Reference Prices and Costs in the Cross-Section: Evidence from Chile

Andres Elberg*

July 2010

Abstract

Using a unique scanner data set of weekly retail prices, quantities sold and wholesale costs for a cross-section of retailers in Chile, I study patterns of price adjustment at the store level. In line with evidence reported for the U.S. (Eichenbaum, Jaimovich and Rebelo, 2010; Klenow and Malin, 2010), posted prices tend to revolve around more persistent reference prices. The implied duration of reference prices is estimated at 2-3 quarters versus 3-4 weeks in the case of posted prices. I find strong evidence that reference prices respond to retailer-level shocks. Comovement in the reference price of a given barcode across retailers is found to be significantly larger for stores belonging to the same retail chain than for stores that belong to different retail chains. Furthermore, most of the variation in the frequency of reference price adjustment is explained by "chain effects". Evidence on the synchronization of price changes suggests that price changes tend to be staggered across stores belonging to different retail chains but synchronized within chains.

*Ph.D. candidate, Department of Economics, UC-Berkeley. I thank Maury Obstfeld, Pierre-Olivier Gourinchas, Yuriy Gorodnichenko and Andy Rose for advice, guidance and encouragement. I am deeply grateful to Jorge Carniglia, Enrique Ostalé, Andrés Solari and Javier Vergara for their generous help in the process of gathering the data I use in this paper, and to Andrés Solari for contributing with his expert knowledge on the Chilean supermarket sector. The usual disclaimer applies. Email: aelberg@econ.berkeley.edu

1 Introduction

Recent research on the patterns of price adjustment at the micro level has uncovered a tendency for retail prices to display sales-like behavior. Retail prices are characterized by large and frequent temporary departures (typically falls) from more persistent underlying prices (Eichenbaum, Jaimovich and Rebelo, 2010; Kehoe and Midrigan, 2007; Klenow and Malin, 2010; Nakamura and Steinsson, 2008). Research by Nakamura and Steinsson (2008) has found that price adjustments of a more transitory nature provide an important contribution to overall price flexibility. Studying a panel of consumer prices underlying the U.S. CPI, they find that removing temporary markdowns or "sales" from the original price series increases the duration of prices from about 4 months to 7-10 months[1]. The increased price flexibility derived from the use of "sales" on the part of retailers has potentially important consequences for monetary economics. If "sales" are nonorthogonal to a monetary policy shock, then sticky price models should account for the changes in price flexibility induced by sales activity in the face of a monetary policy shock.

This paper studies patterns of price adjustment using a unique scanner data set of weekly prices, costs and quantities sold from a cross-section of Chilean retailers. The primary dataset includes retail prices and quantities sold for some 60,000 barcodes sold in 180 stores belonging to 13 supermarket and drugstore chains over the period 2005-2008. A secondary data set includes wholesale costs for the largest two retail chains over the same period for a subset of the barcodes included in the primary data set. Two important features of the data are the availability of a high quality measure of costs (replacement costs) for one of the retailers and the fact that price and quantity data are available for a cross-section of retailers. Typically, previous studies using scanner data have focused on

[1] The magnitude of temporary price adjustments is also about twice as large as the size of –more persistent– regular price changes, which also contributes to a greater degree of price flexibility (Nakamura and Steinsson, 2008).

a single retail chain[2] (e.g. Eichenbaum et al. 2010, Kehoe and Midrigan 2007, Midrigan 2009, and several other papers that use *Dominick's* data set) and/or have relied on a lower quality measure of costs –average costs of items in inventory[3] (e.g. Burstein and Hellwig 2007, Midrigan 2009 and other papers that use *Dominick's* data set).

In line with evidence reported for the U.S. (Eichenbaum et al. 2010, Klenow and Malin 2010), retail prices in the Chilean data tend to revolve about more persistent reference prices[4]. Posted prices are equal to reference prices about 62 percent of the time[5] and have a weighted average frequency of price change of 0.29 per week (an implied duration of 3.4 weeks). In contrast, the typical reference price is adjusted every 2-3 quarters.

Exploiting the cross-sectional dimension of the data I examine how reference prices for a given product covary across retail chains. If reference prices capture primarily shocks which are common across retailers –as is the case with shocks originating at a previous stage of the production chain– we would expect covariation across stores within chains to be similar to covariation across all stores. The data, however, strongly rejects the hypothesis that "chain effects" are unimportant in explaining price comovement. Controlling for product and category effects, the correlation coefficient between the prices of a given barcode across stores is about 0.3 larger when the stores belong to the same retail chain. Evidence on the variance decomposition of the frequency of reference price adjustment points in the same direction. About 60 percent of the variation in the frequency of reference price changes is explained by variation across retail chains. The evidence is consistent with Nakamura (2008) who finds that most of the variation in U.S. retail prices is explained by variation

[2] An exception is Nakamura (2008) who analyzes a cross-section of retailers in the U.S. Her panel is, however, more limited over the temporal dimension (only one year of price data is available).

[3] An exception is Eichenbaum et al. (2010) who use a measure of replacement costs.

[4] Eichenbaum et al. (2010) define reference prices as the most quoted price in a given quarter. In this paper I use an alternative (but similar) definition proposed by Chahrour (2009), who defines a reference price as the most quoted price within a 13 week rolling window centered in the current week.

[5] The reference price phenomenon does not apply to all retailers, however. In one of the largest supermarket chains, prices do not appear to revolve around an attractor price.

across stores within chains but not across chains. The present paper shows that retailer-specific effects matter even in the case of reference price movements.

Prices are found to be substantially less volatile than in the U.S. This is in part due to the fact that temporary price changes are smaller in magnitude than permanent price changes (i.e. changes in reference prices). The size of price changes is on average small, in comparison to the magnitude of price changes previously reported in the literature. I also find evidence that retail chains tend to set prices at two levels: At the chain level and the store level. Chain level prices, proxied by the modal price across stores within a chain, do not correspond to reference prices and are significantly less persistent than them (they are changed every 5 weeks, on average).

Evidence on the behavior of markups reveals that pass-through of changes in wholesale costs is relatively rapid. Markups exhibit a remarkably small volatility. As in Eichenbaum et al. (2010) the retailer appears to choose the duration of reference prices in order to keep the markups within narrow bounds. There is evidence that the probability of repricing is increasing in the gap between the current and average markup.

Finally, I examine the degree of synchronization in the timing of posted and reference price changes. In line with evidence reported for the U.S. (see Klenow and Malin, 2010) I find evidence that both reference and posted price changes tend to be staggered across retailers. Price adjustment within stores, on the other hand, tend to be synchronized. Lach and Tsiddon (1996) present similar evidence for retailers in Israel.

The paper is organized as follows. The next section presents a review of the related literature. Section 3 describes the data sets I use in the analysis. Section 4 characterizes the behavior of reference prices in the data. Section 5 examines the behavior of wholesale costs and markups. Section 6 studies price synchronization within and across stores. Section 7 presents a quantitative model which is able of capturing salient features of the data, in particular, the greater persistence exhibited by reference prices. Finally, Section 7 concludes.

2 Related Literature

This paper is primarily related to the growing literature that studies patterns of price adjustment at the micro level[6]. The seminal paper in this literature is Bils and Klenow (2004), who study the timing of price adjustment underlying the U.S. CPI. Bils and Klenow's major finding is that prices tend to be adjusted much more frequently than previously thought on the basis of studies focusing on narrower sets of goods. While the conventional wisdom by the late 1990s held that prices were changed about once a year (e.g. Taylor 1999), Bils and Klenow (2004) found a median duration of a price change of 4.3 months. This result had important implications for the business cycles literature, as it made price stickiness a less plausible explanation for the observed effects of monetary shocks on economic activity. In particular, the high frequency of price adjustment would require a larger "contract multiplier" in order to be consistent with the available empirical evidence on the real effects of changes in the stock of money[7].

Subsequent research by Nakamura and Steinsson (2007) led to an important qualification to Bils and Klenow's (2004) results. Using the BLS research database, which includes the actual prices underlying the U.S. CPI, they found that temporary price cuts or "sales" were prevalent in the data and that filtering out short-lived prices led to a substantial increase in price durations. They estimated an implied duration of regular prices (i.e. sales-removed prices) ranging between 7 months and 10 months. This finding by Nakamura and Steinsson opened up a debate about the appropriateness of removing temporary

[6] Klenow and Malin (2010) provide a survey of the literature.

[7] On the empirical evidence on the effects of monetary policy on prices and output see, for example, Christiano, Eichenbaum and Evans (1999).

prices from the data when calibrating quantitative macro models featuring sticky prices. Purging the price data from short-lived prices would only be appropriate if "sales" are orthogonal to monetary policy shocks. If, instead, "sales" respond to unexpected changes in the stock of money, then quantitative macro models should incorporate a motive for firms to choose both regular and temporary prices. Kehoe and Midrigan (2007) study an extended menu cost economy in which price-setters face a fixed cost to adjusting prices for an indefinite period of time and, in addition, have the option of paying another (smaller) menu cost for adjusting prices for a single period. The model yields price dynamics that are able to mimic some salient features of the retail price data[8]. Kehoe and Midrigan (2007) then examine the implications of calibrating standard sticky price models (both menu cost and Calvo models) to the frequency of price changes both including and excluding sales. They find that models that match the data including (excluding) sales tend to understate (overstate) the real effects of monetary policy. They further show that standard menu cost models calibrated to match the fraction of prices at the annual mode –instead of the frequency of price changes– are able to better approximate the effects of a monetary shock derived from their extended menu cost model.

Guimaraes and Sheedy (2010) study an economy in which sales arise endogenously as a result of price-setters engaging in intertemporal price discrimination in an environment characterized by the presence of two types of consumers: low-price sensitive "loyal" customers and high-price sensitive "bargain hunters". They find that sales do not contribute to greater price flexibility in response to monetary policy shocks. The reason is strategic substitutability in sales. The incentives for a firm to increase sales are greater the more other firms choose not to use sales. In the face of an aggregate shock, such as a monetary

[8] Kehoe and Midrigan (2007) calibrate their model to match 13 stylized facts from *Dominick's* data set including the frequency of price changes, size of price changes and price dispersion including and excluding sales.

policy shock, firms find it optimal not to vary sales and therefore price responses to the monetary shock are unrelated to changes in sales activity.

Even if consensus is reached on the convenience of purging the data from temporary prices, it remains to be decided how "sales" should be defined. An alternative approach that dispenses with the need of adopting a definition of "sales" was proposed by Eichenbaum, Jaimovich and Rebelo (2010). Analyzing a scanner data set from a large U.S. retailer, they observed that posted prices had a tendency to revolve around reference prices, defined as the most quoted price in a given quarter. They established that reference prices are important according to several different metrics (such as the fraction of the time at which posted prices are equal to reference prices and the fraction of revenues made at reference prices) and that they are substantially more persistent than posted prices. While weekly posted prices are changed every 2-3 weeks, the average implied duration of a reference price is about 1 year. Calibrating a partial equilibrium model to match some of the moments of the price data, Eichenbaum et al. find that even in the presence of highly flexible posted prices, monetary shocks can have persistent effects on economic activity provided that reference prices are adjusted less frequently.

While Eichenbaum et al. (2010) focus primarily on the time-series dimension of retail prices and costs, Eden and Jaremski (2009) analyze the cross-sectional distribution of prices using Dominick's data set. Specifically, they focus on the chain dimension of the data. Based on empirical evidence suggesting that retail chains tend to set prices both at a chain and a store level, they analyze the behavior of modal prices across stores within a chain. They show that about 75 percent of the prices each week are equal to the modal price across stores and that modal prices are quite flexible –they have a frequency of price change of 0.35 per week. They interpret this latter fact as an indication that the distribution of prices tends to respond rapidly to aggregate shocks.

3 Data

The primary data set corresponds to weekly scanner data from the largest supermarket[9] chains operating in the Santiago de Chile metropolitan area over the period 2005-2008 (156 weeks). The data were provided by a market research firm and consist of weekly revenue and quantities sold for about 60,000 European Article Numbers (EANs)[10]. The data include 181 stores belonging to 12 supermarket chains[11] and one chain of convenience stores, which comprise nearly the totality of stores of this type operating in the Santiago metropolitan area.

It is important to note that the degree of supermarket penetration in Chile is high relative to other countries in Latin America. About 80 percent of foodstuffs sales is accounted for by supermarkets, hypermarkets and convenience stores, the remainder 20 percent being accounted for by the so-called "traditional sector" which includes small independent grocery stores (USDA 2009). The data set also includes information on the location of each store, providing the street and commune[12] where a store is located. I use the same product categorization used by the market research firm which provided the data. The products in the sample belong to 190 categories comprising mainly foodstuffs, drugstore and healthcare product (examples of categories include "Breakfast Cereal", "Pasta", "Beer"; see Table 1 for a full description of the categories included in the sample). I made several adjustments

[9] By supermarket I mean any self-service store with at least three cash registers (this is the definition used by the Statistical National Agency, INE, in Chile). Thus, both traditional supermarkets and hypermarkets are included in this definition.

[10] EAN-13 is a barcode symbology prevalent in Europe and Latin America which is similar to the Universal Product Code (UPC) symbology commonly used in the U.S.

[11] By "chain" of supermarkets I mean a group of two of more stores that share a given format (e.g. hypermarket, traditional supermarket, discout store) and brand (e.g. Jumbo, Lider). As is discussed in the Appendix, the largest Chilean retailers typically operate several brands. I have chosen to consider each brand/format as a separate chain because the data suggest that there is important variation in price setting policies across brand/formats within chains.

[12] A "commune" is the smallest adiministrative unit in Chile. The Metropolitan Region is divided into 52 communes.

to the original data set. First, I corrected for outliers by treating prices which lie outside a +/- 3 standard deviations from the series mean as missing observation, where each series corresponds to a store and barcode. Second, I required that each price series had at least one unbroken spell of 13 weeks. Finally, I eliminated all those series with less than 30 observations in the whole sampling period. The imposition of these criteria reduced the total number of observations to slightly more than 60 million data points. Table 2 presents descriptive statistics on the main dataset used in the analysis. Note that the number of observations in the last year of the sample period is substantially smaller than in the earlier period. This is primarily due to a fall in the number of barcodes available from about 20,000 to close to 6,000. Also, data on quantities of goods sold in the later period is only available for the largest two retail chains (Jumbo and Lider). This imposed a trade-off between the use of longer series and the use of a richer cross-section of prices which in addition included data on expenditure weights at the store/barcode level. I chose to carry out the analysis using the shorter period spanned between week 40 of 2005 and week 32 of 2007. The main conclusions of the analysis are essentially unchanged when I use data for the full sampling period.

The measure of retail prices for a given product/store used in the paper is simply obtained by dividing weekly revenue by the quantity sold in that particular product/store. There is strong international evidence that retail chains revise their prices weekly (e.g. Eichenbaum et al. 2010). Informal conversations between the author and executives from the Chilean supermarket industry who participated in the price setting process on a regular basis confirmed that this also applies in the Chilean case. Thus, it is unlikely that observing prices weekly –instead of, say, daily– might lead to an underestimation of the frequency of price adjustment. Other sources of measurement error can, however, potentially affect the results in the paper. These are mainly associated to the use of discounts which are not reflected in the available price measure. Examples include the use of frequent buyer cards, promotions of the type "buy two and pay one", and the use of discount coupons. To the extent that retailers make extensive use of these types of discounts, true prices faced by consumers will tend to differ from the measured prices and hence the estimated price flexibility will tend to understate the true degree of price flexibility. Furthermore, if different retail chains rely on these discount mechanisms to a different extent, measured differences in the frequency of price adjustment can be erroneously attibuted to actual differences in price setting behavior.

A second data set includes total costs and quantities sold for two large retail chains. These data were provided directly by the retailers to the author. Data are available weekly, for the same 2005-2008 period and for a subset of the products in the primary data set. Table 3 presents summary statistics on this secondary data set. The measures of cost available from the two retailers differ in their quality. In one case, costs correspond to the average cost of products in inventory. Hence, it is not a measure of current prices at the wholesale level but it averages the historical costs at which items in inventory were acquired. The measure of cost included in the popular *Dominick's* data set used by several papers on price adjustment (Midrigan 2009, Kehoe and Midrigan 2007, among others) corresponds to the average costs of items in inventory.

The measure of costs provided by the second retailer is of a higher quality. This measure corresponds to current prices charged by sellers at the wholesale level and are treated by the retailer as a measure of replacement cost. These costs are inclusive of shipping and handling costs. It should be pointed out that the Chilean distribution chain has evolved over the years to a structure in which intermediaries between manufacturers and retailers have tended to disappear. Thus, the measure of wholesale cost available corresponds in most cases to the price charged directly to the retailer by the manufacturer. One potential source of measurement error in the measure of wholesale costs has to do with the payment of allowances by wholesalers. It is a common practice in the supermarket/hypermarket industry that wholesalers pay the retailer a lump sum amount in exchange for displaying their products in certain areas within the store or for introducing a new product.

4 Characterization of Reference Prices

This section describes the behavior of reference prices as compared to the behavior of posted prices in the Chilean data and provides greater details on the nature of reference prices. In particular, it examines whether reference prices capture movements in underlying fundamentals of a given product (such as productivity shocks) or whether, instead, they possess a retailer specific component.

The reasons for focusing on reference prices as opposed to regular prices (i.e. posted prices which exclude "sales" or temporary price markdowns) are basically two. First, identifying sales prices involves adopting a mostly arbitrary definition of a sale. Second, and more importantly, "sales" prices in the data do not appear to be as prevalent as has been reported for the U.S. and European retailers. Using a standard sales filter which identifies a sale as any price decrease which is fully reversed over a four week period, I find that less than five percent of prices in the data correspond to "sales"[13]. In contrast, Kehoe and Midrigan (2007) report that 83 percent of price changes in the *Dominick's* data set occur during a "sales" period.

4.1 Reference Prices Defined

Eichenbaum et al. (2010) define reference prices (costs) as the most quoted price (cost) in a given calendar quarter. A problem with this approach is that it may give rise to

[13] Only 4.6 percent of all prices in the data are "sales" prices.

spurious reference price changes or to fail to identify a reference price change. If the price setter does not make adjustment decisions on reference prices on a quarterly basis then the researcher might wrongly identify departures from reference prices what are actually changes in the underlying reference price series (Chahrour 2009). Chahrour (2009) corrects for this limitation in Eichenbaum et al.'s definition by proposing an algorithm that identifies reference prices using a rolling window of 13 weeks centered in the current week. As in Eichenbaum et al. a reference price (cost) is the most commonly quoted price (cost) within a given window[14]. In what follows I use Chahrour's (2009) definition of reference (or attractor) prices but I also present results based on Eichenbaum et al.'s definition in order to facilitate comparison with their work.

Panels a) to d) in Figure 1 display the behavior of posted and reference prices using Chahrour's definition for a number of selected products in a given store: Kellogg's Cornflakes, 500 grams box, Budweiser Beer, 1 liter; Nescafe Instant Coffee, 170 grams, decaf; and Coca-Cola, 350 c.c. The charts suggest that prices tend to spend a large fraction of the time at their reference values. As in Eichenbaum et al. (2010) reference prices are important according to several metrics. The next subsection describes the evidence on the importance of reference prices in the data.

4.2 Importance of Reference Prices

Once at their reference levels, posted prices have a tendency to remain at their reference values and to come back to them when they depart from reference levels. The following matrix presents the estimated transitional probabilities between the states the two states: reference (=1) and nonreference (=0). The first row presents the probabilities that the posted price next period will be at its reference value (column 1) and nonreference value

[14]See the Appendix to Chahrour (2009) for a description of the algorithm used in defining reference or attractor prices.

(column 2) given that this period it was at its reference level. The second row presents the same information conditional on a posted price different from the reference price this period.

$$\begin{matrix} 1 \\ 0 \end{matrix} \begin{bmatrix} 0.727 & 0.273 \\ 0.522 & 0.478 \end{bmatrix}$$

The evidence thus suggests that reference prices act as attractors for posted prices. The probability that a price is equal to its reference value next period given that it is at its reference value this period is 0.73. A nonreference price has a 0.48 probability of moving to a reference price next period. Posted prices spend a large fraction of the time at their reference levels. According to Table 4 posted prices are equal to reference prices about 62 percent of the time.

These results do not hold, however, across all retail chains. As can be seen from Table 4, posted prices are equal to reference prices only 28 percent of the time in the case of one of the retail chains.Thus the reference price concept, while useful in describing price dynamics for most retailers in the sample it does not appear as a necessary trait of retail pricing. It should be pointed out that the retailer for which reference prices do not appear to act as attractors for posted prices is one of the important players in the Chilean supermarket industry.

Other metrics for judging the importance of reference prices include the percentage of total revenue that are made at reference prices. Table 5 presents the share of total revenues that are made at reference prices. Most retailers obtain more than 60 percent of their revenue from sales made at reference prices.

4.3 Persistence of Reference Prices

Reference prices are substantially more rigid than posted prices. Column 3 in Table 6 presents summary statistics on the frequency of reference price adjustment taken across categories. The median frequency of reference price adjustment across categories equals 0.029, which implies a duration of 40 weeks. Using revenue shares as weights, the weighted average median frequency of price adjustment is 0.04 –an implied duration of 25 weeks. That is, the typical reference price remains unchanged for about 2 to 3 quarters. The results using Eichenbaum et al.'s definition of reference price are similar (see Columns 5 and 6 in Table 6). By way of comparison, Eichenbaum et al. (2010) find that reference prices in their data have an average duration of 3.7 quarters.

Column 1 of Table 6 presents summary statistics on the frequency of price adjustment for posted prices. The statistics presented in Table 6 are computed across categories for the median product/store within each category. The median frequency of a price change equals 0.28. Column 2 of Table 6 shows the implied duration of a posted price, computed as the reciprocal of the frequency of price adjustment. The implied duration of the median posted price is equal to 3.6 weeks.

Frequencies of posted price adjustment are similar to the one reported by studies that analyze U.S. scanner data. EJR find that posted prices change, on average, about every 2.4 weeks in the case of the large retailer they study. Kehoe and Midrigan (2008), using *Dominick's* dataset, report an average frequency of price change of 0.33 –an implied duration of 3 weeks. The implied duration of a price change found in the data is also close to previous estimates made using consumer price data for Chile. Medina, Rappoport and Soto (2007) analyzing a micro dataset of prices underlying the Chilean CPI find an average duration prices in the food sector of about one month.

In line with results reported for the U.S. and Europe, there is large heterogeneity in the frequencies of price adjustment –both on posted and reference prices– across categories (see Figures 3 and 4). Table 7 shows that there is also a large variation on both the frequency of reference and posted prices across retail chains. The median reference price does not change at all in two of the retail chains, while it changes every 13 weeks in the highest reference price adjuster. Variation in the frequency of price adjustment across retailers is smaller for reference prices than for posted prices, as we would expect if reference prices capture more permanent, common shocks across retailers. The coefficient of variation of the frequency of reference and posted prices across retailers equals 0.8 and 0.95, respectively.

While frequencies of posted and reference price changes are similar to the figures reported by previous work, the relatively small size of price changes observed in the data suggests that prices are not as flexible as the evidence on frequencies of price adjustment might suggest. The weighted median price change in posted prices equals 2.7 percent (see Column 1 in Table 8). By way of comparison, Kehoe and Midrigan (2007) and Eichenbaum et al. (2010) report an average size of a price change of about 16-17 percent (the median size of a price change in EJR's data is 12 percent). Kehoe and Midrigan (2007) find that only 25 percent of price changes are smaller than 4 percent. Burstein and Hellwig (2007), also using *Dominick's* data, find an average size of non-zero price changes of 10 percent when excluding temporary markdowns and 13 percent otherwise.

There is little dispersion in the magnitude of posted price changes across retail chains (see Column 1 of Table 9). Median absolute logged price changes vary between 1 percent and 4.6 percent. The size of price changes exhibits little variation also across categories –the standard deviation across categories equals 1.1 percent (Column 1 of Table 8).

In contrast to what has been observed in U.S. data, changes in prices of a more permanent nature are larger in magnitude than more transient price changes. Column 2 of Table 8 shows that the weighted median absolute logged price change across categories equals 4.7

percent (5.7 percent using Eichenbaym et al.'s definition of a reference price). Studies that examine U.S. data document that temporary price changes tend to be substantially larger in size than more permanent price changes. Nakamura and Steinsson (2008), for instance, report that price adjustments associated to sales are about twice as large as regular price changes. Klenow and Kryvtsov (2008) find an average absolute price change of 14 percent in posted prices and 11 percent in regular prices.

4.4 Hazard Functions

This subsection turns to examining the behavior of frequencies of price adjustment conditional on the age of a price (i.e. the hazard function). The hazard rate measures the rate at which prices change at time t given that they have remained unchanged until t. Letting T denote a random variable measuring the time since the last price change and t a realization of T, the hazard function, $\lambda(t)$, is defined (in continuous time) as

$$\lambda(t) \equiv \lim_{\Delta t \to 0} \frac{\Pr(t \leq T < t + \Delta t | T \geq t)}{\Delta t}$$

Following Klenow and Kryvtsov (2008), I estimate hazard rates as a weighted average of repricing indicators conditional on the price age τ,

$$\lambda_\tau \equiv \frac{\sum_k \sum_s \sum_t \widetilde{\omega}_{ks,t} I\left\{p^{ref}_{ks,t} \neq p^{ref}_{ks,t-1}\right\} I\left\{\tau_{ks,t} = \tau\right\}}{\sum_k \sum_s \sum_t \widetilde{\omega}_{ks,t} I\left\{\tau_{ks,t} = \tau\right\}}$$

where $p^{ref}_{ks,t}$ denotes the reference price of product k in store s at time t and $\widetilde{\omega}_{ks,t}$ correspond to standard expenditure weights (which add up to one across prices in a given week) divided by the number of weeks for which there are prices with determinate ages. In order to control for potential bias arising from censored spells I exclude from the analysis those spells that are either left- of right-censored. Figure 5a depicts the estimated hazard function for reference prices pooling across all products and stores. The estimated hazard function is roughly decreasing for price ages ranging between 1 and 52 weeks (the range within which most price durations lie) and exhibits a spike at about 26 weeks.

Decreasing hazard rates estimated by pooling across stores and products might be a reflection of heterogeneous unconditional hazards in the sample (see for example Kiefer 1988). In order to account for this possibility, I follow Klenow and Kryvtsov (2008) in adjusting repricing indicators by a fixed effect for each decile of the distribution of unconditional hazards. I first compute unconditional hazards for each product/store, I then assign each series to one decile and finally compute the unconditional hazard for each decile. Letting these fixed effects be denoted by $\gamma_{d(u,s)}$, the adjusted hazards rates are computed as

$$\widehat{\lambda}_\tau \equiv \frac{\sum_k \sum_s \sum_t \widetilde{\omega}_{ks,t} \left[I \left\{ p_{ks,t}^{ref} \neq p_{ks,t-1}^{ref} \right\} / \gamma_{d(k,s)} \right] I \left\{ \tau_{ks,t} = \tau \right\}}{\sum_k \sum_s \sum_t \widetilde{\omega}_{ks,t} I \left\{ \tau_{ks,t} = \tau \right\}}$$

The chart describing the relation between these adjusted hazards rates and the age of the price is presented in Figure 5b. As expected, the negative slope exhibited by the non-adjusted hazard function is less pronounced once one adjusts for heterogeneity. The adjusted hazard function appears to be essentially flat with a spike about 26 weeks. The estimates hazard functions for posted prices instead of reference prices are qualitatively similar. Unadjusted hazard functions appear to be decreasing, especially for low-duration prices, while adjusted hazards appear to be roughly flat. This pattern of conditional hazards is consistent with evidence reported for the U.S. and Europe (Klenow and Malin, 2010).

4.5 Reference Prices and Chain-Level Prices

There is substantial evidence that retail prices tend to be set in two stages: At the chain level and at the store level (Levy, Dutta, Bergen and Venable 1998; Eden and Jaremski 2009)[15]. As pointed out by Eden and Jaremski (2009), this two-level decision marking process is consistent with the exploitation of economies of scale in information processing and decision making on the part of retail chains.

In this subsection I examine the extent to which reference prices correspond –in the context of multiproduct stores– to those prices set in a centralized fashion with nonreference prices representing departures from chain-level prices by individual stores in response to store-level shocks. A close correspondence between chain-level prices and reference prices would provide additional clues on the determinants of reference price movements. I start by examining the evidence on two-stage price setting.

The median supermarket chain keeps posted prices equal to modal prices 87 percent of the time (see Table 10). Only in the case of one retail chain, modal prices appear not to be important (posted prices are equal to modal prices only 36 percent of the time); this supermarket chain coincides with the one for which reference prices appear to be unimportant. Thus, evidence is supportive of multi-level pricing decision making in which most price changes are decided at the chain level. The following transition matrix summarizes movements of posted prices to and from modal prices.

$$\begin{matrix} 1 \\ 0 \end{matrix} \begin{bmatrix} 0.712 & 0.288 \\ 0.517 & 0.483 \end{bmatrix}$$

Modal prices are significantly less persistent than reference prices. While the typical

[15] Informal conversations between the author and executives from the Chilean supermarket industry who participated in the price setting process on a regular basis suggest that this practice is also common among Chilean retailers.

reference price is changed every 2-3 quarters, the median modal price is changed every 5 weeks or 0.38 quarters (see Table 11). Thus, the evidence suggests that retail chains not only decide on changes in reference prices at a centralized level but also decide changes in posted prices to and from nonreference prices. It is not the case that nonreference prices correspond to departures from modal prices at a given store. The following conditional probabilities estimated from the data provide more direct evidence on the relation between modal and reference prices:

$$\begin{aligned} prob(p = p^{ref} | p = p^{\text{mod}}) &= 0.782 \\ prob(p = p^{\text{mod}} | p = p^{ref}) &= 0.899 \\ prob(p = p^{ref} | p \neq p^{\text{mod}}) &= 0.219 \\ prob(p = p^{\text{mod}} | p \neq p^{ref}) & \quad 0.409 \end{aligned}$$

Hence, there is roughly a 0.22 probability that conditional on a price being set at a centralized level (i.e. it is a modal price) it corresponds to a nonreference price. Note, however, that knowledge of a price being at the mode makes more likely that a price is a reference price as the unconditional probability of a price being at its reference value is only equal to 0.62 (versus a 0.78 conditional probability).

I examine the extent to which modal prices capture common shocks across retailers estimating a variance components model. I use the following specification

$$Y_{ik} = \mu + \alpha_k + \beta_i + \varepsilon_{ik} \tag{1}$$

where Y_{ik} is the frequency of modal price adjustment of good k in chain i, α_k are product-level effects, β_i are chain-effects and ε_{ik} is a disturbance term. I assume that product effects, chain effects and idiosyncratic effects are distributed normal with zero mean and constant variance and estimate the model by maximum likelihood. If modal prices respond primarily to aggregate shocks, originating at the good level, then we would expect the chain effect not to explain a large fraction of the variation in the frequency of modal price changes. The evidence suggest, instead, that the frequency of modal price change has a substantial chain component. The results of the variance decomposition, presented in Table 12, imply that only 1.5 percent of the variation in the frequencies of modal prices is explained by variation across products, 71 percent of the variation is explained by variation across chains and the remaining 28 percent of the variation in the frequency of modal prices is completely idiosyncratic to a particular product and chain.

4.6 Do Reference Prices Respond only to Manufacturer Level Shocks?

This subsection examines the extent to which changes in reference prices capture common shocks across retailers. Nakamura (2008) studies this question for posted prices using a rich cross-section of U.S. retailers. She finds that most of the variation in sales-inclusive prices for a given barcode or Universal Product Code (UPC) can be explained by variation common to stores within chains (but not across chains), suggesting that retailers pricing policies (i.e. intertemporal discrimination) drive most of the variation in retail prices. The question is important from a modeling point of view. Models in macroeconomics, international economics and industrial organization typically assume that price-setters face productivity shocks and preference shocks originating at the manufacturing level (i.e. abstracting from a possible role played by retailers). If retailers pricing policies are important in driving retail prices though, then explaining the movements of retail prices would require introducing a motive for intertemporal price discrimination explicitly (see Guimaraes and Sheedy, 2010, for an example applied to macroeconomics).

I measure the comovement in reference prices across stores using Pearson's correlation coefficient between the reference prices of a given product in any two stores. I estimate correlations using monthly averaged prices and, for computational purposes, I restrict the analysis to the 33 product categories which represent 75 percent of total revenues in the sample[16]. I study this question using the following specification:

$$Corr_{kcl} = \beta_0 + \beta_1 INTRA_l + \sum_{k=1}^{K} \delta_k D_k + \sum_{c=1}^{C} \gamma_c F_c + \varepsilon_{kcl} \tag{2}$$

where the dependent variable is Pearson's correlation coefficient between the price of product k in category c between two stores indexed by l. The explanatory variable of interest, $INTRA_l$, is a dummy variable which takes on the value one if the two stores in store-pair l belong to the same retail chain and zero otherwise. The variables D_k and F_c represent product and category dummy variables, respectively. Table 13 presents the results of estimating the above specification by OLS both using reference prices (Panel A) and posted prices (Panel B). Panel A in Table 13 shows that comovement between the reference prices of a given product is significantly different when the stores belong to a given retail chain. The correlation coefficient for stores within a chain is about 0.3 higher than for stores that belong to different chains. It increases from about 0.5 in the case of stores belonging to different chains to about 0.8 for stores belonging to the same chain.

Further evidence on the role played by retail chains in the dynamics of reference prices comes from decomposing the variation in the frequency of reference price adjustment. I decompose the variation in the frequency of reference price adjustment using the following

[16] In addition, I use only prices which are available for at least 6 retail chains and for at least 22 months.

specification:

$$Y_{ijk} = \mu + \alpha_k + \beta_i + \gamma_j + \varepsilon_{ijk} \tag{3}$$

where Y_{ijk} denotes the frequency of reference price change for product k sold in store j which belongs to retail chain i, μ is a constant term, and α_k, β_i and γ_j represent product, chain and store random effects, respectively, while ε_{ijk} is a disturbance term associated to a particular product, store and chain. As in the previous subsection, I assume that the random coefficients are distributed normal with zero mean and constant variance. The estimation considers only products sold in at least six different retail chains.

The results of estimation of equation 2 are presented in Table 14. Variation across products, while controlling for store and chain effects, is relatively limited. In contrast, 63 percent of the variation in the frequency of reference price changes is driven by chain effects. The fraction of total variation explained by variation across stores within chains is relatively small, which provides further evidence that reference prices tend to be set at the chain level and, more importantly, that reference prices have an important chain-specific component. If reference prices were mainly driven by shocks originating at a previous stage of the distribution chain, then we would expect chain effects to be smaller as frequencies of reference price adjustment would be primarily explained by common shocks across chains. The evidence is, thus, consistent with Nakamura's (2008) findings.

Figure 6 displays the relation between the frequencies of posted and reference price adjustment at the chain level. Chains that adjust posted prices relatively more frequently also tend to adjust reference prices more frequently. This provides further evidence that the dynamics of reference prices are driven to an important extent by retailer-level effects.

5 Reference Prices and Reference Costs

The relation between reference prices and reference costs offers further evidence into the nature of the former. As noted in Section 3, cost data are available for two of the retail chains in the primary data set. In one of these cases, the cost data correspond to a measure of replacement costs, and hence reference costs can be meaningfully extracted from the observed cost series. I thus, focus on the data for this particular retailer to examine the behavior of reference costs.

Reference costs share several of the features observed in reference prices. First, posted costs spend most of the time at their reference values. Weekly costs are equal to reference costs in almost 80 percent of the weeks. The typical nonreference cost is lower than the reference value, only about 14 percent of non-reference costs correspond to posted costs that exceed reference costs. The importance of reference costs is similar across categories. The percentage of weekly costs that correspond to reference costs fluctuates between 62 percent ("Whisky") and 88 percent ("Men Fragances").

Second, reference costs are more persistent than posted costs. The implied duration of the median frequency of posted cost changes across categories is about 10 weeks. This is about twice the implied duration of retail prices within the comparable subset of categories (see Columns 1 and 2 in Table 15). Reference costs, on the other hand, change about every 20 weeks while comparable reference prices change every 30 weeks (see Columns 3 and 4 in Table 15). Reference prices and costs appear to be as sticky when computed using Eichenbaum et al.'s definition. The frequency of reference prices and costs is about 0.03 under their definition. Third, the frequency of posted and reference cost changes is highly heterogeneous across categories (see Figures 7a and 7b). Fourth, cost changes are small in magnitude. The average change in posted costs equals 1.5 percent, and the average reference cost change equals 2.4 percent. Thus, as in the case of retail prices, changes in reference costs tend to be larger than changes in posted costs (see Table 16).

Eichenbaum et al. (2010) observe that prices in their data set tend not to change unless costs also change contemporaneously. In contrast, I find that conditional on a posted (reference) cost change, posted (reference) prices change only 33 (6) percent of the time. This might suggest that the retailer tends to delay cost pass-through to retail prices. Consistent with this view, the average markup conditional on a cost change is statistically significantly smaller than the average markup conditional on costs remaining unchanged. The magnitude of the markup differential is however small (on the order of two percentage points), which suggests that prices do respond to an important extent to cost changes (see Table 17).

Markups appear to be remarkably stable over time. Table 18 presents the median time-series standard deviation of markups[17] at the category level. The median standard deviation of markups across categories equals 0.047. By way of comparison, Eichenbaum et al. (2010) find a substantially higher markup volatility in the case of the large US retailer they study. They report a time-series standard deviation of markups of 0.11. As can be seen from Table 18 there is little variation in the markup volatility across categories. The cross-sectional standard deviation of markup volatility equals 0.01. Thus the retailer keeps the markups fairly stable over time across different product categories.

The cross-sectional dispersion of markups is similarly modest in magnitude. Due to confidentiality reasons, I am unable to present statistics on the actual level of markups. Evidence on the deviation of the median markup within a category form the average markup across categories is presented in Figure 8. All markup deviations lie within a +/- 10 percentage points band about the average markup. The standard deviation of markups across categories equals 0.041.

[17] The markup of product k in week t is defined as $\mu_{kt} \equiv \ln(P_{kt}/C_{kt})$.

There is evidence that the retailer chooses price duration so as to keep markups within narrow ranges. Eichenbaum et al. (2010) find evidence of this same type of state-dependence in their data. Figure 9 depicts the relation between the probability of price change and the gap between the current markup and the average reference markup[18]. The figure suggests that the retailer adjusts its price so as to keep the markup close to its average reference level. The probability of a price change conditional on the markup being more than five percentage points apart from the reference markup is about 0.4. When the markup is at the reference level, on the other hand, the probability of the retailer adjusting its price drops to about half that figure (i.e. about 0.2).

6 Synchronization of Price Changes

In this section, I turn to examining the degree of synchronization versus staggering in the timing of price changes both across and within stores. Staggering in price adjustment across price-setters has important implications for the effects of aggregate shocks on real variables. Some degree of staggering in price setting decisions is a necessary, though not a sufficient (see Caplin and Spulber, 1987 for an example), condition for a monetary shock to have persistent effects on output. In the case of multiproduct price-setters it is of interest to understand the extent to which staggering occurs across stores versus across products (within stores). As pointed out by Lach and Tsiddon (1996), the two types of staggering have different implications for price dynamics. In addition, evidence on the degree of within store synchronization in price changes can help us discriminate between competing hypothesis about the technology of price adjustments (Sheshinski and Weiss, 1992).

[18] Reference markup is defined as $\mu_t^{ref} \equiv \ln(P_t^{ref}/C_t^{ref})$, where P_t^{ref} is the reference price in week t and C_t^{ref} is the reference cost in week t.

6.1 Synchronization within Stores

I start by examining the degree of synchronization of price changes within stores. Prices tend to be synchronized within stores when the technology of price adjustment is characterized by increasing returns as well as when prices have positive interactions in the profit function (Sheshinski and Weiss, 1992). Sheshinki and Weiss (1992) distinguish between "menu costs" and "decision costs" of price changes. While "menu costs" do not change with the number of prices changed, "decision costs" are increasing in the number of adjusted prices. Thus, when the cost of price change take the form of "menu costs" intra-store price adjustments tend to be bunched together. Midrigan (2009) offers a model of a multiproduct price-setter which exploits this idea to account for the presence of small price changes observed in U.S. data.

Figure 10 presents the distribution of f_{st}, the fraction of price changes within store s at time t,

$$f_{st} = \frac{\sum_k I\left\{p_{ks,t} \neq p_{ks,t-1}\right\}}{N_{st}}$$

where N_{st} is the number of products sold in store s at time t.There is a large dispersion in the fraction of within store price changes and most of the probability mass is concentrated in values in between zero and one, suggesting that perfect synchronization of price changes within stores is not a feature of the data generating process. One way of assessing the extent of staggering in the data, suggested by Fisher and Konieczny (2000), is to compare the standard deviation of the fraction of price changes to the hypothetical standard deviations that would be observed in the cases of perfect synchronization –in which the price-setter either changes all or none of the prices in a given time period– and uniform staggering –in which the price-setter changes a constant fraction of all prices in every period. In the case of perfect synchronization, the fraction of price changes takes only the values zero or one, and hence its variance is equal to $\overline{f}_s(1-\overline{f}_s)$, where $\overline{f}_s$ is the average proportion of price changes within store s. With uniform staggering, on the other hand, the fraction of price changes takes the same value every period and, hence, its standard deviation is equal to zero. The Fisher-Konieczny index (FK) can be defined as (Dias et al., 2005)

$$FK_s = \sqrt{\frac{1}{T}\frac{\sum_{t=1}^{T}\left(f_{st}-\overline{f}_s\right)^2}{\overline{f}_s\left(1-\overline{f}_s\right)}} = \frac{S_f}{\sqrt{\overline{f}_s\left(1-\overline{f}_s\right)}}$$

where $S_f = \sqrt{\frac{1}{T}\sum_{t=1}^{T}\left(f_t-\overline{f}_s\right)^2}$is the sample standard deviation of f_{st}. It takes the value of one in the case of perfect synchronization and zero in the case of uniform staggering. Figure 11 shows the distribution of the FK index for within-store synchronization in posted prices. The results suggest that posted price adjustments are neither perfectly synchronized not are they uniformly staggered within stores. On average, the variance of the within-store fraction of price changes is about 21 percent of the hypothetical variance under perfect synchronization. While there is some dispersion in the FK index across retail chains (see Table 19), the value of the index is still smaller than 0.22 in the larger retailers (representing above 60 percent of market sales). The degree of staggering in within-store reference price changes is similar to the one observed in posted prices (the average FK index for reference prices equals 0.22).

One interpretation of the lack of evidence supporting within-store price synchronization is that synchronization of price changes occurs at a finer product category level. It might be reasonable to assume that stores are more likely to exploit economies of scope in price setting at the category level than between products belonging to different categories, as products in the same category are usually located in the same aisles within the stores which would presumably reduce the marginal cost of changing a second price within a category

(Midrigan, 2009). In addition, it is more likely that products within a category are hit by symmetric shocks.

Figure 12 presents the distribution of the FK index for within product category price changes. The fraction of price changes f_{cst} that enters the calculation of the index in this case is given by

$$f_{cst} = \frac{\sum_k I\left\{p_{kcs,t} \neq p_{kcs,t-1}\right\}}{N_{cst}}$$

where N_{cst} is the number of products sold within category c in store s at time t. The distribution of the FK index is shifted to the right relative to the distribution of the index for within-store price changes. The average FK index is twice as large as when calculated at the level of the whole store. This suggests that stores tend to synchronize price changes within product categories and is consistent with the view that stores face fixed costs of price adjustment (i.e. "menu costs" as opposed to "decision costs") at the product category level.

Variation in the FK index is essentially explained by both variation across retail chains and product categories. Table 20a presents the results of estimating the following variance components model by restricted maximum likelihood:

$$FK_{crs} = \mu + \alpha_c + \beta_r + \gamma_s + \epsilon_{crs}$$

where α_c denotes category effects, β_r denotes retail chain effects, γ_s denotes store effects and ϵ_{krs} is a random disturbance term. All variance componentes are assumed to be normally distributed with mean zero and constant variance: $\alpha_c \sim N(0, \sigma^2_\alpha)$, $\beta_r \sim N(0, \sigma^2_\beta)$, $\gamma_s \sim N(0, \sigma^2_\gamma)$ and $\epsilon_{crs} \sim N(0, \sigma^2_\epsilon)$. About three quarters of the total variation in FK is explained by category (42 percent) and retail chain (35 percent) effects. The results suggest that both heterogeneity in idiosyncratic shocks at the category level and heterogeneity in the pricing policies of retail firms influence the degree of synchronization of price changes within categories. The fact that store effects explain about 1 percent of total variance in FK suggests that retail chains make pricing decisions at a centralized level.

There is a higher degree of synchronization of price changes within categories for reference prices. The average FK index in this case is 0.5. This is not surprising, as movements in reference prices are likely to capture common shocks across products and retailers. Interestingly, the importance of retail chain effects in explaining the variation in the synchronization of reference prices within product categories is substantially smaller than in the case of posted prices (see Table 20b). The fact that most of the variation in the synchronization index for reference price changes is due to "product category effects" suggests that idiosyncratic retailer pricing policies play a weaker role in determining the behavior of reference prices.

6.2 Synchronization Across Stores

Figure 13 presents the empirical distribution of f_{kt}, the fraction of stores changing the price of product k at time t, given by

$$f_{kt} = \frac{\sum_s I\left\{p_{ks,t} \neq p_{ks,t-1}\right\}}{N_{kt}}$$

where N_{ut} is the number of stores selling product u at time t. About a third of stores changes the price of a given product in a given week. The empirical distribution of f_{ut} is centered at 0.31 and exhibits a large dispersion (the standard deviation is equal to 0.19).The distribution of the FK index for across-stores synchronization is displayed in Figure 14. As in the case of within-store price changes, the evidence does not favor perfect synchronization nor uniform staggering. Percentiles 1 and 99 of the distribution of the FK index are 0.05 and 0.82, respectively. The distribution is centered at 0.31, which suggests that while weekly price changes across stores are more synchronized than within stores, the pattern of price changes across stores appears to adjust more closely to a situation of perfect staggering.

While the FK index is helpful in assessing whether price changes across stores are characterized by perfect synchronization or uniform staggering, it is difficult to interpret when it takes intermediate values between 0 and 1. An alternative approach to assessing the extent to which the price adjustment decisions of different price setters are interdependent involves estimating a discrete choice model (Fisher and Konieczny, 2000; Midrigan, 2009). Letting Y_{ijt} denote a dichotomous variable which takes the value 1 if the price of a given product (the product subindex is omitted for notational convenience) is changed at time t by store j belonging to chain i, the reduced form specification is given by

$$Y_{ijt} = \beta_0 + \beta_1 FRACOWN_{ijt} + \beta_2 FRACOTHER_{ijt} + \zeta_t + \epsilon_{ijt}$$

where $FRACOWN_{ijt}$ is the fraction of other stores within the same chain changing the price of the product at time t; $FRACOTHER_{ijt}$ is the fraction of stores belonging to other chains changing the price of the product in period t, ζ_t denote time effects and ϵ_{srt} is a disturbance term. The results of the probit estimation are presented in Table 21. The estimation is carried out for monthly aggregated data on reference price changes. The results are consistent with strong synchronization of within-chain synchronization but do not favor across chain synchronization. An increase in the fraction of other stores within the same chain from 0 to 1 is roughly associated to an increase of 0.68 in the probability of a reference price change. The probability of a reference price change actually decreases when the fraction of stores in other chains increases. An increase in the fraction of stores in other chains from 0 to 1 is associated to a fall in the probability of reference price changes of about 0.01. Thus, the evidence is consistent with synchronization in price changes of a given good within price-setters and staggering of price adjustments across price-setters.

7 A Model

This section presents a partial equilibrium model in the spirit of Eichenbaum et al. (2010) which is capable of capturing several salient features of the data reported above. As in Eichenbaum et al., it features a monopolistic firm which chooses price plans, consisting of a set of prices. The firm can costlessly change prices within a price plan but must pay a fixed cost in order to choose a new price plan. This specification of the technology of price adjustment can at the same time account for the fact that reference prices act as attractors for the price process and for the fact that nonreference price changes are smaller in magnitude than reference price changes.

Consider a monopolistic firm which produces and sells a single product and faces a demand function

$$q_t = Y p_t^{-\theta}$$

where q_t is the quantity demanded of the good, p_t is the firm's price, Y is a scale parameter, and θ is the price-elasticity of demand. The firm's unit costs c_t are assumed to follow the AR(1) process:

$$\log(c_t) = \rho \log(c_{t-1}) + \epsilon_t$$

where ϵ_t is a disturbance term which is normally distributed with mean zero and variance σ_ϵ^2. Firm's profits are thus given by

$$\pi_t = Y p_t^{-\theta} (p_t - c_t)$$

As in EJR, the firm chooses a price plan Ω, which is defined as a set of prices p_t. The firm can costlessly change prices within a plan but must incurr a fixed cost ϕ in order to change the plan.

Let s denote the state and $F(s'|s)$ denote the conditional density of s' given s. Denote by $V(\Omega, s)$ the value of the firm when there is no change in its price plan, Ω, and the state is s. Let $W(s)$ be the value of the firm when it changes its plan. These two value functions are given by:

$$V(\Omega, s) = \max_{p \in \Omega} [\pi_t] + \beta \int \left\{ \max \left[V\left(\Omega, s'\right), W(s') \right] \right\} dF\left(s'|s\right)$$

and

$$W(s) = \max_{p \in \Omega', \Omega'} \left\{ \pi_t - \phi + \beta \int \left\{ \max \left[V\left(\Omega', s'\right), W(s') \right] \right\} dF\left(s'|s\right) \right\}$$

where β is a discount factor.

Calibration and Solution. I simplify the problem by considering only price plans with cardinality two. I solve the model using value function iteration on a grid. Tauchen's (1986) method is used to approximate the process followed by unit costs using a Markov chain. There are six free parameters in the model: $\beta, Y, \theta, \rho, \sigma_\epsilon^2$ and ϕ. I calibrate the model so that a period corresponds to one week. I accordingly set the discount factor β equal to 0.999. The demand elasticity θ is set at 4 so as to match the average markup assuming that all retailers face the same replacement costs. The values of parameters ρ and σ_ϵ^2 governing the dynamics of unit costs and the cost of price plans adjustment ϕ are chosen so as to match the following moments: The frequency of reference price adjustment; the size of reference price changes; and the standard deviation of weekly markups.

The model is able to capture the coexistence of sticky reference prices and more flexible posted prices. Setting the menu costs, ϕ, at 0.03 the model yields an implied duration of posted and reference prices of 3.5 and 25 weeks, respectively, which matches the durations implied by the data.

8 Concluding Remarks

This paper examined evidence on retail price adjustment from a cross-section of Chilean retailers. Patterns of price adjustment are found to be similar to the ones reported for the U.S. in that posted prices revolve about more persistent attractor prices.Posted prices spend most of the time at their reference values and tend to return to their reference values soon after having departed from them. In contrast to retail price behavior observed in the U.S., however, temporary price changes in the data are of a smaller magnitude and they tend not to return to the previous price. One of the paper's main findings is the fact that reference price changes have a significant retailer-specific component. Comovement in the price of a given product across stores is significantly more pronounced when two stores belong to the same retail chain than otherwise. Furthermore, most of the variation in the frequency of reference price changes is explained by variation across chains. This implies that reference price movements are not only explained by productivity and preference shocks originating at the manufacturer level but are also driven by retailers' pricing policies. This is somewhat surprising as one would expect more permanent reference prices to primarily reflect common shocks across retailers. There is also evidence that retail chains tend to set most of their prices in a centralized fashion. These chain-level prices are, however, adjusted significantly more frequently than reference prices.

Evidence of synchronization of reference price adjustment suggests that neither perfect price synchronization (in which either all the stores change the price of a given product in a given period or none of them do) nor uniform staggering (in which a constant fraction of all stores changes prices each period) is supported by the data. There is evidence of within product category synchronization in the timing of price changes which suggests that the technology of price adjustment might be characterized by a fixed cost of changing a given price plus a small marginal cost of changing an additional price within the same product category. Evidence on across-stores price synchronization suggests that prices for a given product tend to be synchronized across stores within chains but not across stores from different chains. The evidence is thus consistent with within price-setter synchronization but staggering across price-setters. Lach and Tsiddon (1996) report a similar finding for Israeli grocery stores.

9 Appendix

9.1 The Supermarket Industry in Chile: Structure and Major Actors

This appendix presents a brief overview of the Chilean supermarket industry as background information to the analysis presented in the main body of the paper.

The supermarket industry in Chile represents about 26 percent of total sales in the retail sector and about 80 percent of the sales of groceries (USDA, 2009), the remaining 20 percent being represented by independent stores (e.g. Mom and pop stores). The Chilean supermarket industry has undergone substantial structural change over the last 15 years (Díaz, Galetovic and Sanhueza 2008, Galetovic and Sanhueza 2006, Lira 2005). One mayor effect of this restructuring process has been the industry's evolution towards greater concentration . In 1997, the combined market share of the largest two retailers, *D&S* –controlled since January 2009 by the U.S.-based retailer *Wal-Mart*– and *Santa Isabel*, amounted to 33.2 percent (Díaz, Galetovic and Sanhueza 2008). Following several waves of mergers and acquisitions[19], by 2006 the largest two firms, by then *D&S* and *Cencosud,*

[19] *Cencosud* acquired *Santa Isabel* in 2003, *Montecarlo* and *Las Brisas* in 2004, and *Economax* and *Infante* in 2006; *D&S* acquired *Carrefour* in 2004

accounted for more than 60 percent of the market, which totalled sales for $9.6 billion in 2008. Further restructuring occured over the period 2007-2008 led to the emergence of two new players, *SMU* and *Supermercados del Sur*. By the end of 2009, five mayor players could be identified in the industry : *D&S*, with 34 percent of the market; *Cencosud*, with 29.3 percent; *SMU*, with about 16 percent; *Supermercados del Sur* with 8 percent; and *Falabella-Tottus* with 6 percent of the market (*Estrategia* newspaper, December 22, 2009).

Major Chilean retailers have typically followed multi-format strategies. Formats include basically hypermarkets, traditional supermarkets, discount stores and convenience stores. *D&S* operates three different formats under three different brands: Hypermarkets, under the brand *Hiper Lider*; traditional supermarkets, under the brand *Express de Lider*; and discount stores under the brands *Ekono* (re)introduced in January, 2007, and *SuperBodega Acuenta*. Cencosud, operates hypermarkets under the brand *Jumbo* and supermarkets under the brand *Santa Isabel*.

In the data set, 13 different supermarket/hypermarket chains can be identified[20]: *La Bandera Azul*, *Economax*, *Ekono*, *Jumbo*, *Las Brisas*, *Lider*, *Montecarlo*, *Montserrat*, *OK Market*, *Ribeiro*, *Puerto Cristo*, *Santa Isabel* and *Unimarc*. Over the sampling period 2005-2008, the chains *Economax* (since 2006), *Jumbo*, *Las Brisas*, *Montecarlo* and *Santa Isabel* belonged to *Cencosud*; *Lider* and *Ekono* (launched in 2007) belonged to *D&S*; *SMU* acquired *Unimarc* in 2007 and *OK Market* (a chain of convenience stores) in late 2009. The remaining chains were independent retailers (*La Bandera Azul, Puerto Cristo* and *Ribeiro* were acquired by *SMU* in mid-2008).

[20] Chains are not grouped by ownership but by brand/format as pricing policies are found to vary by brand/format.

References

[1] Aucremanne, L. and Emmanuel Dhyne (2004). "How Frequently do Prices Change? Evidence Based on the Micro Data Underlying the Belgian CPI". ECB Working Paper 331.

[2] Bils, Mark and Peter J. Klenow (2004). "Some Evidence on the Importance of Sticky Prices". *Journal of Political Economy*, Vol 112, No. 5.

[3] Burstein, Ariel and Christian Hellwig (2007). "Prices and Market Shares in a Menu Cost Model". Mimeo UCLA.

[4] Calvo, Guillermo A. (1983). "Staggered Prices in a Utility-Maximizing Framework". *Journal of Monetary Economics*, Vol. 50, pp. 1189-1214.

[5] Cencosud S.A.. Annual Report, several years. Online www.cencosud.cl.

[6] Centro de Estudios del Retail (2009). "*Calidad de Servicio en la Industria del Retail en Chile, Caso Supermercados*" ["Quality of Service in the Retail Industry of Chile. Case of Supermarkets"]. Centro de Estudios del Retail, Ingeniería Industrial, Universidad de Chile.

[7] Christiano, Lawrence J., Martin Eichenbaum and Charles L. Evans (1999). "Monetary Policy Shocks: What Have We Learned and to What End". Handbook of Monetary Economics.

[8] Chahrour, Ryan A. (2009). "Sales and Price Spikes in Retail Scanner Data", Columbia University.

[9] Dias, Daniel, C. Robalo Marques, P.D. Neves and J.M.C. Santos Silva (2005). "On the Fisher Konieczny Index of Price Changes Synchronization", *Economics Letters*, vol. 87(2), pages 279-283.

[10] Díaz, Fernando, Alexander Galetovic and Ricardo Sanhueza (2008). "*Entrada, Concentración y Competencia: Supermercados en Chile 1998-2006*" ["Entry, Concentration and Competition: Supermarkets in Chile 1998-2006"]. Mimeo Universidad de Los Andes, Chile.

[11] Distribución y Servicio S.A. Annual Report, several years. Online www.dys.cl.

[12] Dutta, Shantanu, Mark Bergen, Daniel Levy and Robert Venable (1999). "Menu Costs, Posted Prices, and Multiproduct Retailers". *Journal of Money, Credit and Banking*, Vol. 31, No. 4 (November).

[13] Eden, Benjamin and Matthew S. Jaremski (2009). "Rigidity, Discreteness and Dispersion in Chain Prices", Vanderbilt University.

[14] Eichenbaum, Martin, Nir Jaimovich and Sergio Rebelo (2009). "Reference Prices and Nominal Rigidities". Working paper Northwestern University.

[15] Estrategia (2009). "*D&S Lidera en Participacion de Mercado*", *News Release*, December 12, 2009. Online at http://www.estrategia.cl/detalle_noticia.php?cod=25829.

[16] Fisher, T. C. G. and Jerzy Konieczny (2000). "Synchronization of Price Changes by Multiproduct Firms: Evidence from Canadian Newspaper Prices". *Economic Letters* 68, 271-277.

[17] Golosov, Mikhail and Robert Lucas (2007). "Menu Costs and Phillips Curves". *Journal of Political Economy*, 115(2), pp. 171-199.

[18] Guimaraes and Sheedy (2010). "Sales and Monetary Policy". *American Economic Review* (forthcoming).

[19] Kehoe, Patrick J. and Virgiliu Midrigan (2007). "Sales and the Real Effects of Monetary Policy". Working paper, Federal Reserve Bank of Minneapolis.

[20] Kiefer, N. M. (1988). "Economic Duration Data and Hazard Functions". *Journal of Economic Literature* Vol XXVI, pp. 646-679 (June).

[21] Klenow, Peter J. and Benjamin A. Malin (2010). "Microeconomic Evidence on Price-Setting". Handbook of Monetary Economics (Benjamin Friedman and Michael Woodford, editors). Forthcoming.

[22] Klenow, Peter J. and O. Kryvtsov (2008). "State-Dependent or Time-Dependent Pricing: Does It Matter for Recent U.S. Inflation", *Quarterly Journal of Economics* Vol. 123, Issue 3, pp. 863-904.

[23] Lach, Saul and Tsiddon (1996). "Staggering and Synchronization in Price Setting: Evidence from Multiproduct Firms". *American Economic Review*, 1175-1196.

[24] Levy, Daniel, Mark Bergen, Shantanu Dutta and Robert Venable (1997). "The Magnitude of Menu Costs: Direct Evidence from Large U.S. Supermarket Chains". *Quarterly Journal of Economics* (August).

[25] Lira, Loreto (2005). "*Cambios en la Industria de los Supermercados, Concentración, Hipermercados, Relaciones con Proveedores y Marcas Propias*" ["Changes in the Supermarket Industry, Concentration, Hypermarket, Relationship with Suppliers and Private Labels"]. *Estudios Públicos 97.*

[26] Medina, Juan Pablo, David Rappoport, and Claudio Soto (2007). "Dynamics of Price Adjustments: Evidence from Micro Level Data for Chile". Working Papers Central Bank of Chile 432, Central Bank of Chile.

[27] Midrigan, Virgiliu (2009). "Menu Costs, Multi-Product Firms and Aggregate Fluctuations". Mimeo Columbia University.

[28] Nakamura, Emi (2008). "Passthrough in Retail and Wholesale". *American Economic Review, Papers and Proceedings*, Vol. 98, No. 2, pp. 430-437 (May).

[29] Nakamura, Emi and Jon Steinsson (2008). "Five Facts About Prices: A Reevaluation of Menu Cost Models". *Quarterly Journal of Economics*.

[30] Matějka, Filip (2010). "Rationally Inattentive Seller: Sales and Discrete Pricing". Mimeo Princeton University.

[31] Sheshinski Eytan and Yoram Weiss (1977). "Inflation and the Cost of Price Adjustment". *Review of Economic Studies*, 54, 287-303.

[32] ———————— (1983). "Optimal Pricing Policy Under Stochastic Inflation", *Review of Economic Studies*, 50, 513-529.

[33] ———————— (1992). "Staggered and Synchronized Price Policies under Inflation: The Multiproduct Monopoly Case". *Review of Economic Studies*, 59, 331-359.

[34] Taylor, John B. (1999). "Staggered Price and Wage Setting in Macroeconomics". In Handbook of Macroeconomics, Vol. 1B, John B. Taylor and Michael Woodford (eds), New York (Elsevier).

[35] Zbaracki, Mark J., Mark Ritson, Daniel Levy, Shantanu Dutta and Mark Bergen (2004). "Managerial and Customer Costs of Price Adjustment: Direct Evidence from Industrial Markets". *Review of Economics and Statistics*, 86(2), pp. 514-533.

Table 1. Product Categories included in the Sample

1 CLOTH STAIN REMOVER	36 CHAMPAGNE	71 SUN FILTERS
2 BABY ACCESSORIES	37 CHANCHACAS	72 BABY FORMULAS
3 CAT AND DOG ACCESSORIES	38 CIGARETTES	73 MATCHES
4 VEGETABLE OIL	39 KITCHENETTES	74 WOMEN FRAGRANCES
5 AGENDAS	40 COCKTAIL	75 MEN FRAGANCES
6 WATER	41 DOG AND CAT FOOD	76 BABY FRAGANCES
7 CHILLI SAUCE	42 FOOD CANS	77 FROZEN FOOD
8 SWEET BISCUITS	43 CONVENIENCE FOOD	78 CANNED FRUITS
9 LIGHTBULBS	44 FOOD PRESERVATIVES	79 COOKIES AND CHOCOLATES
10 CLOTH STIFFENER	45 LIQUID PAPER	80 CLOTH HANGERS
11 RICE	46 COSMETICS	81 GUM
12 PERSONAL CARE	47 COTTON SWABS	82 SYNTHETIC GLOVES
13 VACUUM CLEANER	48 COFFEE CREAM	83 FROZEN HAMBURGERS
14 PORTABLE AUDIO	49 MILKCREAM	84 FLOUR
15 SUGAR	50 FACIAL CREAM	85 ICECREAM
16 HAIR CONDITIONER	51 SHAVING CREAM	86 ELECTRIC WATER BOILER
17 SODA	52 BABY RASH CREAM	87 HERBS AND SPICES
18 SHOE POLISHER	53 HAND AND BODY CREAM	88 CHLORINE (BLEACH)
19 CAKES	54 NOTEBOOKS	89 RAZOR BLADES
20 SKETCH NOTEBOOKS	55 FOOTCARE	90 MICROWAVES
21 BALL PEN	56 DEPILATORY ITEMS	92 PRINTERS
22 KITCHEN PANS	57 HOME SPRAY	93 INSECTICIDE
23 TRASH BAGS	58 DEODORANTS	94 CLOTH WASHING SOAP
24 COFFEE	59 CLOTHES DETERGENT	95 TOILET SOAP
25 COLOR PENCILS	60 FRUIT CANDIES	96 FLAVORED JUICE POWDER
26 BROTH	61 LIGHTERS	97 TOYS
27 AUDIO CAR	62 SWEETENER	98 KETCHUP
28 SWEETS	63 ENERGY DRINKS/ NECTARS	99 WASHING MACHINES
29 SAUSAGES	64 MOUTH WASH ITEMS	100 DISH WASHER
30 TOOTHBRUSH	65 FOOD PLASTIC CONTAINERS	101 CONDENSED MILK
31 WAX	66 STEREOS	102 POWDER MILK
32 CEREAL BAR	67 SPECIFIC MEDICINES	103 MILK CREAM
33 BREAKFAST CEREAL	68 SHOE SPONGES	104 PULSES
34 PROCESSED CEREAL	69 EXTRACTS AND ESSENCES	105 BAKERS YEAST
35 BEER	70 PASTA	106 OFFICE SUPPLIES

Table 1. Product Categories included in the Sample (cont.)

107 COGNAC
108 GIN LIQUOR
109 RON LIQUOR
110 VERMOUTH LIQUOR
111 VODKA
112 HOME CLEANING ITEMS
113 FLOOR CLEANING ITEMS
114 TOILET CLEANING ITEMS
115 FURNITURE POLISHER
116 BUTTERSCOTCH
117 BUTTER
118 LOWFAT BUTTER
119 MARGARINE
120 FROZEN SEAFOOD
121 CANNED SEAFOOD
122 FROZEN PASTA AND DOUGH
123 MAYONNAISE
124 MARMALADE
125 MIX FOR CAKES
126 MONITORS
127 MUSTARD
128 FRUIT JUICES
129 POTS AND PANS
130 BREAD
131 DIAPERS
132 DISHCLOTH AND SYNTHETIC FABRICS
133 DISPOSABLE HANDKERCHIEF
134 TOILETTE PAPER
135 BABYFOOD
136 TOOTHPASTE
137 TURKEY
138 ADHESIVES
139 NEWSPAPERS
140 FROZEN FISH
141 GENERIC FISH
142 PREMIUM FISH
143 BATTERIES
144 PISCOS
145 ELECTRIC IRON
146 CHICKEN
147 BAKING POWDER
148 POWDER DESSERTS
149 FIRST AID ITEMS
150 CAR CARE ITEMS
151 FEMENINE CARE ITEMS
152 MASHED POTATO
153 CHEESE
154 REFRIGERATOR
155 DVD PLAYER
156 MILK FLAVORING
157 JUICE MAKER
158 SALT
159 TOMATO SAUCE
160 SWEET SAUCE
161 SAUCE AND DRESSING
162 DENTAL THREAD
163 NAPKINS
164 SHAMPOO HAIRCARE
165 SNACKS
166 SOUPS AND CREAMS
167 STYLING AND FIXERS
168 CLOTH SOFTENER
169 NUTRITIONAL SUMPLEMENTS
170 BABYPOWDER
171 PREPAID PHONE CARDS
172 TEA
173 ICED TEA
174 TV
175 WATERCOLORS
176 HAIR DYE
177 FEMENINE PADS
178 BABY WIPES
179 KITCHEN UTENSILS
180 CANNED VEGETABLES
181 CANDLES
182 FROZEN VEGETABLES
183 BULK FROZEN VEGETABLES
184 BULK VEGETABLES AND FRUITS
185 VINEGAR AND LEMON
186 WINES
187 STEEL DISH CLEANER
188 STEEL FLOOR CLEANER
189 WHISKY
190 YOGHURT

Table 2. Primary Sample: Descriptive Statistics

	2005	2006	2007	2008
No. of obs.	7,115,400	24,564,368	19,750,927	5,797,261
No. of stores	89	107	158	157
No. of chains	10	10	11	11
No. of barcodes	18,242	23,348	21,114	6,236
	Price Statistics			
Average	965.0	974.2	1,022.9	1,056.6
Median	659.0	685	724.5	773.3
Standard dev.	1,060.4	1056.0	1,066.8	1,045.1
	Quantity Statistics			
Average	46.7	43.2	42.7	47.0
Median	15.0	15.0	15.0	17.0
Standard dev.	135.3	123.4	118.0	125.7

Notes. The sampling period spans weeks 34 of 2005 to week 24 of 2008. Retail chains included in the sample are: Bandera Azul, Ekono, Jumbo, Las Brisas, Lider, Maicao, Montecarlo, Montserrat, OK Market, Puerto Cristo, Ribeiro, Santa Isabel and Unimarc. Price statistics are expressed in nominal Chilean pesos.

Table 3. Descriptive Statistics on Secondary Data

No. of obs.	5,802,369
No. of barcodes	3,063
No. of categories	34
	Cost Statistics
Average	753.5
Median	567.0
Standard dev.	711.6

Notes. Cost data come from a single retail chain. The data covers the period spanned between weeks 30 of 2005 and week 24 of 2008. Cost statistics are expressed in nominal Chilean pesos.

Table 4. Importance of Reference Prices

Fraction of Posted Prices At, Below, and Above Reference Prices

	Chahrour's Definition			EJR's Definition		
Chain	At Reference (%)	Below Reference (%)	Above Reference (%)	At Reference (%)	Below Reference (%)	Above Reference (%)
B. Azul	76.1	20.8	3.1	77.6	16.3	6.1
Economax	82.1	16.3	1.6	83.3	12.8	3.9
Ekono	80.3	17.4	2.4	79.1	10.9	10.0
Jumbo	27.9	58.9	13.2	28.9	54.9	16.1
Lider	72.0	24.4	3.6	75.2	13.8	10.9
Maicao	86.9	10.9	2.2	87.7	7.2	5.1
Montserrat	76.6	20.7	2.7	77.4	15.5	7.0
Pto. Cristo	79.1	18.8	2.2	79.9	12.4	7.7
Ribeiro	72.4	23.8	3.8	73.2	19.0	7.8
Santa Isabel	66.4	28.6	5.0	67.3	22.2	10.5
Unimarc	61.1	32.8	6.1	61.4	29.4	9.2
Pool	62.0	32.1	5.9	63.5	25.7	10.8

Notes. Chahrour's definition of reference prices is based on an algorithm that identifies a reference price as the most quoted price in a rolling window of 13 weeks centered in the current week. See the Appendix to Chahrour (2009) for a full description of the algorithm. EJR stands for Eichenbaum, Jaimovich and Rebelo (2010) who define a reference price as the most quoted price in a given calendar quarter.

Table 5. Importance of Reference Prices

Fraction of Total Revenue Made at Reference Prices, by Chain

	Chahrour's Definition			EJR's Definition		
Chain	At Reference (%)	Below Reference (%)	Above Reference (%)	At Reference (%)	Below Reference (%)	Above Reference (%)
B. Azul	64.6	30.4	5.0	64.4	9.1	26.5
Economax	65.1	31.3	3.6	66.7	7.4	25.8
Jumbo	19.4	65.9	14.7	20.4	19.1	60.6
Lider	61.4	33.0	5.6	66.3	14.6	19.1
Maicao	83.4	14.2	2.4	83.1	6.2	10.7
Montserrat	60.9	34.8	4.3	63.1	10.6	26.3
Pto. Cristo	64.9	30.9	4.2	67.0	11.8	21.2
Ribeiro	58.5	36.2	5.3	59.8	10.3	29.8
Santa Isabel	47.5	44.9	7.6	49.7	15.1	35.2
Unimarc	44.4	47.3	8.2	45.1	12.0	42.9
Pool	41.9	48.7	9.4	44.2	40.2	15.6

Note: Computations are made for the shorter period mid 2005- mid 2007 for which quantity data is available for all the stores. Chahrour's definition of reference prices is based on an algorithm that identifies a reference price as the most quoted price in a rolling window of 13 weeks centered in the current week. See the Appendix to Chahrour (2009) for a full description of the algorithm. EJR stands for Eichenbaum, Jaimovich and Rebelo (2010) who define a reference price as the most quoted price in a given calendar quarter.

Table 6. Frequency of Price Change

Summary Statistics Across Product Categories

	Posted		Reference (Chahrour)		Reference (EJR)	
	(1) Frequency	(2) Duration	(3) Frequency	(4) Duration	(5) Frequency	(6) Duration
Median	0.279	3.583	0.029	40.000	0.026	38.987
Mean	0.357	2.802	0.030	33.526	0.024	41.568
Weighted mean	0.294	3.402	0.040	25.000	0.032	31.183
Standard dev.	0.233	--	0.020	--	0.014	--

Note. The weighted median is obtained using the weights corresponding to the period mid 2005-mid 2007, for which quantity data is available for all stores. Statistics are computed for the median frequency across categories. Duration corresponds to "implied duration" computed as the reciprocal of the frequency of price change. Chahrour's definition of reference prices is based on an algorithm that identifies a reference price as the most quoted price in a rolling window of 13 weeks centered in the current week. See the Appendix to Chahrour (2009) for a full description of the algorithm. EJR stands for Eichenbaum, Jaimovich and Rebelo (2010) who define a reference price as the most quoted price in a given calendar quarter.

Table 7. Frequency of Price Changes by Retailer

Chain	Posted Prices		Reference Prices (Chahrour)		Reference Prices (EJR)	
	(1) Frequency	(2) Implied Duration	(3) Frequency	(4) Implied Duration	(5) Frequency	(6) Implied Duration
Bandera Azul	0.200	5.000	0.016	62.000	0.000	--
Economax	0.074	13.500	0.000	--	0.000	--
Ekono	0.161	6.200	0.032	31.000	0.032	31.000
Jumbo	0.843	1.186	0.077	13.000	0.053	19.000
Lider	0.165	6.057	0.037	26.800	0.030	33.000
Maicao	0.080	12.550	0.000	--	0.000	--
Montserrat	0.100	10.000	0.021	48.000	0.016	64.000
Puerto Cristo	0.098	10.250	0.027	37.000	0.020	50.000
Ribeiro	0.212	4.714	0.023	43.000	0.016	63.000
Santa Isabel	0.250	4.000	0.036	28.000	0.029	34.000
Unimarc	0.375	2.667	0.033	30.500	0.024	42.000
Median	0.165	6.057	0.027	37.000	0.020	50.000
Mean	0.233	4.300	0.027	36.395	0.020	50.020
St. Dev.	0.221	--	0.021	--	0.016	--

Notes. Frequency corresponds to the median frequency across chains of the frequency calculated at the barcode/store level. Implied duration computed as the reciprocal of frequency and expressed in weeks. Chahrour's definition of reference prices is based on an algorithm that identifies a reference price as the most quoted price in a rolling window of 13 weeks centered in the current week. See the Appendix to Chahrour (2009) for a full description of the algorithm. EJR stands for Eichenbaum, Jaimovich and Rebelo (2010) who define a reference price as the most quoted price in a given calendar quarter.

Table 8. Size of Price Changes

Summary Statistics Across Product Categories

	Posted Prices	Reference Prices (Chahrour)	Reference Prices (EJR)
	(1)	(2)	(3)
Median	0.025	0.043	0.049
Mean	0.024	0.044	0.048
Weighted median	0.027	0.047	0.057
Standard dev.	0.011	0.019	0.026

Notes. Weighted median calculated using revenue shares for the period mid 2005-mid 2007. Chahrour's definition of reference prices is based on an algorithm that identifies a reference price as the most quoted price in a rolling window of 13 weeks centered in the current week. See the Appendix to Chahrour (2009) for a full description of the algorithm. EJR stands for Eichenbaum, Jaimovich and Rebelo (2010) who define a reference price as the most quoted price in a given calendar quarter.

Table 9. Size of Price Changes by Retailer

	Posted Prices	Reference Prices (Chahrour)	Reference Prices (EJR)
	(1)	(2)	(3)
Bandera Azul	0.031	0.046	0.052
Economax	0.033	0.062	0.075
Ekono	0.022	0.061	0.068
Jumbo	0.010	0.012	0.016
Lider	0.032	0.055	0.069
Maicao	0.027	0.053	0.059
Montserrat	0.046	0.059	0.070
Puerto Cristo	0.026	0.049	0.058
Ribeiro	0.022	0.051	0.058
Santa Isabel	0.029	0.052	0.062
Unimarc	0.037	0.046	0.053
Median	0.029	0.052	0.059
Mean	0.028	0.050	0.058
St. Dev.	0.009	0.014	0.016

Notes. Chahrour's definition of reference prices is based on an algorithm that identifies a reference price as the most quoted price in a rolling window of 13 weeks centered in the current week. See the Appendix to Chahrour (2009) for a full description of the algorithm. EJR stands for Eichenbaum, Jaimovich and Rebelo (2010) who define a reference price as the most quoted price in a given calendar quarter.

Table 10. Importance of Chain-Level Modal Prices

Fraction of Posted Prices at the Mode

Bandera Azul	0.935
Economax	0.909
Jumbo	0.396
Lider	0.813
Maicao	0.932
Montserrat	0.912
Puerto Cristo	0.876
Ribeiro	0.868
Santa Isabel	0.788
Unimarc	0.710
Median	0.872
Mean	0.814
St. Dev.	0.163

Notes. Modal prices are computed as the mode of prices for a given product across stores within a chain.

Table 11. Frequency of Modal Price Change

	Frequency	Duration
Bandera Azul	0.281	3.565
Economax	0.134	7.490
Jumbo	0.781	1.280
Lider	0.138	7.228
Maicao	0.127	7.869
Montserrat	0.181	5.523
Puerto Cristo	0.143	6.997
Ribeiro	0.244	4.094
Santa Isabel	0.237	4.221
Unimarc	0.242	4.139
Median	0.209	4.872
Mean	0.251	5.241
St. Dev.	0.195	2.138

Notes. Modal prices are computed as the mode of prices for a given product across stores within a chain.

Table 12. Variance Decomposition of Frequency of Modal Price Change

$$Y_{ik} = \mu + \alpha_k + \beta_i + \varepsilon_{ik}$$

Component	Estimate	Explained variance (%)
product	0.0015 (0.0003)	1.5
Chain	0.0716 (0.0254)	70.5
Residual	0.0285 (0.0254)	28.0

Note. Standard error in parenthesis. Model estimated by Maximum Likelihood.

Table 13. Comovement of Prices Within and Across Retail Chains

$$Corr_{kcl} = \beta_0 + \beta_1 INTRA_l + \sum_{k=1}^{K} \delta_k D_k + \sum_{c=1}^{C} \gamma_c F_c + \varepsilon_{kcl}$$

Panel A. Reference Prices	
$INTRA_l$	0.2943
	(0.0008)
Adj. R2	0.3067
N	598,826
Panel B. Posted Prices	
$INTRA_l$	0.3009
	(0.0007)
Adj. R2	0.3565
N	598,826

Notes. The dependent variable is the correlation coefficient between the monthly averaged prices (in levels) of product *k* in category *c* in a pair of stores indexed by *l*. The model is estimated by OLS. Standard errors in parenthesis.

Table 14. Variance Decomposition of Frequency of Reference Price Adjustment

$$Y_{ijk} = \mu + \alpha_k + \beta_i + \gamma_j + \varepsilon_{ijk}$$

Component	Estimate	Explained variance (%)
product	4.53E-11 (2.07E-08)	1.79E-06
Chain	0.0016 (0.0003)	63.8
Store	0.0007 (0.0007)	27.5
Residual	0.0002 (0.0070)	8.7

Note. Standard error in parenthesis. Model estimated by Maximum Likelihood.

Table 15. Frequency of Cost Change

Summary Statistics Across Product Categories

	Posted		Reference (Chahrour)		Reference (EJR)	
	(1) Cost	(2) Price	(3) Cost	(4) Price	(5) Cost	(6) Price
Median	0.104	0.200	0.049	0.033	0.032	0.029
Mean	0.117	0.205	0.046	0.032	0.030	0.027
Standard dev.	0.068	0.059	0.020	0.010	0.012	0.007

Notes. Even numbered columns present price frequencies computed across the same categories for which cost frequencies were calculated for comparison purposes. Chahrour's definition of reference prices is based on an algorithm that identifies a reference price as the most quoted price in a rolling window of 13 weeks centered in the current week. See the Appendix to Chahrour (2009) for a full description of the algorithm. EJR stands for Eichenbaum, Jaimovich and Rebelo (2010) who define a reference price as the most quoted price in a given calendar quarter.

Table 16. Size of Cost Changes

Summary Statistics Across Product Categories

	Weekly Costs	Reference Costs (Chahrour)
	(1)	(2)
Median	0.012	0.023
Mean	0.015	0.024
Standard dev.	0.012	0.012

Table 17. Markups and Cost Adjustments

A. Posted Markups	
$E[\mu \mid \Delta C > 0] - E[\mu \mid \Delta C = 0]$	-0.0209*** (0.0002)
$E[\mu \mid \Delta C < 0] - E[\mu \mid \Delta C = 0]$	-0.0173*** (0.0002)
B. Reference Markups	
$E[\mu^{ref} \mid \Delta C^{ref} > 0] - E[\mu^{ref} \mid \Delta C^{ref} = 0]$	-0.0268*** (0.0008)
$E[\mu^{ref} \mid \Delta C^{ref} < 0] - E[\mu^{ref} \mid \Delta C^{ref} = 0]$	0.2924*** (0.0012)

Note: (***) denotes significance at 1 percent level.

Table 18. Markup Volatility by Product Category

Category	Volatility
CLOTHES STAIN REMOVER	0.053
VEGETABLE OIL	0.047
WATER	0.052
HAIR CONDITIONER	0.043
SODA	0.040
COFFEE	0.054
TOOTHBRUSH	0.039
CEREAL BAR	0.065
BREAKFAST CEREAL	0.052
BEER	0.033
COCKTAIL	0.058
HOME SPRAY	0.029
DEODORANTS	0.033
CLOTHES DETERGENT	0.034
PASTA	0.048
WOMEN FRAGRANCES	0.042
MEN FRAGANCES	0.043
FROZEN FOOD	0.049
CANNED FRUITS	0.057
COOKIES AND CHOCOLATES	0.062
CHLORINE (BLEACH)	0.035
RAZOR BLADES	0.040
INSECTICIDE	0.044
TOILET SOAP	0.049
DISH WASHER	0.039
RON LIQUOR	0.055
FRUIT JUICES	0.050
BABYFOOD	0.042
TOOTHPASTE	0.029
SHAMPOO HAIRCARE	0.047
CLOTH SOFTENER	0.072
TEA	0.062
WHISKY	0.043
Median	0.047
Mean	0.047
Standard dev.	0.010

Table 19. Within Store Synchronization by Chain

Fisher-Konieczny Index

Chain	Average	St. Dev.
Bandera Azul	0.409	0.006
Economax	0.249	0.055
Ekono	0.360	0.092
Jumbo	0.079	0.018
Lider	0.235	0.031
Maicao	0.320	0.059
Montserrat	0.207	0.041
Puerto Cristo	0.199	0.135
Ribeiro	0.335	0.046
Santa Isabel	0.167	0.036
Unimarc	0.184	0.020
Median	0.250	0.041
Mean	0.235	0.049
St. dev.	0.098	0.037

Table 20a. Variance Decomposition of Within-Category Fisher-Koniezczny Index (posted prices)

$$FK_{krs} = \mu + \alpha_k + \beta_r + \gamma_s + \varepsilon_{krs}$$

Component	Estimate	Explained variance (%)
Category	0.0324 (0.0036)	42.1
Chain	0.0266 (0.0120)	34.6
Store	0.0011 (0.0001)	1.4
Residual	0.0169 (0.0002)	22.0

Note. Standard error in parenthesis. Model estimated by Restricted Maximum Likelihood.

Table 20b. Variance Decomposition of Within-Category Fisher-Koniezczny Index (reference prices)

$$FK_{krs} = \mu + \alpha_k + \beta_r + \gamma_s + \varepsilon_{krs}$$

Component	Estimate	Explained variance (%)
Category	0.0420 (0.0047)	54.0
Chain	0.0118 (0.0054)	15.2
Store	0.0015 (0.0002)	1.9
Residual	0.0224 (0.0002)	28.8

Note. Standard error in parenthesis. Model estimated by Restricted Maximum Likelihood.

Table 21. Synchronization in Across-Stores Reference Price Adjustment

Results of Probit Estimation

$$Y_{srt} = \beta_0 + \beta_1 FRACOWN_{srt} + \beta_2 FRACOTHER_{srt} + \zeta_t + \varepsilon_{srt}$$

Variable	Coefficient	Marginal Effect
$FRACOWN_{srt}$	3.923***	0.675***
	(0.002)	(0.001)
$FRACOTHER_{srt}$	-0.081***	-0.013***
	(0.003)	(0.001)

Note. Standard error in parenthesis. (***) denotes significance at 1 percent level.

Figure 1. Posted and Attractor Prices for Selected Products

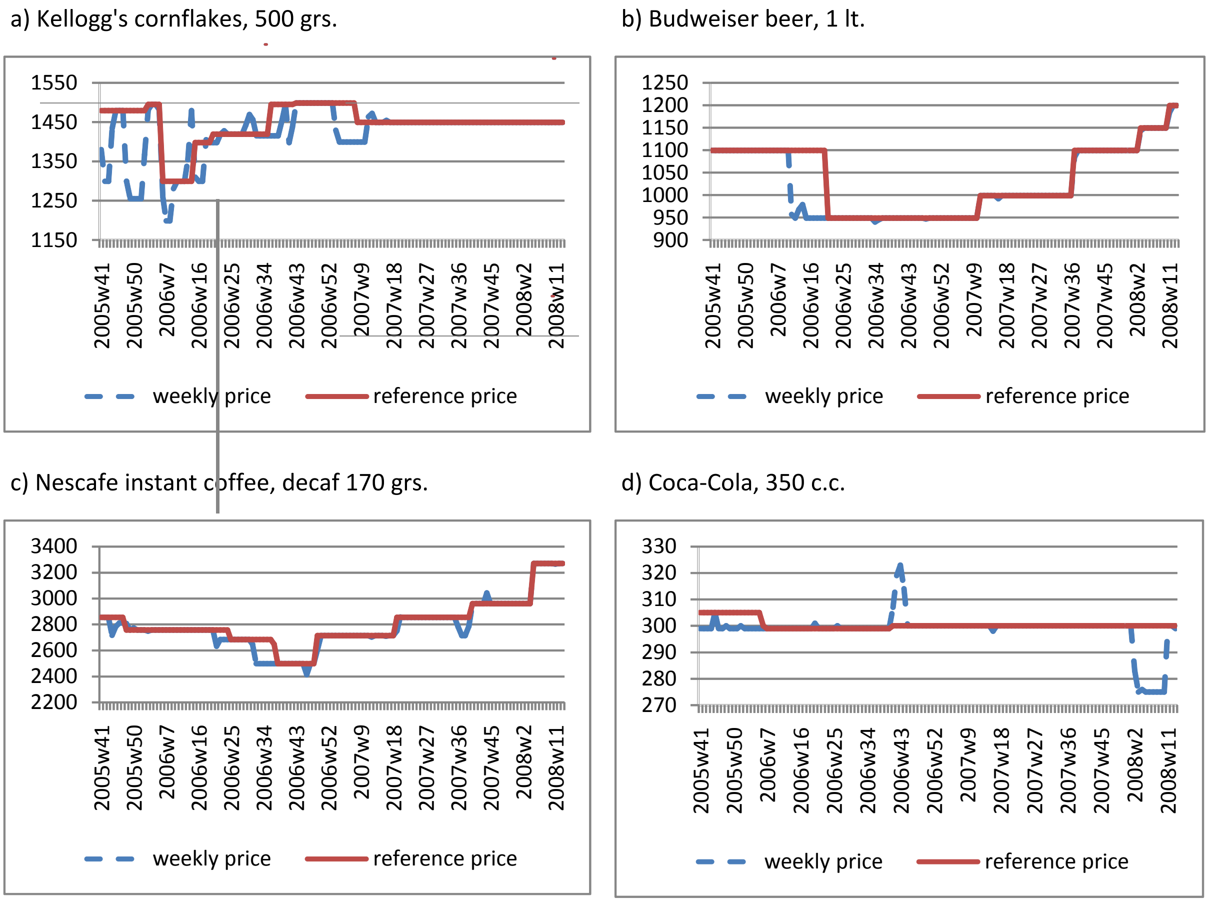


Figure 2. Importance of Reference Prices.

Fraction of Time Spent by Posted Prices at Reference Levels, by Category

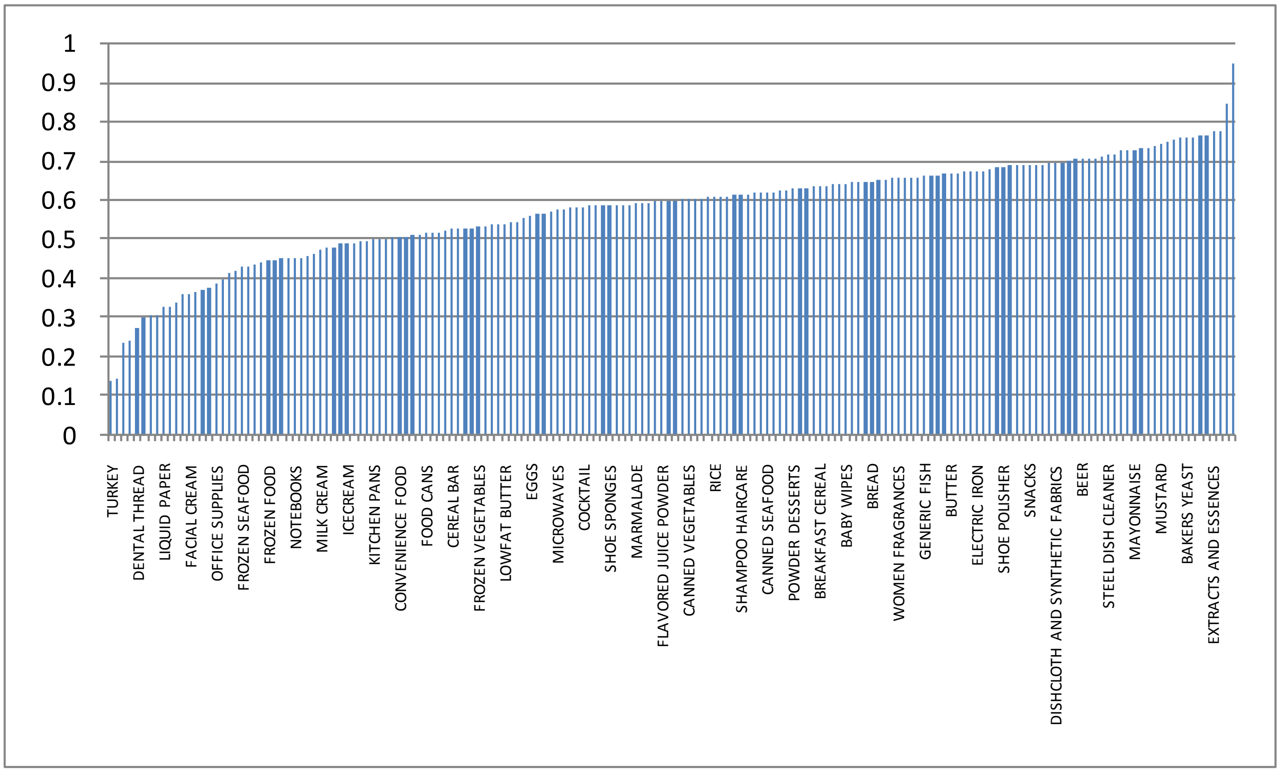


Figure 3. Frequency of Posted Price Changes by Category

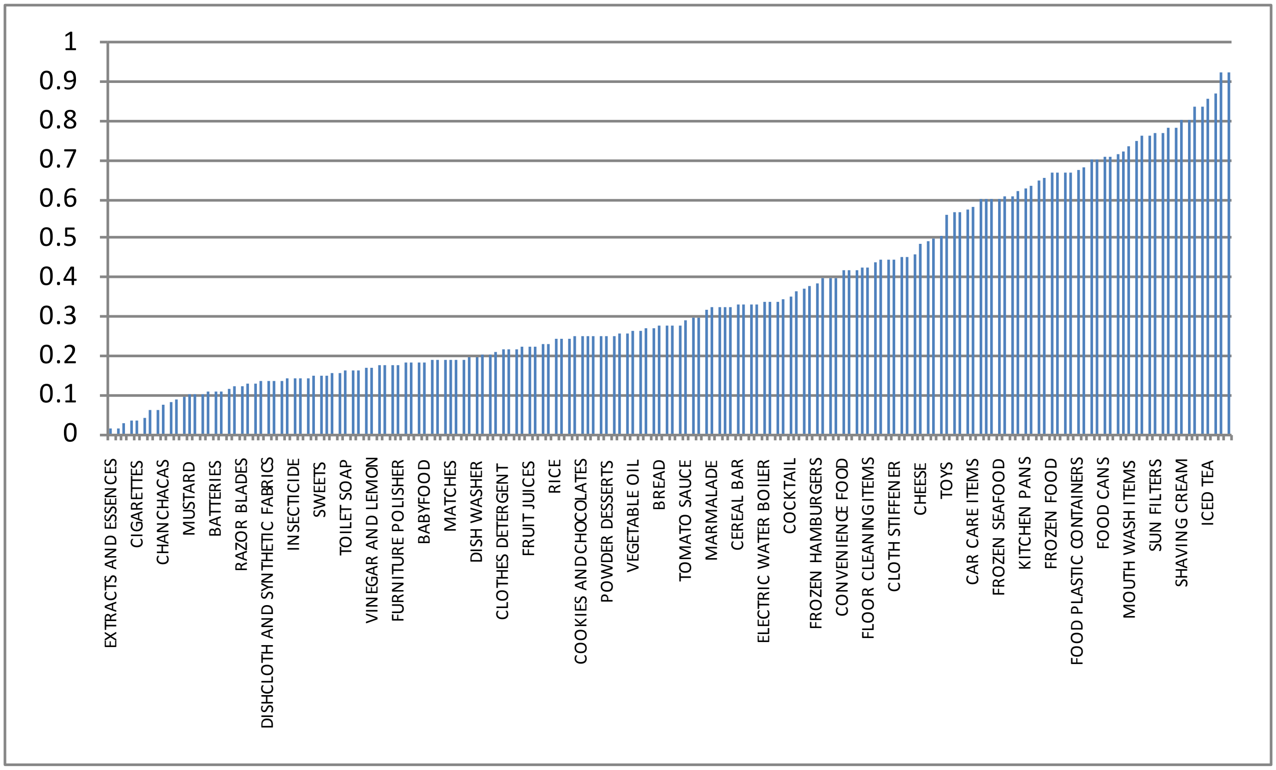


Figure 4. Frequency of Attractor Prices by Category

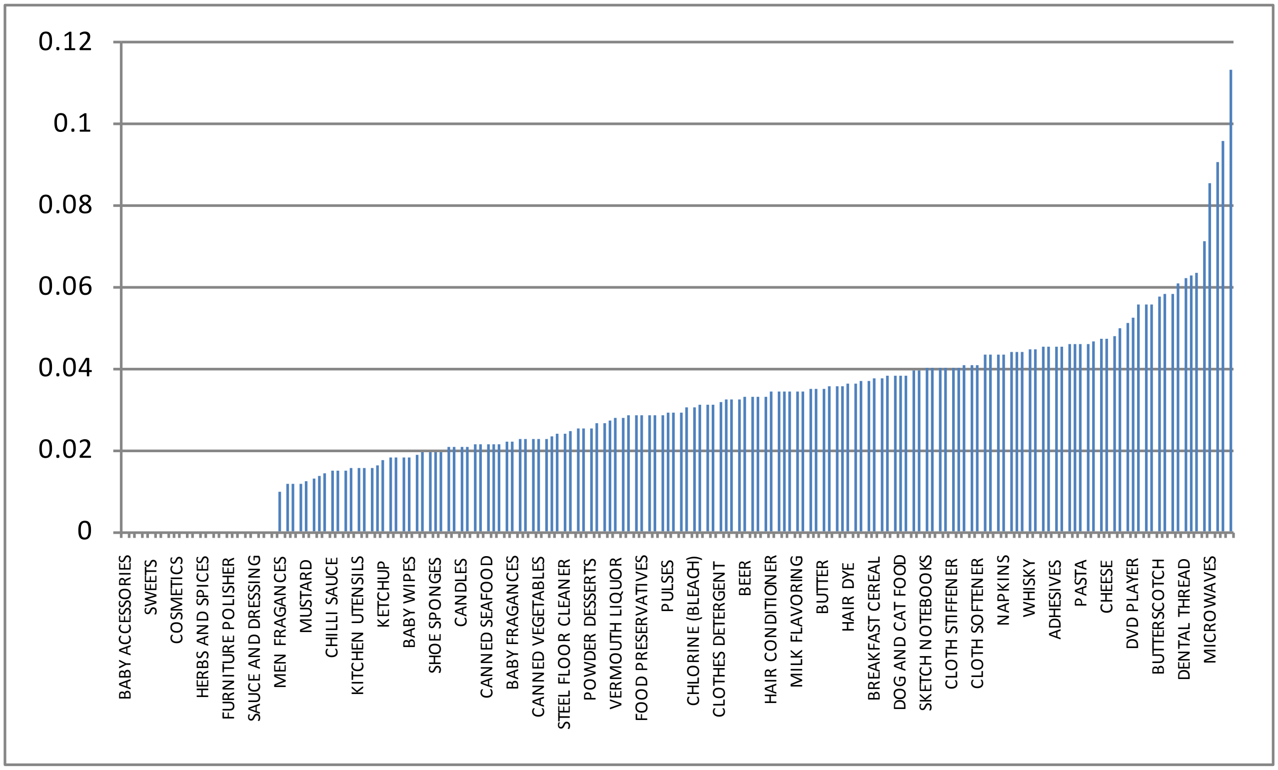


Figure 5a. Hazard Function for Posted Prices

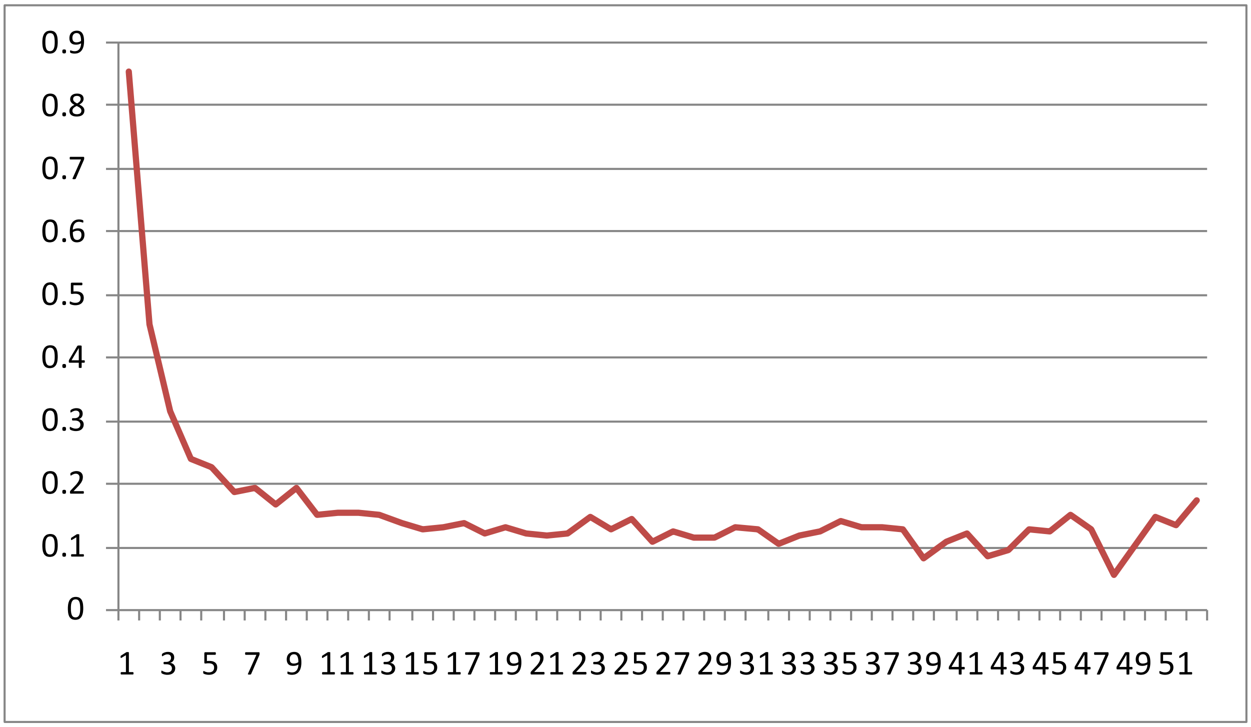


Figure 5b. Adjusted Hazard Function for Posted Prices

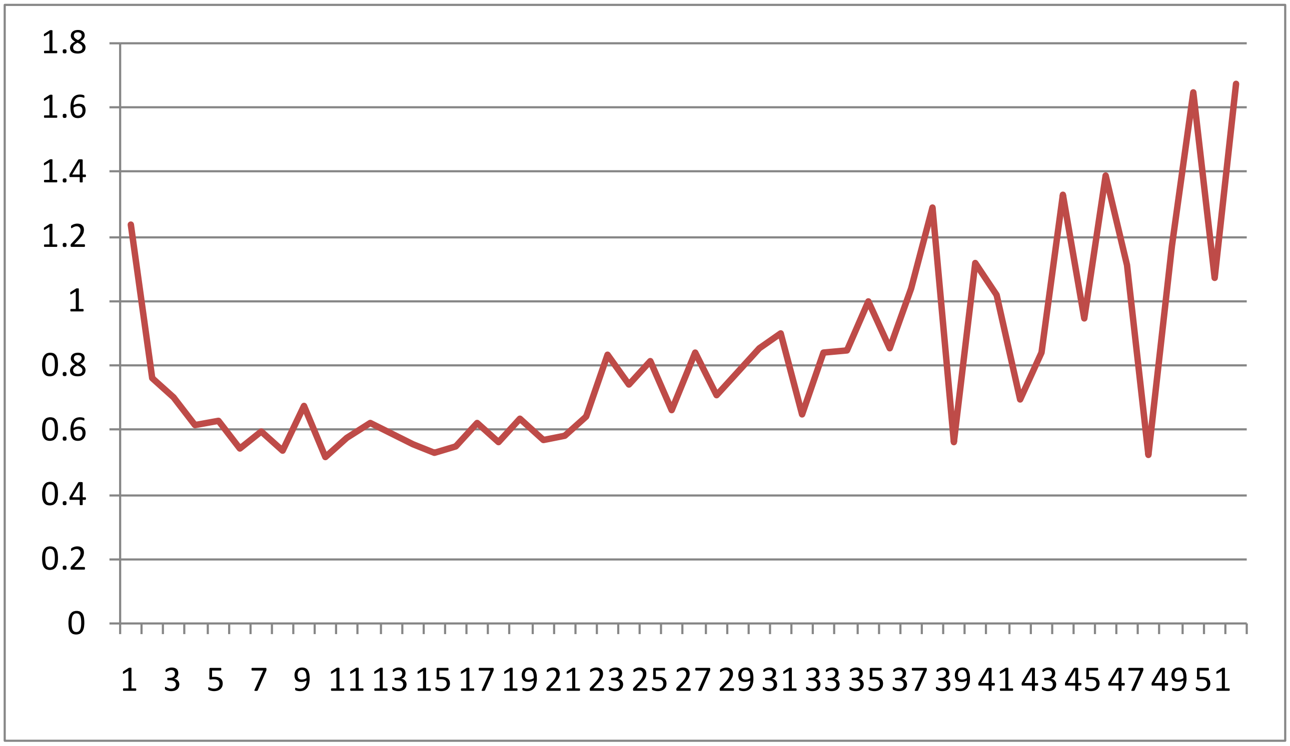
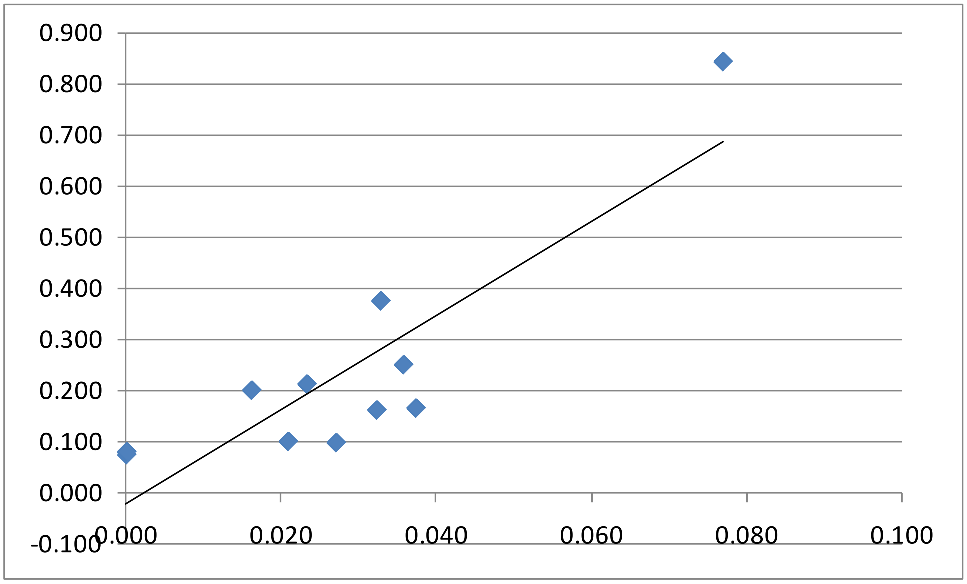


Figure 6. Reference Price versus Posted Price Frequencies by Chain



Notes. Chain level frequencies are computed as the average frequency of price adjustment within chains.

Figure 7a. Frequency of Posted Cost Changes

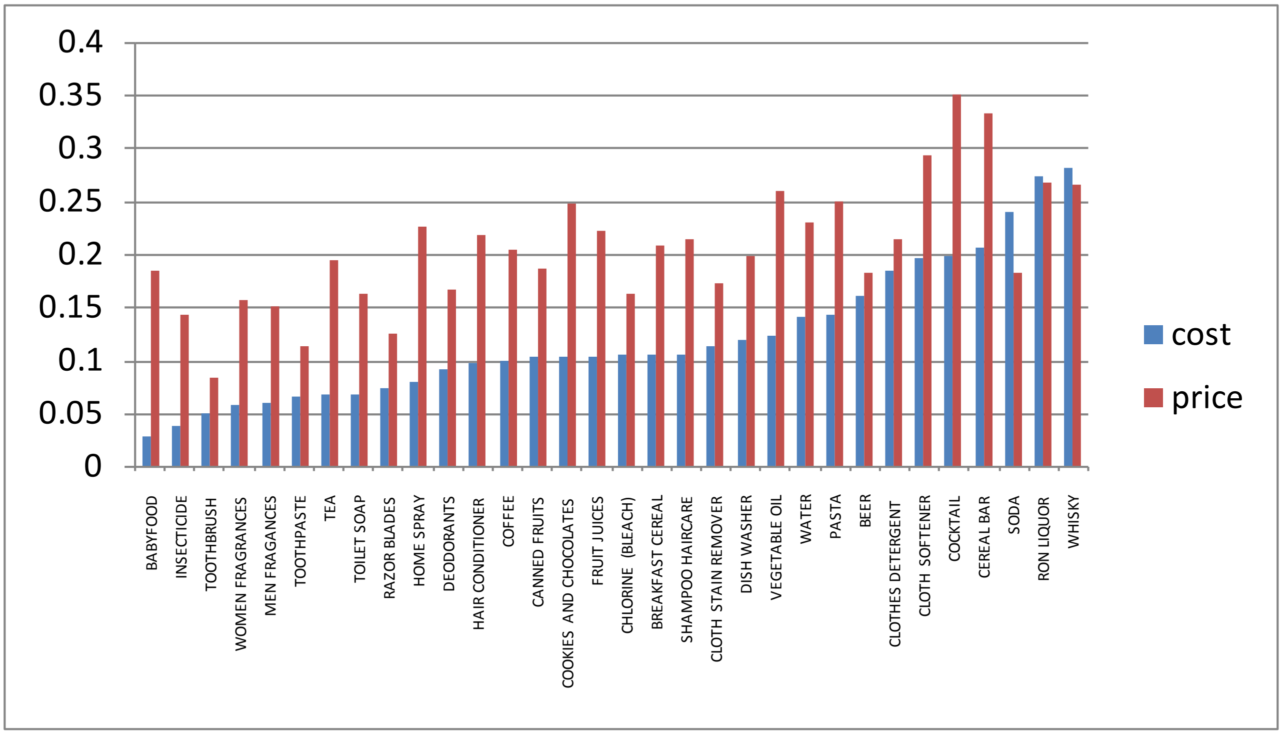


Figure 7b. Frequency of Reference Cost Changes

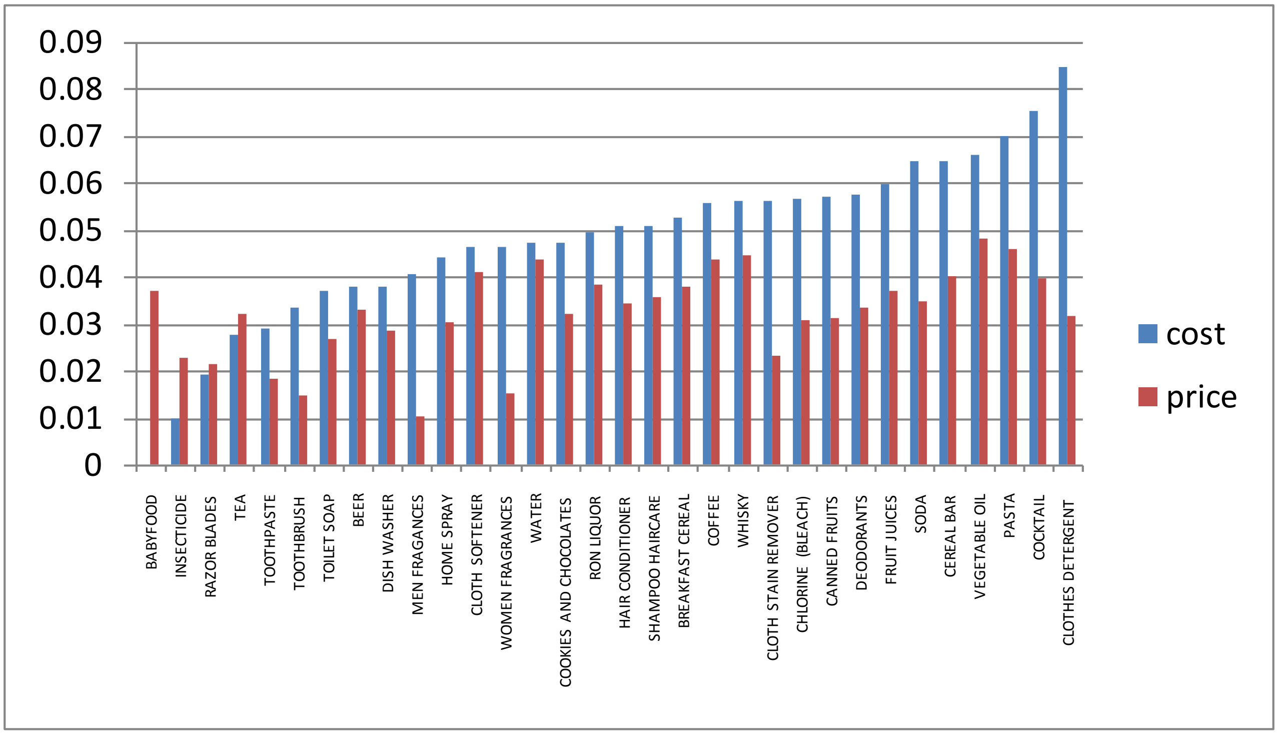


Figure 8. Cross-Sectional Markup Deviations

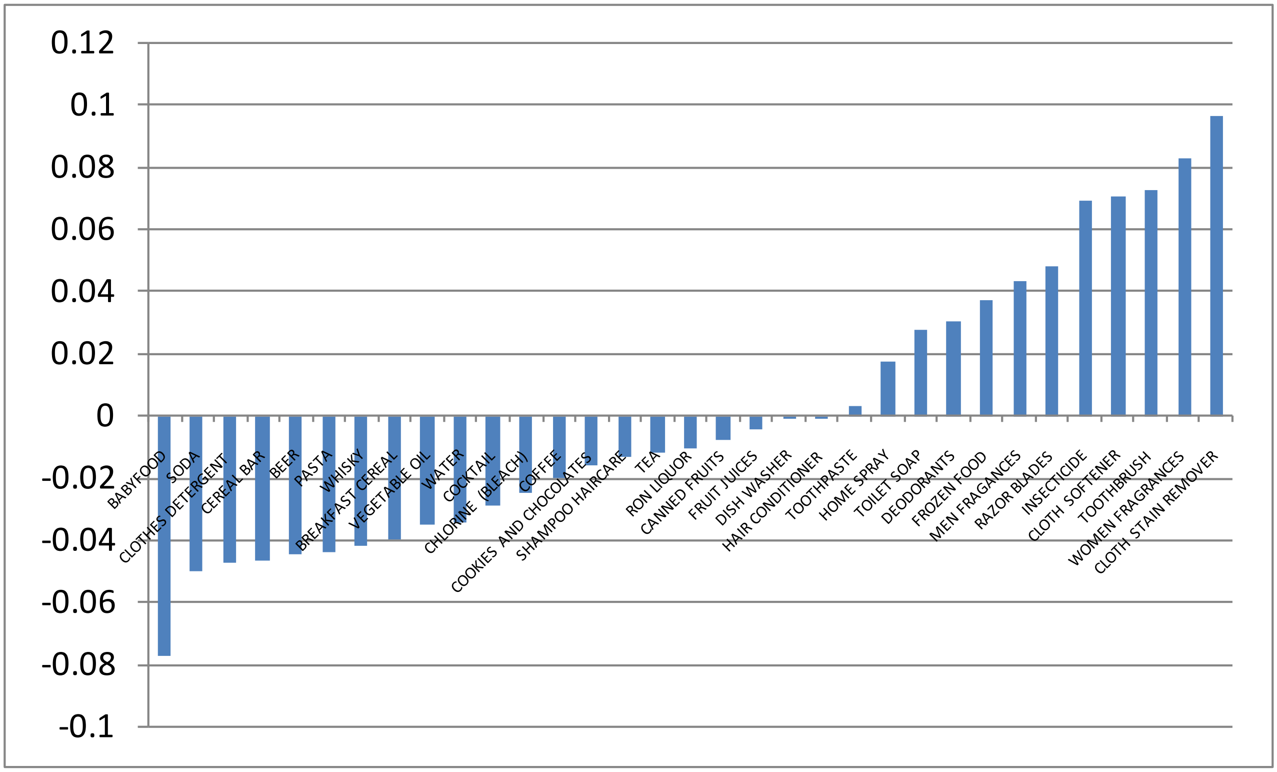


Figure 9. State Dependent Pricing: Deviation from Reference Markup and Probability of Price Change

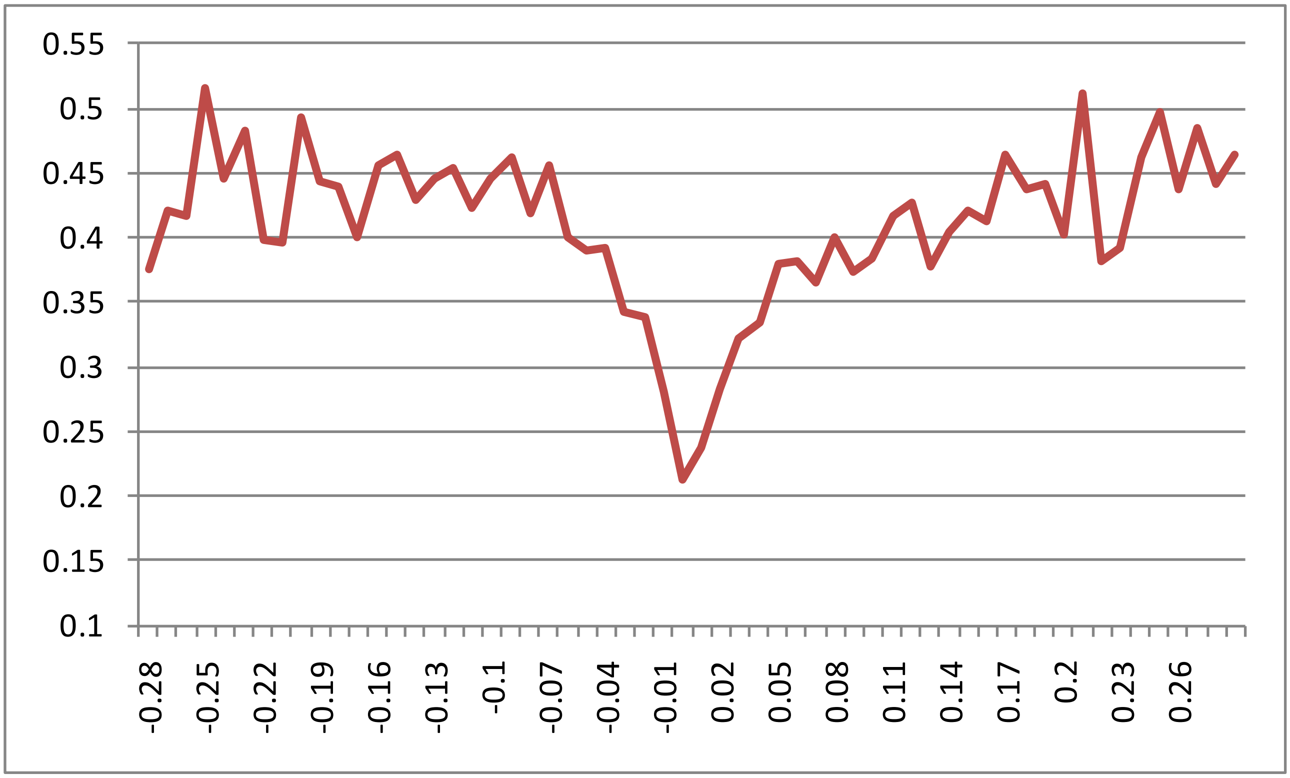


Figure 10. Distribution of the Proportion of Price Changes within a Store

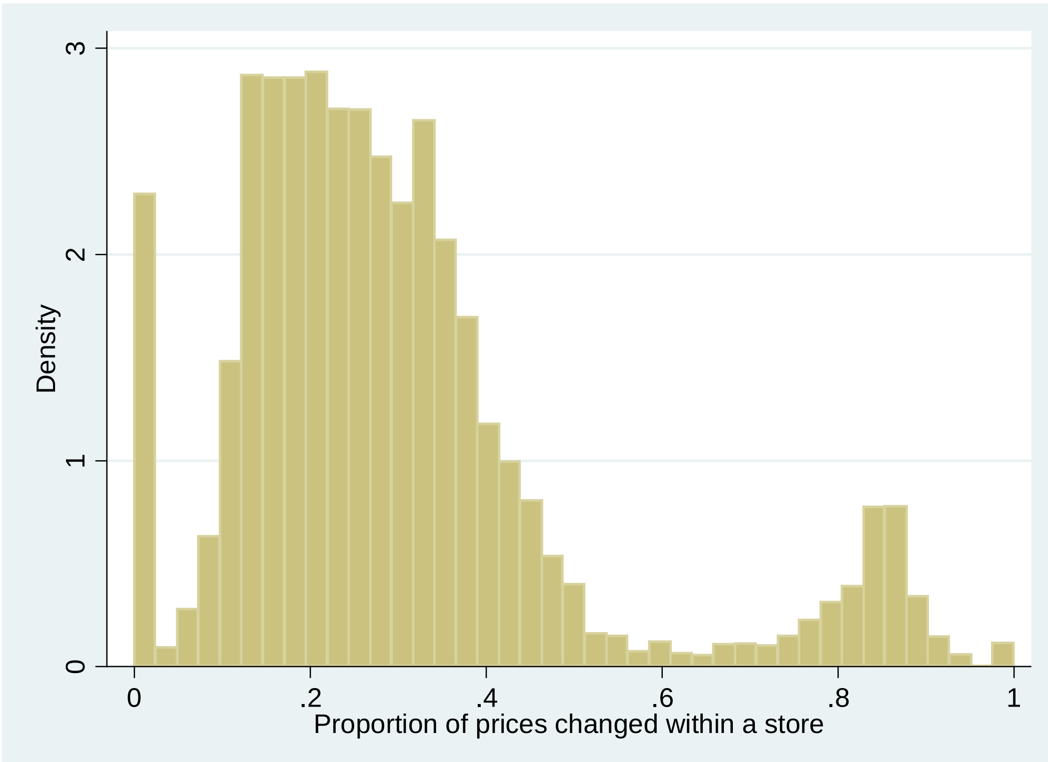


Figure 11. Within Store Price Synchronization

Distribution of Fisher-Konieczny Index for Posted Prices

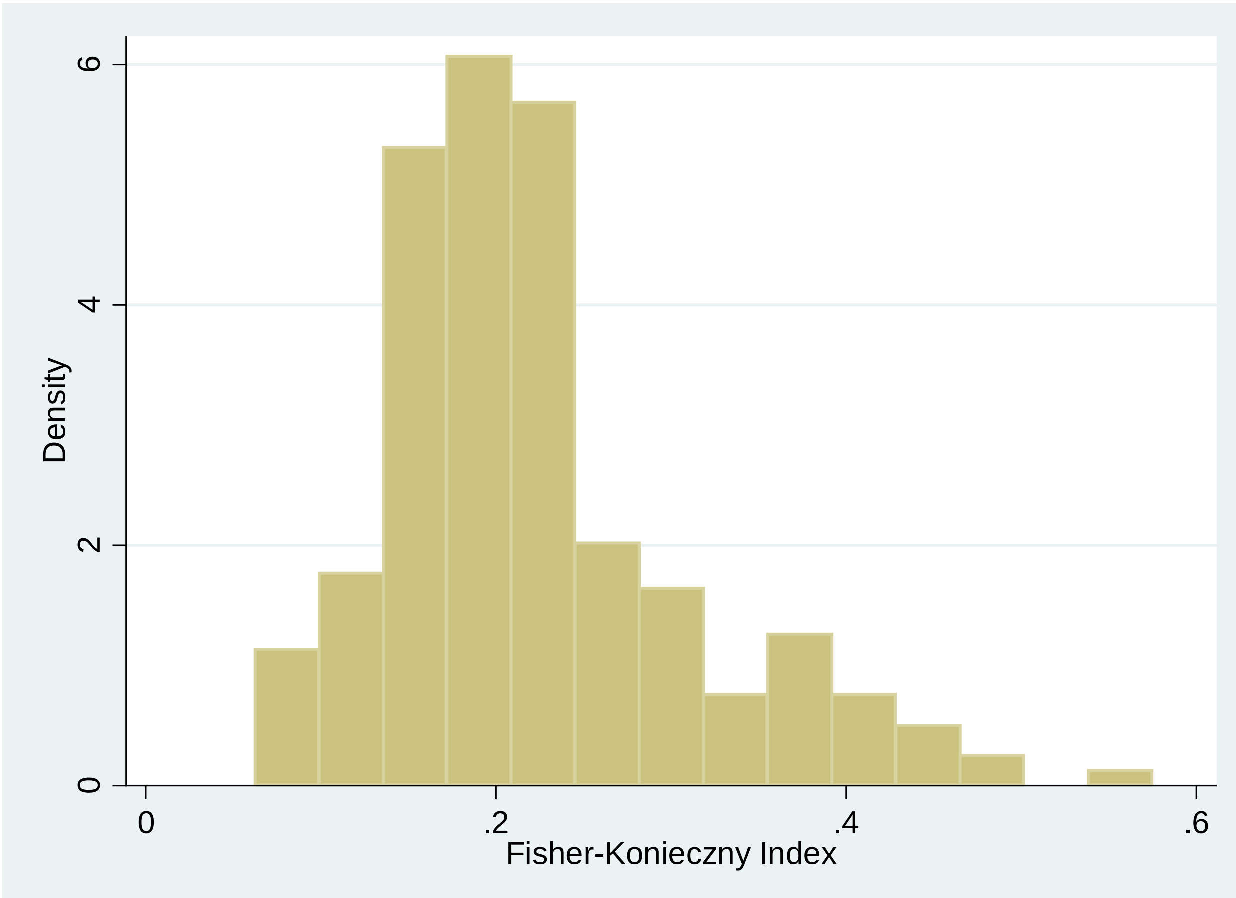


Figure 12. Synchronization of Price Changes within Product Categories

Distribution of Fisher-Konieczny Index

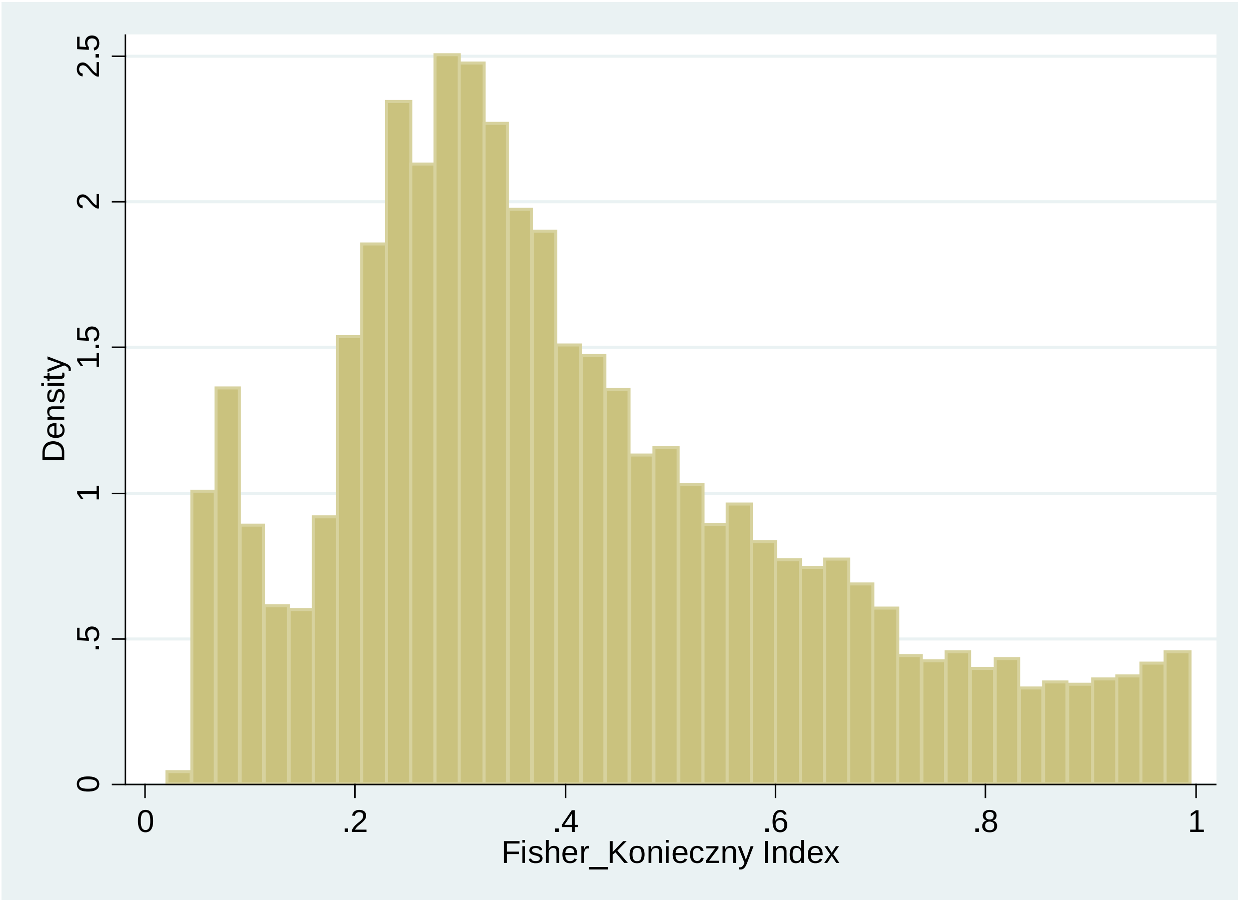


Figure 14. Synchronization of Price Changes Across Stores

Distribution of Fisher-Konieczny Index