NIPA personal consumption deflator over 1959 to 2000.[12] Observations are weighted by the good's relative importance in the December 1997 CPI. Surprisingly, we observe a negative correlation of -0.31 (standard error 0.07) between a good's absolute average inflation rate and its frequency of price changes.

Market Structure and Price Flexibility

Models of price adjustment (e.g., Barro, 1972) predict greater frequency of price changes in markets with more competition because firms therein face more elastic demand. The four-firm concentration ratio is often used as an inverse measure of market competition, with a higher value expected to correlate with less elastic demand. Several papers have found an inverse relation between the concentration ratio and the frequency of price changes or price volatility in producer prices (e.g., Carlton, 1986, Caucutt, Gosh and Kelton, 1999). We examine the relationship between the share of the largest four firms in manufacturing shipments and the frequency of price change for our goods. The concentration ratio is taken from the 1997 Census of Manufactures. To exploit this measure we match the 350 consumer goods categories to manufacturing industries as classified by the North American Industrial Classification System (NAICS). This matching can be done for 232 of the goods. The categories we were unable to match are largely services.

Column A of Table 3 gives the result of regressing the frequency of price changes on the four-firm concentration ratio. (This is a weighted least squares regression with weights given by the goods' importance in the 1997 CPI.) There is an economically and statistically strong negative relation. The coefficient of -0.28 implies that raising the concentration ratio

[12] For the vast majority of categories, the PCE Deflators are based on CPI's. The categories in our sample in which the BEA is using something other than a CPI are (in order of their weight) hospital services, college tuition, airline fares, high school and elementary school tuition, technical and business school tuition, and nursing homes. For these, the BEA puts weight on input prices as well as the CPI. These categories add up to 5.7% of the CPI and 8.5% of our sample.

from 23% (the value for pet food) to 99% (the value for cigarettes) tends to decrease the monthly frequency of price changes by about 20 percentage points.

We consider two other variables related to market competitiveness. One is the wholesale sector's markup, defined as (wholesale sales revenue minus cost of goods sold)/(wholesale sales revenue). The data for wholesale markups are reported in the 1997 Census of Wholesale Trade. We can match 251 of the 350 consumer goods to a corresponding wholesale industry in the NAICS.

Another factor potentially related to market competition is the rate that substitute products are introduced. As mentioned above, the BLS *Commodities and Services Substitution Rate Table* actually focuses on item substitutions. When an outlet discontinues an item, the field agent collecting price quotes searches for the closest substitute at the outlet. The BLS later compares the attributes of the selected item and the discontinued item, and classifies the substitute as either comparable or noncomparable.[13] We expect markets with greater product turnover, as measured by the rate of noncomparable substitutions, to price more flexibly. Changes in the product space may induce changes in the prices of incumbent products. Pashigian's (1988) markdown pricing model for fashion goods has this feature, as do many models in which quality improvements are introduced over time. Another hypothesis is that newer products have falling production costs as firms slide down learning curves. Consistent with this story, a good's rate of noncomparable substitutions is negatively correlated with its trend inflation rate (-0.52, standard error 0.08). Finally, frequent introduction of new products may proxy for ease of market entry more generally.

Column B of Table 3 provides results relating the frequency of price changes to the three measures of market structure (concentration ratio, wholesale markup, and rate of noncomparable substitutions). Each coefficient has the anticipated sign and is economically and statistically significant. The coefficient on the concentration ratio is as large as in column

[13] Item substitutions occur for 3.1% of monthly price quotes in our sample. The BLS deemed 46% of all substitutions noncomparable over 1995-1997.

A. The coefficient of -0.92 on the wholesale margin implies that increasing the margin from 12 percent (the value for meat products) to 35 percent (the value for toys and games) tends to decrease the monthly frequency of price changes by more than 20 percentage points. Categories with a 1% higher noncomparable substitution rate tend to have a 1.8% higher frequency of price changes (standard error 0.3%). The coefficient exceeds unity, meaning price changes are more frequent in the presence of greater product turnover even aside from price changes mechanically associated with item substitutions.[14]

As presented earlier in Table 2, products closely linked with primary inputs (raw products) display more frequent price changes. The regression in Table 3, column C again examines how the frequency of price changes responds to the three measures of market power, but now controlling for whether a good is a raw product. The coefficient implies that price changes are 29% more common for raw products (with a standard error of 2.4%). The four-firm concentration ratio and wholesale markup, both of which appear very important in the column B regression, become quite unimportant when controlling for whether a good is raw or processed. The rate of product turnover robustly predicts more frequent price changes. Its coefficient actually increases, with 1% more monthly substitutions associated with 2.5% more price changes (standard error 0.22%).[15]

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[14] The prices of comparable substitutes enter the CPI without adjustment, so comparable substitutions are associated with price changes only if the substitute's price differs from the previous month's price for the discontinued item. In contrast, the prices of noncomparable substitutes enter the CPI with quality adjustments, so noncomparable substitutions are almost always associated with price changes. See Shapiro and Wilcox (1996) for an explanation of BLS quality adjustments.

[15] We examined several other variables aimed at capturing market structure. A higher import share might be expected to raise competition and the frequency of price changes. (We obtained data on imports from the U.S. Department of Commerce.) We did find a statistically significant correlation of 0.18 between import share and the frequency of price changes. But import share did not help predict price flexibility after controlling for raw goods. We likewise expected higher inventory holdings in industries with market power and higher markups. Therefore greater inventory holdings might be associated with less frequent price changes. The frequency of price changes was indeed very negatively correlated, -0.51, with the ratio of *wholesale* inventories to sales. But, again, this effect was not robust to controlling for the raw-good dummy. The frequency of price changes was also typically lower for goods with a high ratio of *manufacturers* inventories to shipments (correlation -0.18). This variable was modestly significant in explaining less frequent price changes even controlling for whether a good was a raw good. (The data for manufacturing and wholesale inventories were taken, respectively, from the 1997 Censuses of Manufacturing and Wholesale Trade.)

In column D of Table 3 we relate the frequency of price changes simply to the rate of noncomparable substitutions and the raw good dummy. These variables are available for the full set of 350 goods. The two variables explain a sizable fraction of the variation in frequencies across the 350 goods (adjusted R^2 of 0.56). A 1% higher rate of product substitutions is associated with a 3% higher rate of price changes (standard error 0.3%). Thus each product turnover is associated with two price changes in addition to that directly associated with the item substitution.

3. A General Equilibrium Model with Goods of Varying Price Stickiness

In this section we briefly describe the implications of a general equilibrium model with staggered price setting. The critical feature is that firms in the respective consumer goods sectors set their prices for different durations. Our purpose is to illustrate how the flexible-price sector versus the sticky-price sector respond to shocks. Our model borrows heavily from the work of Chari, Kehoe and McGrattan (2000, 2001). Our sole substantive deviation from their closed economy paper (CKM 2000) is in having two consumer good sectors. Their open economy version (CKM 2001) features distinct foreign and domestic consumer goods, so our model is a hybrid of their two models: two consumer goods as in CKM 2001, but a closed economy as in CKM 2000. Within each consumer good sector, price setting is staggered evenly across monopolistically competitive firms.

Consumers have momentary utility given by

$$U(c,m,l) = [(\omega c^{1\text{-}1/\eta} + (1\text{-}\omega)m^{1\text{-}1/\eta})^{\frac{\eta}{\eta\text{-}1}}(1\text{-}l)^{\psi}]^{1\text{-}\sigma}/(1\text{-}\sigma)\ ,$$

where c = a CES consumption aggregate, m = real money balances, l = labor supply, and 1 = the period time endowment. Time subscripts are implicit. Following CKM, we set ω = 0.94 based on the empirical ratio of m/c (M1 to nominal consumption), η = 0.39 based on the interest elasticity of money demand (from regressing log m/c on the nominal three-month Treasury bill rate), ψ = 1.5 so that steady state l is 1/4, and σ = 1 (unit intertemporal elasticities).

The CES consumption aggregate is given by

$$c \;=\; [\omega_f \big(\int_0^1 c_f(i)^\theta di\big)^{\rho/\theta} + \omega_s \big(\int_0^1 c_s(j)^\theta dj\big)^{\rho/\theta}]^{1/\rho} \;,$$

where $c_f(i)$ = production of flexible-price good i by a monopolistic competitor, $c_s(j)$ = production of sticky-price good j by a monopolistic competitor. As shown, there are a continuum of firms of measure 1 in each sector. We set $\omega_f = \omega_s$ = 0.5 so that the sticky and flexible sectors have equal weight in c. We assume θ = 0.9 so that the elasticity of substitution between varieties within each sector is 10. This means firms desire a price markup of 10% above marginal cost, in line with Basu and Fernald (1997) evidence. We set ρ = 0 (Cobb-Douglas) so that the nominal shares of the flexible and sticky sectors are constant.

Firm production technologies are linear in labor:

$$c_f(i) = a\, l_f(i) \;\forall i, \quad c_s(j) = a\, l_s(j) \;\forall j \;.$$

Aggregate productivity shocks are entertained through the parameter a. For simulations, we treat a as a random walk, examining responses to a 1% innovation in productivity.

Labor is mobile across firms and sectors, so the labor market clearing condition is

$$\int_0^1 l_f(i)di \;+\; \int_0^1 l_s(j)dj \;=\; l \;.$$

The exogenous money growth process is

$$\log \mu_t \;=\; \rho_m \log \mu_{t\text{-}1} + \epsilon_t \ ,$$

where $\mu_t = \frac{m_t}{m_{t\text{-}1}}$ is the gross growth rate of the money supply. For simulations, reported in the next section, we employ ρ_m = 0.52, which is the estimated serial correlation of monthly M1 growth. We first, however, examine responses to a 1% money impulse under the assumption that log μ_t follows a random walk (ρ_m = 0). This case is helpful for illustration because the ultimate price change is the same size as the money innovation.

For both sectors, any firm setting its price in period t does so before observing the current period shocks.[16] After prices are set the current shock is realized and all firms hire labor (equivalently, set output) to satisfy the quantity demanded of their variety at their preset price. In the flexible sector prices are preset for 2 periods (the 90th percentile of frequencies in our Table 1). In the sticky-price sector prices are preset for 16 periods (the 10th percentile of frequencies in Table 1). In each sector, price-setting is staggered evenly (1/2 the flexible sector firms set their prices before a period, the other half before the next period; 1/16th of the sticky sector firms set their prices before a period, 1/16th before the next period, and so on).

Firms set their prices to maximize expected discounted profits over the period the prices will be fixed. Their information set includes the entire distribution of preset prices of other firms in their own sector and in the other sector. If prices were preset for only one period, firms would set price equal to the steady state markup over expected nominal marginal cost. The latter is the expected wage divided by the marginal product of labor. In all cases the wage is determined in general equilibrium to equate household labor supply (given the preset aggregate price) to labor demand that is realized at the prices firms post. An Appendix with further details (the budget constraint, first order conditions, numerical computation of a solution to the log-linearized system of equilibrium equations) is available upon request.

[16] In the next section we will compare some predictions of this model to time series data. All of the implications are robust to modeling the current shocks as observed before adjusting firms set their current prices.

Figure 2 presents equilibrium responses to a permanent 1% increase in the money supply. Aggregate consumption and labor supply both jump 1% in the month of the shock, then decline monotonically towards zero over the next 16 months.[17] The decline is sharpest in the first two months as the two cohorts of firms in the flexible-price sector get a chance to respond with higher prices and lower output. In contrast, in the sticky-price sector the price gradually rises and output gradually falls over the 16 months following the shock.

According to Figure 2, both inflation and output growth are more persistent in the sticky sector than in the flexible sector in response to a money shock. This reflects the greater length of time needed for all cohorts to respond in the sticky sector. Note also that the initial impact on inflation is much smaller in the sticky sector than in flexible sector, as a much smaller share of firms respond in the month after the shock in the sticky sector. Thus, in this staggered pricing model, price stickiness dampens the initial inflation impact and spreads it across many periods, thereby lowering the volatility of inflation innovations and boosting the persistence of inflation.

Figure 3 shows model responses to a permanent 1% increase in the technology parameter a. In the first month prices do not respond so labor hours decline, with no impact on aggregate consumption. Beginning in the second month consumption rises, and then continues its rise until the higher productivity passes fully into increased consumption, with no long run impact on labor hours.

Notice from Figures 2 and 3 that, both in the aggregate and in the sticky-price sector, inflation displays high persistence regardless of whether the underlying shock is to money or

[17] We also simulated versions of the model with 4, 5, 8, 15, 20 and 30 sectors, respectively. Each time we set the stickiness and weight of sectors to approximate the empirical distribution in Table 1. Not surprisingly, the aggregate response function was smoother the greater the number of sectors. In each case we compared the aggregate responses to a monetary shock to those in a one-sector model in which all prices were fixed for the same duration. We found that a single-sector model with prices fixed for 4 months, roughly the median duration in the empirical distribution, most closely matched the aggregate response in the multi-sector models. One-sector models with durations near the reciprocal of the mean frequency (3 months) or with the mean duration (7 months) did not mimic the multi-sector model nearly as well, based on squared deviations from 20 months of impulse responses. For this reason we emphasized the median duration when summarizing the empirical distribution of price change frequencies.

to TFP.[18] Related, stickiness dampens the initial response of inflation to TFP and money shocks alike. In the next section we test these predictions for sectoral inflation with time series data on monthly inflation for sectors of varying underlying price stickiness.

4. Time-Series Patterns for Flexible-Price Goods vs. Sticky-Price Goods

We match our 350 categories of consumer goods to available NIPA time series on prices and consumption (from the Bureau of Economic Analysis personal consumption expenditures data by detailed product class). The price deflator is a chain-type index. Real consumption is constructed from the chain-index price deflators and data on nominal expenditures. The data run from January 1959 to June 2000. Although we can match most of our 350 ELI categories to NIPA time-series, in many cases the NIPA categories are broader. The matching results in 123 categories covering 67.3% of overall consumer spending and most of our 350 ELIs (which comprised 71.2% of the CPI).[19]

In Tables 4 and 5 we examine the persistence and volatility of inflation rates and consumption growth for the 123 goods. We place particular emphasis on how inflation rates differ in persistence and volatility across goods in conjunction with differences in goods' frequencies of price change as measured from the BLS panel. Table 4 restricts attention to time series for inflation and consumption growth for the time period of 1995 to 1999. This corresponds to the time period for which we observe the frequency of price changes from the BLS data. Table 5 repeats all statistics for the considerably longer period of 1959 to 2000 for which NIPA time series data are available. Implicit in examining this longer period is an assumption that the relative frequencies of price changes we observe across goods for 1995 to 1999 represent reasonably well the relative frequencies of price changes across goods for the longer sample period.

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[18] The movements in consumption, by contrast, are persistent in response to permanent TFP shocks, but not in response to permanent money shocks.
[19] When aggregating we weighted ELI price-change frequencies by ELI weights in the December 1997 CPI.

We begin by examining persistence and volatility of inflation for an aggregate price deflator, where the aggregation is over the monthly price deflators for the 123 consumer goods. We fit this aggregate monthly inflation rate to an AR(1) process. The top panel of column A in Table 4 shows that the aggregate inflation rate is not very persistent over 1995-1999. The serial correlation is 0.15 and is not statistically different from zero.

The lower panel in column A of Table 4 depicts how persistence and volatility of inflation vary across goods. For each of the 123 categories we fit the good's monthly inflation rate to an AR(1) process. The average serial correlation across the 123 sectors is close to zero (ρ = -0.04). Contrary to the predictions of the staggered pricing and Calvo models of price stickiness, goods with more frequent price changes exhibit inflation rates with *more* serial correlation. The correlation between the frequency of price changes and the degree of serial correlation is 0.26 and is statistically greater than zero. Consistent with the sticky-price models, goods with more frequent price changes do display more volatile innovations to inflation (the correlation between the frequency of price changes and the standard deviation of inflation innovations 0.55).

Column B in Table 4 looks at monthly growth rates of real consumption spending. Here the predictions of sticky-price models are less clear. The models are typically written assuming that output is demand-determined in the presence of a predetermined price. Therefore, price rigidity tends to exaggerate sales responses to product demand shocks, but mute the impact of cost disturbances (e.g., Gali, 1999). For 1995 to 1999 aggregate real consumption across the 123 goods shows negative serial correlation (-0.32, standard error 0.13). Across the 123 categories, goods that exhibit more frequent price changes display more volatile but less persistent consumption growth rates.

Table 5 examines the patterns of persistence and volatility for the broader 1959 to 2000 period. Inflation was low and quite stable for the 1995 to 1999 period. Comparing the top panels of Tables 4 and 5, we see that the volatility of inflation for consumer goods was about 35 percent lower for 1995 to 1999 compared to the overall 1959 to 2000 period.

Volatility of consumption growth was also much lower, by about 30 percent. For inflation the drop in volatility largely reflects the fall in persistence of inflation, whereas for consumption growth it mostly reflects a fall in the volatility of innovations.

Looking across the 123 goods, we see that inflation does show positive serial correlation over the longer period. But the magnitude of this persistence, averaging 0.27 across goods, is fairly modest. There is a negative correlation between a good's frequency of price changes for 1995 to 1997 and the persistence of its inflation rate for 1959 to 2000, as anticipated by the sticky-price model. But it is small in magnitude and not statistically significant. The correlation between the frequency of price changes and the volatility of innovations to inflation is nearly as large for the longer period (0.52) as for the 1995 to 1999 period (0.55). This result is predicted by time-dependent sticky-price models, as less frequent price changes should mute the volatility of inflation innovations. Alternatively, one could infer that sectors facing larger shocks choose to change prices more frequently.

Column B of Table 5 looks at monthly growth rates of real consumption across goods over 1959-2000. Consumption growth rates are typically serially uncorrelated at the disaggregate level, but have more volatile innovations over this longer sample than over 1995 to 1999. Similar to the pattern for 1995 to 1999, goods with more frequent price changes have less persistent, but more volatile growth rates in consumption.

The correlations reported in Tables 4 and 5 do not convey the magnitude by which the inflation processes differ across the goods. For this reason, we regressed inflation's estimated serial correlation and standard deviation of innovation for each of the 123 goods on its frequency of price changes in the BLS data for 1995 to 1997. Table 6 presents the serial correlation (ρ_i) and volatility (σ_i) that these regression imply for a good with monthly frequency of price changes of 48.5% (the 90th percentile of frequencies in our Table 1) versus one with frequency of 6.1% (the 10th percentile of frequencies in Table 1).

Column A of Table 6 gives results based on goods' 1995 to 1999 monthly inflation rates. Persistence is very low for both flexible-price and sticky-price goods. Persistence is actually higher for the flexible-price good ($\rho = 0.04$ versus $\rho = -0.10$). The standard deviation of inflation innovations is far higher, by a factor of 5, for the flexible-price good. Column B of Table 6 shows that consumption growth volatility is also greater for the flexible-price good. Consumption movements are more persistent for the sticky-price goods.

Results based on the broader 1959 to 2000 period appear in column C of Table 6. Now both goods show a significantly positive serial correlation in inflation and the persistence is larger, as expected, for goods with less frequent price changes. But note that persistence remains fairly modest and the greater persistence for the sticky-priced good is modest in size ($\rho = 0.31$, versus 0.22 for the flexible good) and not statistically significant. The patterns for consumption growth across flexible and sticky goods, reported in column D, largely parallel those for the shorter 1995-1999 sample period.

Inflation persistence and volatility in the data vs. in the staggered pricing model

We argue that the workhorse models of price stickiness imply much more persistent and much less volatile inflation rates than we observe in the data. We find it is even more difficult for the models to explain the cross-good patterns we observe for persistence and variability of inflation. We illustrate these points in two ways. First, we take our staggered pricing model from section 3 and ask how goods' inflation and consumption growth respond to realistic aggregate monetary and supply shocks as well as sizable idiosyncratic shocks. We compare these responses to the patterns in the data described in Tables 4 through 6. Second, we focus on the pricing equation central to the staggered pricing and Calvo models of price stickiness. We find it is not possible to explain the volatility and transience of inflation rates for the 123 goods for reasonable depictions of time series for the marginal costs of producing. In sum, we do not see support for popular time-dependent models of price stickiness. More promising, we believe, would be state-dependent models of price stickiness, such as Willis (2000), in which the frequency of price changes is endogenously greater in the presence of more volatile shocks. In these models firm price adjustments can be much more synchronized in response to sectoral shocks, producing much larger inflation innovations and much less inflation persistence in line with the data.

Employing the sticky-price model from Section 3, we produce model statistics for persistence and volatility of inflation for goods with monthly frequencies of price change of 1/2 and 1/16. These statistics parallel those reported from the data in Table 6. For exposition, we first treat the case of only aggregate shocks to money growth and productivity. The monetary growth rate (μ_t from Section 3) is calibrated to the behavior of monthly M1 growth for 1959 to 2000 to exhibit serial correlation of 0.52 with a standard deviation of innovations equal to 0.44%. The growth rate of productivity is calibrated to quarterly TFP growth for 1959 to 2000 (with parameters translated suitably to reflect an underlying monthly process). We treat the growth rate of TFP as i.i.d., as this is consistent with the data. The standard deviation of its monthly innovation is 0.40%.

Results appear in column A of Table 7. The principal finding is that both the flexible and sticky good exhibit much greater inflation persistence in the model than is observed in the data.[20] For both goods the serial correlation is approximately equal to $(1 - \lambda_i)$, where λ_i is the good's monthly frequency of price changes. The mismatch with the data is particularly striking for the sticky-priced good. Here the model predicts persistence of 0.92. By sharp contrast, the value for the data is only 0.31 for 1959 to 2000, and is slightly negative for 1995 to 1999. The model does mimic the data in that inflation innovations are much more volatile for the flexibly-priced good. In fact, the model yields innovations to inflation that are 6 or 7 times as large (in terms of standard deviation) for the flexible goods as for the sticky good. In the data this ratio is on the order of 3 or 4. This is perhaps not surprising, given to this point we have only entertained aggregate shocks.

Column B of Table 7 provides similar model statistics, but for the growth rate in consumption for each of the goods. The model predicts persistence in consumption growth

[20] The reported statistics for model simulations reflect 100 separate stochastic simulations, with 480 time periods (months) per simulation.

that is roughly consistent with observed values (Table 6, columns B and D). It does not capture the much greater volatility of consumption for flexibly-priced goods. This can potentially be solved by allowing for idiosyncratic shocks concentrated on these goods.

Column C of Table 7 allows for such productivity shocks idiosyncratic to each good. These shocks are orthogonal to the aggregate shocks, as well as to shocks in the other sector. We calibrate the volatility and persistence of these shocks to the behavior of industry TFP for the 459 manufacturing industries in the NBER Productivity Database.[21] This yields an autocorrelation, in levels, of 0.98, with a standard deviation for innovations of 1.3%. Adding these idiosyncratic shocks has very little impact on inflation persistence for the goods. Persistence (ρ_i) stays at 0.48 for the flexible-price good, and drops only to 0.91 from 0.92 for the sticky-price good. Inflation innovations become about 60 percent more volatile. As a result, inflation volatility in the model is fairly close to that observed in the data for both goods. The upshot is that the sticky-price model, calibrated to the frequency of price changes observed in the BLS panel, is not able to generate the low persistence of inflation we see in the data. This is particularly so for goods with less frequent price changes.

Column D of Table 7 considers the impact of the good-specific shocks on consumption growth rates. These real shocks particularly add volatility to consumption growth for the flexible-price good, and eliminate the negative persistence in its growth rate.

It is natural to ask if hitting the sticky-price sector with less persistent idiosyncratic shocks can enable the model to better fit the data. We explored a number of possibilities. The model's inability to capture the transience of inflation rates appears quite robust. Suppose, for instance, that sticky-price goods are subject to idiosyncratic productivity shocks with no serial correlation in levels (even though the industry TFP is at adds with this assumption). Although this lowers the persistence of inflation, it also dramatically reduces the volatility of a good's inflation rate, as the sticky-price model predicts little response of prices to transitory shocks.

[21] The NBER Productivity Database contains annual for 1959 through 1996. We map the parameter values estimated from annual data to values for an underlying monthly process.

If firms in a sector adjust their prices only every (say) 16 months, they put little weight on shocks that are around for only a month or two. To overcome this the transitory shocks must be very large. To illustrate we chose the persistence and volatility of idiosyncratic shocks to each sector to match the persistence and volatility of inflation rates for both the flexible and sticky goods. Idiosyncratic productivity in the sticky-price sector must display serial correlation in levels of only 0.3 and must have the implausibly large monthly standard deviation of 59%.

Inflation persistence and volatility in response to realistic marginal cost processes

One could object that the preceding exercises embedded staggered pricing in a particular general equilibrium model. The model featured money in the utility function and monetary policy shocks as innovations to exogenous money supply growth, both calibrated in particular ways to the data (e.g., the latter to M1 growth). There is little consensus on how to model and calibrate money demand and monetary policy shocks, so we made these assumptions for simplicity rather than for realism.

We contend that the transience and volatility puzzles documented above are not simply a byproduct of the way we modeled money demand and shocks to monetary policy. Time-dependent models of infrequent price changes contain a very strong force for ratcheting up the persistence of inflation and holding down its volatility, judged relative to the underlying time-series for marginal cost of producing those goods. Consider the Calvo (1983) model as outlined in Rotemberg (1987), Roberts (1995), and in many recent papers on price stickiness. In each period firms in category i change their price with probability λ_i. This probability is fixed and therefore independent of how many periods have elapsed since a firm's last price change. Conditional on changing price in period t, firms set price as a markup over the average (discounted) marginal cost the firm expects to face over the duration of time the price remains in effect. The natural log of this price (minus the constant desired markup) is

$$x_{it} = [1-(1-\lambda_i\beta)]\sum_{\tau=0}^{\infty}(1-\lambda_i)^{\tau}\beta^{\tau}E_t(z_{it+\tau}) \ ,$$

where z_{it} is the period's marginal cost and β is the discount factor. If shocks are not too large, the average price in category *i* at time *t* is approximately

$$p_{it} = (1-\lambda_i)p_{it-1} + \lambda_i x_{it} \ ,$$

as each period $1-\lambda_i$ of the firms carry prices forward, with λ_i setting price at x_{it}.

To illustrate, suppose that the log of marginal cost follows a random walk, an assumption that, as we discuss below, is roughly consistent with the evidence. In this case the model implies a process for inflation for good *i* of

$$\pi_{it} = (1-\lambda_i)\pi_{it-1} + \lambda_i\varepsilon_{it} \ ,$$

where ε_{it} is the i.i.d. growth rate of good *i*'s marginal cost. If price changes are infrequent (that is, λ_i is well below one), the sticky-price model exerts a powerful mechanism for creating persistence in inflation while sharply dampening its volatility. Across all consumer goods examined in Section 2, the average monthly probability of price change is roughly 0.2. If, as an example, we reduce λ_i from 1 (perfect price flexibility) to 0.2, the serial correlation in inflation implied by the model goes from zero to 0.8. At the same time, the standard deviation of innovations to the inflation process is reduced by 80% and the unconditional standard deviation of the inflation rate is reduced by two-thirds. These predictions are shared quantitatively by the model with staggered price setting discussed above.

Figure 4 makes this point more generally. Across the 123 categories of consumer goods for which we have monthly time-series for inflation rates, the frequency of price changes (based on the BLS panel) varies dramatically from less than 0.05 to 0.70. The solid line graphs the serial correlation of monthly inflation predicted by the Calvo model as a function of this frequency of price change. Under the assumption that the growth rate of marginal cost is serially uncorrelated, this predicted serial correlation is simply one minus the frequency of price change. The figure also graphs the observed serial correlation for each of the 123 consumer goods for the shorter sample period of 1995 to 1999. With only a couple of exceptions, the observed serial correlation falls far below the model's prediction. The average observed serial correlation is close to zero, whereas the average predicted value is close to 0.8. For goods with frequencies of price change below the median value of 23%, no good exhibits a serial correlation in the data that is within 0.3 of the model's prediction.

Figure 5 repeats the exercise in Figure 4, except that it presents inflation's observed serial correlation by good for the entire 1959 to 2000 period. The goods' inflation rates are more often positively serial correlated for the longer sample period, as reported in Table 5. But, for all but a handful of goods, the observed persistence is well below that anticipated by the Calvo model. In fact, the observed persistence is typically closer to zero than to the model's prediction, especially for goods with less frequent price changes.

Figures 4 and 5 presume a growth rate for marginal cost that is serially uncorrelated. Perhaps the failure of the Calvo model in these figures is an artifact of our assuming too much persistence in innovations to marginal cost. Addressing this question requires a measure of marginal cost, or at least its persistence. Bils (1987) creates a measure of movements of marginal cost under the assumption that output, Y_{it}, can be linked by a power function to at least one of its inputs, call it N_{it},

$$Y_{it} = N_{it}^{\alpha} f_{it}(\text{all other inputs}) \ .$$

The Cobb-Douglas is a special case for which any input can take the role of input N. Bils focuses on the case where N is production labor. Marginal cost can be expressed as the price of *N*, call it *W*, relative to *N*'s marginal product. For the production function above, the natural log of marginal cost is simply

$$z_{it} = ln(\alpha) + w_{it} + n_{it} - y_{it}$$

where *w*, *n*, and *y* refer to the natural logs of their upper case counterparts.

Suppose we treat labor as the relevant input, *n*, and measure *WN* simply as payments to labor.[22] In this case, $z_{i,t}$ is, up to a constant term, simply the natural log of the ratio of the wage bill to real output. The BLS publishes a quarterly time series on this ratio, labeled unit labor costs, for the aggregate business sector.[23] We examined the persistence in the growth rate of this quarterly series. For our shorter sample period, 1995 to 1999, the growth rate of unit labor cost is actually positively serially correlated, but not significantly so. The AR(1) parameter is 0.12 with standard error 0.25. For the broader 1959 to 2000 sample the growth rate of unit labor cost is more serially correlated. The AR(1) parameter equals 0.41, with standard error 0.07. This is consistent with the observation from Tables 4 and 5 of greater serial correlation in inflation over the longer period. None of these estimates suggest less persistence in marginal cost than presumed by our assumption of a random walk for marginal cost. In fact, the persistence in the growth rate for this measure of marginal cost suggests the lack of persistence in inflation rates is even more problematic for the Calvo and staggered pricing models.

We also examined the persistence and volatility of unit labor cost as measured for 459 manufacturing industries in the *NBER Productivity Database*. The advantage of this source is that the data is much more disaggregate than the BLS measure of unit labor cost. The

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[22] Bils (1987) argues against this assumption. If labor is quasi-fixed he shows that the marginal price of labor may be much more procyclical than the average wage rate paid to labor. We plan to pursue this. We also plan to allow for the impact of overhead labor in this calculation, as executed by Rotemberg and Woodford (2000).
[23] The BLS publishes a comparable series for the nonfarm business sector. Results for this slightly narrower set of industries are extremely similar to those reported in the text.

drawbacks are that it is only available annually and only for manufacturing.[24] For each of the 459 industries we estimate a separate AR(1) model for the level of production workers' unit labor cost. Based on the annual data for years 1959 to 1996, the average estimate of the AR(1) parameter is 0.98 (standard deviation 0.05 across industries) and the average standard deviation of innovations to marginal cost is 6.9% (standard deviation 3.1%). This is not statistically different from a random walk.[25] If we take only the most recent third of the NBER data, years 1984 to 1996, the data show less persistence and less volatility in unit labor cost. The average AR(1) parameter falls to 0.75 (standard deviation 0.27) and the average innovation standard deviation to 4.9% (standard deviation 2.6% across industries).[26]

Lastly, we compare these estimates to the behavior of marginal cost needed to explain the behavior inflation rates for the 123 consumer goods. Figures 6 and 7 plot, with a point for each good, what persistence and volatility of marginal cost to reconcile the Calvo model with the observed persistence and volatility of that good's inflation rate. Figure 6 is based on inflation rates for 1995 to 1999, Figure 7 on those for 1959 to 2000. The figures make clear that the empirical problem for these time-dependent sticky-price models is not just that they predict far too much persistence – they also predict far too little volatility.

Looking at Figure 6, to be consistent with observed inflation, many of the goods require little or no persistence in marginal cost in conjunction with tremendous volatility of innovations. In most cases marginal cost innovations need to exhibit a standard deviation well above 10 percent monthly. The figure employs three separate symbols for goods that rank among the most, middle, and least in terms of frequency of price change in the BLS panel.

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[24] Manufacturing output is considerably more volatile than consumption. Also, the average sales of the 459 manufacturing industries is about an order of magnitude smaller than average consumption across the 123 categories. Both of these might be expected to make marginal cost more volatile and less persistent in these manufacturing industries than in the consumption sectors.

[25] The implied monthly AR(1) process consistent with this annual evidence has serial correlation of 0.997 and standard deviation of innovations equal to 2.5%. Estimates based on unit labor cost for all workers, not just production workers, yield almost the same results. Estimates based on unit materials cost yields remarkably similar results as well, with an average AR(1) parameter in annual data of 0.99 rather than 0.98.

[26] The implied mean serial correlation for a monthly AR(1) process is 0.96, and the mean standard deviation of innovations is 2.1%.

The volatility of the required marginal cost process is especially enormous for goods with infrequent price changes. The figure also plots, for reference, the average persistence and volatility of marginal cost estimated for 1984 to 1996 of the *NBER Productivity Database*. Even if we move two standard deviations below the mean persistence and two standard deviations above the mean volatility, these values are far removed from what is needed for the Calvo model to fit the behavior of most good's inflation rates.

Figure 7 is based on inflation rates for years 1959 to 2000 and presents mean patterns for marginal cost based on years 1959-1996 of the *NBER Productivity Database*. Here a handful of goods do exhibit inflation rates that are consistent with the average estimated process for marginal costs. But, for the vast majority of goods, inflation is far too transient and its innovations far too volatile to be consistent with the Calvo model under plausible behavior for marginal cost.

5. Conclusions

We have exploited unpublished data from the BLS for 1995 to 1997 on the monthly frequency of price changes for 350 detailed categories of consumer goods and services. We found considerably more frequent price changes than have previous studies of producer prices or consumer prices based on narrower sets of goods. The time between price changes was 4.3 months or shorter for half of consumption. Taylor (1999, p.1020) summarized the prior literature as finding that prices typically change about once a year.

We examined whether time series for inflation are consistent with the workhorse Calvo (1983) and staggered pricing models, given the frequency of price changes we observe. We found that these models predict inflation rates that are much more persistent and much less volatile than we observe. This is particularly true for goods with infrequent price changes.

We hope to clarify our results with additional work. We aim to eventually acquire panel data on price levels. Such data would allow us to investigate whether prices often decline temporarily below a "baseline" that is much stickier. Panel data would also allow us to observe the extent to which price changes are synchronized for a given good. One might expect this if sectors are subject to large sector-specific shocks to demand or costs. Such behavior, consistent with state-dependent pricing, might help to explain the volatility and transience of actual inflation rates: many firms change their prices at once, and few remain who need to adjust their prices in the same direction in the future.

Table 1

The Frequency of Price Changes by Category

Name		ELI	Freq.	Mo.	Wgt.	CDF
Weighted Statistics:	Mean		25.1	3.8		
	Median		20.8	4.3		
	Standard Deviation		17.6	5.2		
Vehicle inspection		52014	0.9	110.5	0.01	0.0
Driver's license		52013	1.1	89.4	0.05	0.1
Coin-operated apparel laundry and drycleaning		44012	1.3	75.4	0.17	0.3
Coin-operated household laundry and drycleaning		34045	1.3	73.7	0.02	0.3
Local automobile registration		52012	1.8	55.3	0.05	0.4
Vehicle tolls		52054	2.0	49.5	0.04	0.5
Newspapers		59011	2.1	47.4	0.38	1.0
Automobile towing charges		52055	2.2	45.3	0.01	1.0
Parking fees		52053	2.3	42.6	0.07	1.1
Haircuts and other barber shop services for males		65021	2.4	40.5	0.12	1.3
Intracity mass transit		53031	2.5	39.3	0.30	1.7
Beauty parlor services for females		65011	2.7	36.4	0.45	2.3
State automobile registration		52011	2.7	36.0	0.27	2.6
Legal fees		68011	3.1	31.4	0.50	3.3
Safe deposit box rental		68021	3.2	31.1	0.04	3.4
Care of invalids, elderly and convalescents in the home		34071	3.3	30.3	0.05	3.5
Household laundry and drycleaning, excl coin-operated		34044	3.3	30.1	0.10	3.7
Water softening service		34042	3.6	27.2	0.01	3.7
Alterations and repairs		44013	3.6	27.1	0.03	3.7
Postage		34011	3.6	27.0	0.25	4.1
Repair of television, radio and sound equipment		34061	3.9	25.3	0.09	4.2
Domestic services		34031	4.2	23.6	0.24	4.5
Intrastate telephone services		27061	4.4	22.1	0.23	4.8
Services by other medical professionals		56041	4.7	20.9	0.17	5.1
Encyclopedias and other sets of reference books		66022	4.8	20.4	0.05	5.2
Shoe repair and other shoe services		44011	4.8	20.3	0.03	5.2
Garbage and trash collection		27041	5.1	19.1	0.22	5.5
Taxi fare		53032	5.2	18.9	0.08	5.6
Pet services		62053	5.2	18.7	0.06	5.7
Day care and nursery school		67031	5.5	17.8	0.39	6.2
Magazines		59021	5.5	17.7	0.17	6.5
Hearing aids		55034	5.6	17.5	0.03	6.5
Film processing		62052	5.7	17.0	0.13	6.7
Physicians' services		56011	5.7	17.0	1.90	9.4
Moving, storage, freight expense		34043	6.0	16.1	0.10	9.5
Technical and business school tuition and fixed fees		67041	6.0	16.0	0.16	9.7
Apparel laundry and drycleaning, excl coin-operated		44021	6.1	16.0	0.29	10.1
Tenants' insurance		35011	6.1	15.9	0.03	10.2
Other information processing equipment		69015	6.1	15.8	0.001	10.2
Watch and jewelry repair		44015	6.2	15.6	0.01	10.2
Dental services		56021	6.5	14.9	1.11	11.8
Photographic and darkroom supplies		61022	6.6	14.6	0.002	11.8

Table 1

The Frequency of Price Changes by Category

Name	ELI	Freq.	Mo.	Wgt.	CDF
Other entertainment services	62055	6.7	14.3	0.23	12.1
Veterinarian services	62054	6.9	14.0	0.21	12.4
Reupholstery of furniture	34063	6.9	14.0	0.04	12.4
Checking accounts and special check services	68022	6.9	13.9	0.15	12.6
Club membership dues and fees	62011	7.1	13.5	0.35	13.1
Plumbing supplies and equipment	24015	7.3	13.2	0.00	13.1
Gardening and lawn care services	34041	7.4	13.0	0.15	13.4
Fees for lessons or instructions	62041	7.5	12.9	0.26	13.7
Miscellaneous supplies and equipment	24041	7.5	12.9	0.03	13.8
Cemetery lots and cripts	68032	7.5	12.8	0.11	13.9
Residential water and sewer service	27021	8.0	12.0	0.80	15.0
Books not purchased through book clubs	59023	8.0	11.9	0.16	15.2
Breakfast or brunch	19032	8.3	11.5	0.27	15.6
Coolant, brake fluid, transmission fluid, and additives	47022	8.6	11.1	0.02	15.6
Interstate telephone services	27051	8.7	11.0	0.31	16.1
Tax return preparation and other accounting fees	68023	8.8	10.8	0.21	16.4
Telephone services, local charges	27011	8.9	10.8	1.12	17.9
Lunch	19011	9.0	10.6	2.10	20.9
Dinner	19021	9.2	10.4	2.51	24.4
Eyeglasses and eyecare	56031	9.3	10.2	0.34	24.9
Admission to movies, theaters, and concerts	62031	9.3	10.2	0.60	25.7
Nursing and convalescent home care	57022	9.5	10.0	0.15	25.9
Plastic dinnerware	32031	9.6	9.9	0.003	25.9
Nonelectric articles for the hair	64012	9.6	9.9	0.01	25.9
Wine away from home	20052	9.6	9.9	0.19	26.2
Intercity train fare	53022	9.7	9.8	0.07	26.3
Beer, ale, and other alcoholic malt beverages away from home	20051	10.0	9.5	0.31	26.7
Photographer fees	62051	10.2	9.3	0.04	26.8
Vehicle parts and equipment other than tires	48021	10.3	9.2	0.26	27.2
Medical equipment for general use	55032	10.4	9.1	0.01	27.2
Power tools	32042	10.6	8.9	0.04	27.2
Clothing rental	44014	10.7	8.8	0.02	27.2
Inside home maintenance and repair services	23011	10.9	8.7	0.11	27.4
Tobacco products other than cigarettes	63012	10.9	8.7	0.15	27.6
Supportive and convalescent medical equipment	55033	11.0	8.6	0.01	27.6
Electrical supplies, heating and cooling equipment	24016	11.1	8.5	0.004	27.6
Tools and equipment for painting	24012	11.1	8.5	0.003	27.6
Repair of household appliances	34062	11.1	8.5	0.05	27.7
Fees for participant sports	62021	11.3	8.4	0.40	28.3
Nonpowered hand tools	32044	11.4	8.2	0.03	28.3
Distilled spirits away from home	20053	11.5	8.2	0.26	28.7
Cosmetics, bath/nail/make-up preparations and implements	64031	11.6	8.1	0.26	29.0
Books purchased through book clubs	59022	11.8	8.0	0.03	29.1
Hospital services	57041	12.1	7.8	2.16	32.1
Other hardware	32043	12.1	7.8	0.03	32.1
Automotive maintenance and servicing	49031	12.1	7.7	0.49	32.8
Kitchen and dining room linens	28013	12.2	7.7	0.02	32.9

Table 1

The Frequency of Price Changes by Category

Name	ELI	Freq.	Mo.	Wgt.	CDF
Stationery, stationery supplies, giftwrap	33032	12.2	7.7	0.18	33.1
Records and tapes, prerecorded and blank	31033	12.3	7.6	0.10	33.2
Laundry and cleaning equipment	32014	12.4	7.6	0.03	33.3
Videocassettes and discs, blank and prerecorded	31022	12.4	7.5	0.02	33.3
Film	61021	12.6	7.4	0.06	33.4
Purchase of pets, pet supplies, and accessories	61032	12.8	7.3	0.11	33.6
Tableware and nonelectric kitchenware	32038	12.9	7.2	0.07	33.7
Electric personal care appliances	64017	13.0	7.2	0.01	33.7
Coal	25022	13.4	7.0	0.03	33.7
Deodorant/suntan preparations, sanitary/footcare products	64016	13.4	6.9	0.08	33.8
Calculators, adding machines, and typewriters	69014	13.5	6.9	0.00	33.8
Women's hosiery	38043	13.6	6.9	0.10	34.0
Sewing notions and patterns	42012	13.7	6.8	0.01	34.0
Topicals and dressings	55031	13.8	6.8	0.08	34.1
Paint, wallpaper and supplies	24011	13.9	6.7	0.02	34.1
Blacktop and masonry materials	24014	14.0	6.6	0.001	34.1
Internal and respiratory over-the-counter drugs	55021	14.1	6.6	0.25	34.5
Shaving products, nonelectric shaving articles	64015	14.3	6.5	0.02	34.5
Cigarettes	63011	14.4	6.4	1.52	36.6
Smoking accessories	63013	14.7	6.3	0.02	36.7
Toys, games and hobbies	61011	14.7	6.3	0.30	37.1
Snacks and nonalcoholic beverages	19031	14.7	6.3	0.74	38.1
Dental products, nonelectric dental articles	64014	14.8	6.3	0.07	38.2
Clocks	32021	14.9	6.2	0.01	38.2
Landscaping items	24043	15.0	6.2	0.003	38.2
Hard surface floor covering	24042	15.0	6.2	0.01	38.2
Infants' and toddlers' underwear	41013	15.1	6.1	0.13	38.4
Funeral expenses	68031	15.2	6.1	0.29	38.8
Unpowered boats and trailers	60012	15.4	6.0	0.02	38.9
Products for the hair	64011	15.7	5.9	0.14	39.1
Slipcovers and decorative pillows	28015	15.7	5.9	0.01	39.1
Floor coverings	32011	16.0	5.7	0.06	39.2
Automobile insurance	50011	16.1	5.7	2.65	42.9
Replacement of installed wall to wall carpet	23013	16.3	5.6	0.02	42.9
Candy and chewing gum	15011	16.4	5.6	0.19	43.2
Lawn and garden supplies	33052	16.6	5.5	0.09	43.3
Other laundry and cleaning products	33012	16.8	5.4	0.15	43.5
Infants' furniture	29042	16.8	5.4	0.03	43.5
Nonelectric cookingware	32037	17.0	5.4	0.03	43.6
Photographic equipment	61023	17.1	5.3	0.05	43.7
Truck rental	52052	17.3	5.3	0.05	43.7
Glassware	32034	17.5	5.2	0.03	43.8
Indoor, warm weather and winter sports equipment	60021	17.5	5.2	0.16	44.0
Miscellaneous household products	33051	17.5	5.2	0.26	44.3
Salt and other seasonings and spices	18041	17.6	5.2	0.06	44.4
Men's nightwear	36032	17.8	5.1	0.02	44.5
Prescription drugs and medical supplies	54011	17.8	5.1	0.90	45.7

Table 1

The Frequency of Price Changes by Category

Name	ELI	Freq.	Mo.	Wgt.	CDF
Hunting, fishing, and camping equipment	60022	17.9	5.1	0.05	45.8
Household decorative items	32023	18.0	5.0	0.16	46.0
Infants' equipment	32013	18.0	5.0	0.01	46.0
Fabric for making clothes	42011	18.1	5.0	0.04	46.1
Computer software and accessories	69012	18.2	5.0	0.01	46.1
Boys' underwear, nightwear and hosiery	37014	18.2	5.0	0.02	46.1
Pet food	61031	18.4	4.9	0.21	46.4
Music instruments and accessories	61013	18.4	4.9	0.06	46.5
Indoor plants and fresh cut flowers	32061	18.6	4.9	0.15	46.7
Lamps and lighting fixtures	32022	18.7	4.8	0.05	46.8
Men's underwear and hosiery	36031	18.8	4.8	0.08	46.9
Sewing materials for household items	28016	19.0	4.8	0.05	47.0
Automotive brake work	49022	19.0	4.7	0.12	47.1
Boys' accessories	37015	19.3	4.7	0.02	47.2
Repair to steering, front end, cooling system and air conditioning	49023	19.4	4.6	0.15	47.4
Elementary and high school books and supplies	66021	19.7	4.6	0.02	47.4
Men's accessories	36033	19.7	4.5	0.08	47.5
Community antenna or cable TV	27031	19.9	4.5	0.58	48.3
Soaps and detergents	33011	20.0	4.5	0.23	48.6
Other condiments (excl olives, pickles, relishes)	18044	20.1	4.5	0.05	48.7
Rolls, biscuits, muffins (excl frozen)	2022	20.1	4.5	0.10	48.9
Telephone, peripheral equipment and accessories	69013	20.1	4.5	0.01	48.9
Automotive drive train repair	49021	20.2	4.4	0.18	49.1
Portable cool/heat equipment, small electric kitchen appliances	32052	20.2	4.4	0.07	49.2
Bicycles	60013	20.3	4.4	0.04	49.3
Watches	43011	20.3	4.4	0.08	49.4
Sweet rolls, coffee cake and doughnuts (excl frozen)	2063	20.6	4.3	0.07	49.5
Living room tables	29032	20.7	4.3	0.06	49.6
Flatware	32033	20.7	4.3	0.03	49.6
Canned ham	4032	20.7	4.3	0.01	49.6
Tires	48011	20.8	4.3	0.26	50.0
Automotive body work	49011	20.8	4.3	0.17	50.2
Distilled spirits at home (excl whiskey)	20022	20.8	4.3	0.12	50.4
Baby food	18062	20.9	4.3	0.06	50.5
Cakes and cupcakes (excl frozen)	2041	21.0	4.3	0.10	50.6
Window coverings	32012	21.0	4.3	0.06	50.7
Nondairy cream substitutes	16013	21.0	4.2	0.03	50.7
Tea	17052	21.0	4.2	0.04	50.8
Other noncarbonated drinks	17053	21.1	4.2	0.05	50.9
China and other dinnerware	32032	21.4	4.2	0.04	50.9
Serving pieces other than silver or glass	32036	21.5	4.1	0.01	50.9
Nuts	18032	21.6	4.1	0.04	51.0
Automotive power plant repair	49041	21.9	4.0	0.41	51.6
Outboard motors and powered sports vehicles	60011	22.1	4.0	0.13	51.7
Intercity bus fare	53021	22.4	3.9	0.02	51.8
Other sweets (excl candy and gum)	15012	22.5	3.9	0.06	51.9
Occasional furniture	29044	22.6	3.9	0.12	52.0

Table 1

The Frequency of Price Changes by Category

Name	ELI	Freq.	Mo.	Wgt.	CDF
Bedroom furniture other than mattress and springs	29012	22.6	3.9	0.20	52.3
Girls' hosiery and accessories	39017	22.7	3.9	0.05	52.4
Sugar and artificial sweeteners	15021	22.9	3.8	0.09	52.5
Men's footwear	40011	23.4	3.7	0.22	52.8
Mattress and springs	29011	23.5	3.7	0.16	53.0
Women's underwear	38042	23.6	3.7	0.09	53.2
Portable dishwashers	30033	23.8	3.7	0.002	53.2
Bathroom linens	28011	23.8	3.7	0.06	53.2
Lumber, paneling, wall and ceiling tile, awnings, glass	24013	23.9	3.7	0.01	53.3
Admission to sporting events	62032	24.0	3.6	0.13	53.4
Girls' underwear and nightwear	39016	24.2	3.6	0.04	53.5
Instant and freeze dried coffee	17032	24.3	3.6	0.11	53.6
New motorcycles	45031	24.3	3.6	0.09	53.8
College textbooks	66011	24.3	3.6	0.19	54.0
Girls' footwear	40022	24.5	3.6	0.08	54.2
Other processed vegetables	14023	24.6	3.5	0.13	54.3
Motor oil	47021	24.7	3.5	0.04	54.4
Lawn and garden equipment	32041	24.8	3.5	0.09	54.5
Outdoor equipment	32015	24.8	3.5	0.01	54.5
Canned and dried fruits	13031	24.9	3.5	0.08	54.6
Whiskey at home	20021	24.9	3.5	0.09	54.7
Noncarbonated fruit flavored drinks	17051	25.0	3.5	0.05	54.8
Cleansing and toilet tissue, paper towels, napkins	33031	25.0	3.5	0.19	55.1
Jewelry	43021	25.2	3.4	0.32	55.5
Other fats and oils	16012	25.3	3.4	0.14	55.7
Macaroni and cornmeal	1032	25.5	3.4	0.05	55.8
Cereal	1021	25.5	3.4	0.27	56.2
Curtains and drapes	28014	25.6	3.4	0.05	56.3
Pies, tarts, turnovers (excl frozen)	2065	25.6	3.4	0.04	56.3
White bread	2011	25.7	3.4	0.26	56.7
Kitchen and dining room furniture	29041	25.8	3.4	0.15	56.9
Canned beans other than lima beans	14021	25.8	3.3	0.02	56.9
Sofas	29021	26.2	3.3	0.23	57.2
Canned and packaged soup	18011	26.3	3.3	0.10	57.4
Lamb, organ meats, and game	5014	26.4	3.3	0.03	57.4
Rice	1031	26.5	3.2	0.05	57.5
Lodging while out of town	21021	26.6	3.2	2.09	60.4
Canned or packaged salads and desserts	18061	26.6	3.2	0.03	60.4
Other dairy products	10012	26.9	3.2	0.07	60.5
Radio, phonographs and taperecorders/players	31031	26.9	3.2	0.02	60.6
Prepared Flour Mixes	1012	27.1	3.2	0.05	60.7
Other frozen fruits and fruit juices	13012	27.1	3.2	0.02	60.7
Canned fish or seafood	7011	27.4	3.1	0.07	60.8
Women's accessories	38044	27.4	3.1	0.07	60.9
Boys' suits, sportcoats, and pants	37016	27.6	3.1	0.08	61.0
Sauces and gravies	18043	27.6	3.1	0.14	61.2
Margarine	16011	27.9	3.1	0.04	61.2

Table 1

The Frequency of Price Changes by Category

Name	ELI	Freq.	Mo.	Wgt.	CDF
Men's suits	36011	27.9	3.1	0.19	61.5
Bologna, liverwurst, salami	5012	28.0	3.0	0.09	61.6
Housing at school, excl board	21031	28.0	3.0	0.24	62.0
Bedroom linens	28012	28.0	3.0	0.13	62.2
Men's pants and shorts	36051	28.0	3.0	0.21	62.5
Video game hardware, software and accessories	31023	28.1	3.0	0.01	62.5
Other canned or packaged foods	18063	28.1	3.0	0.18	62.7
Olives, pickles, relishes	18042	28.1	3.0	0.03	62.8
Living room chairs	29031	28.4	3.0	0.12	62.9
Lunchmeats	5013	28.7	3.0	0.18	63.2
Wine at home	20031	29.1	2.9	0.19	63.4
Potato chips and other snacks	18031	29.1	2.9	0.17	63.7
Dryers	30022	29.3	2.9	0.04	63.7
Ship fares	53023	29.4	2.9	0.05	63.8
Bread other than white	2021	29.7	2.8	0.14	64.0
Women's footwear	40031	29.7	2.8	0.34	64.5
Automobile finance charges	51011	29.8	2.8	0.57	65.3
Infants' and toddlers' sleepwear	41014	29.8	2.8	0.02	65.3
Elementary and high school tuition and fixed fees	67021	30.0	2.8	0.52	66.0
Frozen bakery products & frozen/refrigerated doughs & batters	2064	30.3	2.8	0.06	66.1
Microwave ovens	30032	30.4	2.8	0.04	66.2
Frozen vegetables	14011	31.0	2.8	0.09	66.3
Peanut butter	16014	31.0	2.7	0.04	66.3
Floor covering equipment and sewing machines	32051	31.2	2.7	0.04	66.4
Beer, ale, and other alcoholic malt	20011	31.3	2.7	0.42	67.0
College tuition and fixed fees	67011	31.3	2.7	1.69	69.3
Ice cream and related products	10041	31.4	2.7	0.16	69.6
Bread and cracker products	2062	31.5	2.7	0.01	69.6
Boys' footwear	40021	31.6	2.6	0.08	69.7
Other fresh milk and cream	9021	31.6	2.6	0.26	70.0
Flour	1011	31.7	2.6	0.02	70.1
Bottled or tank gas	25021	31.7	2.6	0.08	70.2
Canned cut corn	14022	31.9	2.6	0.02	70.2
Window air conditioners	30034	31.9	2.6	0.02	70.2
Men's sportcoats and tailored jackets	36012	32.1	2.6	0.03	70.3
Outdoor furniture	29043	32.2	2.6	0.03	70.3
Videocassette recorders, disc players, cameras and accessories	31021	32.3	2.6	0.04	70.4
Carbonated drinks other than cola	17012	32.4	2.6	0.14	70.6
Men's coats and jackets	36013	32.4	2.6	0.09	70.7
Televisions	31011	32.8	2.5	0.13	70.9
Cheese	10021	32.9	2.5	0.34	71.3
Women's pants and shorts	38033	33.0	2.5	0.35	71.8
Luggage	42013	33.3	2.5	0.04	71.9
Stoves and ovens excluding microwave ovens	30031	33.6	2.4	0.04	71.9
Men's shirts	36041	33.6	2.4	0.27	72.3
Cookies	2042	33.7	2.4	0.15	72.5
Fresh, canned, or bottled fruit juices	13013	33.7	2.4	0.20	72.8

Table 1

The Frequency of Price Changes by Category

Name	ELI	Freq.	Mo.	Wgt.	CDF
Girls' skirts and pants	39014	34.1	2.4	0.09	72.9
Frozen orange juice	13011	34.4	2.4	0.05	73.0
Fresh whole milk	9011	34.4	2.4	0.35	73.5
Diesel	47017	34.5	2.4	0.23	73.8
Refrigerators and home freezers	30011	34.9	2.3	0.08	73.9
Components and other sound equipment	31032	35.4	2.3	0.08	74.0
Other poultry	6031	36.0	2.2	0.09	74.1
Frankfurters	5011	36.1	2.2	0.09	74.3
Other beef	3043	36.4	2.2	0.08	74.4
Frozen prepared foods other than meals	18022	36.5	2.2	0.11	74.5
Infants' and toddlers' play and dresswear	41012	36.8	2.2	0.04	74.6
Shellfish (excl canned)	7021	37.0	2.2	0.09	74.7
Roasted coffee	17031	37.1	2.2	0.15	74.9
Washers	30021	37.1	2.2	0.06	75.0
Frozen prepared meals	18021	37.4	2.1	0.06	75.1
Boys' shirts	37013	37.5	2.1	0.07	75.2
Pork sausage	4042	37.9	2.1	0.09	75.3
Playground equipment	61012	37.9	2.1	0.001	75.3
Infants' and toddlers' outerwear	41011	38.3	2.1	0.004	75.3
Cola drinks	17011	38.8	2.0	0.21	75.6
New trucks	45021	39.3	2.0	0.89	76.9
Fresh whole chicken	6011	39.4	2.0	0.15	77.1
Men's active sportswear	36035	39.8	2.0	0.04	77.1
Personal computers and peripheral equipment	69011	40.6	1.9	0.04	77.2
Fresh or frozen chicken parts	6021	40.7	1.9	0.21	77.5
New cars	45011	41.0	1.9	3.84	82.9
Apples	11011	41.4	1.9	0.12	83.0
Women's coats and jackets	38011	41.5	1.9	0.18	83.3
Women's nightwear	38041	42.1	1.8	0.07	83.4
Other roast (excl chuck and round)	3041	42.2	1.8	0.05	83.4
Automobile rental	52051	42.3	1.8	0.21	83.7
Fish (excl canned)	7022	42.4	1.8	0.21	84.0
Crackers	2061	42.5	1.8	0.11	84.2
Bananas	11021	43.0	1.8	0.07	84.3
Electricity	26011	43.4	1.8	2.27	87.5
Bacon	4011	43.5	1.7	0.11	87.6
Women's active sportswear	38034	44.6	1.7	0.07	87.7
Girls' tops	39013	45.2	1.7	0.06	87.8
Butter	10011	45.5	1.6	0.04	87.8
Ground beef	3011	46.1	1.6	0.31	88.3
Men's sweaters	36034	46.7	1.6	0.04	88.3
Pork roast, picnics, other pork	4041	46.8	1.6	0.12	88.5
Other steak (excl round and sirloin)	3042	46.8	1.6	0.22	88.8
Other motor fuel	47018	47.1	1.6	0.02	88.8
Boys' coats and jackets	37011	47.2	1.6	0.02	88.8
Potatoes	12011	47.3	1.6	0.10	89.0
Women's tops	38031	47.3	1.6	0.36	89.5

Table 1

The Frequency of Price Changes by Category

Name	ELI	Freq.	Mo.	Wgt.	CDF
Boys' sweaters	37012	47.6	1.5	0.01	89.5
Pork chops	4021	47.9	1.5	0.14	89.7
Round steak	3051	48.2	1.5	0.08	89.8
Sirloin steak	3061	48.4	1.5	0.07	89.9
Girls' active sportswear	39015	48.5	1.5	0.02	89.9
Women's suits	38051	49.0	1.5	0.17	90.2
Girls' coats and jackets	39011	49.2	1.5	0.01	90.2
Women's skirts	38032	50.1	1.4	0.05	90.2
Boys' active sportswear	37017	50.4	1.4	0.02	90.3
Ham (excl canned)	4031	50.4	1.4	0.13	90.5
Women's dresses	38021	50.8	1.4	0.25	90.8
Fuel oil	25011	52.5	1.3	0.25	91.2
Other fresh vegetables	12041	52.8	1.3	0.34	91.6
Round roast	3031	53.1	1.3	0.05	91.7
Chuck roast	3021	54.3	1.3	0.08	91.8
Oranges	11031	54.7	1.3	0.08	91.9
Girls' dresses and suits	39012	58.4	1.1	0.04	92.0
Other fresh fruits	11041	59.7	1.1	0.47	92.7
Eggs	8011	61.8	1.0	0.19	92.9
Premium unleaded gasoline	47016	62.3	1.0	0.91	94.2
Lettuce	12021	62.4	1.0	0.08	94.3
Mid-grade unleaded gasoline	47015	63.9	1.0	0.83	95.5
Utility natural gas service	26021	64.2	1.0	1.14	97.1
Regular unleaded gasoline	47014	65.6	0.9	0.94	98.4
Airline fares	53011	70.4	0.8	1.04	99.8
Tomatoes	12031	71.0	0.8	0.12	100.0

ELI = Entry Level Item in the CPI (each of which contains 4-5 items priced in each geographic area).

Freq. = the estimated average monthly frequency of price changes over 1995-1997 (λ in the text).

Mo. = the mean duration between price changes implied by λ [$= -1/\ln(1-\lambda)$].

Wgt. = Relative importance in the December 1997 CPI (these sum to 71.2).

CDF = cumulative distribution function of FREQ within the share of the CPI covered.

Data Source: U.S. Department of Labor (1997).

Table 2

Monthly Frequency of Price Changes for Selected Categories

	% of Price Quotes with Price Changes	% of Price Quotes with Price Changes *Net* of the Item Substitution %
All goods and services	25.1 (0.9)	22.0 (0.9)
Durable Goods	31.5 (2.5)	23.1 (2.5)
Nondurable Goods	28.3 (1.4)	25.3 (1.3)
Services	19.8 (1.4)	18.2 (1.4)
Food	26.4 (1.7)	24.7 (1.7)
Home Furnishings	25.8 (1.8)	23.6 (1.8)
Apparel	30.0 (3.0)	20.8 (3.1)
Transportation	36.3 (1.8)	31.1 (1.8)
Medical Care	8.8 (2.8)	7.6 (2.8)
Entertainment	11.7 (3.7)	8.9 (3.7)
Other	16.7 (2.6)	15.1 (2.6)
Raw Goods	50.7 (1.8)	49.6 (1.6)
Processed Goods	20.1 (0.8)	16.6 (0.7)

Notes: Frequencies are weighted means of category components. Standard errors are in parentheses. Durables, Nondurables and Services coincide with U.S. National Income and Product Account classifications. Housing (reduced to home furnishings in our data), apparel, transportation, medical care, entertainment, and other are BLS Expenditure Classes for the CPI. Raw goods include gasoline and motor oil, fuel oil and other fuels, electricity, natural gas, meats, fish, eggs, fresh fruits, fresh vegetables, and fresh milk and cream.

Data Source: U.S. Department of Labor (1997).

Table 3

Predicting Price Changes Across Goods

Dependent Variable = Frequency of Price Changes across ELIs

Regressors ↓	(A)	(B)	(C)	(D)
4-firm Concentration Ratio	-0.28 (0.04)	-0.32 (0.03)	-0.04 (0.03)	
Wholesale Markup		-0.92 (0.10)	0.002 (0.11)	
Noncomparable Substitution Rate		1.83 (0.27)	2.50 (0.22)	2.99 (0.27)
Raw Good			28.6 (2.4)	34.7 (1.7)
Adjusted R^2	0.19	0.40	0.64	0.56
Number of goods (ELIs)	232	222	222	350

Notes: Each regression is weighted by the importance of the ELI in the December 1997 CPI. Standard errors are in parentheses.

Table 4

Aggregate and Sectoral Inflation Rates (Short Sample)

Variable ↓	(A) Monthly Inflation	(B) Monthly Growth of Real Consumption
Aggregate of 123 Sectors		
ρ	0.15 (0.13)	–0.32 (0.13)
σ_{ε}	0.19	0.54
Across i = 1, ..., 123 sectors		
Mean ρ_i	–0.04	–0.06
Mean $\sigma_{\varepsilon,i}$	0.80	1.56
Correlation between ρ_i and λ_i	0.26 (0.09)	–0.52 (0.09)
Correlation between $\sigma_{\varepsilon,i}$ and λ_i	0.55 (0.08)	0.49 (0.08)

Notes:

dx_t = first difference of x_t , where x_t is the log of the price or real consumption.

$dx_t = \rho\, dx_{t-1} + \varepsilon_t$, where ε_t is i.i.d. with S.D. σ_ε ; so that S.D.(dx_t) = $[\sigma_\varepsilon^2/(1-\rho^2)]^{½}$, equals 0.19 for inflation and 0.57 for consumption growth.

$dx_{i,t} = \rho_i\, dx_{i,t-1} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}$ is i.i.d. with S.D. $\sigma_{\varepsilon,i}$, so that S.D. ($dx_{i,t}$) = $[\sigma_{\varepsilon,i}^2/(1-\rho_i^{\,2})]^{½}$

The sample is 1995:M1 to 1999:M12. The 123 sectors represent 67.3% of the December 1997 CPI, and each sector is weighted by its relative importance. Standard errors are in parentheses.

Table 5

Aggregate and Sectoral Inflation Rates (Longer Sample)

Variable ↓	(A) Monthly Inflation	(B) Monthly Growth of Real Consumption
Aggregate of 123 Sectors		
ρ	0.64 (0.03)	–0.13 (0.04)
σ_{ε}	0.21	0.76
Across i = 1, ..., 123 sectors		
Mean ρ_i	0.27	–0.09
Mean $\sigma_{\varepsilon,i}$	0.90	2.38
Correlation between ρ_i and λ_i	–0.14 (0.09)	–0.32 (0.09)
Correlation between $\sigma_{\varepsilon,i}$ and λ_i	0.52 (0.08)	0.40 (0.08)

Notes:

dx_t = first difference of x_t , where x_t is the log of the price or real consumption.

$dx_t = \rho\, dx_{t-1} + \varepsilon_t$, where ε_t is i.i.d. with S.D. σ_ε so that σ = S.D.(dx_t) = $[\sigma_\varepsilon^2/(1-\rho^2)]^{½}$, equals 0.27 for inflation and 0.77 for consumption growth.

$dx_{i,t} = \rho_i\, dx_{i,t-1} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}$ is i.i.d. with S.D. $\sigma_{\varepsilon,i}$ and σ_i = S.D.($dx_{i,t}$) = $[\sigma_{\varepsilon,i}^2/(1-\rho_i^{\,2})]^{½}$

The sample is 1959:M1 to 2000:M6. Standard errors are in parentheses.

Table 6

Observed Inflation for Flexible-Price and Sticky-Price Goods

Variable ↓	From 1995-99 data (A) Price Inflation	(B) Growth of Real Consumption	From 1959-2000 data (C) Price Inflation	(D) Growth of Real Consumption
Flexibly-priced good				
ρ	0.04	–0.33	0.22	–0.19
σ_{ε}	1.40	2.73	1.43	3.49
Sticky-priced good				
ρ	–0.10	0.18	0.31	–0.01
σ_{ε}	0.28	0.55	0.45	1.43
Flexible versus sticky				
$\rho_{flexible} - \rho_{sticky}$	0.14 (0.05)	–0.51 (0.08)	–0.09 (0.06)	–0.18 (0.05)
$\sigma_{\varepsilon, flexible} - \sigma_{\varepsilon, sticky}$	1.13 (0.16)	2.18 (0.35)	0.98 (0.15)	2.06 (0.43)

Notes:

dx_{it} = first difference of x_{it} , where x_{it} is the log of the price or real consumption.

$dx_{i,t} = \rho_i \, dx_{i,t-1} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}$ is i.i.d. with S.D. $\sigma_{\varepsilon,i}$ and σ_i = S.D.($dx_{i,t}$) = $[\sigma_{\varepsilon,i}^{2}/(1-\rho_i^{\,2})]^{½}$.

$\rho_{flexible}$ and $\sigma_{\varepsilon, flexible}$ refer to the serial correlation and volatility fitted for a good with monthly frequency of price changes of 48.5% (the 90th percentile of frequency in Table 1); ρ_{sticky} and $\sigma_{\varepsilon, sticky}$ refer to those fitted for a good with monthly frequency of price changes of 6.1% (the 10th percentile).

Table 7

Inflation from a Staggered Pricing Model

Variable ↓	Only Aggregate Shocks (A) Price Inflation	(B) Growth of Real Consumption	Aggregate and Sector Shocks (C) Price Inflation	(D) Growth of Real Consumption
Flexible-price good				
ρ	0.48 (0.03)	–0.30 (0.04)	0.48 (0.03)	0.16 (0.04)
σ_{ε}	0.68 (0.02)	0.67 (0.02)	1.01 (0.04)	1.08 (0.04)
Sticky-price good				
ρ	0.92 (0.01)	0.01 (0.05)	0.91 (0.02)	0.09 (0.05)
σ_{ε}	0.10 (0.01)	0.86 (0.03)	0.16 (0.01)	0.91 (0.04)

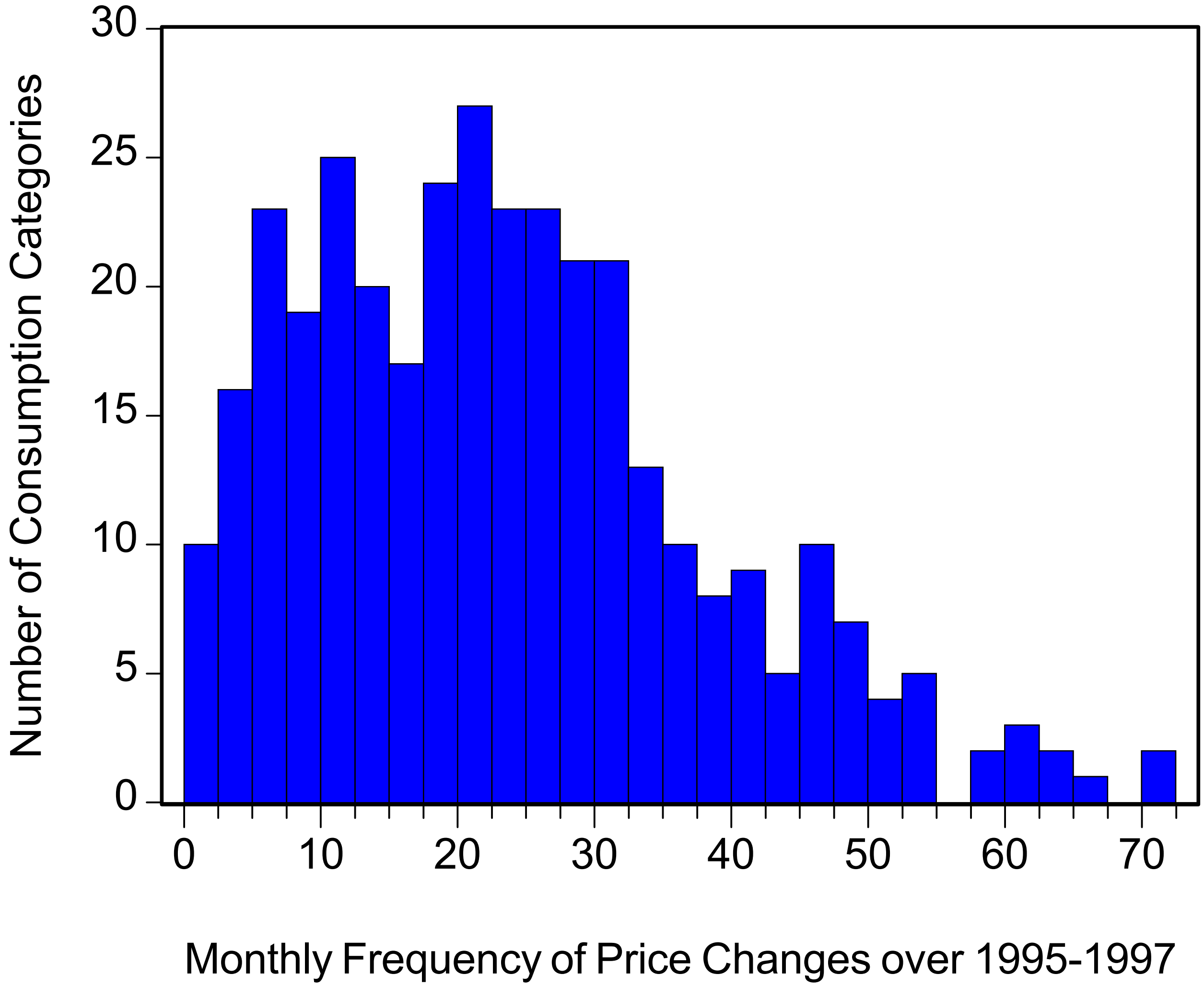
Notes:

dx_{it} = first difference of x_{it} , where x_{it} is the log of the price or real consumption.

$dx_{i,t} = \rho_i \, dx_{i,t-1} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}$ is i.i.d. with S.D. $\sigma_{\varepsilon,i}$ and σ_i = S.D.($dx_{i,t}$) = $[\sigma_{\varepsilon,i}^{2}/(1-\rho_i^{2})]^{½}$.

$\rho_{flexible}$ and $\sigma_{\varepsilon, flexible}$ refer to the serial correlation and volatility predicted by the staggered-pricing model for a good with monthly frequency of price changes of 1/2 (near the 90th percentile of frequency in Table 1); ρ_{sticky} and $\sigma_{\varepsilon, sticky}$ refer to those predicted by the model for a good with monthly frequency of price changes of 1/16 (near the 10th percentile).

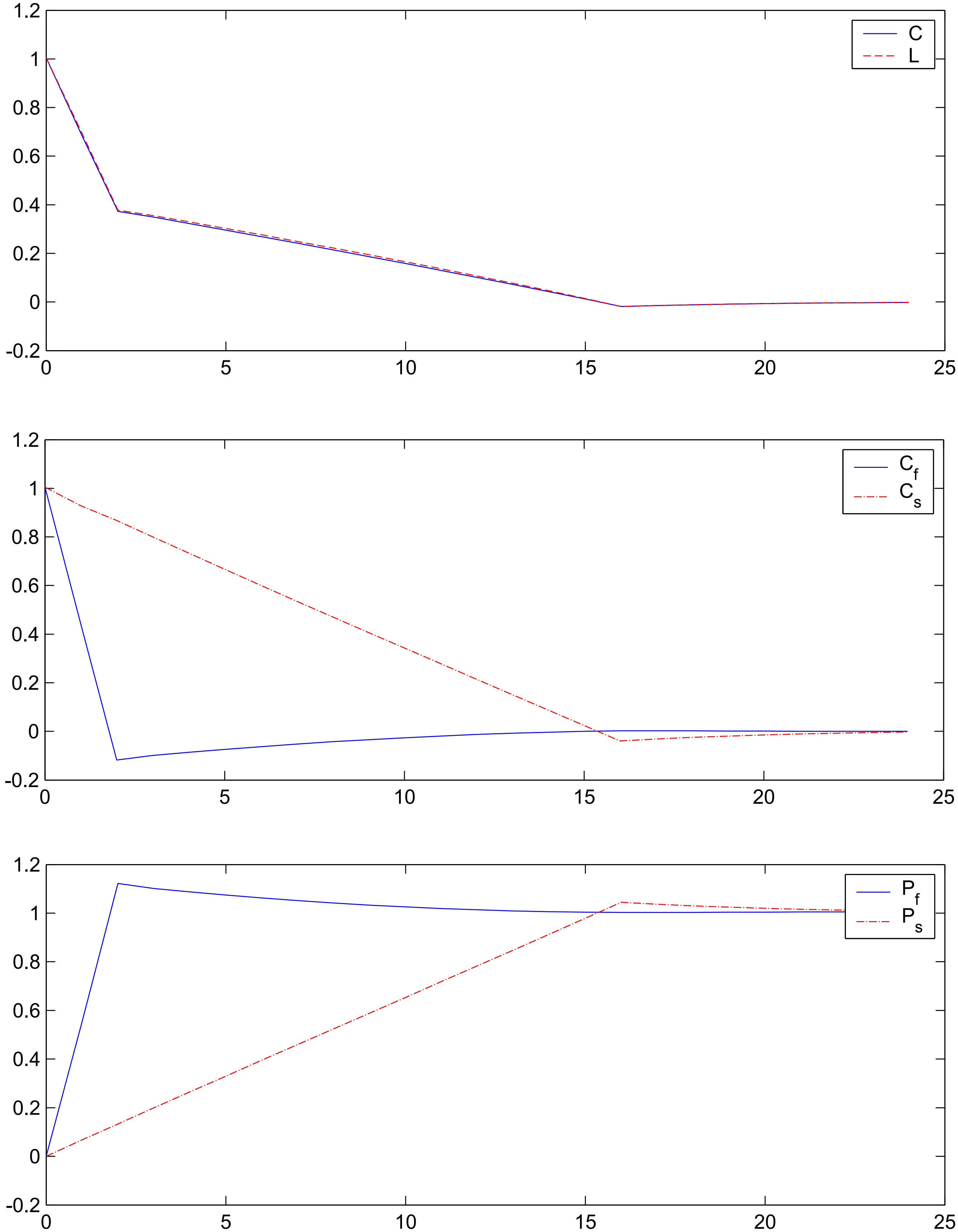
Figure 1



30
25
20
15
10
5
0
Number of Consumption Categories
0
10
20
30
40
50
60
70
Monthly Frequency of Price Changes over 1995-1997

Figure 2

% responses to a 1% money supply shock (persistence of money growth is $\rho_m = 0$)



Months (flexible = fixed for 2 months, sticky = fixed for 16 months)

Figure 3

% responses to a 1% productivity shock (persistence is $\rho_a = 1$)

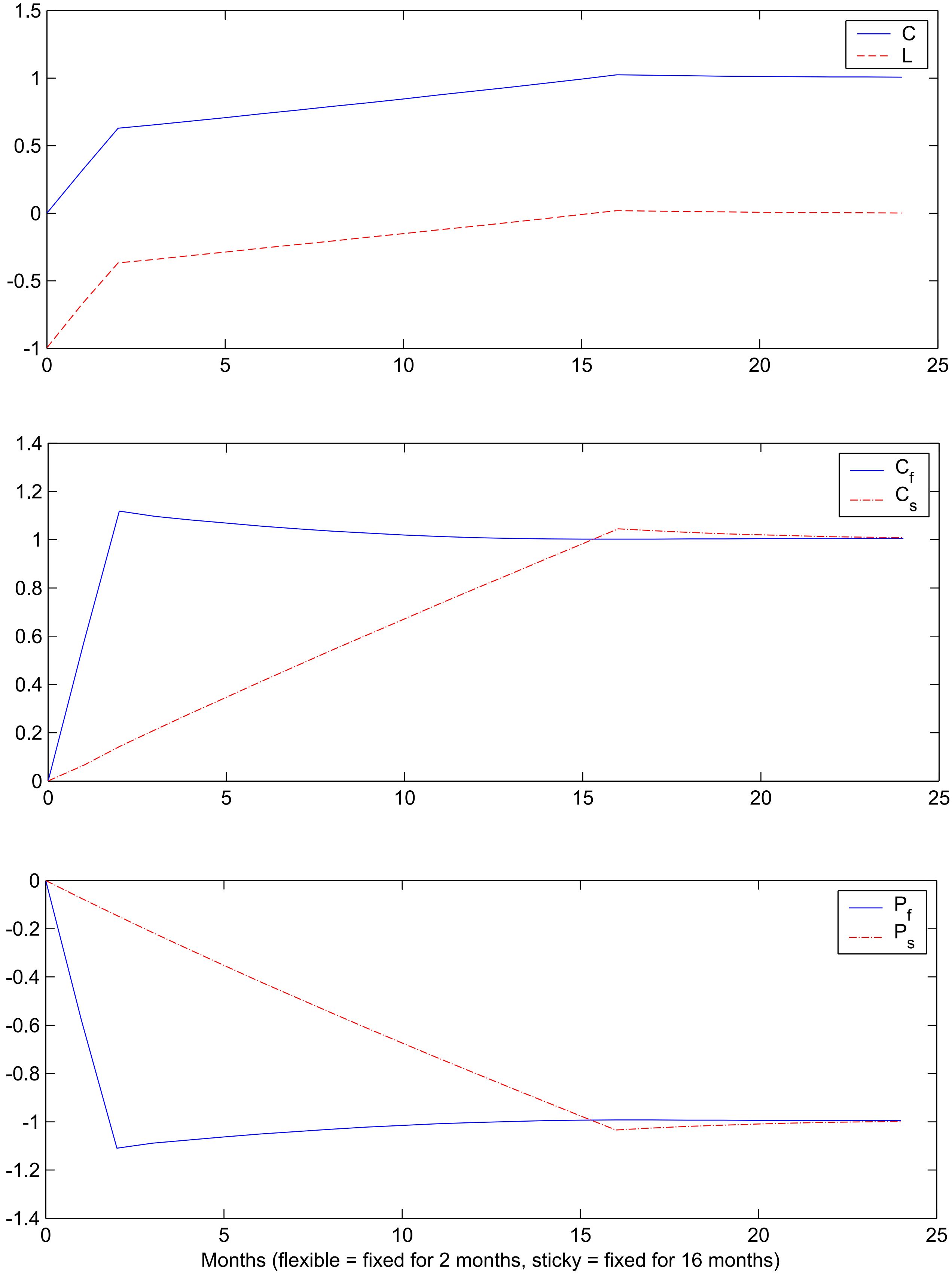


Figure 4: Predicted vs. Actual Inflation Persistence
(Calvo model; 1995-1999, 123 consumption categories)

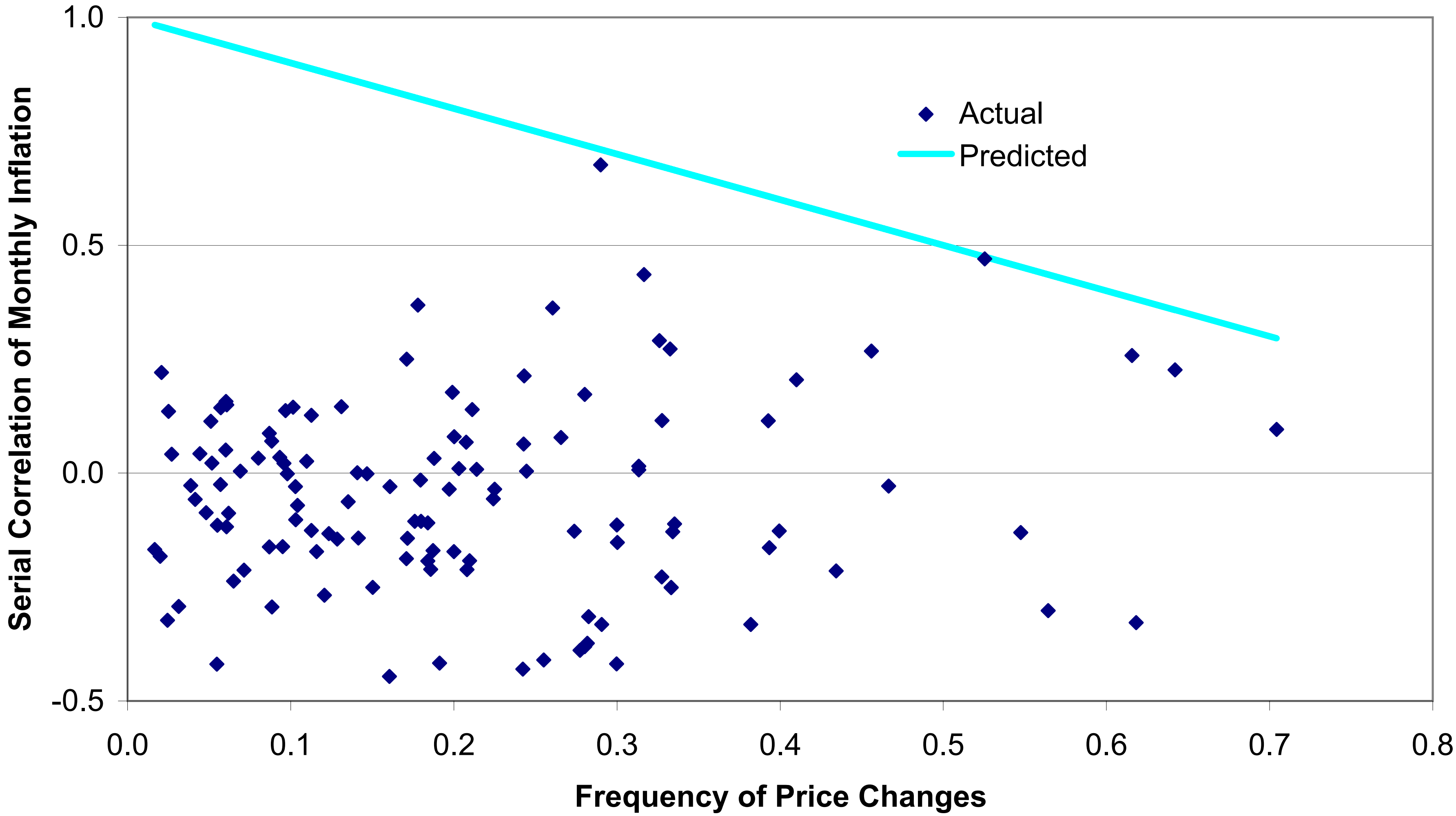


Figure 5: Predicted vs. Actual Inflation Persistence
(Calvo model; 1959-2000, 123 consumption categories)

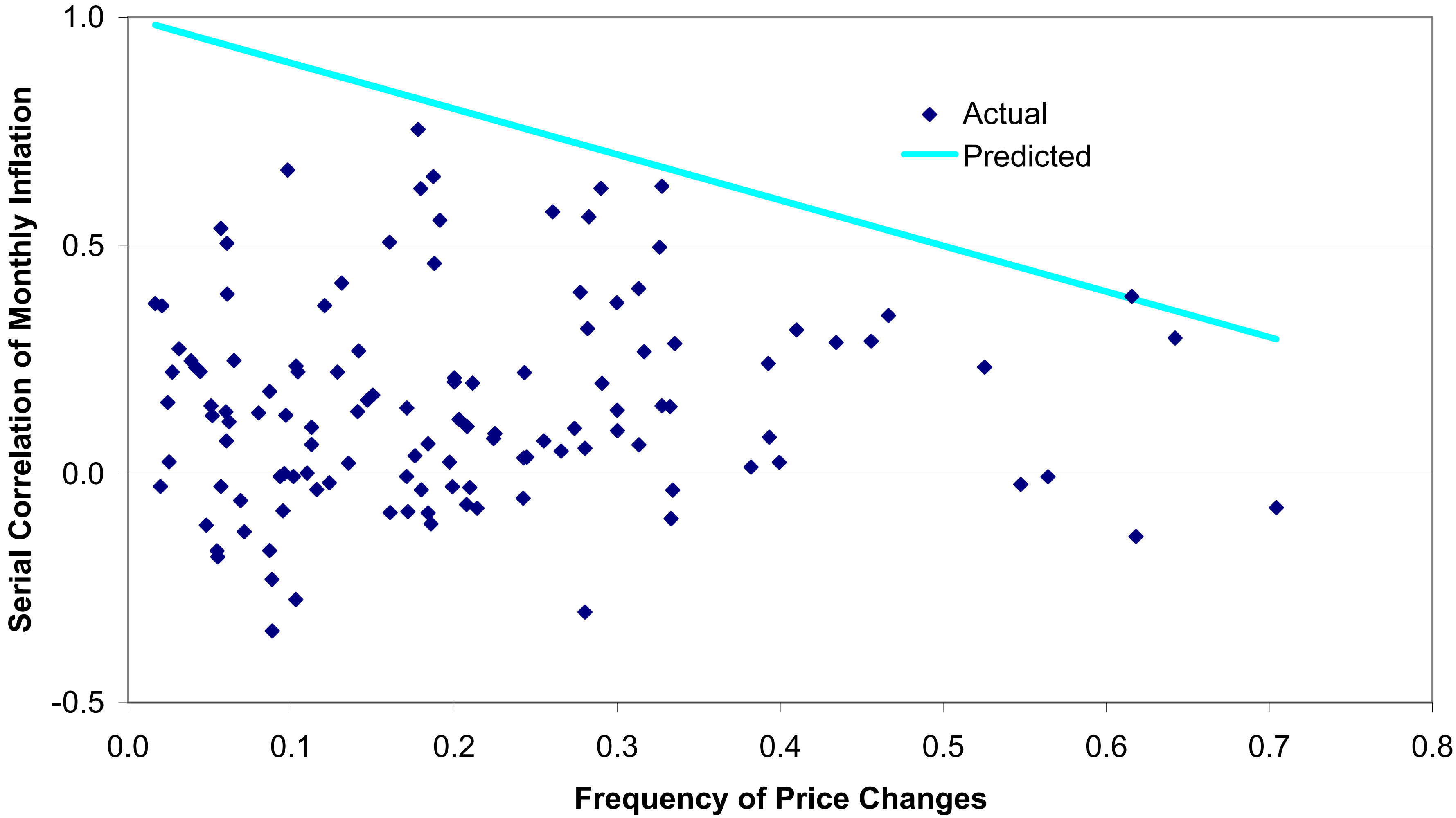


Figure 6: Marginal Cost Needed to Generate Sectoral Inflation (Calvo model; 1995-1999 data for 123 categories)

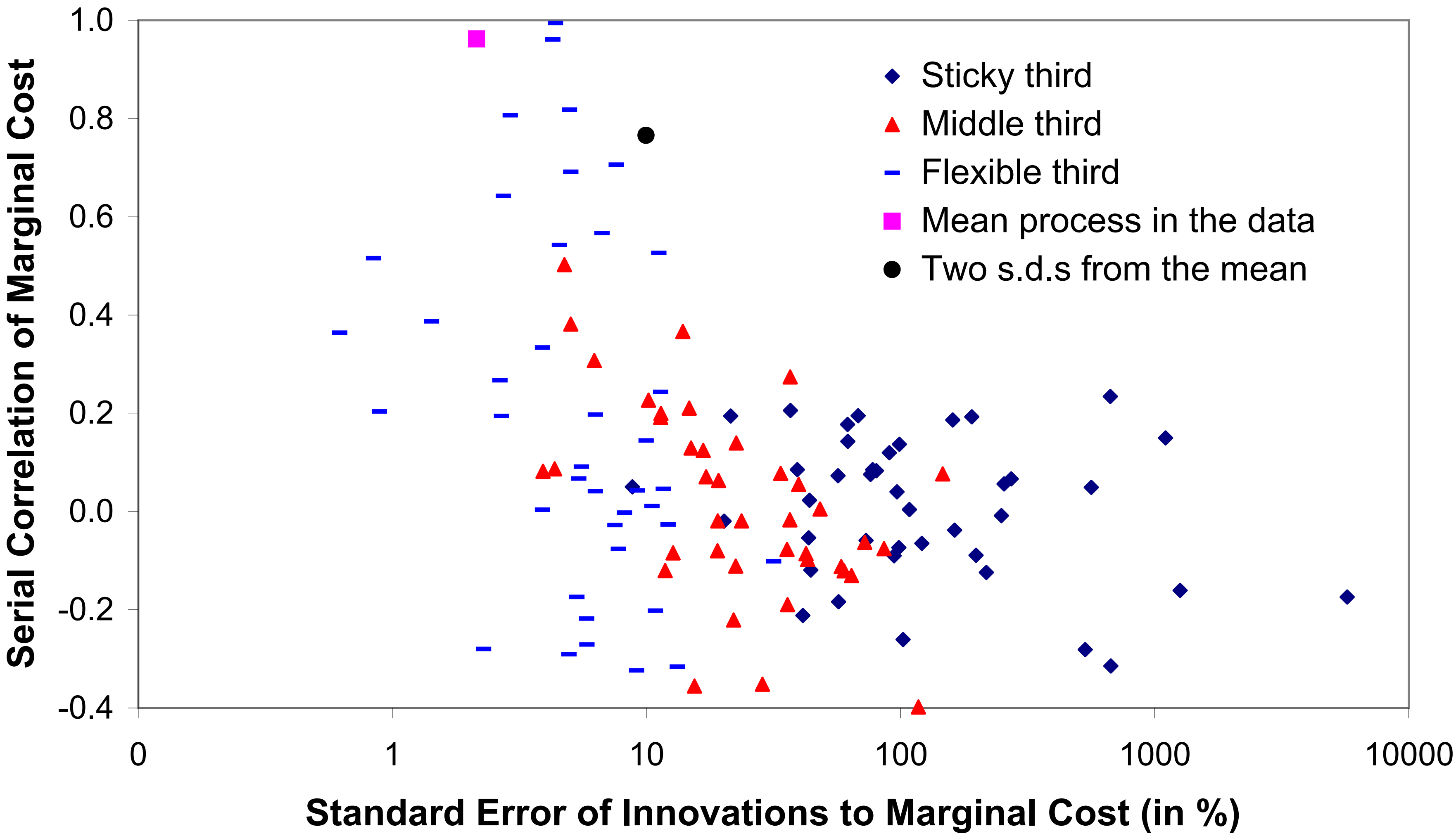
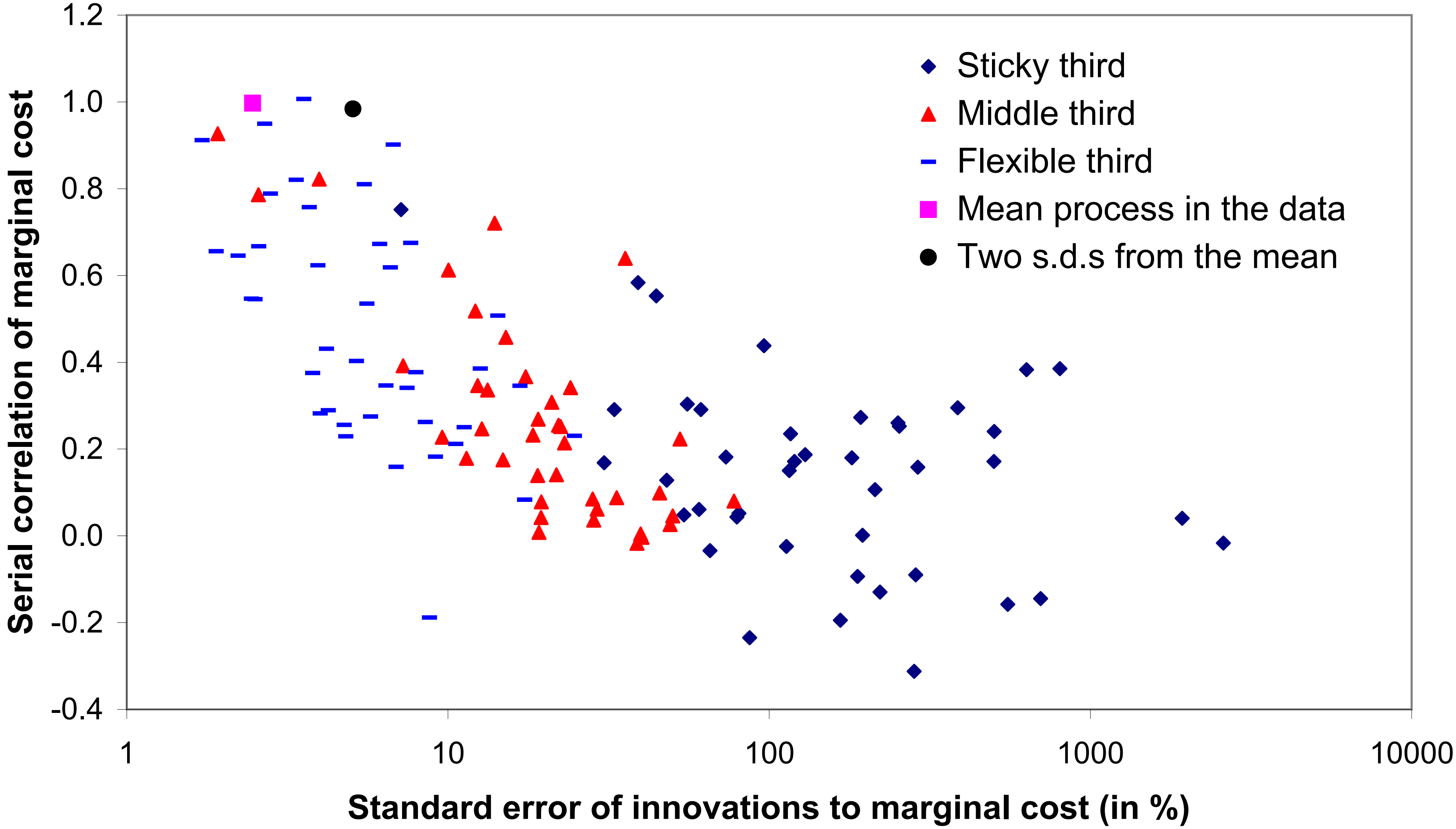


Figure 7: Marginal Cost Needed to Generate Sectoral Inflation (Calvo model; 1959-2000 data for 123 categories)



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