# INFLATION AND PRICE ADJUSTMENT: AN ANALYSIS OF MICRO DATA

Benjamin Eden*

The University of Haifa

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I use large data sets on prices by products and stores from recent inflationary periods in Israel to compare simple menu cost models to simple uncertain and sequential trade (UST) models. The main empirical findings are: (a) Even in high inflation periods, price erosion due to inflation explains only a tiny fraction of the variation in non-zero nominal price changes; (b) There is an error correction type behavior in the choice of nominal prices: Stores which their last nominal price change was relatively low are likely to choose a nominal price change which is relatively high; (c) Stores that reduce their nominal price charge a lower price relative to store that increase their nominal price and (d) Relative price variability is not related to inflation. I argue that these findings are not consistent with simple menu cost models but are consistent with a simple UST model.

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## 1. Introduction

This paper uses large data sets on prices by products and stores from recent inflationary periods in Israel to test predictions of simple menu cost models and a prediction of a simple uncertain and sequential trade (UST) model.

In menu cost models there is a fixed cost for changing nominal prices and therefore nominal price changes occur discretely, in jumps. This behavior was observed empirically by many researchers. See for example, Carlton (1986), Cecchetti (1986) and Lach and Tsiddon (1992).

In a UST equilibrium there is price dispersion and sellers are indifferent among prices in the equilibrium range because lower real prices promise a higher probability of making a sale. When inflation erodes the real price many sellers are fully compensated by the increase in the probability of making a sale and therefore may choose not to change their nominal price even in the absence of menu type costs. The observation that nominal price changes occur in jumps cannot therefore distinguish between the two type of models. We need some further observations.

## 2. Simple (S,s) models

Simple (S,s) models assume that stores have some monopoly power and face a fixed cost for changing nominal price. The tradeoff is between the frequency of nominal price changes and the average deviation from the optimal monopoly price. Barro (1972) and Sheshinski and Weiss (1977) show that the optimal strategy in a stationary environment is to increase the nominal price whenever the real price hits a certain threshold level s to the target level S.

When stores have different profit functions arising from different production and demand functions and face different fixed costs for changing nominal prices, they will follow store specific (S,s) policies. The time difference (td) between two consecutive nominal price changes and the size of the "jump" in the nominal price (dp) are related by:

$$dp = \pi td, \tag{1}$$

where $\pi$ denotes the rate of change in the general price level (the inflation rate) which is assumed to be constant over time. The term $\pi td$ is often referred to as the real price erosion. Equation (1) simply says that non-zero nominal price changes cover the real price erosion due to inflation which occurred since the last nominal price change. It requires that the store chooses the same real price target (S) whenever it adjusts its nominal price, but it does not require a threshold level s which is stable over time.

In their 1983 article, Sheshinski and Weiss extended the analysis to the case in which inflation is a stochastic process. The rate of change of the price level can be positive or zero and the time spent in each state are of random duration. They show that the optimal policy in this stochastic environment is (S,s) in the real price.

To formulate the price erosion hypothesis under stochastic inflation we should allow the rate of inflation to change over time and use the average rate of inflation during the time between the last and the current nominal price change in (1).

To allow for product specific shocks it is common to allow for product specific inflation rates in (1). In the empirical part of this paper I allow inflation to vary over time and products.

A product specific inflation rate may be negative even when the general inflation rate is positive. This may occur as a result of a decline in the relative price of the product due to a real product specific shock. Tsiddon (1993) considers the case in which the log of nominal balances follows a Wiener process and the cost of deviating from the optimal monopoly price is quadratic. He cites Vial (1972) and Harrison, Selke and Taylor (1983) who show that in this case the optimal policy is characterized by three numbers: (b,I,u). According to the optimal policy the store changes its nominal price whenever the real price hits the lower bound (b) or the upper bound (u) to reach the target level (I). This policy is sometimes called a two sided (S,s) policy.

Since the relationship (1) requires only that the target real price does not change over time, it holds also for the two sided (S,s) policy. Thus under both versions of the (S,s) model:

(a) Price erosion - the decline in the price of the store relative to the price of the same good in other stores - explains non-zero nominal price changes.

I now state two predictions for the specialized versions: One for the one sided model and one for the two sided model.

In a one sided (S,s) policy the jump in the nominal price is the same in all nominal price change episodes and is equal to the size of the band: S - s. When the size of the store specific bands does not change over time we should observe that if store j increased its nominal price in a certain month by more than the average across other stores which change the price of the same product then it should increase its price by more than the average also in the next nominal price change episode. This leads to:

(b) A positive serial correlation in the relative non-zero nominal price change.

The two sided (S,s) model says that nominal price reductions and nominal price increases are made to achieve the same real price target (I). Therefore,

(c) The level of the real price immediately after the change in nominal price does not depend on the sign of the nominal price change.

In the empirical section I operationalize and test hypotheses (a) - (c). I now turn to describe the UST model.

## 3. UST models

Uncertain and sequential trading (UST) models are based on ideas in Prescott (1975) and Butters (1977). Prescott considers an environment in which sellers set prices before they know how many buyers will eventually appear. He assumes that less expensive goods will be sold before more expensive ones and obtains an equilibrium trade-off between the price and the probability of making a sale. A similar trade-off arises in Butters (1977). In both models sellers commit to prices before the realization of demand. In the UST approach taken by Eden (1990), trade is sequential and an equilibrium distribution of prices is obtained even though sellers are allowed to change their prices during trade. In this model, price dispersion arises because sellers have to make irreversible selling decisions before they have complete information about the realization of demand. The UST approach was recently used in monetary economics by Eden (1994a), Lucas and Woodford (1994), Bental and Eden (1996), Woodford (1996) and Williamson (1996).

Since the UST model is less known I now turn to describe a simple version based on Eden (1994a).

## A monetary UST model

I consider an overlapping generations model in which at the beginning of each period a large number of ex-ante identical individuals are born. Individuals live for two periods. They produce and sell their output for money in the first period. They then use, in the second period, the proceeds of first period sales plus any transfer that they receive from the government to buy goods. Fiat money is the only asset.

Transfer payments are like rain. Everyone observes the amount of money rain as it occurs but no one knows when it will stop. Trade occurs sequentially as the money rain is falling. Buyers costlessly observe all available price offers and spend their money on the cheapest available offer.

The representative agent is risk neutral and his utility function is given by: $c - v(x)$, where $c$ is consumption when old and $v(x)$ is the labor cost of creating $x$ units of capacity (when young). The cost function $v(\ )$ has the standard properties: $v' > 0$ and

$v'' > 0$.

At time t the representative buyer has $M_t$ dollars. He then gets transfer payments which occur sequentially and are proportional to the initial amount of money held. The first amount of transfer is of $(\theta_1\lambda - 1)$ dollars per dollar, where $\lambda - 1$ denotes the anticipated rate of change in the money supply and $\theta_1$ is the lowest realization of an i.i.d. random variable $\theta$ which takes the realizations: $\theta_1 < \theta_2 <...< \theta_S$. The realization $\theta_s$ occurs with probability $\pi_s$. For convenience I define $\theta_0 = 0$.

After the first amount of transfer the buyer has $(\theta_1 - \theta_0)\lambda M_t$ dollars and in equilibrium, he spends it on the cheapest available goods. If there are no additional transfers, trade for period t stops. But, with probability $q_2 = 1 - \pi_1$, he gets an additional transfer of $(\theta_2 - \theta_1)\lambda M_t$ dollars and spends it. In general, the transfer $(\theta_s - \theta_{s-1})\lambda M_t$ will be realized with probability $q_s = \sum_{j=s}^{S} \pi_j$ and the buyer spends it immediately after getting it. The end of period money supply is: $M_{t+1} = \theta\lambda M_t$.

I divide all nominal magnitudes by $M_t$. This normalization is equivalent to using the (beginning of period) money supply as a unit of account. I therefore define a normalized dollar by the money supply per household. A price of one normalized dollar means that you must pay the average per household money supply to get a unit of whatever is being sold.

From the representative seller's point of view demand arrives in batches. The first batch of $(\theta_1 - \theta_0)\lambda$ normalized dollars arrives with certainty. The second batch of $(\theta_2 - \theta_1)\lambda$ normalized dollars arrives with probability $q_2$ and so on. Each batch of dollars that arrives opens a new market. The price in market s is $p_s$ normalized dollars per unit, where $p_s > p_{s-1}$.

The representative seller chooses total capacity and allocates it among the S potential markets. This allocation can be viewed as a contingent plan which specifies how much he will sell to each batch of money that arrives.

To make the allocation choice the seller has to compute the purchasing power of a normalized dollar earned in each market. I use z to denote the expected consumption that a normalized dollar held at the beginning of the period will buy. Since this period earnings will be used only in the next period we must take into account the fact that when the money supply is increasing a normalized dollar earned this period will "contain" less regular dollars than one normalized dollar in the next period. I therefore compute the coefficient $\omega_s$ which is used to convert normalized dollars earned today in market s into next period's normalized dollars. The product $\omega_s z$ is the expected purchasing power of a normalized dollar earned today in market s. I now get to the details of the calculation.

Since a normalized dollar held at the beginning of the period promises a transfer of $(\theta_j - \theta_{j-1})\lambda$ normalized dollars if market j opens, the expected purchasing power of a normalized dollar held at the beginning of the period is:

$$z = \sum_{j=1}^{S} q_j(\theta_j - \theta_{j-1})\lambda/p_j, \tag{2}$$

where $p_j$ is the normalized price in market j.

A normalized dollar earned this period will be worth $M_t/M_{t+1} = 1/\theta\lambda$ in terms of next period's normalized dollars. Therefore, $\omega^j = 1/\lambda\theta_j$ is the number of next period's normalized dollars that a current normalized dollar will be worth if exactly j markets open this period. Given that market s opens the probability that exactly $j \geq s$ markets will open is: $\pi_j/q_S$. Therefore, a normalized dollar earned in market s is worth:

(3) $$\omega_S = \Sigma_{j=s}^{S} (\pi_j/q_S)\omega^j,$$

in terms of next period's normalized dollars. The expected purchasing power of a normalized dollar earned in market s is $\omega_S z$ and the expected purchasing power that a young seller can get by supplying a unit to market s is: $q_S p_S \omega_S z$.

The representative young agent's problem is to choose the capacities $x_S$ which solve:

(4) $$\max \Sigma_S\, q_S(p_S\omega_S z)x_S - v(x = \Sigma_S\, x_S).$$

The first order conditions for an interior solution to (4) require that the expected real revenue per unit of capacity is equal to the marginal cost:

(5) $$q_S(p_S\omega_S z) = v'(x) \quad \text{for all s.}$$

Since $(\theta_S - \theta_{S-1})\lambda$ normalized dollars will buy in market s if it opens, the market clearing conditions are:

(6) $$(\theta_S - \theta_{S-1})\lambda/p_S = x_S \qquad \text{for all s.}$$

A solution $(p_1, p_2, ..., p_S, x_1, x_2, ..., x_S)$ to (5) and (6) is a symmetric steady-state equilibrium.

Asymmetric equilibria

In the symmetric steady state equilibrium each seller allocates a fraction $\mu_s = x_s/x$ of his capacity to market s. Since our risk neutral sellers are indifferent about the way they allocate capacity across markets, there exists an equilibrium in which a fraction $\mu_s$ of the sellers supply all their output to market s.[1] In this asymmetric equilibrium it is enough that only some sellers will change their posted dollar prices in response to an increase in the money supply, because most sellers are compensated for the reduction in the normalized price by the increased probability of making a sale.[2]

To illustrate, I assume that the range of the equilibrium distribution of normalized prices p = P/M is between p = 1 to p = 4. Assume that in the previous period the money supply was M = 10 and in the current period it doubled to M' = 20. A seller whose dollar price in the previous period was P = 30 (and his normalized price was 3) will have a normalized price of 1.5 in the current period if he keeps his price quotation in regular dollars unchanged. This seller will not care about the decline in his normalized price because he is compensated by the increase in the probability of making a sale. But a seller whose dollar price was P = 15 will have a current normalized price of 0.75 if he does not change his quoted dollar price. Since

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[1] There are many other asymmetric equilibria arising from the observation that equilibrium conditions determine the total capacity allocated to each market and not the number of sellers in each market.

[2] Strictly speaking this requires a model in which sellers live for many periods, or that the selling itself is done by a (valueless) firm which is inherited from father to son.

this seller can increase his dollar price to 20 (and normalized price to 1) without affecting the probability of making a sale, he will definitely choose to increase his dollar price. Thus, the distribution of normalized prices may be always in equilibrium even when some sellers do not change their dollar price quotations.

## The main implications of the model

Markets in our model are abstract constructs used to model the sellers' choice of prices. Sellers make contingent plan which specify the amount that will be sold to each batch of purchasing power that arrives. The notion that each batch opens a market allows us to formulate the price choice problem as a relatively standard quantity choice problem: The seller chooses the amount allocated to each of the S potential markets.

It is useful to distinguish between the quoted prices: $(p_1, ..., p_S)$ and the prices of units which were actually sold ($p_1, ..., p_s$ when s markets open). The distribution of quoted prices can be derived, by solving (5) and (6), without knowing the current and past realizations of $\theta$. Furthermore, (5) implies: $p_S/p_1 = (q_1/q_S)(\omega_1/\omega_S)$, which does not depend on $\lambda$.[1] Thus, the **relative** quoted price distribution does not depend on the parameter $\lambda$ and on the current and past realizations of $\theta$.

The current realization of $\theta$ does affect the transaction weighted average price of units sold: $\Sigma_{j=1}^{s} k_j p_j / \Sigma_{j=1}^{s} k_j$. Since

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[1] Since $\omega^j = 1/\lambda\theta_j$, (3) implies that the ratio $\omega_1/\omega_S$ does not depend on $\lambda$.

$p_j > p_{j-1}$, this weighted average is positively correlated with the price range of units which were sold: $p_s - p_1$.

Given the distinction between quoted prices and transaction weighted prices we may state the main implications of the model as follows.[1]

1. There is a positive correlation between output (capacity utilization) and unanticipated money (the current realization of $\theta$).
2. An unanticipated change in the money supply (change in the current realization of $\theta$) affect output first and quoted prices only in the following period.
3. The distribution of relative quoted prices ($p_s/p_1$) depends only on the distribution of the unanticipated rate of change in the money supply $\theta$ and not on the expected rate of change $\lambda$ and the current and past realizations of $\theta$.

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[1] As in any abstraction, there are predictions of the model which are "obviously wrong". For example, it was assumed that upon arrival buyers see all available price offers and buy at the cheapest available offer. As a result, in each period there is a price $p_s$ such that all goods which are priced below it are sold and all the goods which are priced above it are not sold. I expect that in a more realistic model in which buyers have different search costs, some goods with high price tags will sell and some goods with low price tags will not sell but the fraction of low price goods sold will be higher. I this environment sellers will face a tradeoff between the fraction of supply sold (rather than the probability of making a sale) and the price. I expect that implications 1 - 3 will still hold in this case but implication 4 should be modified: Instead of a range we should expect some measure of variability of transaction weighted prices to be positively correlated with the mean.

4. The average transaction weighted price, $\Sigma_{j=1}^{S} k_j p_j / \Sigma_{j=1}^{S} k_j$, does depend on the current realization of θ and is positively related to the range of the prices of units which were actually sold: $p_S - p_1$.

The first two implications are in line with the recent observations made by Christiano, Eichenbaum and Evans (1997, forthcoming) and are discussed in Eden (1994a). Given that I have data about quoted prices only, I focus here on implication 3 which, at first sight, seems to go against the "stylized fact" stated in the literature.

I start with a discussion of the connection between prices as they are actually measured and prices in our model.

List prices, prices which are actually quoted and unit value:

The literature distinguishes among three different measures of prices: List prices, transaction prices and unit value. I use the term quoted price instead of transaction price because in the UST model there are typically no transactions in some quoted prices.[1]

The list price is the price which appears in the catalogue.

The price which is actually quoted to a surveyor who asks at the counter for say the cost of a particular brand of coffee may

[1] The term "transaction price" was used by Stigler and Kindahl (1970, 1973) in their attempt to distinguish between Means administered prices and market (standard Walrasian) prices. Since none of the competing hypotheses in their study distinguishes between goods which are sold and goods which are not sold, they did not focus on this distinction.

include a discount and may therefore be different from the official list price.

Unit value is the average price per unit which was actually sold. It is measured by asking the store for the value of sales during the month and for the quantity that was actually sold. We then divide sales by the quantity sold.[1]

Implication 4 is about unit values. The test of this implication may be possible soon when scanner data becomes available.[2] We may expect a positive correlation between the change in the average unit value of a product and a measure of variability of the unit values across stores.

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[1] Weiss (1977) compares the BLS list prices, with Stigler-Kindahl (1970) transaction (quoted) prices and unit values obtained in two census of manufacturers (1963 and 1958). He finds a correlation of 0.5 between the unit value of 40 five digit products and indexes of the Stigler-Kindahl prices. When elemental gases are excluded the correlation goes up to 0.7.

[2] Scanner data are described by Jorgen Dalen in the first page of his article "Experiments with Swedish Scanner Data" presented at the third meeting of the Ottawa group: International conference on price indices.

"The problem in elementary aggregation in a CPI is to a high degree due to the fact that, for most products, Statistical agencies have not so far had access to sales volumes, which could serve as weights for measured price changes for varieties of commodities in outlets. This is now about to change through the rise of so called scanner data, in which all purchases are registered, typically at the cashier's desk in the outlet. These data thus contains both the price paid for a commodity and the exact number of items purchased at that price." The conference papers which report on recent experiments in scanner data are in: http://www.statcan.ca/secure/english/ottawagroup/pdf/14DAL3.pdf.

The surveyor of the central bureau of statistic in Israel, reports the prices quoted to him at the counter and does not ask about the volume sold at these prices. These are quoted prices according to our definition. I assume that the prices $(p_1,...,p_S)$ in the model refer to prices which are actually quoted rather than list prices.

In our model quoted dollar (not normalized) prices change in response to changes in the beginning of period money supply $(M_t)$ and changes in the policy parameter $\lambda$. But under the assumption that the probability distribution of $\theta$ does not change over time, the distribution of relative quoted prices does not change over time. Thus,

(d) Changes in the average quoted price are not correlated with the variance of the relative quoted prices.

## 4. The evidence

I now operationalize and test the hypotheses (a) - (d). I use monthly data collected by Israel's Central Bureau of Statistics as inputs for computing the CPI. These are prices actually quoted to the surveyor when visiting the store (quoted price data) and not transaction weighted or unit value data.[1] The sample periods are:

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[1] See the Israeli bureau of statistic technical report number 60, which was written in 1992 in hebrew. The weights for the stores were updated in 1975 and 1990. The data were collected by a visit of the surveyor to the store (and not by phone as was the case for some products not in our data set). I would like to use this opportunity to thank Yoel Finkel who is currently in charge of

1978-1979, 1981-1982 and 1991-1992. For the first two sample periods there are data on the prices of 26 food products (mostly meat and wines). These data were used by Lach and Tsiddon (L-T) and are described in their 1992 article.[1]

The data from 1991-92 are new. These data contain 115,394 monthly observations of prices by stores and products, collected from 458 stores which sold 390 different products (each store sold only a subset of the products). I excluded all products whose prices are controlled by the government. The definition of a product is rather narrow. There are, for example, 10 different kinds of bread, two kinds of bottled Coca-Cola, and three kinds of olives, see the Appendix in Eden (1994b) for a list of the products.

I used four sub samples from the 1991-92 data. The sub sample "All" refers to all products; "food" to food products and "defined food" to food products in which the quantity is well specified. For example 500 gram Hala bread is found in all three categories. Finally, 23 of the 26 products in the earlier samples (1978-79 and 1981-82) are also in the 1991-92 data; this sub sample is called "comparable".[2]

There was a problem of missing price observations in all samples. I report the results when using samples of all stores with complete records. The results when using the complete samples are

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prices in the bureau for his explanations about the actual data collecting process and for pointing out to me the papers on the recent experiments in scanner data.

[1] One observation was clearly a typing error and I have corrected for that (January 1979, product number 3).

[2] I am grateful to Yoram Weiss for suggesting this subsample as well as many other useful suggestions.

qualitatively similar.[1] In the Appendix I provide summary statistics and definitions.

(a) The importance of store specific shocks

I start by examining the hypothesis that price erosion explains the size of the nominal price change. I allow for product specific inflation rate and use $t_{ijn}$ to denote the time that the nth nominal price change of product i occurred in store j; $\pi_{in}$ to denote the realized average rate of product i inflation in the neighborhood of time $t_{ijn}$ and $td_{ijn} = t_{ijn} - t_{ijn-1}$ to denote the time since the last nominal price change (time difference). Under the assumption that the target level ($S_{ij}$ or $I_{ij}$ in the two sided model) does not change over time, store j should increase its nominal price at time $t_{ijn}$ by:

(7) $$dp_{ijn} = \pi_{in} td_{ijn}.$$

[1] In case of a temporary stock out the surveyor of the central bureau in Israel does not report a price. Since in our model, prices of goods which are stocked out are cheaper, this may introduce a spurious negative correlation between the change in the average quoted price and the variance of the relative quoted price. When the money supply is high and a large number of markets open, the surveyor may observe many stock outs and report only the upper tail of the distribution of quoted prices. In this case, he may find a high rate of change and low variability in quoted prices. The fact that the results when using the complete samples are qualitatively similar to the results when using the samples of stores with complete records suggests that this potential bias is not important empirically.

If all stores which changed their nominal price at time $t_{ijn}$ follow (7) and the realized average product specific inflation rate is the same for all stores, then the average (across stores that changed their nominal price at time $t_{ijn}$) nominal price change, $dp_{in}$, and the average time interval, $td_{in}$, should satisfy the same relationship, namely:

$$(8) \qquad dp_{in} = \pi_{in} td_{in}.$$

Dividing (7) by (8), yields:

$$(9) \qquad X_{ijn} = dp_{ijn}/dp_{in} = Y_{ijn} = td_{ijn}/td_{in}.$$

This is a rather intuitive relationship. It says that a store which waited Y% longer before changing its nominal price, will increase it by X% more, all relative to the average in the cell (i,t).

To be exact the relationship (9) requires that the typical store changes its nominal price to achieve a real price target which is always x% above the price of all other stores that changed their nominal price at the same time. The relationship (9) may therefore not be exact because of sampling errors: The store may achieve a real price target of x% above the entire population of stores that changed their nominal prices but we observe only a sample of the population. The relationship (9) requires also that the realized product specific inflation rates will not change in the neighborhood of time $t_{ijn}$. A departure from these assumptions as well as measurement errors will lead to less than perfect correlation.

In Table 1 I report summary statistics, using the sub samples of strictly positive nominal price changes. The Pearson correlation coefficients are very low. These correlations are even lower when negative nominal price changes are included in the sample.

**Table 1*: The relative nominal price increase (X) and the relative time interval (Y)**

| | Corr. Y and X | SD(X) | SD(Y) | SD(Y - X) |
|---|---|---|---|---|
| 1978-79 | 0.228<br>Prob. = 0.00<br>N = 2162 | 0.55 | 0.51 | 0.67 |
| 1981-82 | 0.199<br>Prob. = 0.00<br>N = 3275 | 0.52 | 0.46 | 0.63 |
| 91-92; comparable | -0.065<br>Prob. = 0.04<br>N = 1004 | 0.53 | 0.55 | 0.80 |

* The first column reports the correlation between the relative nominal price increase (X) and the relative time interval (Y). Prob. is the probability that this correlation is zero and N is the number of observations. The last three columns report the standard deviations of X, Y and Y - X.

Note that the standard deviations of Y and X are less than the standard deviation of Y - X. This says that the assumption that stores change their nominal price according to the average in their cell (X = 1) predicts better than the model: X = Y.

A simple regression of dp on td which does not allow for product specific inflation rates, yields very low Adj.$R^2$ (0.08, 0.02 and - 0.0005 for the 78-79, 81-82 and 91-92 comparable samples). The poor predictive power of the time interval variable suggests that we are missing some important variables or that store specific shocks are important.

(b) The serial correlation in the relative nominal price change

In a one sided (S,s) model the size of the nominal price change may be used as a signal for the size of the band: S - s. Therefore stores which increase their nominal price by a relatively large amount are expected to increase it by a relatively large amount in the next nominal price change episode. To operationalize this hypothesis, I look at the non-zero nominal price change of firm j at time $t_{ijn}$ relative to all stores which changed the nominal price of the same product at the same time. I define the relative conditional price change (Rdp) by:

$Rdp_{ijn}$ = the non-zero nominal price change of product i in store j at time $t_{ijn}$ minus the average nominal price change across all stores which changed the nominal price of product i at the date $t_{ijn}$.

I ran the following regression:

(10) $$Rdp_{ijn} = b\ Rdp_{ijn-1} + \varepsilon_{ijn},$$

where the error term $\varepsilon_{ijn}$ arises from sampling and measurement errors.[1] We expect $b > 0$. As can be seen from Table 2, the actual coefficient is negative and highly significant.

[1] The sampling error is due to the fact that we do not observe all the stores that changed the nominal price of good i at time $t_{ijn}$. In addition I assume classical measurement errors to account for the negative nominal price changes in the data.

**Table 2*: The serial correlation in the relative nominal price change: OLS estimates of (14).**

| | coefficient of $Rdp_{-1}$** |
|---|---|
| 78-79 | -0.194<br>(-9.3) |
| 81-82 | -0.264<br>(-15.9) |
| 91-92; All | -0.397<br>(-45.2) |
| 91-92; food | -0.385<br>(-35.2) |
| 91-92; defined food | -0.365<br>(-19.8) |
| 91-92; comparable | -0.352<br>(-15.1) |

* The relative nominal price change is the nominal price change minus the average change across all stores that changed the nominal price of the same product at the same time. The Table reports the regression of the relative nominal price change on its lagged value.

** t statistic in parenthesis.

We can therefore reject the hypothesis that the serial correlation in the relative nominal price change is positive.

(c) Nominal price reductions and a two sided (S,s) policy

According to two sided (S,s) policy, the level of the real price (I) after a nominal price change should not depend on the sign of the nominal price change. To test this hypothesis, I looked at all the stores that changed the nominal price of product i at a given month and calculated the price of each store relative to the mean price quoted in this group. This conditional relative prices (RP) are calculated in the same way that the relative price are calculated in the Appendix, but here I used the sample of non-zero nominal price changes (which was obtained from the original sample by eliminating all observations with dp = 0).

I calculated the mean of the conditional relative price (RP) for the group that increased its nominal price (dp > 0) and for the group that reduced it (dp < 0). As can be seen from Table 3, the relative price of stores which reduced their nominal price is lower by about 8 to 4 percent relative to stores which increased their nominal price. To test whether the difference in the mean between the two groups is significant, I ran RP on a constant and a dummy variable which gets unity if dp < 0 and zero otherwise. The t statistics of this dummy variables are reported in the last column. They suggest that the differences in the means are highly significant.

**Table 3*: Relative price conditional on the sign of the nominal price change**

| | Obs. | RP | SD(RP) | t stat. for Dummy |
|---|---|---|---|---|
| 1978-79; dp > 0 | 2382 | 1.005 | 0.125 | -5.8 |
| dp < 0 | 306 | 0.960 | 0.140 | |
| 1981-82; dp > 0 | 3536 | 1.006 | 0.157 | -8.2 |
| dp < 0 | 278 | 0.925 | 0.157 | |
| 91-92; comp. dp>0 | 1197 | 1.017 | 0.149 | -6.3 |
| dp<0 | 736 | 0.973 | 0.142 | |

* The first column reports the means of the relative price for the stores which increased the nominal price and for the stores which decreased it. The second column reports the standard deviation of the relative price in each group and the third is the t statistic of the dummy variable in a regression of the relative price on a constant and a dummy that gets unity in the case of a nominal price reduction and zero otherwise.

We can therefore reject the hypothesis that the relative price immediately after the change does not depend on the sign of the change in nominal price.

(d) The relationship between the change in average quoted price and relative quoted price variability

In the UST model of section 3, changes in the average quoted price of a product reflects changes in the money supply which occurs in the last period or changes in the policy parameter $\lambda$. As was stated in the testable implication (d) these changes do not affect the distribution of relative quoted prices. To test this hypothesis I ran a measure of the standard deviation of relative prices on the mean rate of change in quoted prices. The measure of relative price variability (RPV) used is[1,2]:

$$(11) \qquad SD(lnp_{it}) = \{\Sigma_j [lnp_{ijt} - (\Sigma_j lnp_{ijt}/N_{it})]^2/N_{it}\}^{0.5},$$

where $p_{ijt}$ is the price quoted by store j of product i at time t, lnx is the natural log of x, $lnp_{it} = \Sigma_j lnp_{ijt}/N_{it}$ is the mean of $lnp_{ijn}$ and $SD(lnp_{it})$ is the standard deviation across all the $N_{it}$ stores which quoted a price for product i at time t.

---

1 Assuming that the deflator, $M_{it}$, is common to all stores which belongs to the same cell, the variance of $ln(p_{ijt}/M_{it})$ across j (stores) is the same as the variance of $ln(p_{ijt})$.

2 Reinsdorf (1994) uses the coefficient of variation: $C_{it} = [\Sigma_j (p_{ijt} - p_{it})^2/N_{it}]^{0.5}/p_{it}$. He reports that $SD(lnp_{it})$ and $C_{it}$ yield the same qualitative results.

Here I used the entire sample which includes also observations of nominal prices which did not change. I obtained measures of $SD(lnp_{it})$ and $dp_{it} = \Sigma_j dp_{ijt}/N_{it}$ for each (i = product, t = month) cell and ran a simple OLS regression of $SD(lnp_{it})$ on $dp_{it}$.

As can be seen from Table 4 the coefficient of $dp_{it}$ is not significantly different from zero.[1]

**Table 4*: OLS of Relative price variability on inflation: Dependent variable = $SD(lnp_{it})$**

| observations | | coefficient of $dp_{it}$ | adj. t** |
|---|---|---|---|
| 78-79 | 575 | 0.067 | 1.0 |
| 81-82 | 552 | -0.160 | -1.1 |
| 91-92; All | 8740 | -0.138 | -1.6 |

*I calculated a measure of relative price variability and the mean rate of nominal price change for each (month, product) cell. The table reports the results of OLS regression of the relative price variability on the mean.

** Adj. t = t statistic adjusted for asymptotic variance.

The finding of no relationship between relative price variability and inflation is consistent with the prediction of the UST model about quoted prices. The prediction about unit values will have to be tested in the future when scanner data becomes available.

[1] The results for the other subsamples of 91-92 are qualitatively the same and are therefore not reported. To take possible problems of heteroscedasticity into account, I also ran these regressions weighted by the square root of $N_{it}$. The results were qualitatively the same. I also ran the above regression for each good separately and for groups of goods and could not reject the hypothesis of no correlation between inflation and RPV.

## 5. Discussion

It was argued that the predictions of simple (S,s) models about the behavior of individual stores do not work well, while the prediction of the UST model about the behavior of the aggregate distribution of relative quoted price works surprisingly well. This leave open the question about the performances of more general (S,s) model.

A recent example which uses a generalized (S,s) model is in Dotsey, King and Wolman (DKW, 1999). In their model the fixed cost of changing nominal price is an i.i.d random variable. After drawing the fixed cost the firm decides whether or not it wants to change its nominal price to the target price which is common to all firms. A firm which did not change its nominal price for a long time is more likely to change it because its deviation from the target price is large. A firm that changed its nominal price recently will change it only if it draws a small fixed cost.

The generalized (S,s) model in DKW is a policy in which both the target (S) and the floor (s) fluctuate over time. The fluctuations in the target introduces a noise to the relationship (11) and therefore works in the direction of explaining the very low correlation between X and Y.

DKW calibrate their model and find a positive relationship between the standard deviation of relative price and inflation. I find no such correlation in the data.

Because the fixed cost for changing nominal prices is i.i.d., the DKW model should predict zero serial correlation in the relative nominal price change and should therefore have difficulty in explaining the negative correlations in Table 2. Indeed, these negative serial correlations seems to support the time depended model of the type suggested by Calvo (1983). In the Calvo model, there are no fixed menu costs but the firm cannot change its nominal price at any time: It gets an opportunity to adjust its nominal price at random and exogenous time intervals. A firm that by mistake increased its nominal price by "too much" will correct this mistake by increasing it by a relatively small amount in the next nominal price change opportunity. This may lead to a negative serial correlation in the relative nominal price change.

In contrast, firms which face menu type costs but are free to choose the time at which nominal price changes are made will correct mistakes by adjusting the time interval rather than by adjusting the size of the nominal price jump.

Figure 1 illustrates this point. I consider two stores which attempt to follow the same (S,s) policy. One store made a mistake and increased its real price to the level A > S. The other store made a mistake and increased its real price to the level B < S. After the initial mistakes their real price paths coincide and they did not make more mistakes. The store that jumped to A will wait longer before making a nominal price change. In this sense changes in the time interval are used to correct mistakes and therefore price choice mistakes cannot account for the negative serial correlations in Table 2.

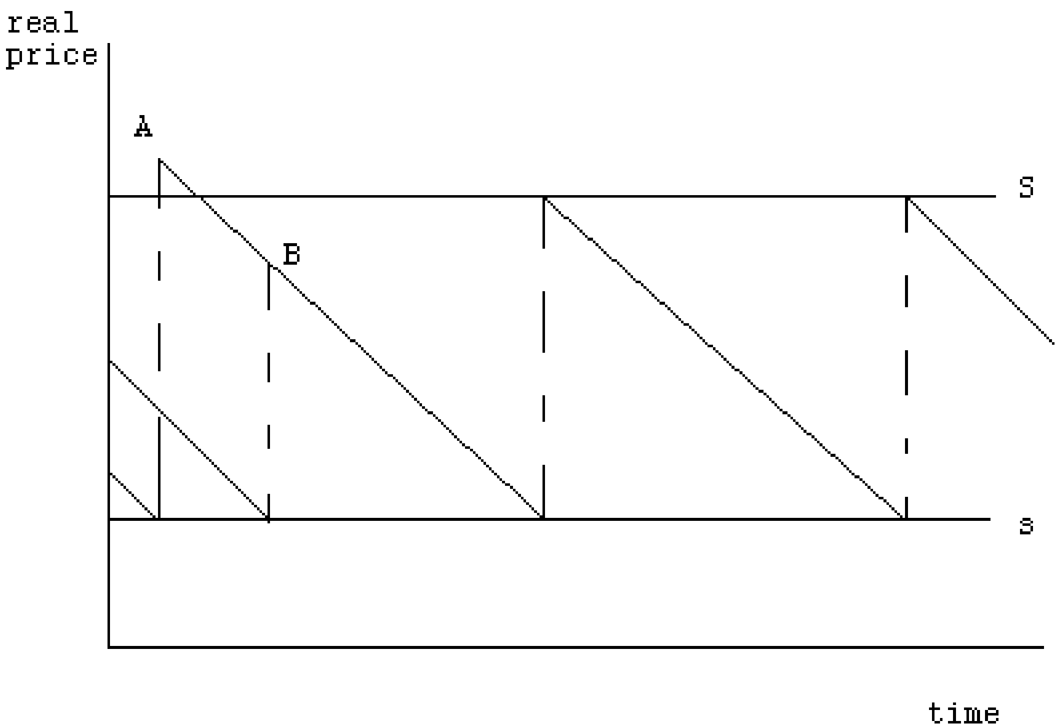



Figure 1

The findings in Table 3 are consistent with the prediction of the UST model but are different from the "stylized fact" which is often reported. As explained in the Appendix, the source of the difference is in the distinction between price change variability (PCV) and relative price variability (RPV).

Lach and Tsiddon (1992) decomposed inflation into expected and unexpected components and found that both components have a positive effect on PCV. They reject Lucas' model because expected inflation affects PCV.

There are two differences between my approach and the approach in Lach and Tsiddon. They define expected inflation as the rate predicted on the basis of past variables. I equate expected inflation with actual inflation in quoted prices because in my model sellers choose prices (market) at the beginning of the period and are not surprised by their own price quotations.[1] Another difference is that Lach and Tsiddon follow a literature which uses PCV rather than RPV. Which is the more appropriate measure?

When changes in nominal prices are not synchronized across stores, the measurement of PCV depends on the length of the period in the data. To demonstrate this claim, I consider the case in which 1/3 of the stores changes their nominal price in the first month of each quarter, 1/3 changes it in the second month of the quarter and 1/3 in the last month of the quarter. They all change it by x%. In this case, if we have a quarterly data we will find no variation in the rate of nominal price change. If we have monthly data we will find some PCV ($Var(dp) = 2x^2/9$ in this case) because of the difference between the mean of those who changed their nominal price (x) and the mean of those who did not change their nominal price (0).

The correlation between inflation and PCV can arise spuriously as a result of sampling errors. To demonstrate this claim, consider our previous example in which 1/3 of the stores change their nominal price at the beginning of each month. Let $\gamma_{it}$ denote the fraction of stores in the sample, which changed the nominal price of good i at month t. Because of sampling errors $\gamma_{it}$ may be different from 1/3. The estimated mean of the rate of nominal price change in cell (i,t) is: $dp_{it} = \gamma_{it}x$. The estimated variance is: $Var(dp_{it}) \equiv \gamma_{it}(1 - \gamma_{it})x^2$. When $\gamma_{it} \leq 1/2$, the derivative of both the estimated mean and the estimated variance with respect to $\gamma_{it}$ is positive. In this case, cells in which the fraction of stores which did change their nominal price is high will have both a high mean and a high variance, leading to a positive correlation between the

[1] Sellers may be surprised by changes in the average unit value.

estimated mean and the estimated variance. This suggests that for the purpose of distinguishing among abstract competing theories which are not specific about the definition of the "period", we should focus on the behavior of RPV rather than PCV.

Lach and Tsiddon (1992) also look at the distribution of $Y_{ijt} = \ln p_{ijt} - (1/N_{it})\Sigma_j \ln p_{ijt}$ across two periods (1978-1979:06 and 1982) and conclude that the changes in the distribution of Y "are probably not strong enough to support any decisive answer" (page 381). Reinsdorf (1994) found a negative relationship between inflation and his measure of RPV during the Volcker disinflation period of 1980-82. It seems that more studies about the relationship between inflation and RPV are required to reach a consensus on this point.

Inventories and price adjustment: Recently Aguirregabiria (1999) developed a model in which a monopolistically competitive store chooses both price and inventories facing fixed menu cost for changing nominal prices and fixed transportation cost for placing new orders. He analyzes the interaction between price and inventories choice and show that an increase in the amount of inventories leads to a reduction in the real price (markup) because an increase in inventories lowers the probability of a stock out and increase the elasticity of demand.

A similar result is obtained in a UST model with storage. In Eden (1997) I showed that when storage costs are increasing UST sellers are no longer indifferent about prices in the equilibrium range. Sellers who accumulated a relatively large amount of inventories will prefer a low real price (a low indexed market) and a low probability of accumulating inventories (high probability of making a sale).

Looking at inventories and price choices together seems a promising way for future research. This approach says that price erosion is not the only variable that explains non-zero nominal price changes: We should look at inventories as well. As was shown in Eden (1997) a UST model with inventories is also consistent with the finding of a negative serial correlation in the relative nominal price change.

## 6. Concluding remarks

Weiss (1993) opens his survey of the empirical literature on inflation and price adjustment with the following statements: "First, came the realization of potentially important empirical regularity, namely, nominal price changes occur in discrete jumps. ...By definition, nominal rigidities affect real variables. The question is whether these effects are in any way systematic. The second discovery was that inflation, combined with nominal rigidities at the level of the firm, indeed affects the distribution of relative prices in a clear way. As inflation rises, the variance of relative prices across products and sellers increases."[1]

Here I argue against these inferences. The observation that nominal price changes occur in discrete jumps does not imply price rigidity. It is consistent with a UST model in which sellers can

[1] For other surveys see Cukierman (1983) and Marquez and Vining (1984). See Hartman (1991) for a critique of some of this literature.

costlessly change the nominal price at any time. Furthermore, inflation increases the variance of nominal price changes but not the variance of relative prices.

I used a large data set on prices by store and product to examine the implications of the hypothesis that stores follow an (S,s) policy in the real price. As a deflator I used the average price by all stores that changed the nominal price of the same product. This choice allows for product specific inflation rate.

If the typical store tries to achieve a price target which is S% above all other stores that changed the nominal price of the same product, then we should find that a store which waited Y% longer before changing its nominal price should change it by X% more all relative to the average nominal price changing store. In the data the correlation between X and Y is close to zero. Furthermore, the model X = 1, which says that the rate of nominal price increase is the same as the mean across relevant stores, predicts better than the model X = Y.

If a typical store always changes its price by (S - s)% more than all other stores which changed the nominal price of the same product then we should find a positive serial correlation in the relative non-zero nominal price change. The serial correlations in the data are strongly negative.

If a two sided (S,s) policy is optimal, then there should be no difference in the relative prices between stores that increased their nominal prices to stores that reduced their nominal prices. In the data there is a significant difference between the two.

The simple UST model presented here lacks sharp predictions about the behavior of individual sellers but does have a strong prediction about the behavior of the distribution of relative quoted prices. The data do not reject the hypothesis of no relationship between relative price variability and changes in the average quoted price.

The relationship between the average unit value and the variance of prices of goods actually sold is an additional test of the model which may be performed once scanner data becomes available.

APPENDIX: SUMMARY STATISTICS AND DEFINITIONS

Here I describe the sample of all nominal prices including nominal prices which were not changed.

I use $p_{ijt}$ to denote the nominal price of good i in store j at time t, and N to denote the total number of nominal price changes in the sample. I use $dp_{ijt} = lnp_{ijt} - lnp_{ijt-1}$ for the rate of change; $dp = \Sigma_t\Sigma_i\Sigma_j \ dp_{ijt}/N$ for the mean rate of nominal price change across all goods, stores and months, and

$SD(dp) = \{\Sigma_t\Sigma_i\Sigma_j \ [dp_{ijt} - dp]^2/N\}^{0.5}$ for the standard deviation. Note that I use the same notation for the mean and the name of the variable: SD(dp) is the standard deviation of a variable with a mean of dp.

Table A1 contains summary statistics about price changes.

**Table A1: Price-change variability (PCV)**

| | N | dp | SD(dp) |
|---|---|---|---|
| 1978-79 | 5934 | 0.043 | 0.089 |
| 1981-82 | 6394 | 0.063 | 0.099 |
| 1991-92; All | 64446 | 0.007 | 0.061 |
| 1991-92; food | 36800 | 0.008 | 0.059 |
| 1991-92; defined food | 11638 | 0.008 | 0.063 |
| 1991-92; comparable | 5842 | 0.007 | 0.069 |

Figures 1-3 describes the disribution of dp for three of the six samples: 1978-79, 1981-82 and 1991-92 comparable.

PLEASE INSERT FIGURES HERE

Figure 1
Nominal price changes (DP)
1978 - 79 sample

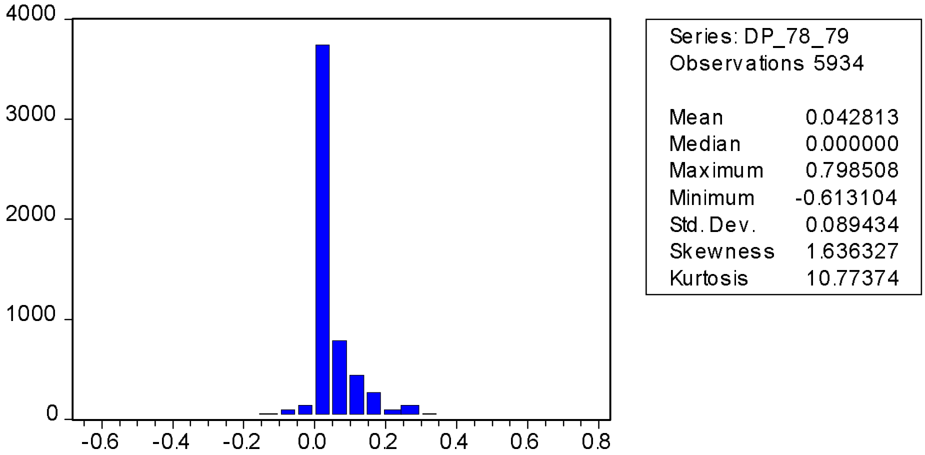



Figure 2
Nominal price changes (DP)
1981 - 82 sample

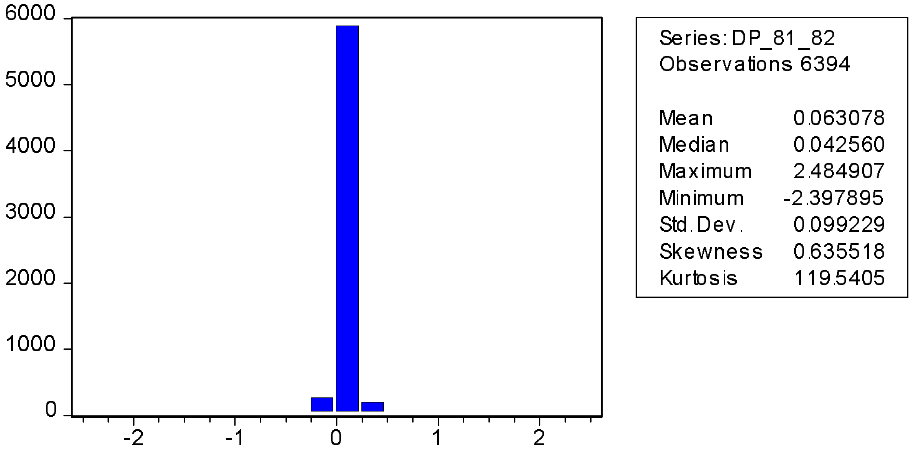



Figure 3
Nominal price changes (DP)
1991 - 1992 comparable sample

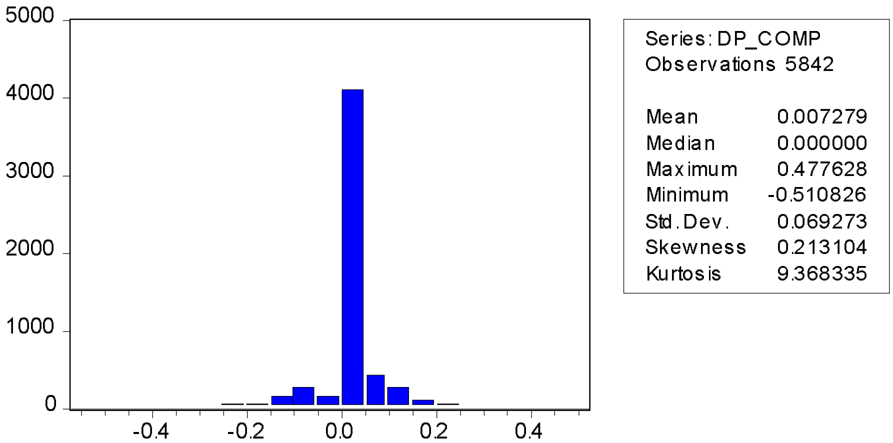
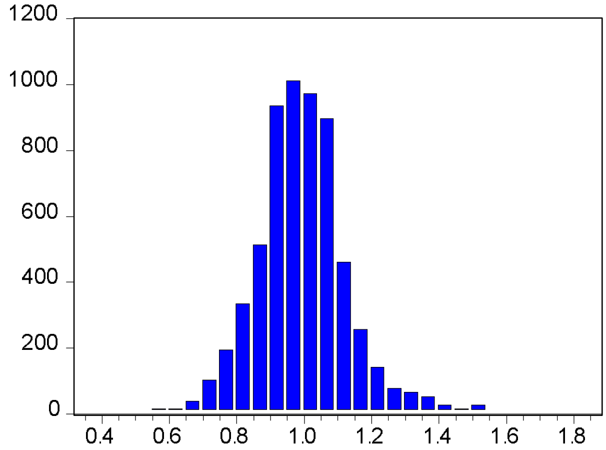
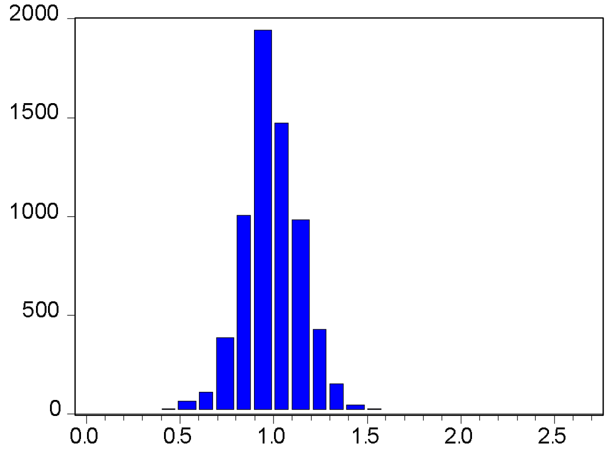


Figure 4
Relative prices (RP)
1978 - 79 sample



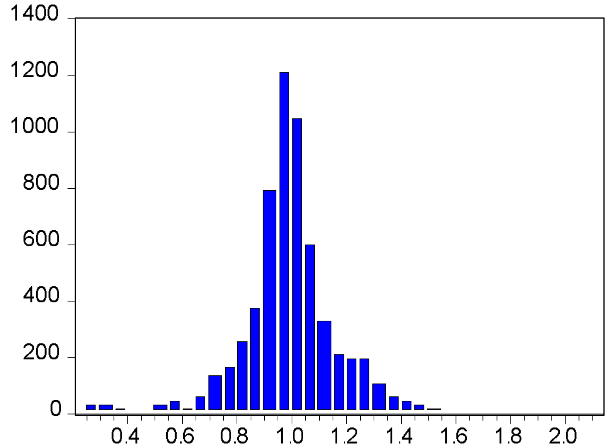

| Series: RP_78_79 | |
|---|---|
| Observations 6192 | |
| Mean | 1.000000 |
| Median | 0.996034 |
| Maximum | 1.845227 |
| Minimum | 0.368142 |
| Std. Dev. | 0.140653 |
| Skewness | 0.406751 |
| Kurtosis | 5.416544 |

Figure 5
Relative prices (RP)
1981 - 82 sample




| Series: RP_81_82 | |
|---|---|
| Observations 6672 | |
| Mean | 1.000000 |
| Median | 0.987589 |
| Maximum | 2.634327 |
| Minimum | 0.088409 |
| Std. Dev. | 0.169042 |
| Skewness | 0.551904 |
| Kurtosis | 7.197847 |

Figure 6
Relative prices (RP)
1991 - 92 comparable sample




| Series: RP_COMP | |
|---|---|
| Observations 6096 | |
| Mean | 1.000000 |
| Median | 0.992556 |
| Maximum | 2.099808 |
| Minimum | 0.259504 |
| Std. Dev. | 0.184338 |
| Skewness | 0.125667 |
| Kurtosis | 7.471559 |

I now look at the price of good i in store j in month t relative to its mean in month t across stores. Specifically, let

$N_{it}$ = number of stores in the sample that reported a price for good i in month t;

$p_{it} = \Sigma_j\ p_{ijt}/N_{it}$ = the mean of the price of good i in month t across stores;

$RP_{ijt} = p_{ijt}/p_{it}$ = a relative price: the price of good i in store j at time t in terms of the average price of good i at time t;

$RP_{it} = \Sigma_j\ RP_{ijt}/N_{it} = 1$ = the average relative price for good i in month t across stores;

$RP = \Sigma_t\Sigma_i\ RP_{it} = 1$ = the average relative price across products stores and months;

$SD(RP) = \{\Sigma_t\Sigma_i\Sigma_j\ [RP_{ijt} - 1]^2/N\}^{0.5}$ = the standard deviation of relative prices;

$lnRP = \Sigma_t\Sigma_i\Sigma_j\ lnRP_{ijt}/N$ = the mean of the natural log of relative prices;

$SD(lnRP) = \{\Sigma_t\Sigma_i\Sigma_j\ [lndRP_{ijt} - lnRP]^2/N\}^{0.5}$ = the standard deviation of the natural log of relative prices.

Table A2 shows measures of RPV: SD(RP), and SD(lnRP). There is no clear relationship between inflation and RPV. This is both surprising and different from the behavior of the price-change variability reported in Table A1.

**Table A2: Relative price variability (RPV)**

| | Obs. | SD(RP) | SD(lnRP) |
|---|---|---|---|
| 78-79 | 6192 | 0.141 | 0.144 |
| 81-82 | 6672 | 0.169 | 0.175 |
| 91-92; All | 67248 | 0.305 | 0.320 |
| 91-92; food | 38400 | 0.310 | 0.322 |
| 91-92; defined food | 12144 | 0.302 | 0.307 |
| 91-92; comparable | 6096 | 0.184 | 0.210 |

Figures 4-6 describes the distribution of RPV for the above three samples.

PLEASE INSERT FIGURES HERE

The time between two consecutive nominal price changes ($td_{ijn} = t_{ijn} - t_{ijn-1}$) plays an important role in various theories of price adjustment. As can be seen from Table A3 it depends on the average rate of inflation.

**Table A3: The time interval**

| | N | td | SD(td) |
|---|---|---|---|
| 78-79 | 2503 | 1.9 | 1.4 |
| 81-82 | 3586 | 1.6 | 1.1 |
| 91-92; All | 13839 | 2.7 | 2.7 |
| 91-92; food | 8413 | 2.6 | 2.6 |
| 91-92; defined food | 2874 | 2.5 | 2.4 |
| 91-92; comparable | 1767 | 2.2 | 2.3 |

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