

NBER WORKING PAPER SERIES

REFERENCE PRICES AND NOMINAL RIGIDITIES

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Working Paper 13829
<http://www.nber.org/papers/w13829>

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
March 2008

We would like to thank Liran Einav, Pete Klenow, John Leahy, Aviv Nevo, Frank Smets, and Sofia Villas-Boas for their comments. We gratefully acknowledge financial support from the National Science Foundation. The views expressed herein are those of the author(s) and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 13829
March 2008
JEL No. E30

ABSTRACT

We assess the importance of nominal rigidities using a new weekly scanner data set from a major U.S. retailer, that contains information on prices, quantities, and costs for over 1,000 stores. We find that nominal rigidities are important but do not take the form of sticky prices. Instead, nominal rigidities take the form of inertia in reference prices and costs, defined as the most common prices and costs within a given quarter. Weekly prices and costs fluctuate around reference values which tend to remain constant over extended periods of time. Reference prices are particularly inertial and have an average duration of roughly one year. So, nominal rigidities are present in our data, even though weekly prices change very frequently, roughly once every two weeks. We argue that the retailer chooses the frequency with which it resets reference prices so as to keep the realized markups within plus/minus twenty percent of the desired markup over reference cost.

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1. Introduction

A central question in macroeconomics is whether nominal rigidities are important. In addressing this question the literature generally assumes that these rigidities take the form of sticky prices, that is, prices that stay constant over an extended period of time. From this perspective, assessing the importance of nominal rigidities means evaluating how often prices change. In this paper we argue that nominal rigidities are important but they do not necessarily take the form of sticky prices. Rather, in the data set that we examine, these rigidities take the form of inertia in ‘reference prices.’ By reference price we mean the most often quoted price within a given time period, say a quarter. In our data set prices change very frequently: the median price duration is only three weeks. However, the duration of reference prices is almost one year.

Our analysis is based on a new weekly scanner data set from a major U.S. retailer, that contains information on prices, quantities, and cost for over 1,000 stores. We find that reference prices are important, in the sense that a high percentage of price observations correspond to reference prices, half of all quantities sold are sold at reference prices, more than half of the sales revenue is collected at reference prices, and the variance of quantities sold at reference prices is roughly the same as the variance of quantities sold at non-reference prices.

Reference prices serve as an attractor around which weekly prices revolve. When prices move away from the reference price (either by increasing or decreasing), they often return to the reference price. In fact, one third of all price changes in our data set involve movements from a non-reference price to a reference price. For illustrative purposes Figure 1 displays time-series observations on the prices of six of the 60,000 goods in our data set. For all these goods there is clear inertia in the reference price and prices tend to return to the reference price after having

deviated from it.

A unique feature of our data set is that it includes high-quality cost measures for each item sold by the retailer. We find that reference costs have a duration of roughly two quarters, while weekly costs have a duration of roughly two weeks. So, as with prices, nominal rigidities take the form of inertia in reference costs, rather than sticky costs.

We use our data set to shed light on how prices are related to costs. We find that prices are systematically but imperfectly related to costs. Strikingly, prices rarely change unless there is a change in cost. However, prices do not always change when costs change. Since changes in costs and prices are imperfectly related, there is substantial variation in realized markups.

Our analysis suggests that the retailer chooses the duration of reference prices so as to limit markup variation. We base this inference on three findings. First, in over 95 percent of the observations the realized weekly markup is between plus and minus twenty percent of the average markup.¹ Significantly, this pattern holds for groups of goods with different median reference price durations. Second, there is sharp evidence of state dependence in the probability of price changes. The probability of a price change is increasing in the difference between the markup that would obtain if the price did not change and the unconditional value of the markup. This pattern of state dependence holds both for weekly and reference prices. Third, when the retailer decides to change their reference prices it re-establishes the value of the unconditional markup, i.e. the retailer passes through all the changes in reference costs that have occurred since the last reference price change. Taken together, these findings support the view that the retailer chooses the duration of reference prices to keep markups within relatively narrow bounds.

¹Our agreement with the retailer does not permit us to report information about the level of the markup for any one item or group of items.

One of our objectives is to assess the empirical plausibility of competing pricing models that are used in macroeconomics. We document three other features of the data that are useful in this regard. First, demand shocks are pervasive. Second, there are many small price changes, both in weekly and in reference prices. Third, prices are more volatile than our measure of marginal cost, regardless of whether we work with weekly prices and costs or reference prices and costs.

We argue that our evidence is inconsistent with the three most widely used pricing models in macroeconomics: flexible price models, standard menu cost models, and Calvo-style pricing models. There is, however, a simple pricing rule that is consistent with our evidence. This rule can be described as follows. Prices do not generally change unless costs change. For any given good the nominal reference price is *on average* a particular markup over nominal reference cost. The retailer sets the frequency with which they reset the reference price so as to keep the actual markup within plus/minus twenty percent of the desired markup over reference cost. The unconditional markup and the duration of the reference price is good specific. When the retailer changes the reference price they re-establish the unconditional markup. With this rule reference prices can exhibit substantial nominal rigidities even though weekly prices change frequently.

Our paper is related to the recent literature which uses micro data sets to measure the frequency of price changes. The seminal article by Bils and Klenow (2004) argues that prices are quite flexible. Using monthly CPI data, they find that median duration of prices is 4.3 months. This estimate has become a litmus test for the plausibility of monetary models.² In contrast, Nakamura and Steinsson (2007) focus on non-sale prices and argue that these prices are quite inertial. When sales are excluded, prices change on average every 8 to 11 months. Kehoe

²See, for example, Altig, Christiano, Eichenbaum, and Linde (2004), and Golosov and Lucas (2006).

and Midrigan (2007) also examine the impact of sales on price inertia. They use an algorithm to define sales prices that they apply to weekly supermarket scanner data. They find that, when sales observations are excluded, prices change once every 4.5 months. When sales are included, prices change every 3 weeks. Excluding ‘sales prices’ from the data has a major impact on inference about price inertia. Not surprisingly, there is an ongoing debate in the literature about how to define a sale and whether one should treat ‘regular’ and ‘sales’ prices asymmetrically. An advantage of working with ‘reference prices’ is that we do not need to take a stand on what sales are or whether they are special events that should be disregarded by macroeconomists.

This paper is organized as follows. Section 2 describes our data and discusses the relation between our measure of cost and marginal cost. In Section 3 we compare the behavior of weekly prices and reference prices. In Section 4 we contrast the behavior of weekly costs and reference costs. In Section 5 we examine the importance of demand shocks and small price changes. In addition, we study the relative volatility of prices and costs. In Section 6 we discuss the implications of our empirical findings for various price-setting models. Section 7 contains concluding remarks.

2. Data

Our analysis is primarily based on scanner data from a large food and drug retailer that operates more than one thousand stores in different U.S. states. The sample period is 2004 to 2006. We have observations on weekly quantities and sales revenue for roughly 60,000 items in each of the retailer’s stores. By an item we mean a good, as defined by its universal product code (UPC), in a particular store. We only include items that are in the data set for a minimum of twelve weeks in every quarter of the entire three-year period. Most of the items in our data set

are in the processed food, unprocessed food, household furnishings, and “other goods” categories of the consumer price index (CPI).³ The retailer classifies items as belonging to one of 200 categories (e.g. cold cereal). We use the retailer’s classification in our analysis.

We use our data on sales revenue and quantities sold to compute the price for each individual item. The retailer adjust prices on a weekly basis, so daily movements in prices are not a source of measurement error in our weekly prices measures. Despite the high quality of scanner data there are several potential sources of measurement error associated with our price measure. First, some items are sold at a discount to customers who have a loyalty card. Second, some items are discounted with coupons. Third, there are two (or more) for one promotions. If there are changes over time in the fraction of customers who take advantage of these types of discounts, then our procedure for computing prices would produce spurious price changes. For these reasons, our estimates of the duration of weekly and reference prices are a lower bounds on the true duration statistics.

We construct a weekly measure of the retailer’s cost for each item in each store, using data on sales and adjusted gross profit. The latter is defined as:

$$\text{Adjusted gross profit} = \text{Sales} - \text{Cost of goods.}$$

The cost of goods is the vendor cost net of discounts and inclusive of shipping costs. This measure is the most comprehensive cost measure available to us.

The relation between our cost measure and marginal cost depends on the nature of the retailer’s production function. Suppose, for example, that to sell one unit of an item, the retailer must have one unit of that item and one unit of a composite factor produced using labor and capital. We denote by L the number of units of the composite factor and by w the price of this factor. The wholesale

³Examples of items in the “other goods” categories include laundry detergents, flowers, and magazines.

price of the item is given by c . It seems reasonable to assume that, in the short run, L is predetermined. Suppose that the cost of selling Y units of the item is given by:

$$C(Y) = \begin{cases} wL + cY & \text{if } Y \leq L, \\ wL + cL + \psi(Y - L) & \text{if } Y > L. \end{cases}$$

The firm chooses a scale of operation which is summarized by its choice of L . At any point in time, the number of customers entering the store, Y , need not equal L . When Y is greater than L the cost of providing the extra $Y - L$ goods is ψ . We assume that $\psi > w + c$. We can interpret $\psi - (w + c)$ as the implicit cost of a stockout, or the cost of meeting unusually high demand, say by hiring overtime labor and obtaining rush orders from the wholesaler. Nothing of importance that follows depends on this admittedly simplistic model of the cost of meeting unusually high demand.

The retailer chooses L to minimize the expected cost of selling Y units:

$$\min_L E[C(Y)] = \int_0^L (wL + cY) f(Y) dY + \int_L^\infty [wL + cL + \psi(Y - L)] f(Y) dY,$$

where $f(y)$ is the probability density function of Y . Here we make the simplifying assumption that c is known when L is chosen. The optimal value of L , L^* , satisfies:

$$F(L^*) = 1 - \frac{w}{\psi - c},$$

where $F(\cdot)$ denotes the cumulative density function of Y . Realized total cost is given by:

$$c(Y) = \begin{cases} wL^* + cY & \text{if } Y \leq L^*, \\ (w + c)L^* + \psi(Y - L^*) & \text{if } Y > L^*. \end{cases}$$

As long as $Y \leq L^*$ marginal cost is given by c . Under these circumstances, our cost measure is a very good proxy for marginal cost. When $Y > L^*$ our cost measure understates actual marginal cost.

There are other production functions for which our cost measure may not correspond closely to marginal cost. For example, suppose that retail output, Y , is given by:

$$Y = AL^{1-\alpha}Q^\alpha,$$

where Q is the number of items purchased by the retailer from the wholesaler. The cost of each item is given by c . As above, suppose that L is predetermined but optimally chosen. Then, short run marginal cost is given by:

$$C'(Y) = \frac{w^{1-\alpha}c^\alpha Y^{(1-\alpha)/\alpha}}{\alpha^\alpha (1-\alpha)^{1-\alpha} A \left[\int_0^\infty (Y^{1/\alpha}) f(Y) dY \right]^{1-\alpha}}.$$

Note that, absent uncertainty, marginal cost is constant.⁴ The presence of uncertainty makes marginal cost an increasing function of output. As α goes to one, short-run marginal cost approaches c . So, the higher α is the better our cost measure is as a proxy for marginal cost. In the remainder of the paper we proceed under the assumption that our cost measure is a reasonable proxy for marginal cost.

As a robustness check we use a second data set obtained from Dominicks, a chain of grocery stores in the Midwest with one hundred outlets. This data set has

⁴In this case, $C'(Y) = w^{1-\alpha}c^\alpha / [A\alpha^\alpha (1-\alpha)^{1-\alpha}]$.

been used in a variety of other studies (e.g. Chevalier, Kashyap, and Rossi (2003) and Midrigan (2006)). The Dominicks data set includes weekly observations on price and sales revenue for 3,500 items over the period 1989-1997. This set includes a cost measure. However, this measure does not correspond to the replacement cost or the last wholesale price at which Dominicks bought the item. Instead, it is the average acquisition cost of the items in inventory. Consequently, we do not use this cost measure.

Our scanner data has advantages and disadvantages relative to the consumer price index data used by authors such as Bils and Klenow (2004) and Nakamura and Steinsson (2007). A disadvantage is that our data sets do not cover all of the goods in the CPI. However, the median frequency of price change is the same for the items in our data sets and the CPI basket. In this sense, the items in our data set are not unrepresentative of those in the CPI basket. An important advantage of our scanner data is that it is available at a weekly frequency and includes information about quantities and costs, as well as prices.

Given the large number of items in our data set we must adopt a procedure to parsimoniously report our findings. Unless stated otherwise, the statistics that we report are computed as follows. First, we calculate the median value of a statistic across all items in a given category. We then compute the median of the 200 category medians.⁵

3. The behavior of prices

In this section we compare the behavior of reference prices and weekly prices. Recall that the reference price of an item is the most commonly observed price

⁵An alternative procedure would be to compute the median value of the statistic across all items in all categories. A disadvantage of this procedure is that it overweights categories such as cold cereal which have a large number of very similar items.

for that item within a quarter. We refer to all other prices as non-reference prices. Non-reference prices do not necessarily correspond to “sales prices.” In fact, 25 percent of non-reference prices in our sample are actually *higher* than the corresponding reference price (see Table 1). Figure 2 shows that there is substantial heterogeneity across categories in the fraction of non-reference prices that are higher than the corresponding reference price. The value of this statistic ranges from a low of 7.9 percent (for weight-control products) to a high of almost 100 percent (for grapes).

One might be concerned that reference prices just correspond to sticky prices. For example, if prices were literally constant, a reference price would account for 100 percent of the price observations. In fact, reference prices do not necessarily correspond to ‘sticky prices’. The median percentage of quarters across categories in which weekly prices are constant for an entire quarter is only ten percent. In fact reference prices are quite volatile. According to Table 2 reference prices are roughly 60 percent as volatile as weekly prices.⁶

The importance of reference prices Within a given quarter, weekly prices typically fluctuate between reference and non-reference prices. To summarize these within-quarter fluctuations we estimate a two-state Markov chain. In state one the weekly price is equal to the reference price. In state two the weekly price is different from the reference price. The average estimated Markov chain across categories is given by:⁷

⁶We obtain a similar finding for the relative volatility of new weekly prices and new reference prices (see Table 2).

⁷We estimate the transition matrix for the Markov chain for each item in every quarter in our sample and take the average over all quarters. We then compute the average transition matrix for items within a category. Finally, we compute the average transition matrix across categories.

$$M_p = \begin{bmatrix} 0.74 & 0.26 \\ 0.36 & 0.64 \end{bmatrix}. \quad (3.1)$$

It is evident from M_p that, for most weeks in a given quarter, the weekly price coincides with the reference price. Interestingly, the matrix M_p is consistent with the notion that prices have ‘memory.’ Non-reference prices return to a given reference price with 36 percent probability.

The matrix M_p pertains to within-quarter price fluctuations. We now quantify the importance of reference prices using statistics calculated across quarters. Unless otherwise indicated these statistics are reported in Table 1. First, 32 percent of all price changes involve movements from a non-reference price to a reference price. Second, the weekly price is equal to the reference price in 62 percent of the weeks. Third, half of the total quantities sold are sold at reference prices. Fourth, 56 percent of the revenue is collected at reference prices. Fifth, the standard deviation of quantities sold at reference prices is roughly the same as the standard deviation of quantities sold at non-reference prices (46 versus 51 percent, see Table 2). The first three observations imply that prices are often equal to reference prices and price movements are often movements toward reference prices. The last two observations imply that reference prices are important in terms of the level and volatility of quantities sold.

There is substantial heterogeneity in the importance of reference prices across categories. To illustrate this point, Figure 3 displays the distribution of weeks spent and quantities sold at the reference price.⁸ For 75 percent of the categories

⁸Recall that for a given item in a given quarter to be included in the data set we require that there be either 12 or 13 weeks of observations for that item and for that quarter. This rule implies that there are only 24 possible values (1/12, 2/12...12/12, 1/13, 2/13, ... 12/13) for the percentage of weeks spent at the reference price.

the price of the median item within a category is equal to the reference price more than 50 percent of the time. However, there are some extreme outlier categories. For magazines the price never changes in our sample. In contrast, for the categories grapes, bananas, and pears the weekly price coincides with the reference price only 8 percent of the time. The second panel of Figure 3 shows that, for 72 percent of the categories, the quantity of the median item sold at the reference price is above 40 percent of total sales. Again, magazines, bananas and pears are outlier categories.

Throughout this paper we calculate reference prices as the most common price within a quarter. We choose the quarter as the unit of time since most quantitative macro models use quarterly data. However, the basic reference phenomenon emerges even when we define reference prices as the most common price in a month. During the 36 month included in our sample 42 percent of the monthly reference prices are identical. So, even at the monthly frequency, there is a reference price that serves as an attractor around which weekly prices fluctuate.

Price persistence We now contrast the persistence properties of weekly prices and reference prices. According to Table 3 the probability of a weekly price change is 0.41. So, the implied duration of a weekly price is 0.19 of a quarter, or roughly 2.5 weeks.⁹ Panel A of Figure 4 displays the distribution of the duration of weekly prices across categories.¹⁰ All but four categories have a duration of weekly prices

⁹To facilitate comparisons with other estimates in the literature we calculate duration as the inverse of the frequency of price change. A shortcoming of this calculation is that it abstracts from the bias associated with Jensen's inequality (see Campbell and Eden (2005) for a discussion).

¹⁰Recall that for an item to be included in our data set we require that there be 12 quarters of data for this item. This rule implies that there are only 11 possible values for the frequency of reference price changes. The number of reference price changes can be equal to one, two,..., 11. Consequently there are 12 possible values for the quarterly frequency of reference price change, 0, 1/11, 2/11, ... 11/11. There are also 12 possible values for the duration of reference prices: ∞ , 11, 11/2, 11/3,... 1. In Figure 4 these quarterly durations are multiplied by 13 to convert

that is less than 10 weeks.¹¹ Clearly, weekly prices change all the time, so they do not exhibit nominal rigidities.

In sharp contrast to weekly prices, the probability of a reference price change is 0.27. So, the implied duration of reference prices is roughly 3.7 quarters (see Table 3).¹² Panel B of Figure 4 displays the distribution of the duration of reference prices across categories. This figure shows that 85 percent of the categories have reference price duration greater than 20 weeks. Clearly, there is substantial inertia in nominal reference prices.¹³ These prices exhibit nominal rigidities that are not revealed by studying weekly prices. So nominal rigidities can, in fact, be very important even though there are high frequency movements in prices.

Results for Dominicks data set We conclude this section by briefly discussing the results that we obtain with the Dominicks data set. As Tables 1 through 3 show, these results are very similar to those obtained with our primary data set. Reference prices are important. First, weekly prices are often equal to reference prices (77 percent of the weeks). Second, price movements are often movements toward reference prices. The fraction of price changes that are from a non-reference price to a reference price is 41 percent. Third, reference prices continue to be

them to weekly durations.

¹¹Since magazine prices never change in our sample, they have an infinite weekly price duration. For this reason we excluded magazines from the second panel of Figure 4.

¹²Intriguingly, this duration roughly coincides with the modal response that Blinder, Canetti, Lebow, and Rudd (1998) obtained when they asked firms: how often does the prices of your most important product change in a given year?

¹³The inertia of reference prices is different from the inertia of non-sales prices, when ‘sales’ are identified by the algorithm used by Kehoe and Midrigan (2007). Duration of non-sales prices, as defined by Kehoe-Midrigan, is roughly 4.5 months in our data set, while the duration of reference prices is roughly one year. Approximately half of the difference between these two duration statistics results from instances in which the weekly price is above the reference price. We reached this conclusion as follows. We modify our data set by setting the weekly price equal to the reference price whenever the former is higher than the latter. Applying the Kehoe-Midrigan algorithm to the modified data set we find that the duration of non-sales prices is seven months.

important in terms of the fraction of quantities sold at reference prices (66 percent) and the volatility of quantities sold at reference prices (41 percent).

Finally, we find the same sharp contrast between the duration of weekly and reference prices. The duration of weekly prices is 0.32 quarters while the duration of reference prices is roughly 3 quarters.

4. Reference costs

In this section we compare the behavior of reference costs and weekly costs. The former is defined as the most commonly observed cost for that item within a quarter. As with reference prices, one might be concerned that reference costs just correspond to sticky costs. This concern is not warranted. Across all categories, the median percentage of quarters in which weekly costs are constant is only six percent. In fact reference costs are quite volatile. According to Table 2 reference costs are roughly 60 percent as volatile as weekly costs.¹⁴

The importance of reference costs We summarize the within-quarter fluctuations in costs using a two-state Markov chain with the following states. In state one the weekly cost is equal to the quarterly reference cost. In state two the weekly cost is different from the reference cost. The average Markov chain across categories is given by:

$$M_c = \begin{bmatrix} 0.70 & 0.30 \\ 0.32 & 0.68 \end{bmatrix}.$$

The estimated Markov chain for costs is quite similar to the analogue Markov chain for prices. In most weeks in a given quarter, the weekly cost coincides with

¹⁴We obtain a similar finding for the relative volatility of new weekly costs and new reference costs (see Table 2).

the reference cost. And, as with prices, non-reference costs often return to a given reference cost.

To quantify the importance of reference costs we use statistics calculated across quarters. First, 29 percent of all cost changes involve movements from a non-reference cost to a reference cost (see Table 1). Second, the weekly cost is equal to the reference cost in 54 percent of the weeks in our sample (see Table 1). As with prices, there is substantial heterogeneity in the importance of reference costs across categories. Figure 5 displays the distribution of weeks in which the weekly cost is equal to the reference cost. There are some extreme outlier categories. For magazines the cost never changes in our sample. In contrast, for the categories grapes, bananas, and pears the weekly cost coincides with the reference price only 8 percent of the time.

Cost persistence As with prices, there is a sharp contrast between the persistence properties of weekly costs and reference costs. From Table 3 we see that the probability of a weekly cost change is 0.48. So, the implied duration of a weekly cost is 0.16 of a quarter, or roughly 2.1 weeks. Panel A of Figure 6 displays the distribution of duration of weekly costs across categories. Note that 97 percent of the categories have a duration of weekly costs that is less than or equal to eight weeks. Clearly, weekly costs do not exhibit significant nominal rigidities.

The probability of a reference cost change is 0.45. So, the implied duration of reference costs is roughly 2.2 quarters. Panel B of Figure 6 displays the distribution of durations of reference costs across categories. Roughly 77 percent of the categories have reference cost duration exceeding 20 weeks. Clearly, there is substantial inertia in nominal reference costs. The existence of nominal rigidities would not be revealed by analyzing weekly costs.

5. The determinants of price changes

In this section we investigate the relation between prices and costs. We begin by analyzing the probability of price changes conditional on cost changes and the volatility of markups. We then study state dependence in price changes and the endogeneity of reference price duration across goods. Finally, we investigate the relation between price changes and macroeconomic aggregates.

The relation between prices and cost changes A striking property of our data is that prices generally do not change absent a change in costs. In Table 1 we report that the probability that the weekly price changes without a change in the weekly cost is only one percent. The analogous probability for reference prices is 13 percent. Figure 7 shows the distribution of this probability across categories. Panel A pertains to weekly prices and costs, while panel B pertains to reference prices and costs. In both cases there is relatively little heterogeneity across categories.

While prices generally do not change absent a change in costs, a change in cost is not sufficient to induce a change in price. Consider, for example, the markup associated with the most common price over the three year sample.¹⁵ Figure 8 shows that there is non-trivial variation in this markup, so that the same price is associated with different costs.¹⁶

Table 1 presents additional evidence that changes in cost are necessarily associated with changes in prices. This table reports that, conditional on a change in the weekly cost, the probability that the weekly price changes is 88 percent. Conditional on a change in the reference cost, the probability of a change in the

¹⁵This price accounts for 38 percent of the weeks in our three-year sample.

¹⁶In this figure, as well as in Figure 9, we display the average, instead of the median, probability across the items in each category. We proceed in this way so that the probabilities across categories sum to one.

reference price is only 57 percent.

The fact that prices do not always change when costs change means that there are substantial variations in markups. According to Table 2 the standard deviation of the weekly markup is 12 percent. The standard deviation of the reference markup, defined as the standard deviation of the ratio of reference prices to reference costs, is 9 percent.

We now consider in greater detail the relation between markups and reference prices. To this end, we compute the percentage difference between the realized weekly markup and the mean unconditional markup for weeks in which the weekly price coincides with the reference price. Panel A of Figure 9 displays the distribution of this statistic. While there is substantial mass at zero, the markup is equal to the average markup in only 6 percent of the observations. Interestingly, 96 percent of the probability mass is between plus and minus twenty percent of the average markup. This finding suggests that the retailer resets its reference prices so that variations in the realized markup fall within a reasonably small interval.

To assess this hypothesis, we compute the analogue of Panel A, Figure 9 for different categories of goods, classified according to the median duration of the reference price. The results are displayed in Panel B of Figure 9 for groups of goods with median durations ranging from two to eleven quarters. All of the distributions are similar to those displayed in Panel A of Figure 9. This finding is consistent with the hypothesis that the retailer chooses the duration of the reference price for each item to keep realized markups within similar small bounds. Panel A of Figure 10 provides further evidence in support of this hypothesis. This figure shows that categories with a high probability of a reference cost change have a high probability of a reference price change.¹⁷ Panel B of Figure 10 shows that

¹⁷Recall that there are only 12 quarters in our sample, so the probability of a change in reference price or cost can only take a discrete number of values.

categories with a high probability of a weekly cost change have a high probability of a weekly price change.

Volatility of prices and marginal cost In our data set prices are more volatile than our measure of marginal cost. We obtain this result for both weekly prices and costs as well as reference prices and costs. The median of the ratio of the standard deviation of $\log(\text{weekly price})$ to the standard deviation of $\log(\text{weekly cost})$ is 1.05. The median (mean) of the ratio of the standard deviation of $\log(\text{reference price})$ to the standard deviation of $\log(\text{reference cost})$ is 1.11. We also find that prices are more volatile than costs if we focus on new prices and new costs or if we work in growth rates (see Table 2).

There is substantial heterogeneity in the relative volatility of prices and costs across categories. Figure 11 displays, for both weekly and reference prices, the distribution of these statistics across categories. The fraction of categories where weekly (reference) prices are more volatile than weekly (reference) costs is 58 percent (65 percent). We conclude that, regardless of whether we work with weekly or reference prices and costs, the volatility of prices generally exceeds that of marginal cost.

Is there state dependence? We note above that the probability that the reference price changes when the reference cost changes is 57 percent. A natural question to ask is whether there is any state dependence in the probability of reference price changes. To address this question, we define the ‘hypothetical reference markup’ as the reference markup that would obtain if the retailer did not change its reference price between quarter $t - 1$ and quarter t . Thus, the hypothetical reference markup is the ratio of the reference price in quarter $t - 1$ to the reference cost in quarter t . Panel A of Figure 12 displays the median probability

that the reference price changes as a function of the percentage deviation of the hypothetical reference markup from the average markup. The probability that the reference price changes when the hypothetical reference markup is equal to the mean markup is very low. Strikingly, the larger is the percentage difference between the hypothetical reference markup and the average markup, the larger is the probability of a change in reference prices. So, there is clear evidence of a selection effect with regards to changes in reference prices. Panel B of Figure 12 shows that this selection effect continues to be present when we group categories by reference price duration. Consistent with Figure 9, this result supports the hypothesis that the retailer chooses a reference price duration for each item to keep realized markups within small bounds that are similar for different items.

Weekly prices exhibit a similar pattern of state dependence. Define the “hypothetical weekly markup” as the ratio of the price in week $t - 1$ to the cost in week t . The realized markup coincides with the hypothetical markup if the retailer does not change its price in week t . Panel A of Figure 13 shows that the contemporaneous probability of a change in the weekly price increases with the percentage deviation of the hypothetical markup from its unconditional mean. So, there is evidence of a selection effect in weekly price changes.

Pass-through from costs to prices Suppose that a decision has been made to change the reference price. By how much does the reference price change? Panel C of Figure 12 displays the realized markup as a percentage deviation from the mean markup, conditional on the reference price changing. From this figure we see that the retailer sets the reference price so as to re-establish the average markup. Put differently, once the retailer decides to change its reference price it passes through 100 percent of the cumulative change in reference cost that occurred since the last reference price change. Panel B of Figure 13 shows a similar pattern for weekly

prices. When there is a weekly price change, the new markup is close to the unconditional markup.

6. Other useful statistics

In this section we document two additional features of the data that are useful for discriminating between alternative price setting models. These features pertain to the importance of demand shocks and small price changes.

Demand shocks Conditional on the weekly price being constant and equal to the reference price, the standard deviation of quantities sold is roughly 46 percent.¹⁸ This conditional volatility is roughly 75 percent of the unconditional volatility of quantities sold. Clearly, demand shocks are quantitatively important. Figure 14 shows the distribution of this statistic for different categories. The main finding is that there is not much heterogeneity across categories. Demand shocks seem to be important for most of the categories.

Small price changes In our data set there are many small weekly and reference price changes. Figure 15 displays the cumulative distribution of weekly and reference price changes between zero and ten percent. There is, of course, an element of arbitrariness in deciding what constitutes a small price change. Midrigan (2006) defines a small price change as a change that is smaller than 1/2 of the average price change. In his Dominicks data set the average price change is 7.6 percent, so a small price change is one that is less than 3.8 percent. In our data set, the average price change is 16 percent for both weekly and reference prices.

¹⁸A caveat to our calculation is that we are conditioning on the nominal price being constant instead of the real price being constant. By real price we mean the price of the good relative to the CPI basket. Since we focus on a short time period during which inflation is quite low, it seems unlikely that inflation effects are important for this calculation.

Given the large difference between the average and the median price change we focus on the latter. Applying the Midrigan definition to our data set, a small price change is roughly 6 percent. By this definition, roughly 1/3 of weekly and reference price changes are small. Consistent with Midrigan (2006) we conclude that there are many small price changes in our data set.

7. Reconciling different pricing models with our findings

In this section we discuss the implications of our empirical findings for three pricing models that are widely used in macroeconomics: flexible price models, menu cost models, and Calvo models.

Flexible price models The Dixit-Stiglitz model of monopolistic competition lies at the core of many flexible price macroeconomic models. In this model, the elasticity of substitution across different goods is constant. The optimal policy for each monopolist is to set the price (P_t) equal to a constant markup (μ) over marginal cost (C_t), $P_t = \mu C_t$. This model is clearly inconsistent with our data, since it implies that there should be no variation in the markup. Table 2 indicates that the standard deviation of the logarithm of the realized weekly markup and reference markup is 0.12 and 0.09, respectively.

It is possible to reconcile a flexible price model with the data by introducing demand shocks that generate markup fluctuations. But, matching the data requires an incredible configuration of cost and demand shocks. Consider the following simple specification in which demand takes the linear form:

$$P_t = a_t - b_t Q_t,$$

where Q_t represents the quantity sold. The variables a_t and b_t are stochastic demand shifters. The monopolist's variable profits, π_t are given by: $\pi_t = P_t Q_t -$

$C_t Q_t$, where C_t is the monopolist's cost. The monopolist's optimal price and quantity are given by:

$$P_t^* = \frac{a_t + C_t}{2},$$

$$Q_t^* = \frac{a_t - C_t}{2b_t}.$$

Changes in b_t only affect the quantity sold. Changes in a_t affect both price and quantity. Given observations on P_t^* , Q_t^* , and C_t , we can deduce the time series for a_t and b_t such that P_t^* and Q_t^* match the data exactly. We perform this calculation each of the roughly 60,000 items in our data set. Three key results emerge. First, the median standard deviation of $\log(a_t)$ and $\log(b_t)$ are 0.16 and 0.77, respectively. So, to match the data demand shocks the variable a_t must be roughly as volatile as prices and cost (see Table 2). The volatility of b_t must be higher than the volatility of quantities and roughly four times more volatile than prices and costs. We conclude that an empirically plausible flexible price specification must allow for volatile demand shocks. Second, the correlation between $\log(a_t)$ and $\log(b_t)$ is positive (0.7). This positive correlation helps the model match the negative unconditional correlation between prices and quantities, reported in Table 4, while allowing for volatile demand. Third, and most importantly, matching the data requires an implausible pattern of comovement between a_t and C_t . In at least 40 percent of our observations the same price corresponds to different costs.¹⁹ To match these observations, the change in a_t must *exactly* offset the change in C_t . Although possible, this pattern of shocks strikes us as incredible. A similar argument applies to Dixit-Stiglitz demand with stochastic

¹⁹This statistic is computed as follows. For each good we identify the modal price and cost over the three-year sample period. We then compute the fraction of weeks in which the price is equal to the modal price but the cost is not equal to the modal cost. This calculation provides a lower bound on the percentage of weeks in which the same price corresponds to different costs.

elasticity of substitution between goods. This specification generates variability in markup. However, it requires that in 40 percent of the observations shocks to the elasticity of substitution exactly offset movements in marginal cost in order to rationalize a constant price.

Menu cost models Standard menu cost models have three shortcomings with respect to our data. First, as noted by Midrigan (2006) and others, these models counterfactually imply that there should not be many small price changes. Second, Table 2 documents that prices are more volatile than marginal cost, whether we work with levels or growth rates. However, calibrated versions of menu cost models imply that prices are *less* volatile than marginal cost. For example, Golosov and Lucas' (2006) model implies that the unconditional standard deviation of cost changes are 40 percent more volatile than the unconditional standard deviation of price changes. A similar pattern obtains in Burstein and Hellwig's (2007) model, which incorporates demand shocks into the Golosov-Lucas framework. The unconditional standard deviation of cost changes is twice as large as the unconditional standard deviation of price changes in the Burstein-Hellwig model.²⁰ Third, we need an incredible configuration of cost and demand shocks to explain why firms return often to an old (reference) price.

Midrigan (2006) remedies the first shortcoming of standard menu cost models by assuming that, once the firm pays a menu cost to change one price, it can change some other price for free. Kehoe and Midrigan (2007) make progress on the third shortcoming by assuming that firms set two kinds of prices, 'regular' prices and 'sales' prices. Sales prices are temporary price reductions. After a sale is over the price returns to the 'regular' price. Kehoe and Midrigan assume that the menu cost associated with a sales price change is lower than the menu cost associated

²⁰We thank Ariel Burstein for computing the volatility of prices and costs in the Golosov-Lucas model and in the Burstein-Hellwig model.

with a regular price change. While interesting, their model is inconsistent with the fact that there are many small changes in both reference and non-reference prices. In principle one could remedy this shortcoming by combining Midrigan (2006) and Kehoe and Midrigan (2007). In particular, we could assume that: (i) once the firm pays a menu cost to change one reference price, it can change some other reference price for free; and (ii) once the firm pays a menu cost to change one non-reference price, it can change some other non-reference price for free. It remains an open question whether such a model can rationalize the fact that prices, both weekly and reference, are more volatile than marginal cost.

Calvo models Perhaps the most widely used pricing model in macroeconomics is the one associated with Calvo (1983).²¹ An obvious failing of standard Calvo (1983) pricing models is they are inconsistent with the selection effects that we document in Figures 12 and 13. The Calvo model assumes that the probability of a price change is constant. In fact, we find that the probability of a reference price change is increasing in the deviation of the realized markup from its unconditional mean. It also remains an open question whether standard Calvo pricing models are useful to understand data sets like ours in which prices are more volatile than costs.

A simple pricing rule We argue that our empirical findings pose a severe challenge for the kinds of pricing models routinely used in macroeconomics. Although we have not derived a pricing rule that is consistent with our findings, we can describe the properties of such a rule. These properties are as follows. Prices rarely change unless the cost changes. For any given good, a firm sets prices so that, *on average*, the nominal reference price is a particular markup over nominal

²¹See, for example, Rotemberg and Woodford (1997), Gali and Gertler (1999), Smets and Wouters (2003), and Christiano, Eichenbaum, and Evans (2005).

reference cost. Firms choose the frequency with which they reset reference prices so as to keep actual markups within plus/minus twenty percent of the desired markups over reference costs. This rule implies that the unconditional markup and the duration of the reference price is good specific. Firms are more likely to change reference and non-reference prices when not doing so would imply a larger deviation between the realized markup and the unconditional markup. When firms change their price they tend to re-establish the unconditional markup.

This simple pricing rule implies that observed prices change frequently. However, this rule does not coincide with a flexible price rule and is consistent with the importance of nominal rigidities. Although this rule summarizes our empirical findings, it is purely descriptive. A derivation of this rule from first principles and understanding its implications for the effects of nominal shocks in a general equilibrium setting is a task that we leave for future research.

8. Conclusion

We present evidence that is consistent with the view that nominal rigidities are important. However, these rigidities do not take the form of sticky prices, i.e. prices that remain constant over time. Instead, nominal rigidities take the form of inertia in reference prices and costs. Weekly prices and costs fluctuate around reference values which tend to remain constant over extended periods of time. Reference prices are particularly inertial and have an average duration of roughly one year. So, nominal rigidities are present in our data, even though prices and cost change very frequently, roughly once every two weeks. We document the relation between prices and costs and argue that our findings pose a challenge to the most commonly pricing models used in macroeconomics.

References

- [1] Altig, David, Lawrence Christiano, Martin Eichenbaum, and Jesper Linde “Firm-specific capital, nominal rigidities and the business cycle,” mimeo, Northwestern University, 2004.
- [2] Bilts, Mark, and Peter J. Klenow. “Some evidence on the importance of sticky prices,” *Journal of Political Economy* 112 (October): 947–85, 2004.
- [3] Blinder, Alan S., Elie R. D. Canetti, David E. Lebow, and Jeremy B. Rudd “Asking about prices: a new approach to understanding price stickiness,” New York: Sage Found, 1998.
- [4] Burstein, Ariel and Christian Hellwig, “Prices and market shares in a menu cost model,” mimeo, UCLA, 2007.
- [5] Calvo, Guillermo, A. “Staggered prices in a utility-maximizing framework,” *Journal of Monetary Economics* 12 (September): 383–98, 1983.
- [6] Campbell, Jeffrey and Benjamin Eden “Rigid Prices: Evidence from U.S. Scanner Data,” mimeo, Vanderbilt University, October, 2005.
- [7] Chevalier, Judith A., Anil Kashyap and Peter E. Rossi “Why don’t prices rise during periods of peak demand? Evidence from scanner data,” *American Economic Review*, 93 (1), pp. 15-37, 2003.
- [8] Christiano, L., Eichenbaum, M. and C. Evans, ‘Nominal rigidities and the dynamic effects of a shock to monetary policy’, *Journal of Political Economy*, 113 (1), 1-45, 2005.
- [9] Gali, Jordi, and Mark Gertler, “Inflation dynamics: a structural econometric analysis,” *Journal of Monetary Economics*, 1999, 44, pp. 195-222.

- [10] Golosov, Mikhail, and Robert E. Lucas, Jr. “Menu costs and Phillips curves,” *Journal of Political Economy*, 2006.
- [11] Kehoe, Patrick and Virgiliu Midrigan “Sales and the real effects of monetary policy,” mimeo, University of Minnesota, 2007.
- [12] Kimball, Miles, “The quantitative analytics of the basic neomonetarist model,” *Journal of Money, Credit, and Banking*, 27(4), Part 2, pp. 1241-1277, 1995.
- [13] Midrigan, Virgiliu “Menu costs, multiproduct firms, and aggregate fluctuations,” Mimeo, Federal Reserve Bank of Minneapolis, 2006.
- [14] Nakamura, Emi, and Jón Steinsson “Five facts about prices: A reevaluation of menu cost models,” Mimeo, Harvard University, 2007.
- [15] Rotemberg, Julio J. and Michael Woodford, “An optimization-based econometric framework for the evaluation of monetary policy,” *National Bureau of Economic Research Macroeconomics Annual*, 1997.
- [16] Smets, Frank and Raf Wouters “An estimated dynamic stochastic general equilibrium model of the Euro area,” *Journal of the European Economic Association*, September 2003, Vol. 1, No. 5, 1123-1175.

Table 1: Basic statistics

	Primary data set	Dominicks data set
Basic statistics		
Fraction of weeks spent at the reference price	0.62	0.77
Fraction of weeks spent at the reference cost	0.54	n.a.
Fraction of quarters in which weekly prices are constant for the whole quarter	0.10	0.19
Fraction of quarters in which weekly cost is constant for the whole quarter	0.06	n.a.
Fraction of non-reference prices that are above reference prices**	0.25	0.30
Fraction of price changes that are from a non-reference price to a reference price	0.32	0.41
Fraction of cost changes that are from a non-reference cost to a reference cost	0.29	n.a.
Fraction of quantities sold at reference prices	0.50	0.66
Fraction of revenue collected at reference prices	0.56	0.68
Probability of weekly price changing when weekly cost does not change	0.01	n.a.
Probability of reference price changing when reference cost does not change	0.13	n.a.
Probability of weekly price changing when weekly cost changes	0.88	n.a.
Probability of reference price changing when reference cost changes	0.57	n.a.

**Computed out of the total weeks in which the weekly price is different from the reference price.

Table 2: Volatility properties

	Primary data set	Dominicks data set
STANDARD DEVIATION OF LEVELS		
Standard deviation of quantities		
Log(weekly quantity)	0.62	0.67
Log(quantities sold at reference price)	0.46	0.41
Log(quantities sold at non-reference prices)	0.51	0.42
Standard deviation of prices		
Log(weekly price)	0.13	0.11
Log(reference price)	0.08	0.07
Log(weekly price), conditional on weekly price change	0.15	0.15
Log(reference price), conditional on reference price change	0.10	0.07
Standard deviation of costs		
Log(weekly cost)	0.12	n.a.
Log(reference cost)	0.07	n.a.
Log(weekly cost), conditional on cost change	0.13	n.a.
Log(reference cost), conditional on cost change	0.07	n.a.
Standard deviation of prices/Standard deviation of costs*		
Weekly prices/weekly costs	1.05	n.a.
Reference prices/reference costs	1.11	n.a.
Weekly prices, conditional on price changes/weekly cost conditional on cost change	1.04	n.a.
Reference price, conditional on price changes/reference cost, conditional on cost changes	1.10	n.a.
Standard deviation of markup		
Log(weekly markup)	0.12	n.a.
Log(reference markup)	0.09	n.a.
STANDARD DEVIATION OF CHANGES		
Standard deviation of prices		
Log changes in weekly prices	0.13	0.09
Log changes in reference prices	0.07	0.04
Log changes in weekly prices, conditional on price change	0.20	0.19
Log changes in reference prices, conditional on price change	0.14	0.07
Standard deviation of costs		
Log changes in weekly cost	0.11	n.a.
Log changes in reference cost	0.06	n.a.
Log changes in weekly cost, conditional on cost change	0.16	n.a.
Log changes in reference cost, conditional on cost change	0.08	n.a.
Standard deviation of prices/Standard deviation of costs*		
Weekly growth rate of prices/weekly growth rate of costs	1.03	n.a.
Reference growth rate of prices/growth rate of costs	1.12	n.a.
Weekly growth rate of price, conditional on price changes/weekly growth rate of cost, conditional on cost change	1.14	n.a.
Growth rate of reference prices conditional on price changes/growth rate of reference costs, conditional on cost changes	1.14	n.a.

*Note: the median of the ratio of standard deviations is not the ratio of the median standard deviations.

Table 3: Persistence properties

	Primary data set	Dominicks data set
Price persistence		
Probability of a weekly price change	0.41	0.24
Implied weekly price duration (in quarters)	0.19	0.32
Probability of reference price changes	0.27	0.33
Implied reference price duration (in quarters)	3.70	3.03
Cost persistence		
Probability of weekly cost changes	0.48	n.a.
Implied weekly cost duration (in quarters)	0.16	n.a.
Probability of reference cost changes	0.45	n.a.
Implied reference cost duration (in quarters)	2.22	n.a.

Table 4: Correlation properties

Correlations, primary data set

	In(weekly price)	In(weekly quantity)	In(weekly cost)	In(weekly markup)
In(weekly price)	1	-0.45	0.66	0.50
In(weekly quantity)		1	-0.23	-0.33
In(weekly cost)			1	-0.18
In(weekly markup)				1

	In(reference price)	In(reference quantity)	In(reference cost)	In(reference markup)
In(reference price)	1	-0.17	0.41	0.7
In(reference quantity)		1	-0.02	-0.18
In(reference cost)			1	-0.44
In(reference markup)				1

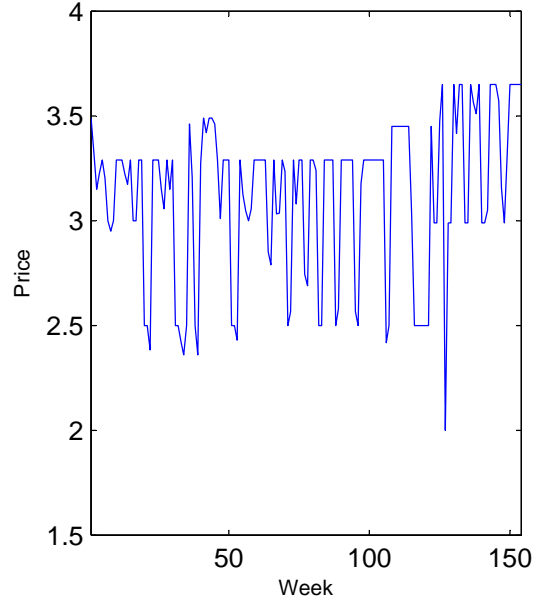
Correlations, Dominicks data set

	In(weekly price)	In(weekly quantity)
In(weekly price)	1	-0.37
In(weekly quantity)		1

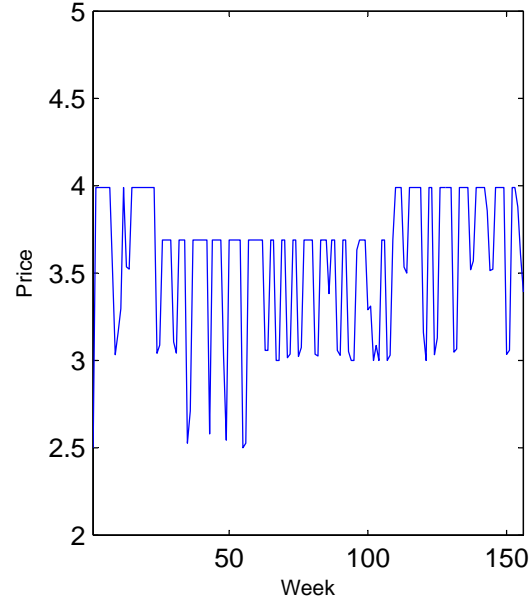
	In(reference price)	In(reference quantity)
In(reference price)	1	-0.05
In(reference quantity)		1

Figure 1

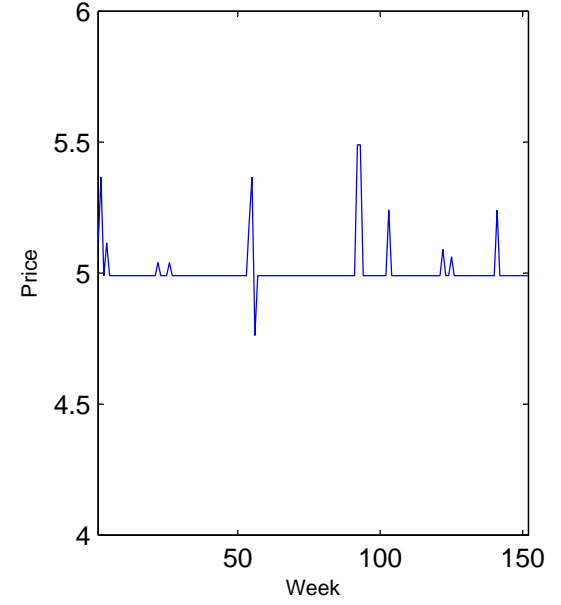
Newman`s own balsamic vinaigrette salad dressing



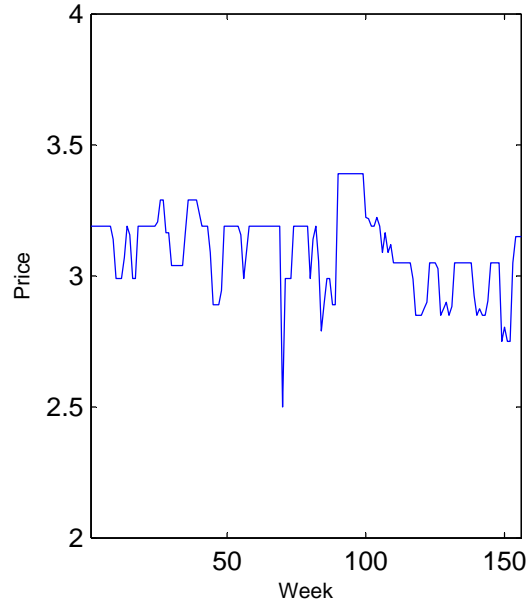
Tims Jalapeno potato chips



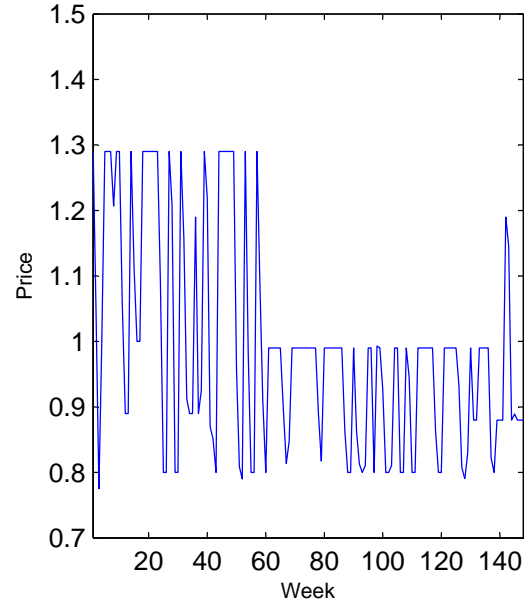
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Motts clamato juice



Skinner long spaghetti



Alpo pet care chicken strips

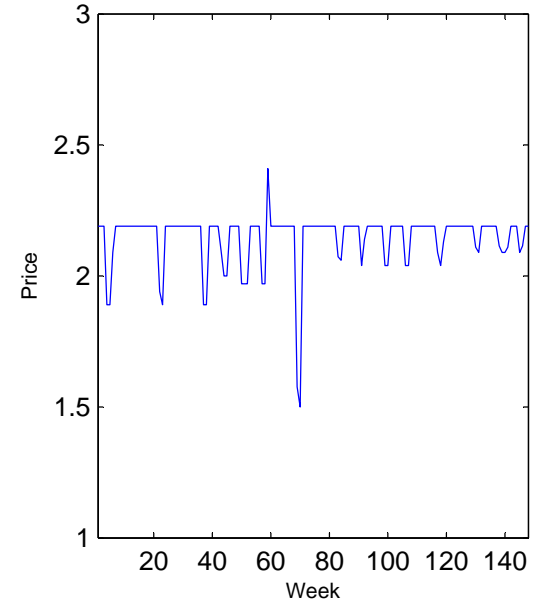


Figure 2
 Fraction of non-reference prices that are above reference prices,
 by category

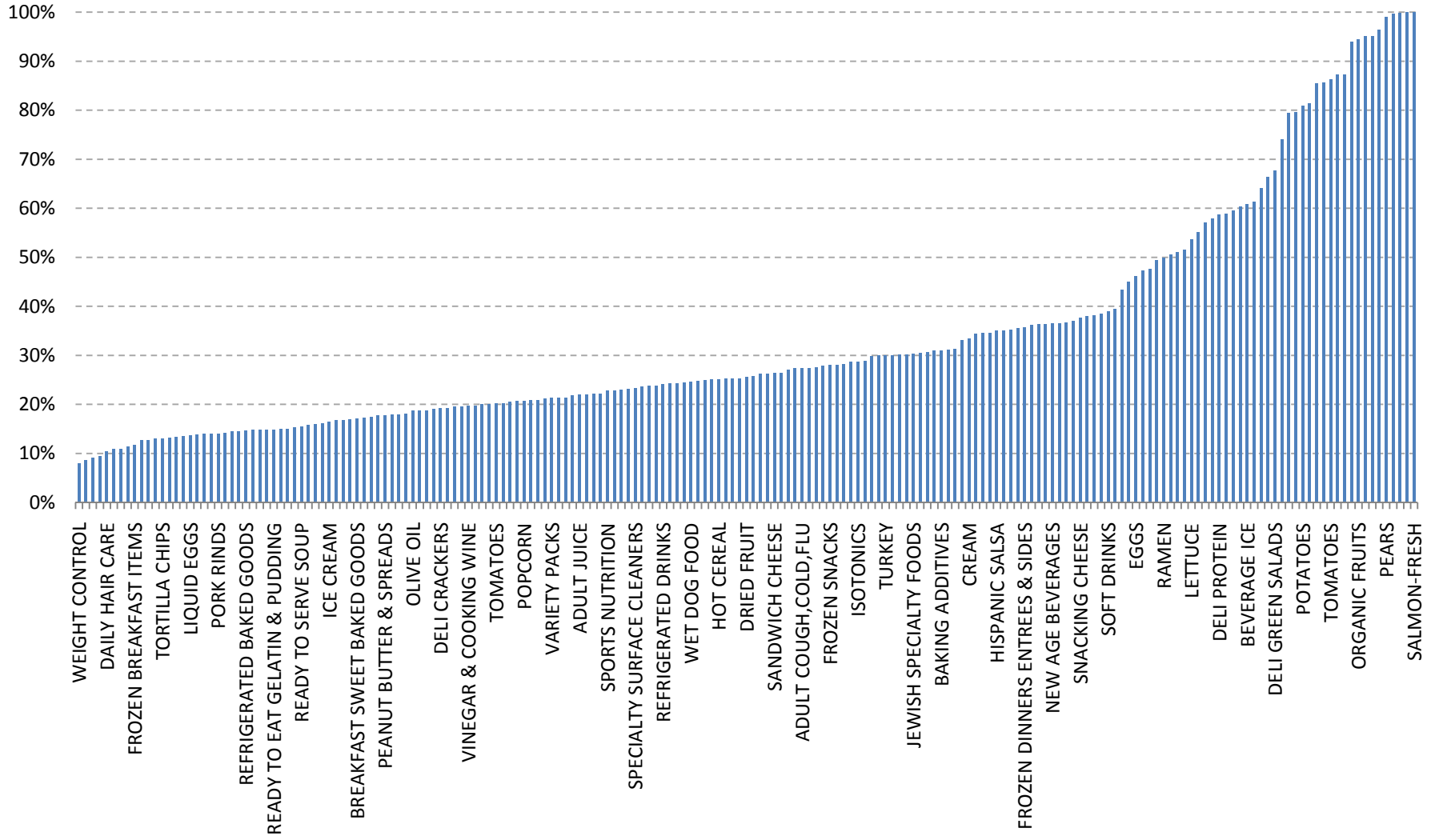


Figure 3

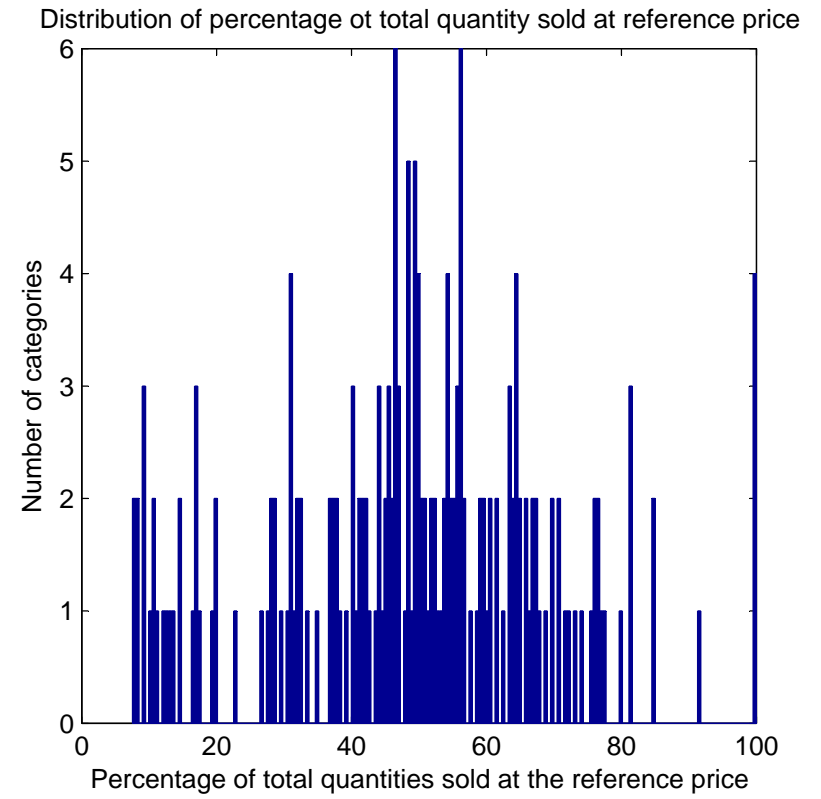
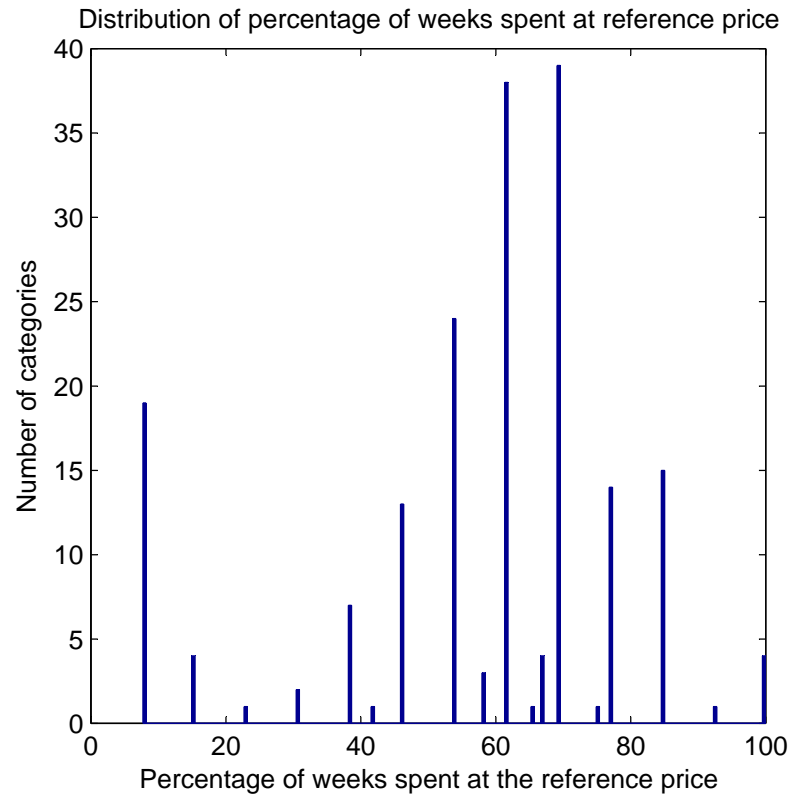
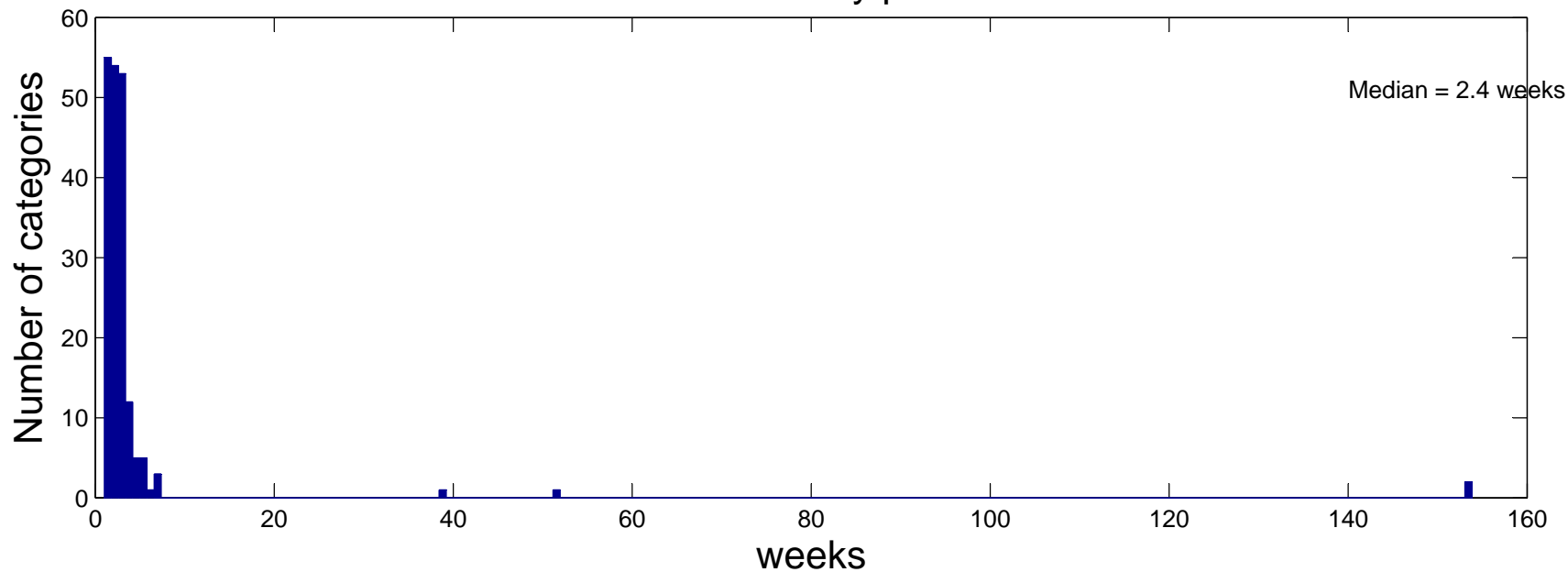


Figure 4

Distribution of weekly price duration



Distribution of reference price duration

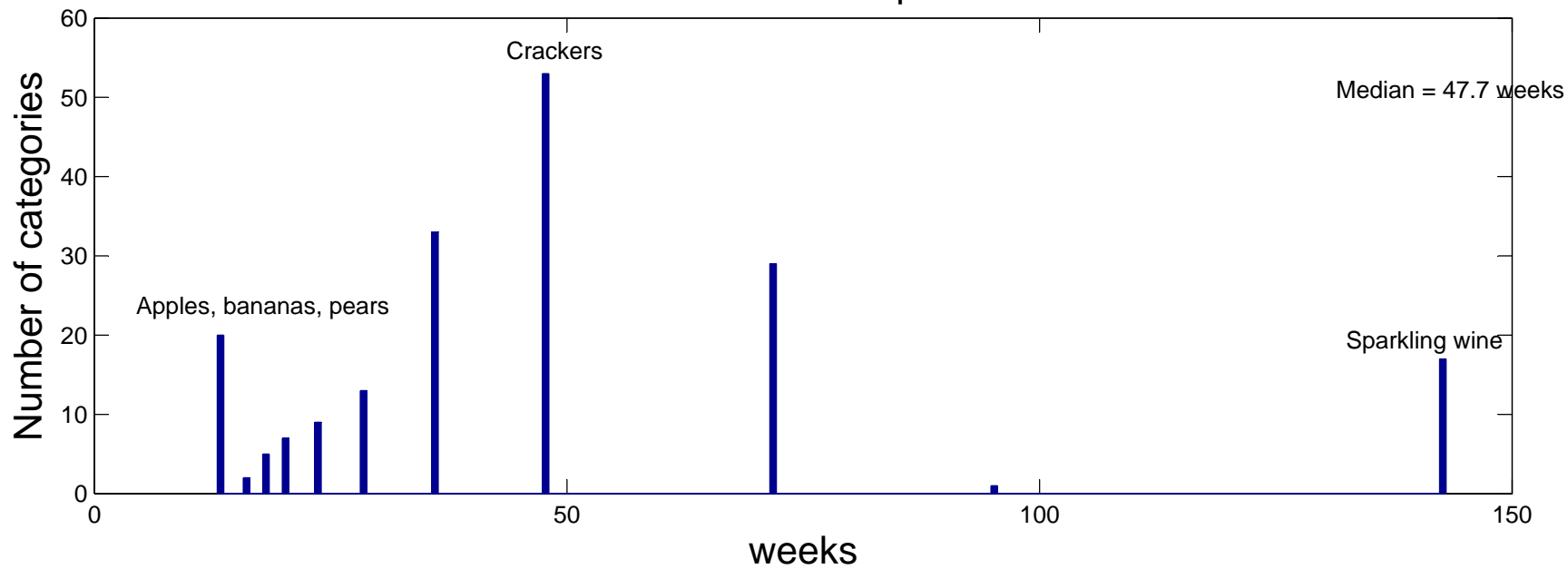


Figure 5

Percentage of weeks spent at the reference cost

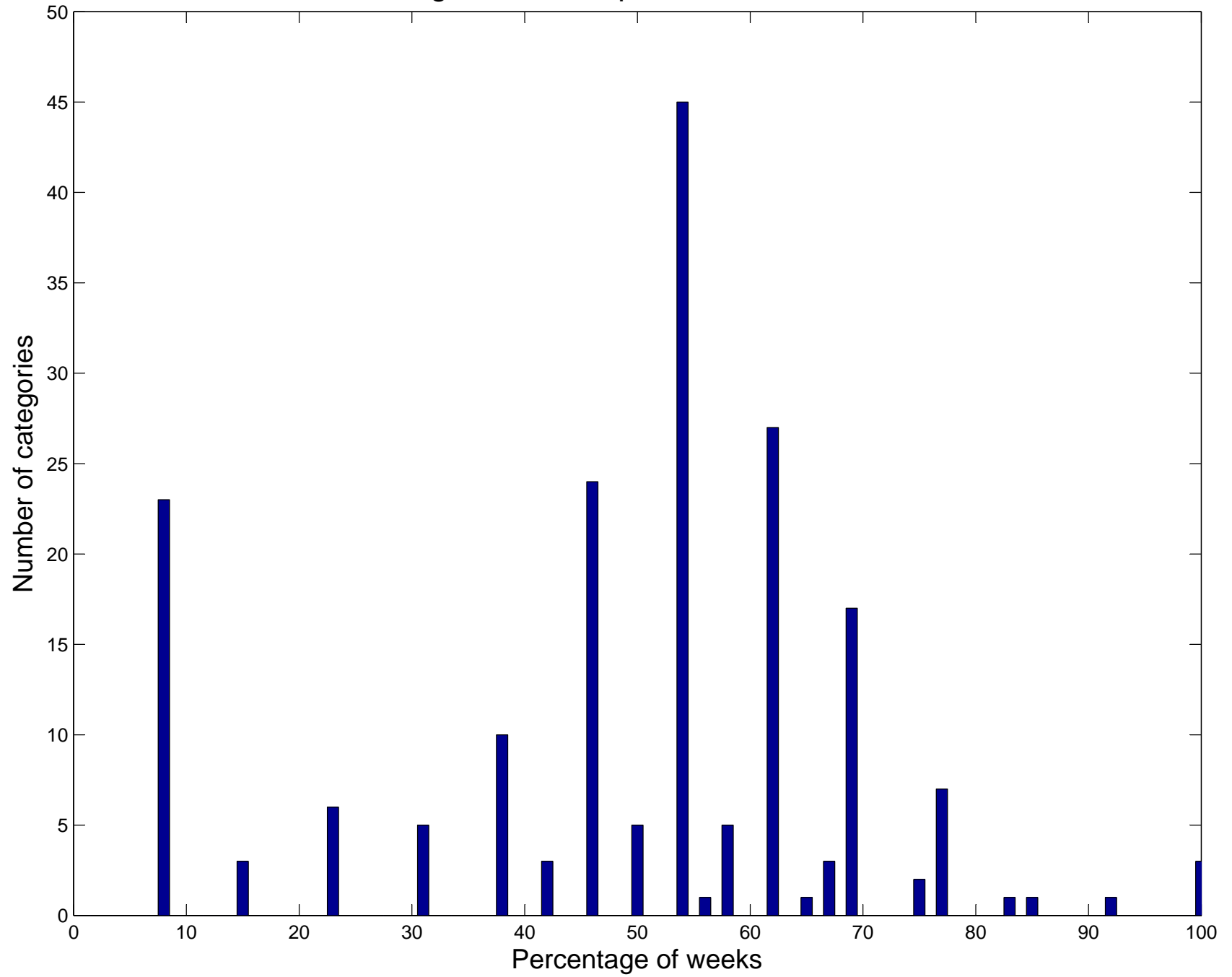
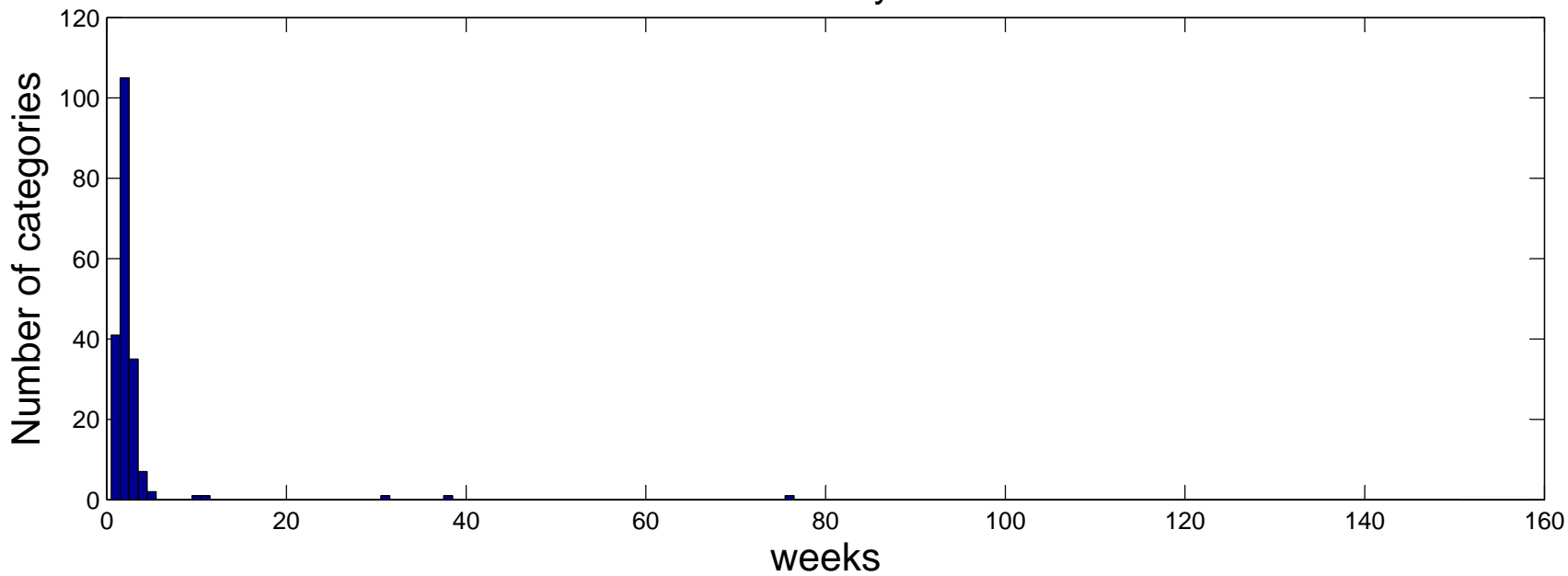
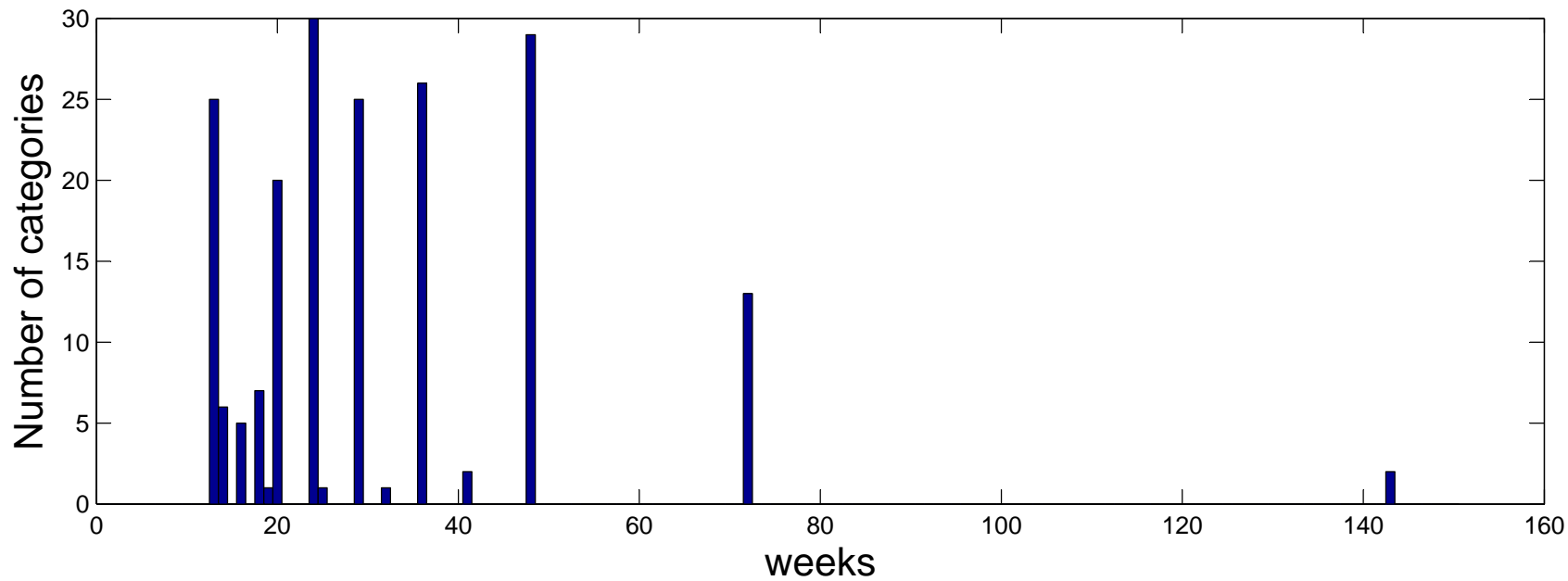


Figure 6

Distribution of weekly cost duration



Distribution of reference cost duration



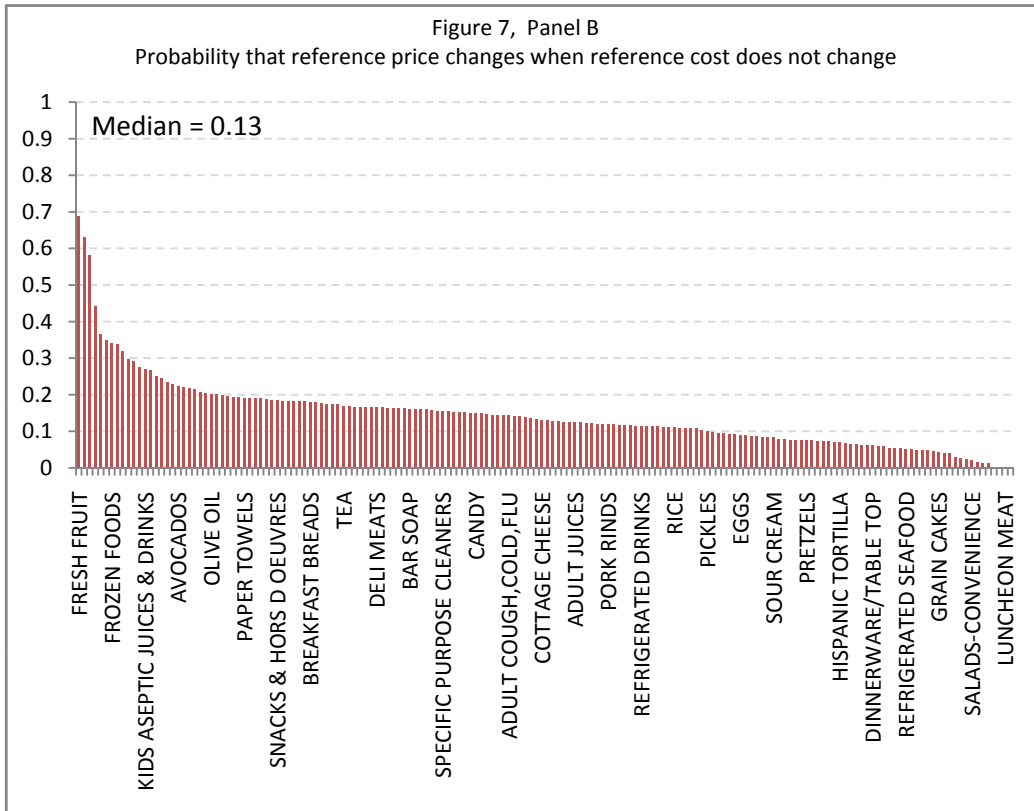
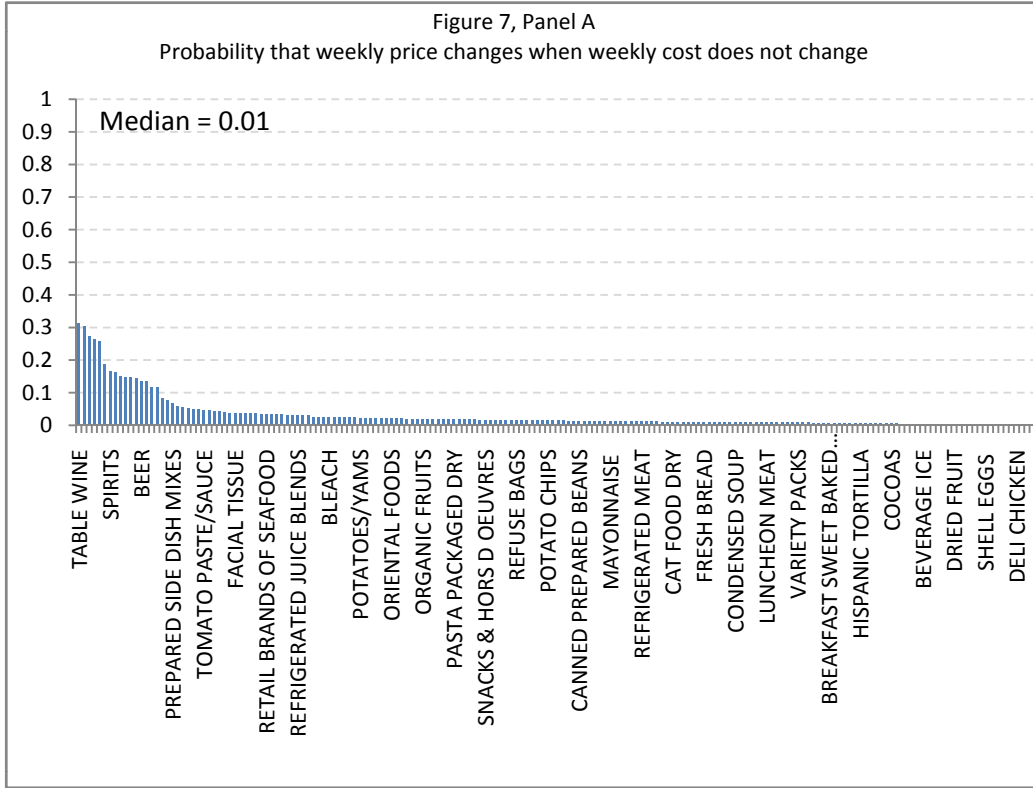
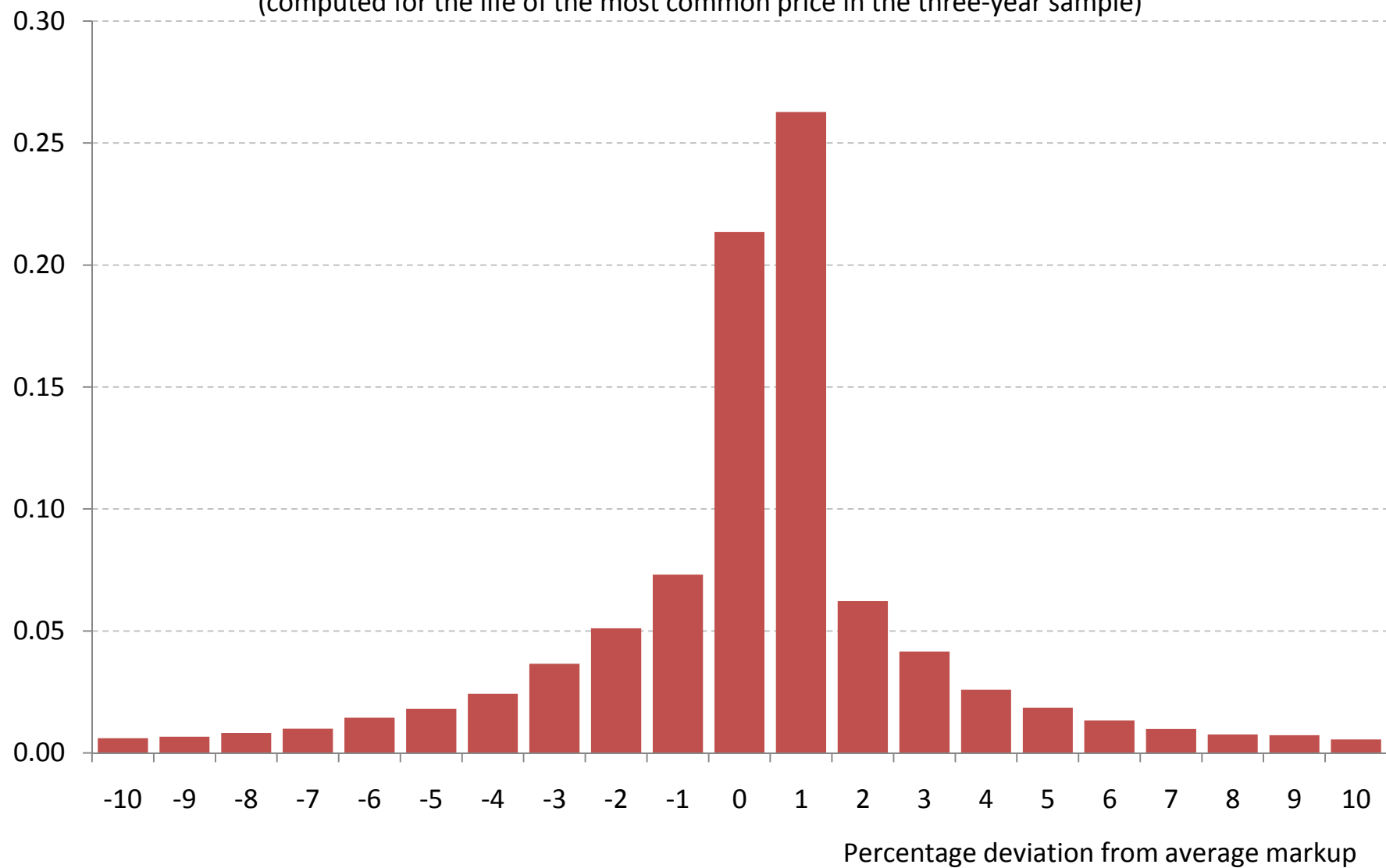
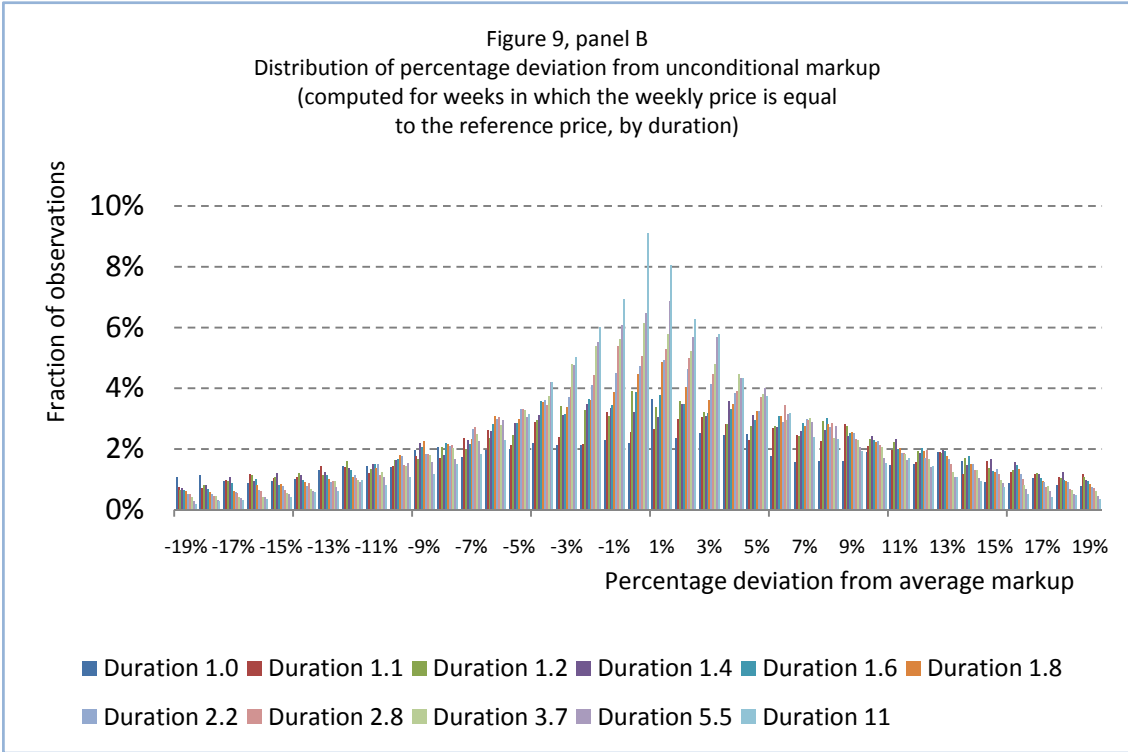
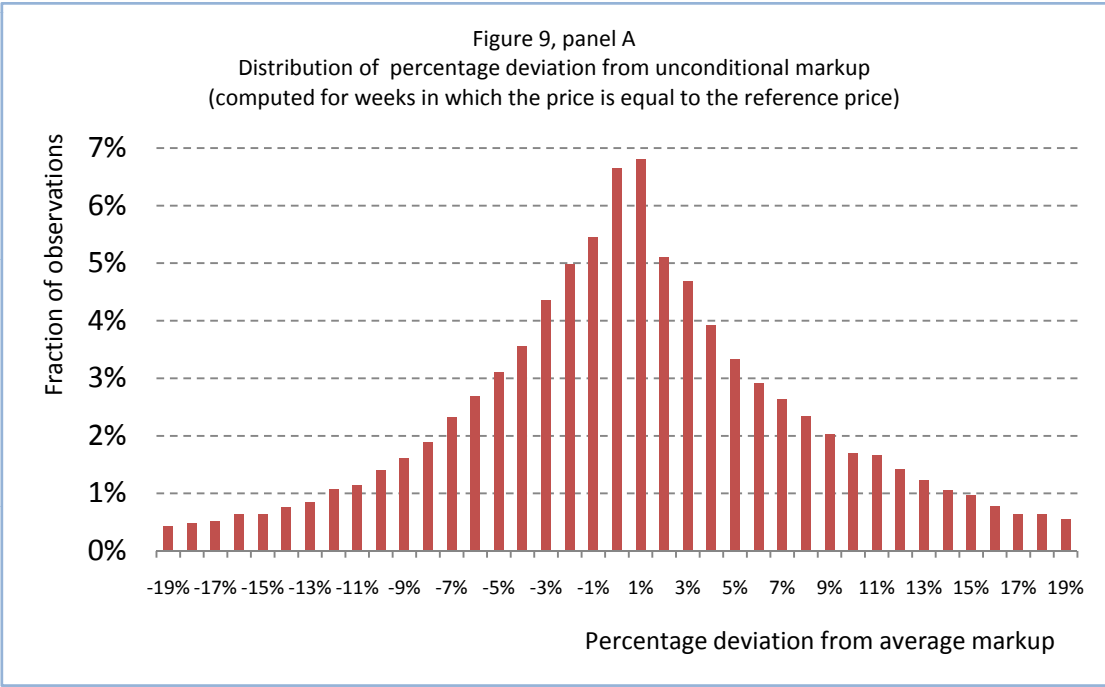
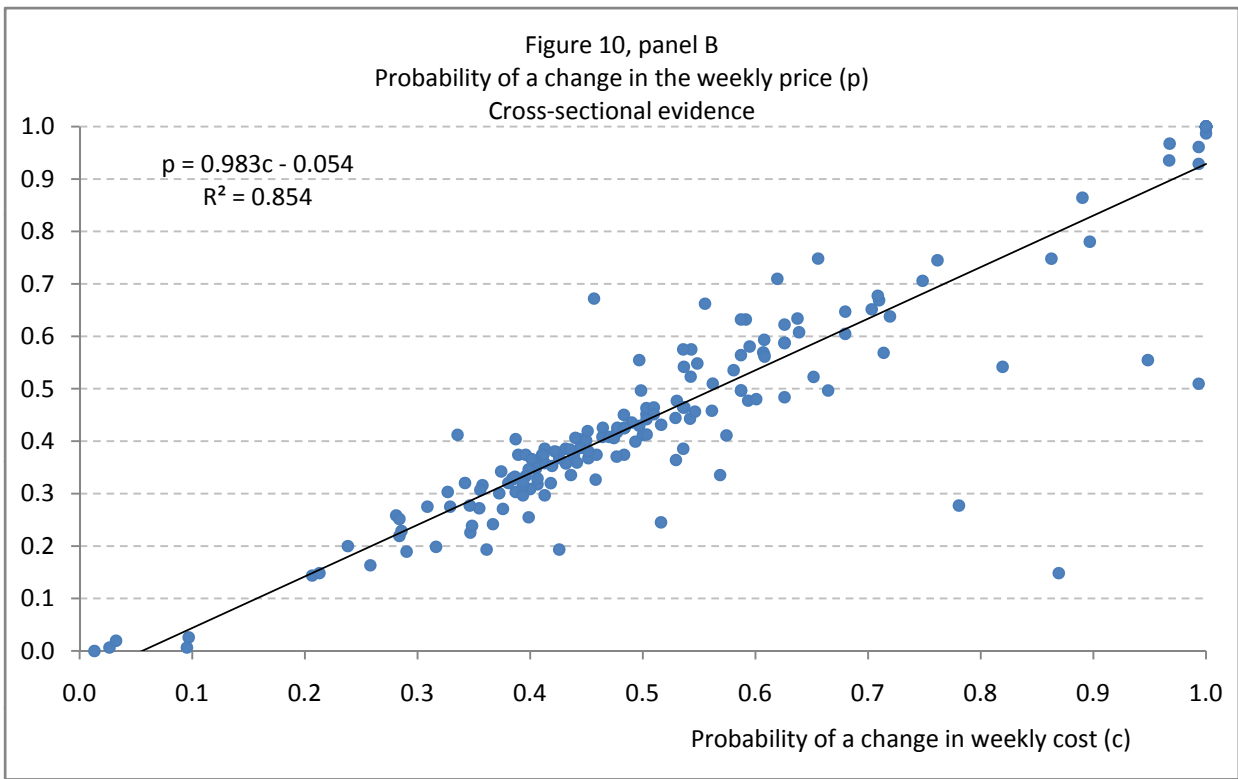
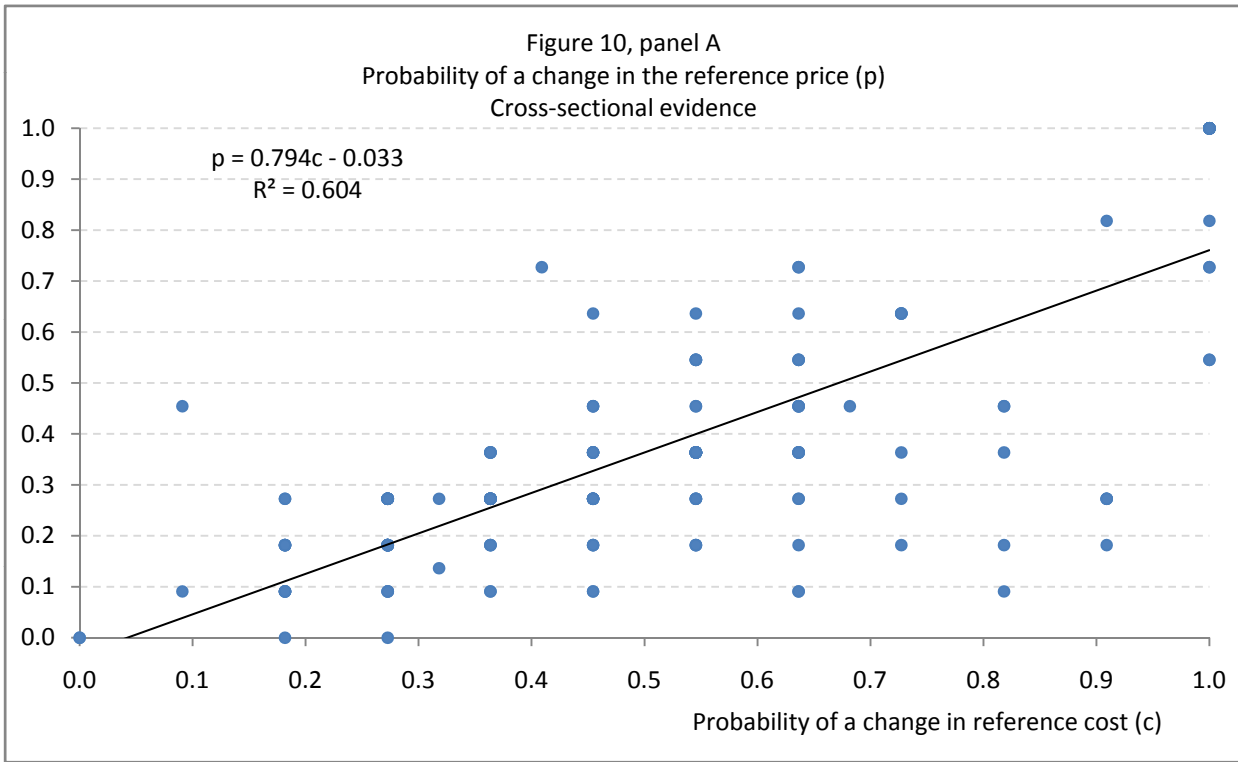


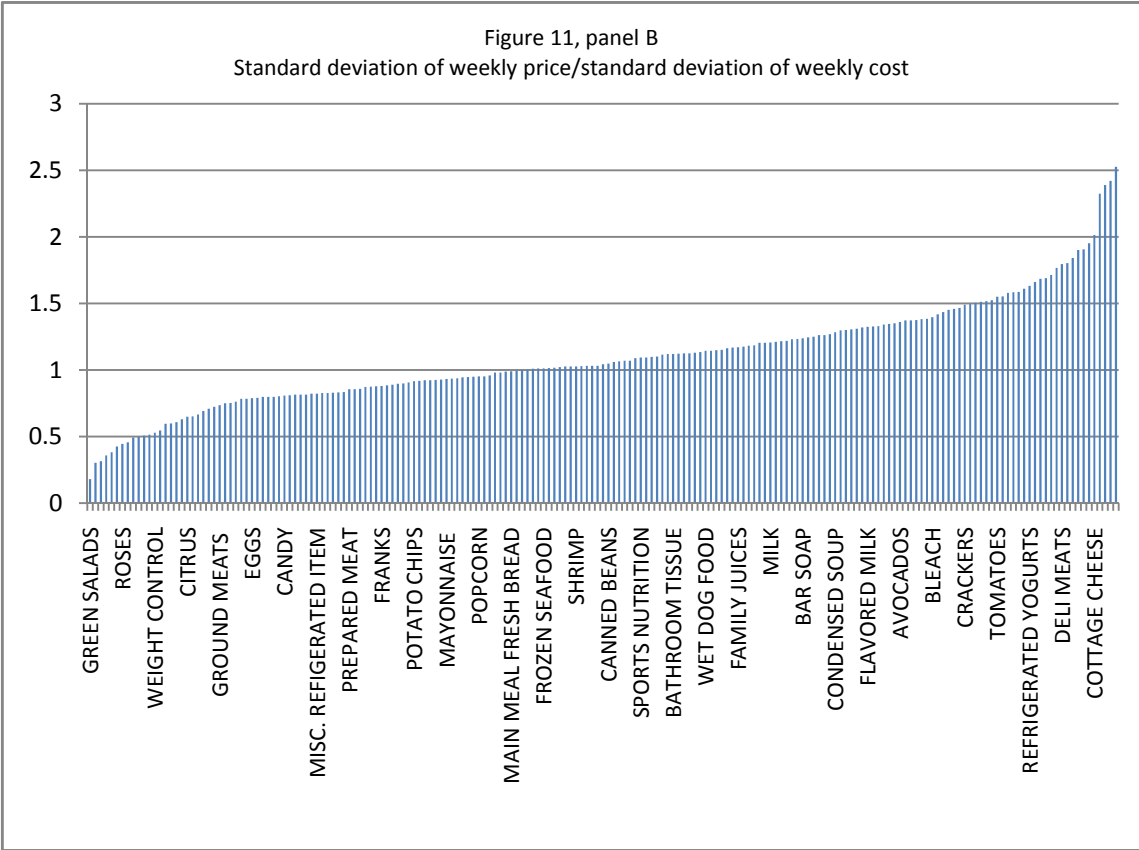
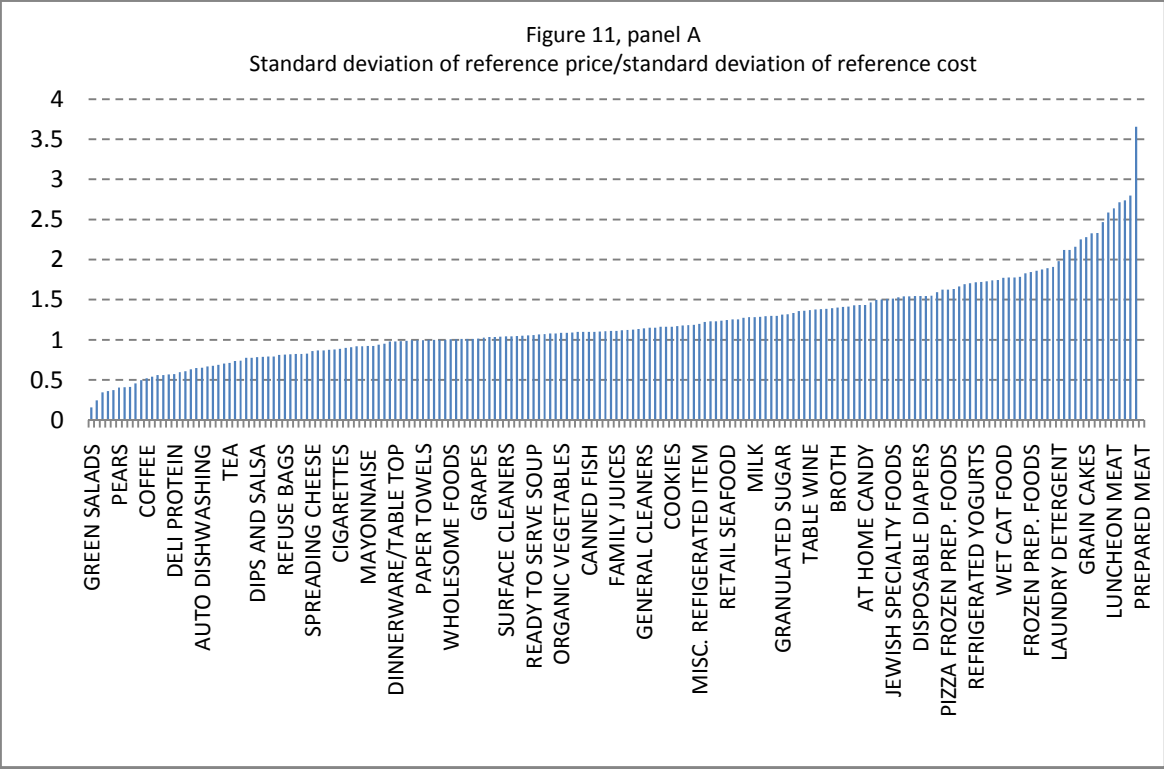
Figure 8

Distribution of percentage deviation of markups from unconditional average
(computed for the life of the most common price in the three-year sample)









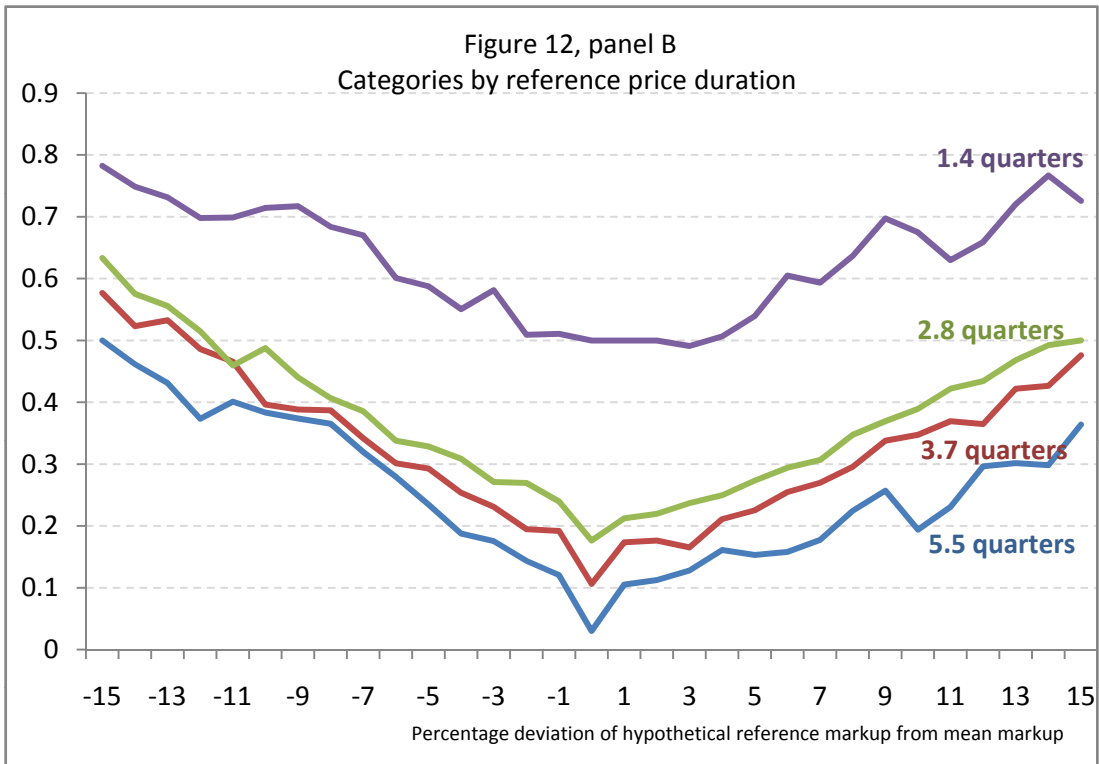
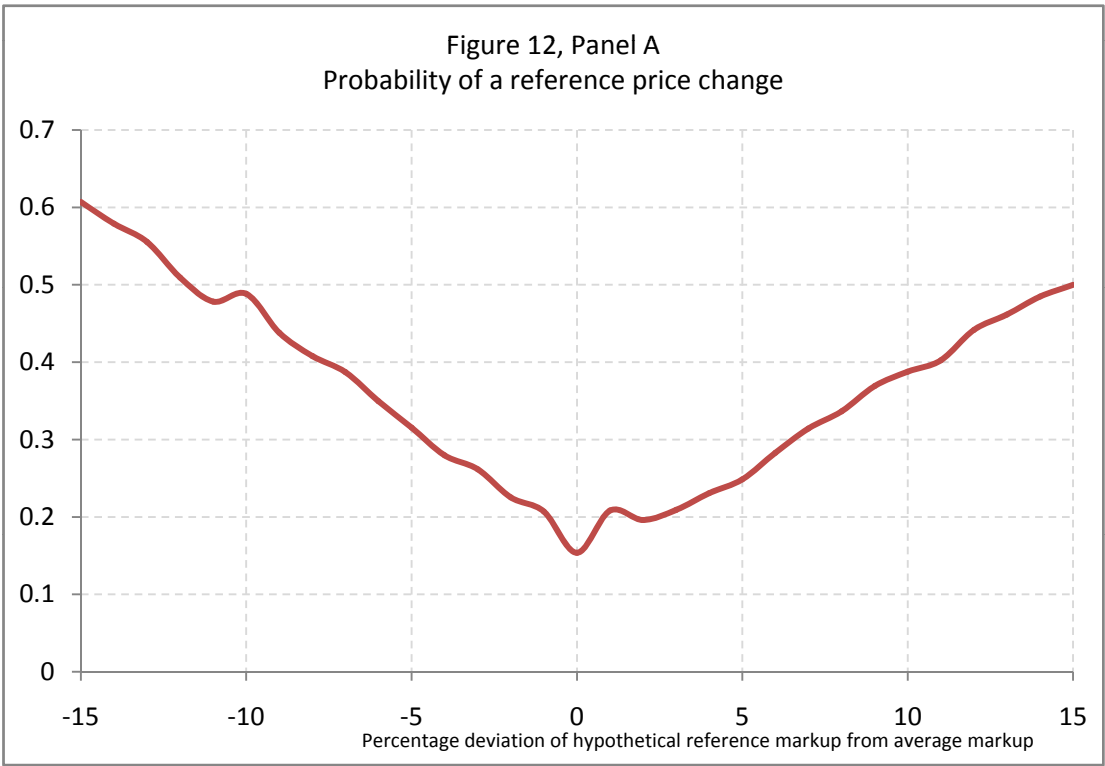
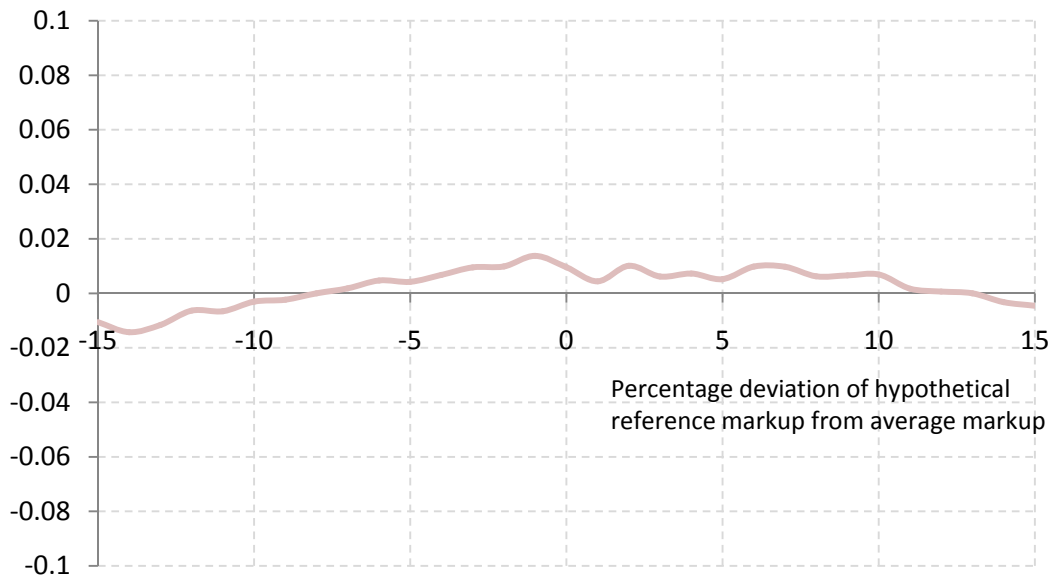


Figure 12, panel C
Realized reference markup as percentage deviation from average markup
conditional on reference price changing



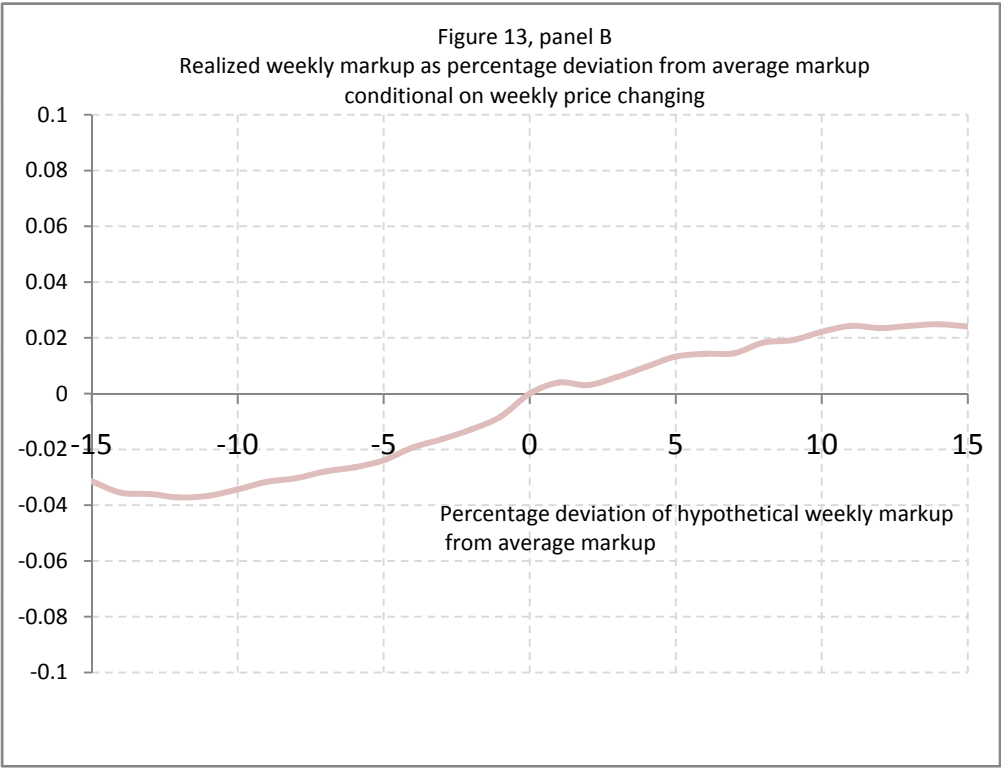
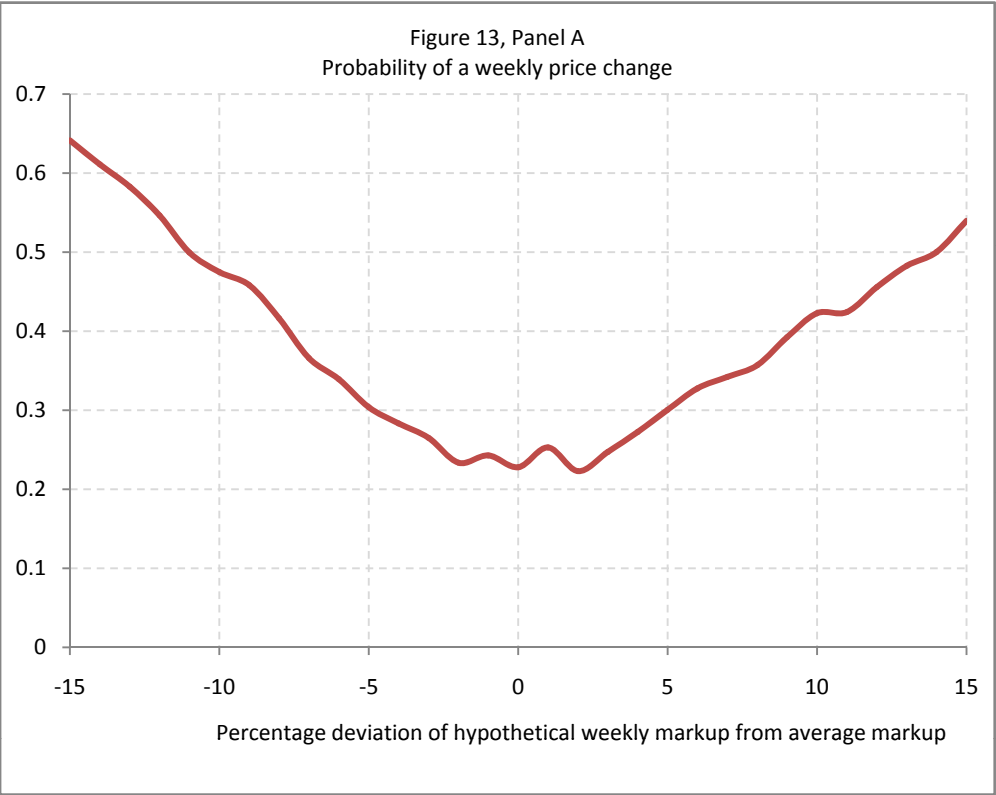


Figure 14
Standard deviation of log(quantities sold) at same reference price

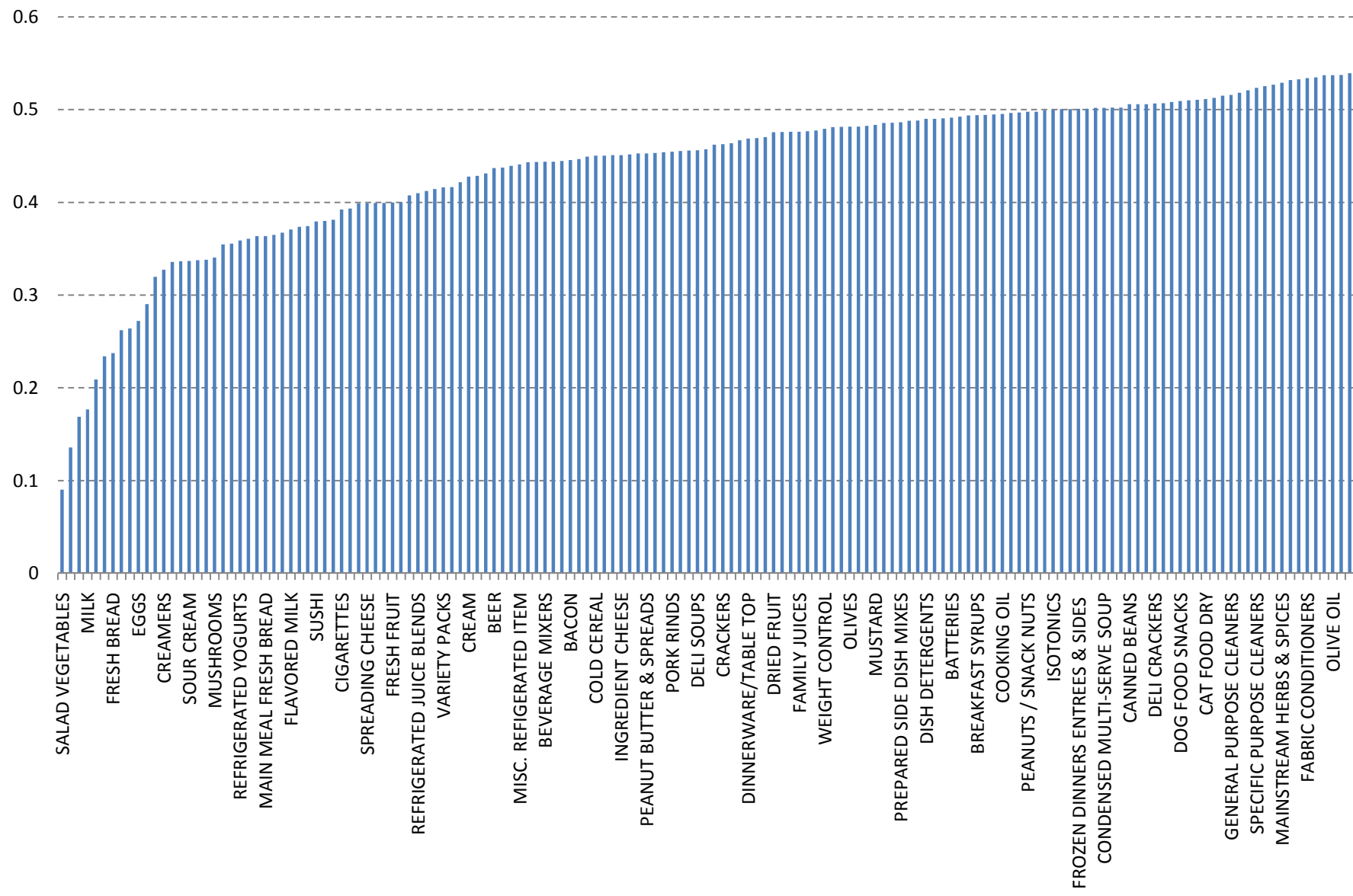


Figure 15
Cummulative distribution of small price changes

