Retailer Heterogeneity and Price Dynamics: Scanner Data Evidence from UK Food Retailing

T.A.Lloyd[1], S.McCorriston[2], C.W.Morgan[1], E. Poen[2] and E. Zgovu[1]

[1] University of Nottingham, UK
[2]University of Exeter, UK

Working Paper No. 8
Transparency of Food Pricing
TRANSFOP
October, 2012

Seventh Framework Programme
Grant Agreement No. KBBE-265601-4-TRANSFOP

TRANSFOP
Transparency of Food Pricing

Retailer Heterogeneity and Price Dynamics: Scanner Data Evidence from UK Food Retailing

T.A.Lloyd[1], S.McCorriston[2], C.W.Morgan[1], E. Poen[2] and E. Zgovu[1]

[1] University of Nottingham, UK
[2]University of Exeter, UK

Abstract

This paper contributes to recent research on price dynamics using micro-price data sets. We emphasize a previously neglected aspect, the role of retailer heterogeneity. Our key findings are: (i) the frequency of price adjustment and the implied duration of prices varies considerably across retailers; (ii) price promotions (sales) also vary across retailers with some retailers seldom using sales, while for others sales are a common feature of pricing; (iii) the duration of reference prices is-at most-26 weeks but the duration of reference prices is around 16 weeks for some retailers; (iv) branded products have shorter durations than private label products; (v) decomposition analysis suggests price adjustment is evenly split between sales and reference prices but, for some retailers, reference prices are the main source of price changes; (vi) there is low correlation between the frequency of price and costs changes across both products and retailers. Taken together, while confirming the significance of price stickiness after accounting for sales, price dynamics vary considerably across retailers. In turn, retailer heterogeneity has important implications for interpreting aggregate price dynamics in both theoretical and empirical research.

Retailer Heterogeneity and Price Dynamics: Scanner Data Evidence from UK Food Retailing

Introduction

This paper contributes to the recent body of work that focuses on price dynamics using micro-price data sets. In broad terms, this research has explored the extent of underlying price stickiness that is at the heart of neo-Keynesian models and where, when prices are sticky for periods of time, monetary policy can have real effects. Early work on this issue suggested prices change only once per year (Taylor, 1999). As the research has progressed, issues have arisen in both the theoretical and empirical literature addressing temporary reductions in prices (sales) and the underlying 'reference price'. Klenow and Malin (2010) and Maćkowiak and Smets (2008) provide an overview of the recent micro-price data evidence. Recent work provides a range of estimates: most notably, Bils and Klenow (2004) report a median duration of just over 5 months if sales are excluded; Nakamura and Steinsson (2008) report a median duration of around 11 months using non-sale prices; Eichenbaum *et al*. (2011) report that reference prices have a median duration of 1 year; Berka *et al*. (2011), using the Eichenbaum *et al.* reference price measure for an on-line food retailing report price stickiness in the region of 3 years. Bunn and Ellis (2012) report shorter price durations for the UK using monthly or quarterly reference prices calculated from weekly supermarket prices[1]. One key outcome from a variety of recent micro-pricing studies is the extent of heterogeneity in price dynamics; in large part, however, this heterogeneity has been highlighted principally at the product group (pasta, coffee) and sector (food, clothing) levels (see Maćkowiak and Smets, *op.cit*)

Our analysis departs from much of the previous research in that we focus on differences in price adjustment between national retail chains in a single sector, UK food retailing. The key insight from our work is that price dynamics also vary considerably *within* the sector and that the variation in price dynamics across retailers - even where they are retailing the identical product - is equally as important as the variation in price dynamics between major product groups.

[1] We also use the same data source for weekly supermarket data as Bunn and Ellis (2012) but for a different time period.

If the main insight from recent research is to question the assumption of the uniform pricing behaviour due to the sector/product group heterogeneity in price dynamics, this criticism also extends to the case when we consider price dynamics within a given sector: if price dynamics vary across retailers even when they are retailing identical products, this questions the legitimacy of the 'representative firm' commonly used in theoretical models. Specifically, most scanner studies have data confined to a single retail chain, but clearly the implications one can draw from this evidence will be contingent on whether the retailer is in some way 'typical'. However, retailers do differ: by market share, with respect to bargaining power vis-à-vis upstream suppliers, in the use of private label as opposed to branded products, all of which potentially provide greater control over price adjustment. Central to this are their marketing strategies and whether within this, sales feature as an important component of these strategies. The only work that provides evidence on the variation across retailers is Nakamura (2008) and Nakamura *et al*. (2011) who report that price adjustment varied more across retail chains than by stores, the implication being that price changes across retail chains are driven by idiosyncratic changes in costs or demand[2]. Their data focussed on the US. Our results with UK data show clearly that retailer, not just product, heterogeneity matters.

We investigate the role of retailer heterogeneity in several dimensions of pricing: namely, price dispersion, the implied stickiness of reference prices, the use of sales and the correlation between price change frequency and changes in costs by retailer. A variance decomposition by retailer highlights the extent to which price dynamics are affected by the use of sales compared to changes in the underlying (reference) price. We also scrutinise the extent to which retail chains use branded products, many of which are common to all retailers, and private label products, showing that the characteristics of price dynamics vary between these two groups.

A further contribution of our study is to add to the evidence on price dynamics using scanner data from a non-US data set. Most of the recent work on micro-pricing dynamics has focussed on the US. For Europe, much of the recent evidence on the micro-aspects of price adjustment has arisen from the European Central Bank's

[2] Nakamura *et al.* (2011) also note that retail heterogeneity has implications for the calculation of inflation.

Inflation Persistence Network[3] that used the data that underpins the calculation of consumer and producer price indices. Dhyne *et al*. (2006) provide an overview of the outcome from this research. While insightful, these data have several drawbacks, not least because they were monthly. The evidence using high-frequency scanner data for European countries has been relatively sparse. Berka *et al*. (*op. cit*.) report evidence on price dynamics from a single Swiss on-line food retailer. Bunn and Ellis (*op. cit.)* report evidence for the UK, but because their focus is on broad categories of consumer purchases, they have little to say about retailer heterogeneity. Our analysis of data for the seven main UK food retailers indicates some important differences from other studies on Europe. First, prices are sticky but much less sticky than reported in other studies and our comparable measure of the underlying reference price suggests an implied duration of 26 weeks, considerably less than the 3 year estimate reported with the comparable measure in Berka *et al.* (*op. cit*.). Second, sales are an important feature of price adjustment; this is in contrast to the conclusion drawn in Dhyne *et al*. (*op. cit*.) that sales were less important in Europe than they were in the US.

It is common in micro-pricing studies to distinguish between temporary price changes brought about by sales and those attributed to changes in the underlying reference price. As Eichenbaum *et al*., (*op. cit*.) have noted it is the latter that is important for menu cost models. We use Eichenbaum *et al.*'s reference price definition but since this constrains prices to change only at a given frequency, we also employ a variant which allows for more flexibility in the reference price. Again, we find substantial heterogeneity in sales and reference price behaviour across UK food retailers: some retailers use sales frequently while others do not. Taken as a whole, for some food retailers, reference prices are the main form of price adjustment - even for the identically branded products offered by all retailers.

In summary, our main results are as follows: (i) the frequency of price adjustment and the implied duration of prices varies considerably across retailers; (ii) sales, though not widely used - an observation consistent with recent evidence on price adjustment in Europe - do vary across retailers with some retailers seldom using sales, while for

[3] See http://www.ecb.int/home/html/researcher_ipn.en.html

others sales are a common feature of pricing; (iii) more surprisingly, the implied duration of reference prices is similarly diverse, varying between 16 and 26 weeks; (iv) branded products have shorter price durations than private label products; (v) at an aggregate level, a decomposition analysis suggests price adjustment is evenly split between sales and reference prices but, for some retailers, reference prices are the main source of price changes; (vi) there is considerable variation across retailers in reference price adjustment following a change in costs. Taken together, while scanner data studies have highlighted the role of product heterogeneity in the nature of price stickiness, the results reported here emphasise the importance of recognising retailer heterogeneity.

The remainder of the paper is organised as follows. In Section 2, we outline the nature of our data set and, in Section 3, we highlight the procedure for dealing with sales and reference prices. We report the main features of price dynamics in UK food retailing in Section 4, highlighting the heterogeneity that arises across retailers. In Section 5, we report the results from a decomposition of pricing behaviour accounting separately for the role of sales and reference prices. Consistent with other studies on price dynamics, we relate the frequency of price adjustment at the product and retailer dimension with underlying costs and report the results of this in Section 6; again, one of the principal features that follows through from this is that the frequency of price changes at the retailer and private label levels is as important as the heterogeneity that has been reported at the product levels. Finally, we summarise and conclude in Section 7.

2. Raw Price Data

We utilise an extensive and high-frequency panel of supermarket food prices derived from electronic point of sale data obtained from *Nielsen Scantrak*, a leading market research company that collects data relating to in-store transactions. The data derive from the records of the seven largest UK supermarkets that, as a group, represented around three-quarters of all food sales in the UK during the sample period. The UK food retail sector is dominated by large national supermarket chains which, for our sample period, included the following companies: Tesco, Sainsbury, ASDA, Somerfield, Safeway, Kwik Save and Waitrose. The remaining 25% of the market is accounted for by small national and regional supermarket chains as well as independent retailers. While the firms in our sample share the key characteristic of being large national chains they are potentially different in many other aspects particularly in their use of private labels and also their general pricing strategies. As the evidence in the paper will indicate, marketing strategies vary; some chains offer "every day low pricing" (EDLP) where products are rarely put on sale (e.g. ASDA) whereas "high-low" pricing sees firms offering substantial price cuts periodically but after which prices return to their pre-sale level (e.g. Safeway). The proportion of total lines offered that are accounted for by private labels also varies greatly with Tesco and Sainsbury having a higher proportion of private labels than others[4]. In addition, the UK market is served by so-called soft and hard discounters that offer a smaller range of products but at strongly discounted prices. In the analysis below, the Kwik Save chain is clearly a 'hard discounter'; other hard discounters such as Lidl, Netto and Aldi did not submit data to Nielsen at the time of the sample. Other characteristics across retailers that are likely to distinguish them are not directly observable in the data but likely to be implicit in the heterogeneity in price adjustment that we observe: for example, inventory management, relationships with upstream suppliers, bargaining power, store location and format and so on. In summary, the differences between these retail chains underlie the potential for the variation in price dynamics across retailers which we explore econometrically.

The price information contained in the data set is based on the details recorded by laser bar-code scanners as products pass through supermarket check-outs. As a result, prices are based on 100% of transactions of the sampled products rather than derived from consumer surveys. Overall, the data cover 231,069 weekly price observations on 507 products in 15 categories of food.[5] They relate to a 137 observation sample frame running from 8th September 2001 to 17th April 2004. Some 90% of products are available throughout this period, the minimum number of observations for any product being 103 weeks. [6]

[4] One chain, Marks and Spencer did not sell branded goods and thus was excluded from our sample.

[5] The 15 categories are orange juice, instant coffee, breakfast cereals, teabags, yoghurt, wrapped bread, tinned tuna, tinned tomatoes, tinned soup, corned beef, fish fingers, frozen peas, frozen chips, Jam and frozen pizza.

[6] Time series are contiguous in that there are no missing observations once the time series has begun in 100% of cases, although some (10%) start later than 8th September. All time series finish in the week ending 17th April 2004.

Each price observation in the sample represents the total value of the product sold divided by the number of units sold for the week ending on the Saturday of each week by retail chain. Prices are thus retailer-based average revenues and represent the average of posted prices weighted by the volume of transactions.[7] While store managers may have some flexibility over pricing, particularly for perishable items, the large number of products stocked in most stores, which typically exceeds 25,000, mitigates against widespread differences between stores. Moreover, national pricing strategies are the norm for bar-coded food products sold in the UK's largest national chains (Competition Commission, 2000).

One key feature of the prices is that they incorporate the effect of promotional activity. Given the average revenue nature of the *Nielsen Scantrak* prices, they include promotional activity, whether in the form of pure price discounts (e.g. '50% off') or quantity discounts ('buy-one-get-one-free'). Discounts relating to store 'loyalty' cards are not included since they apply to the consumer's total spend rather than the prices of specific products. While other micro-data sets may have a sales 'flag', with scanner data it is often necessary to identify sales from the raw data. Our procedure is outlined in the following section.

The data set identifies products at a highly detailed level. In general, two products are distinct if they have different bar-codes, so that 100 gram and 200 gram jars of the same brand of instant coffee are different products for which separate prices are recorded. Furthermore, many of the products are national brands that are sold by all retail chains, so the data set contains retailer-specific prices of such products. We identify each retailer-product combination with a Unique Product Code (UPC) so that, for example, a 100 gram jar of Nescafe 'Gold Blend' instant coffee stocked by Tesco and Sainsbury are two separate UPCs each with their own time series of weekly prices. In all there are 1,704 such UPC price series, the distribution of which is summarised in Table 1.[8] Data as a percentage of the data set are most prevalent in the

[7] Since posted prices are weighted by the proportion of total sales transacted at each posted price, an average revenue price can change even when posted prices remain constant (e.g. through quantity promotions such three-for-two, or where price lists differ by store format). As a result, average revenue prices tend to exhibit frequent yet small changes, making the series appear 'noisy', reflecting the composition of purchases rather than actual changes in posted prices.

[8] Each price observation is uniquely identified by its UPC and the week ending date but because the data set is an unbalanced panel (in that not all products are sold in all supermarket chains in all weeks)

bread (34%), soup (18%), coffee (8%) and orange juice (6%) categories, each of which contain in excess of 100 UPCs. The least populated categories, such as frozen fish fingers (1%) and frozen pizza (1%), contain 20 UPCs each. As is evident from these figures, the data set does not fully reflect consumer spending on food in the UK (fresh fruit and vegetables are not part of the dataset since they do not carry unique bar-code indicators) but the range of categories is broad, spanning beverages and foods across a range of formats namely fresh, chilled, ambient and frozen.

As Table 1 also shows, seven categories contain products in both branded and private label forms. Private label products with the same product profile (e.g. an 800 gram standard medium sliced white loaf) are treated as one product and have the same product code in the data base. Retailer-specific prices of these products represent the Tesco private label 800 gram standard medium sliced white loaf or the Sainsbury private label 800 gram standard medium sliced white loaf, for example. Hence, private label versions of the same product are treated analogously to the branded products stocked by multiple retailers. In the UK, where sales of private label products account for a significant minority of the total consumer spend, this dimension of the data set offers potential insights in to any differences between the pricing of manufacturer - and retailer - branded products. Private label products account for nearly one-fifth of the products listed in the data set.

Table 1 Here

One of the most interesting aspects of the data set is that prices are available by retail chain, facilitating comparison of price and sales behaviour for identically bar-coded products across retailers. The 1,704 UPCs belong to 507 bar-coded products. Not every product is stocked by all retailers but 64% (325/507) are sold in at least 2 retailers, and 18% sold in all seven. In terms of the distribution of products by label, some 71% (267/375) of branded products are sold in at least 2 retailers with 21% sold in all seven. For private label products, comparable statistics are 43% and 11%

---

summary statistics vary slightly depending on the standardisation that is used. For example, orange juice accounts for 5.33% of the product codes, 6.34% of the UPCs (product code × retailers stocking the product) and 6.40% of the observations (product code × retailers × weeks). Unless specifically stated, UPC (i.e. the product code-retailer combination) will be taken to represent the principal unit of analysis when describing the dataset.

suggesting that coverage is reasonably broad across the market as a whole, particularly for branded goods[9].

To give a flavour of the data, Figure 1 presents the prices of four well-known branded products. Although accounting for a small fraction of the prices in the data set, they display a number of interesting features, in particular, the way that sales punctuate the price series, albeit with a frequency and intensity that varies by product and retailer. When not on sale, each retailer's price tends to coalesce around a particular level, which changes at discrete points in the sample. It is also apparent that, despite representing the prices of identically bar-coded products, there are large and persistent differences in the prices charged by retail chains, a characteristic that is compounded by the presence of sales. Thus, any analysis of price dynamics must begin by identifying within the data both sales episodes and reference prices.

Figure 1 Here

3. Constructing Reference Prices and Sales Prices

In order to determine the main features of scanner price data, it is helpful to apply filters that identify (a) sales and (b) the underlying reference prices in the raw data for each UPC. As noted, it is the reference price that matters for menu cost models (Eichenbaum *et al*. (*op. cit.)*) while sales may also matter for inflation dynamics (Guimares and Sheedy, 2011).

(a) Sales Filter

In some micro price studies (e.g. Nakamura and Steinsonn, *op. cit*.), products are explicitly recorded as being on sale or not by the agents collecting price data. In studies where a sales flag is not available (for example, Hosken and Rieffen, 2004; Campbell and Eden, 2005; Berck *et al.,* 2008), a simple algorithm is applied to the price data that exploits the depth and duration of price declines relative to some 'regular' price of the product to identify sale episodes. While all sales filters are arbitrary to some extent, each attempts to capture the tell-tale signature of a sale,

[9] We also have fairly even coverage across the retail chains with the range of retailer share in the data varying between 17% for Tesco, the market leader, and Waitrose (11%).

namely a temporary period of marked price decline. Here, we define a sale as a period, lasting no more than 12 weeks, in which prices are at least *x*% lower than the regular price. This definition is informed by inspection of the data at hand, and is mindful of a number of considerations: first, it allows for sales of long duration i.e. up to 3 months. While sales of 2-4 weeks are typically believed to be the norm in UK food retailing and sales of longer than 6 weeks rare (Competition Commission, 2000 p.116), we do not wish to exclude longer sale durations that occur in the sample. Second, it is the cumulative price drop (i.e. the peak-to-trough difference) rather than any week-on-week change in price that is used to define the magnitude of price change. This allows sales to be detected when sales are staggered over adjacent weeks. Third, it is the level of actual prices, rather than a mode, that acts as the regular (i.e. non-sale) price, since no single non-sale price may be expected to be representative over the two and half year sample frame. Hence, in our work, the *regular price* refers to a state of nature, paralleling the status of the term *sale price*, rather than a fixed value such as the mode. Fourth, the sale period ends when a regular price resumes. With this condition, prices do not need to return to their pre-sale level, merely the threshold value. Here we consider three thresholds, namely 10%, 25%, and 35%.

(b) Reference Price Filter

We employ two measures of the reference price. The first is the Eichebaum *et al.* (*op. cit.*) measure which is defined as the modal price in each full quarter, which we refer to as the quarterly reference price. Defining the reference price in this way ensures it is both stable as it can change at most once per quarter and also reflects the central tendency of posted prices since neighbouring average revenue prices have a tendency to coalesce. It does however mean that changes in the reference price are confined to the start of each quarter irrespective of their actual timing, and because actual prices (i.e. regular and sales) are used to compute the mode, there is nothing in principle precluding a sales price being selected as the reference price. Moreover, because the quarterly reference price can change at most once per quarter by construction, there is the possibility that the inertia of the quarterly mode may be more apparent than real. In recognition of this, we also consider a "rolling reference price" defined as the modal non-sale price six weeks either side of each point of time. Unlike the quarterly reference price, the rolling measure is neither constrained to change at most once per quarter nor does it include sale prices. We employ both measures of reference prices in the empirical analysis below.

4. Pricing Behaviour across Retailers

Having now identified the key aspects of sales and reference prices in our dataset, we are now able to explore pricing behaviour in some detail. In this section, we report the main features of price dynamics and, in the process, highlight the extent of retailer heterogeneity in UK food retailing. We divide this issue into three parts: the extent of price dispersion between retailers; the characteristics of reference prices; and finally, the role of sales between retailers.

(i) Price Dispersion

As it applies to our micro data, a literal interpretation of the law of one price might suggest that identical products retail for more or less the same price in each retail chain. However, a glance at Figure 1 reveals persistent differences in the prices of an identically bar-coded product across retailers. To investigate this in the dataset as a whole, we define price dispersion as the median weekly difference between the highest and lowest prices for an identical product across retailers. Using all products sold by at least two retailers the median (mean) price dispersion is 21.6% (26.4%). This suggests that the typical price range observed for the same bar-coded product sold in two or more supermarkets during the sample period is close to one-quarter. Such is the skew of the distribution of price dispersion that for some products the typical range in price confronting the consumer is much greater than this; almost 10% of products exhibit price dispersion in excess of 50%.

Figure 2 summarises price dispersion across various classifications of the dataset. While the figure clearly indicates substantial variation in prices in certain categories of food (e.g. the typical range for identical products within frozen peas exceeding 40%), an additional dimension to note is the high degree of dispersion for private label products compared to brands (33% versus 20%).

Figure 2 here

Of course, it may be the case that price dispersion between retailers is simply due to sales; as we show below, there is also substantial heterogeneity in the use of sales for the same products across retailers. To separate out sales in the calculation of price dispersion, we compute statistics for the reference price data which exclude sales by construction. Not only are patterns similar to those in Figure 2 using reference prices, but so too is the degree of dispersion, which only falls by 3 or 4 percentage points to just short of 19% for both rolling and quarterly measures (see Table 2).

Table 2 here

The main observations on price dispersion across retailers are as follows. First, while sales contribute to price dispersion, their infrequency and brevity ensure the role is a relatively minor one compared with other aspects of retailer heterogeneity. Second, price dispersion is a pervasive feature of supermarket pricing in UK food retailing. Indeed, despite the everyday nature of the products considered here, it appears that the law of one price seldom applies at the micro level in food retailing. However, it is the nature of price dynamics not the levels that matter for macro-modelling and it is this that we turn to next.

(ii) Price Dynamics

The majority (57%) of prices in the data set do not change. Where they do, changes tend to be small, 53% being one penny changes, with price declines being slightly less common than price rises (47% versus 53%) giving an implied price duration for the median UPC of 2.4 weeks.[10] While very small price changes predominate, they co-exist with large price changes that most likely reflect sales, giving rise to a mean absolute price change of 4.8%, well in excess of the median (1.8%). These observations are broadly consistent with other studies involving high frequency scanner data (see Bunn and Ellis *op. cit*; Klenow and Malin, *op. cit*. Kehoe and Midrigan 2007) which suggest that prices change frequently. While this finding is at odds with the notion of significant menu costs that gives rise to sticky prices, what all these studies have in common is that they use prices that are the result of a weighting procedure that, by itself, tends to overstate the number and magnitude of changes in

[10] Implied price duration is given by the reciprocal of the frequency.

posted prices. For this reason, reference prices are preferred when assessing questions of price inertia. Nevertheless, since all prices are affected equally by the procedure, what average revenue prices can more reliably indicate is the variation in the frequency of price changes and the implied duration of prices that is observed by retail chain, product category, format and label (Figure 3). The data show that price changes are more frequent for brands, perishable products and staples such as bread and beverages. Of particular note is the wide variation in the frequency of price changes that is observed by retailer implying that with a duration of 3.7 weeks, prices last almost twice as long in Asda as in Safeway or Somerfield. Furthermore, the price of the median UPC in frozen food lasts around 3.3 weeks, nearly 80% longer than prices for fresh products; private label products have implied price durations 30% longer than branded products[11].

Figure 3 here

(iii) Implied Duration of Reference Prices

Owing to the noise inherent in average revenue prices we employ reference prices to explore the underlying level of price stickiness in food retailing. Over the dataset as a whole, some 63% of actual prices are at the rolling reference price, compared to 58% using the quarterly measure. Differences between the two measures are more apparent in terms of the price duration that they imply and statistics are reported in Table 3 for various classifications of the dataset along with those using the raw data (as used in Figure 3) for comparison. Both types of reference price possess markedly longer price durations than the raw data: the median being around 14 weeks for the rolling measure and 26 weeks for the quarterly measure, compared to 2.4 weeks for the raw data. Implied duration statistics of the rolling references prices are generally half those of the quarterly measure, suggesting that the latter may indeed over-emphasise price rigidity[12].

[11] An additional feature of price dynamics (covering actual prices and sales and reference prices which we report on below) is seasonality; to save space, we do not report on these results here.

[12] Bunn and Ellis (2012) report a shorter reference price duration of around 18 weeks which may reflect the data period or the range of products covered by their supermarket prices which includes household, personal and alcohol products as well as food products which are covered in our dataset.

Despite differences in the *magnitude* of price duration, the *pattern* of duration by retailer, format and label that that is so apparent in the raw prices represented in Figure 3 is captured by both definitions of the reference price, so that both emphasize the variation of price durations. Specifically, rolling (quarterly) reference prices of private label products last around 25% (30%) longer than brands; frozen products last 100% (50%) longer than fresh. Retailer heterogeneity is particularly pronounced in relation to reference price durations which last 130% (75%) longer in Asda and Tesco than in Safeway.

Table 3 here

(iv) Sales

Dhyne *et al*. (*op. cit*.) suggested that sales were less of a feature in Europe compared with the US. While the data here are broadly consistent with this, there is again considerable heterogeneity among retailers; some seldom use sales, while in others sales are a common feature of pricing decisions. We start with some general observations about the role of sales in retailer price dynamics. The typical UPC experiences a 10% sale a little under once per year, a figure that rises to 1.5 per year if we consider only those UPCs that have been discounted in the sample period. Discounts in excess of 50% are rare (accounting for less than 5% of all sales) so that the majority of sales represent discounts of between 10 and 30%, the median discount being 24%.

Table 4 reports summary statistics of the sales defined according to 10, 25 and 35% thresholds. Nearly 8% of prices are classed as 'on sale' using the 10% threshold, a figure that drops to 3.5% and 1.4% for the larger discounts. Thus while sales are clearly the exception to the normal rule of pricing, only very deep sales are rare. Table 4 also reports the proportion of time series that contain at least one sale episode and here the incidence of sales is more evenly distributed. Specifically, two-thirds of all time series have been on a 10% sale, one-fifth experiencing 35% sales. These averages mask notable differences between branded and private label products. While the duration of sales is (at four weeks) broadly the same, branded products tend to be discounted twice as frequently and more deeply than private label products.

Table 4 here

To investigate the use of sales in each of the UK's national food retailers, Figure 4 shows the proportion of each retailer's prices that are sales under the three thresholds. Marked differences are evident: Asda uses sales rarely, almost one-tenth of the average; Safeway, Somerfield and Kwik Save form a group of 'discounters' in that the use of sales is above average for the food retailing sector as a whole; Tesco, Sainsbury and Waitrose are "average" users of promotional activity. This classification is consistent across the depth of sales but becomes increasingly apparent the deeper the sale. All use deep sales rarely, this being even less common for Tesco, Sainsbury Waitrose and Asda.

Figure 4 here

This section has shown that there is a great deal of heterogeneity in the price dynamics across food retailers in the UK. Prices are sticky but much less so than others find with a much shorter implied duration on average. Sales also appear to be far more prevalent than evidence suggest for other European countries. Based on these findings, it is insightful to examine to what extent this heterogeneity in price dynamics is due to sales behaviour or changes in reference prices.

5. Decomposing Price Dynamics across Retailers

In this section, we explore the extent to which reference prices and sales account for price adjustment in UK food retailing. We conduct this decomposition for the market as a whole and by retailer. Given the high degree of price dispersion – some 22% for the median UPC - it seems more appropriate to express the variation in prices in terms of each UPC mean rather than the product mean. As a consequence, we estimate price regressions in which the deviation in UPC price about its mean $p_{it} = (P_{it} - \bar{P}_i)$ is regressed on two sets of dummy variables; one containing reference price spell dummies, the other containing dummies indicating sales. Since every price observation occurs at either a reference price or during a sale, the two sets of dummies are orthogonal, a feature that we usefully exploit in the attribution of price variation. Specifically, we estimate regressions of the following form:

$$p_{it} = \beta Ref_{it} + \varepsilon_{it} \quad (1)$$

$$p_{it} = \gamma Sales_{it} + \varepsilon_{it} \quad (2)$$

$$p_{it} = \beta Ref_{it} + \gamma Sales_{it} + \varepsilon_{it} \quad (3)$$

where Ref_{it} is a matrix containing reference price spell [0,1] dummies, each of which represents a new reference price spell that switches on for a single reference price spell and is zero elsewhere. $Sales_{it}$ is a matrix containing sales spell [0,1] dummies, with each dummy switching on for a single sale episode, and zero elsewhere. With a separate variable for each and every spell the coefficient matrices β and γ represent estimates of the deviation about each UPC's mean during each of its spells of reference prices and sales. Our interest is not however in these estimates but the explanatory power of the models, for which we use the coefficient of determination, R^2. Owing to the orthogonality of Ref_{it} and $Sales_{it}$ there is a straightforward decomposition of the variation such that $R^2(3) = R^2(1) + R^2(2)$ from which the contribution of reference prices and sales in overall variation can be determined. While equations (1) to (3) are simple enough to estimate in principle, the dimensions of the Ref_{it} and $Sales_{it}$ are too unwieldy to use in practice.[13] Our solution is to recover the required R^2 for these aggregate regressions using output from the individual UPC regressions. With *N* UPCs, *T* time periods, and prices expressed in deviation form, the explained sum of squares $\left[\sum_{t=1}^{T}(\hat{p}_{it})^2\right]$ and total sum of squares $\left[\sum_{t=1}^{T}(p_{it})^2\right]$ from the individual UPC regressions, combine to form the coefficient of determination of the aggregate regressions, given by,

$$R^2 = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T}(\hat{p}_{it})^2}{\sum_{i=1}^{N}\sum_{t=1}^{T}(p_{it})^2} \quad (4)$$

It is noteworthy that this differs from the average coefficient of determination of the individual regressions,

$$\frac{1}{N}\sum_{i=1}^{N}\left[\frac{\sum_{t=1}^{T}(\hat{p}_t)^2}{\sum_{t=1}^{T}(p_t)^2}\right]_i \quad (5)$$

[13] Stata 12 can handle up to 11,000 regressors, well short of the dimensions of the Ref_{it} and $Sales_{it}$ matrices, which contain 18,805 (9,827) and 4,214 (4,293) dummy variables respectively using the rolling (quarterly) definition of reference prices and sales.

since whereas R^2 is a ratio of sums, (5) is a sum of ratios. Mindful of this, we calculate R^2 as in (4) for Models (1), (2) and (3) using both the rolling and fixed mode definitions of reference prices in two samples: one for all UPCs and another that includes only those UPCs that have experienced a sale. Results are summarised in Table 5. The principal finding underlines the importance of sales in price variation. Despite occupying less than 9% of the dataset, sales are responsible for about 43% of the variation in prices, about the same as reference prices. Focussing on those UPCs that have experienced at least one sale episode, sales emerge as the primary source of variation in prices, accounting for about 49% of the variation in prices. As the results in the table show, the choice of reference price makes relatively little difference, save for the fact that quarterly (Eichenbaum) reference prices attribute more of the variation to idiosyncratic factors owing to the greater inertia in fixed as opposed to rolling quarterly modes.

Table 5 here

Of equal interest is how the contribution of reference prices and sales to price changes varies across retailers. Using 'all UPCs' and the rolling mode measure of reference prices, the contribution of reference prices in price variation varies between 29% and 82% whereas the sales contribution varies between 6% and 56%. The results are summarised in Figure 5 where we also report the breakdown for private label and branded products, this being another distinguishing feature of UK food retailing. The results indicate that retailers are less likely to use sales in the process of adjusting private label prices, however the difference by brand status is much less marked than by retailer, emphasising that here too, it is retailer heterogeneity that imparts the greatest effect.

Figure 5 here

6. Retailer Reference Prices and Inflation

One important implication of menu cost models highlighted in the recent literature is that the frequency of price adjustment should be related to cost or demand shifts but in identifying this effect that it is reference, not actual, prices that is the relevant metric. Consistent with recent micro data research, we test this but again highlight the significance of reference price adjustment across retailers. The focus here is not to address the cost-price transmission process but, more narrowly whether cost changes are reflected in contemporaneous price changes downstream i.e. whether nominal rigidities are reflected in price dynamics. If menu costs were negligible and retailers homogenous, we would anticipate a high correlation between the category cost measure and the frequency of retail price changes in each product group. The existence of menu costs may reduce the correlation which will weaken further if retailer pricing decisions reflect idiosyncratic features of price adjustment that are specific to each retail chain. Variation by retailer questions the assumption of homogenous pricing agents, even within the same sector[14].

Over the data period, aggregate inflation was relatively low and stable. However, food inflation was more volatile, varying between 6% and -2% year-on-year. To explore the correlation between price change frequencies and inflation, we obtained manufacturing output price indices that tie closely with the UPC product categories used in the Nielsen Scantrak retail price data. For example, the manufacturing price index for bread, fresh pastry and cakes was matched with retail bread prices. Since manufacturing price indices represent the stage closest to the retail sector, they represent a reasonable measure of the cost changes in the corresponding product category of the food retailing sector.

Manufacturing food price indices are available at a monthly frequency only, so we derived monthly average price change frequencies based on the weekly data. We then calculated the contemporaneous correlation between the frequency of price changes at the retail level and manufacturing output price inflation for the six categories listed in Table 6. We report on the correlation across product groups using actual prices and rolling reference prices,. Being free of the influence of sales the latter of which may be expected to reflect changes in manufacturing inflation better than raw prices. [15]

As with other studies, the existence of product heterogeneity in price adjustment is apparent. In general, the correlation between monthly changes in category-specific

[14] See also Nakamura *et al*. (2011) on the implications of idiosyncratic pricing by retail chains.
[15] Since the correlation between the quarterly reference price frequency and cost changes would be low by construction, we restrict the correlation results to the raw and the rolling reference price data.

cost indices and the frequency of price changes is low and depends on whether we use actual prices which are inclusive of sales and rolling reference prices which are not. While overall the correlations are low by either measure, for 5 of the 6 categories the (absolute) value of the correlation coefficients are higher with the rolling reference price measure.

Table 6 here

However, the correlation between average price change frequencies and category costs varies across retailers and across retailers for the same product category. The top half of Figure 6 highlights this variation across retailers using actual prices; no pattern across retailers emerges i.e. there is no one retailer where the correlation between price changes and cost changes is consistently higher or lower compared with other retailers for the same product category. Of course, since we know that from above that sales behaviour varies by product and retailer, the lack of any consistent pattern may reflect variation in the use of sales by retailer. In the bottom half of Figure 6, we report the outcome where we have the frequency of rolling reference prices and cost changes by retailer and category. Again, it is apparent that no obvious pattern emerges and that the heterogeneity across products and retailers persists. Overall, the correlation of price adjustment between manufacturing and retailing is low with substantial variation across product groups and across retailers. The data indicate that no single retailer consistently adjusts reference prices in the face of cost changes across all product categories.

Figure 6 here

The results reported above are robust to a number of alternative specifications. For example, rather than using the full data set, we also constrained the analysis to the products that are sold across all retailers, and dropped those products that are sold by single retailers. The results did not change to any substantive degree from those reported above. Similarly, using the CPI an alternative measure of inflation again closely matched to the product category did not matter for the results. In sum, retailer and product heterogeneity in the correlation between the frequency of price adjustments and manufacturing output price inflation persists.

7. Summary and Conclusions

Using weekly scanner data for the seven main food retailers in the UK, we have shown that there is considerable heterogeneity in price dynamics across retailers. This relates to the use of sales, to the implied duration of reference prices, and the extent to which retailers adjust prices either via sales or reference prices. Moreover, when closely tying the retail prices with underlying manufacturing prices, the correlation of the frequency of price changes with changes in retailers' costs varies markedly across the seven major retailers whatever measure of price is used. The observation that there are significant retailer differences in price dynamics complements the observations in recent micro-price studies relating to product heterogeneity. The retailer dimension has seldom featured in this research and, what evidence does exist, relates to the US only. The observation of retailer diversity in price adjustment also has implications for the assumption of representative firms that underpin many macroeconomic models and also indicates that idiosyncratic factors are likely to play a role in explaining how price dynamics vary across retailers.

References

Berka, M., M.B.Devereux and T. Randolph (2011) "Price setting in a leading Swiss online supermarket" NBER Working Paper No. 17126. Mass.

Berck, P. J. Brown J.M. Perloff and S.B. Villas-Boas (2008). "Sales: tests of theories on causality and timing". *International Journal of Industrial Organisation* 26(6), 1257-1273.

Bils, M. and P.J.Klenow (2004) "Some evidence on the importance of sticky prices" *Journal of Political Economy*," 112: 233-261.

Bunn, P. and C. Ellis (2012) "Examining the behaviour of individual UK consumer prices" *Economic Journal*, 122: F35-F55.

Campbell, J.R. and B. Eden (2005) "Rigid prices: evidence from US scanner data" Mimeo, Federal Reserve Bank of Chicago and Vanderbilt University.

Competition Commission (2000). *Report on the Supply of Groceries from Multiple Stores in the United Kingdom (3 Volumes).* CM 4842. London HMSO.

Dhyne, E., L.J. Álvarez, H.L.Bihan, G. Veronese, D. Dias, J. Hoffmann, N. Jonker, P. Lunnemann, F. Rumler, and J. Vilmunen (2006). "Price setting in the Euro Area and the United States: some facts from individual consumer price data". *Journal of Economic Perspectives* 20, 171-192.

Eichenbaum, M., N. Jaimovich and S. Rebelo (2011) "Reference prices, costs and nominal rigidities" *American Economic Review*, 101: 234-262

Golosov, M. and R.E. Lucas Jr. (2007) "Menu costs and Phillips curves" *Journal of Political Economy*, 115: 533-572

Guimarães, B. and K.D.Sheedy (2011) "Sales and monetary policy" *American Economic Review*, 101: 844-876

Hosken, D. and D. Reiffen (2004). "Patterns of retail price variation". *RAND Journal of Economics* 35, 128-146.

Klenow, P.J. and O. Kryvstov (2008) "State-dependent or time-dependent pricing: does it matter for recent US inflation?" *Quarterly Journal of Economics*, 123: 863-904.

Maćkowiak, B. and F. Smets (2008) "On the implications of micro price data for macro models" CEPR Discussion Paper Series No. 6961. London.

Nakamura, E. (2008). "Pass-through in retail and wholesale". *American Economic Review: Papers and Proceedings* 98, 430-437.

Nakamura, A.O., E. Nakamura and L.I. Nakamura (2011) "Price dynamics, retail chains and inflation measurement" *Journal of Econometrics*, 161: 47-55.

Nakamura, E. and J. Steinsson (2008). "Five facts about prices: a re-evaluation of menu cost models". *Quarterly Journal of Economics* 123, 1415-1464.

Taylor, J.B. (1999) *Handbook of Macroeconomics*. Vol. 1, part B.

Figure 1: Weekly Prices (pence) of a Selection of Products sold by UK Retail Chains

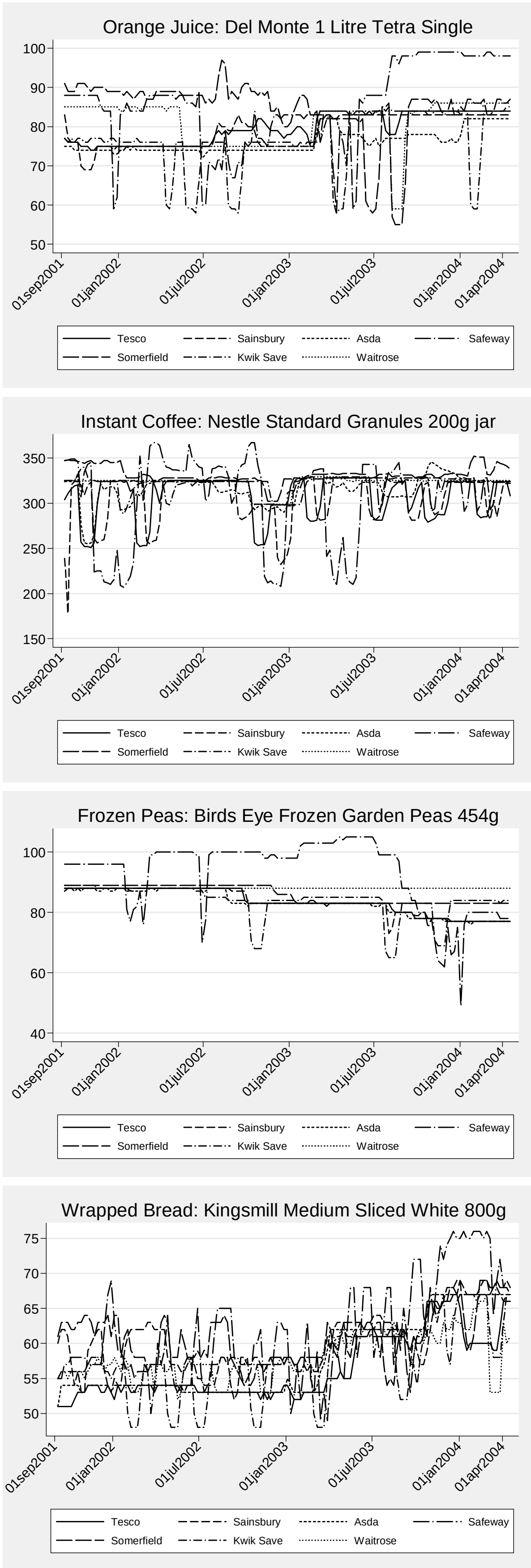
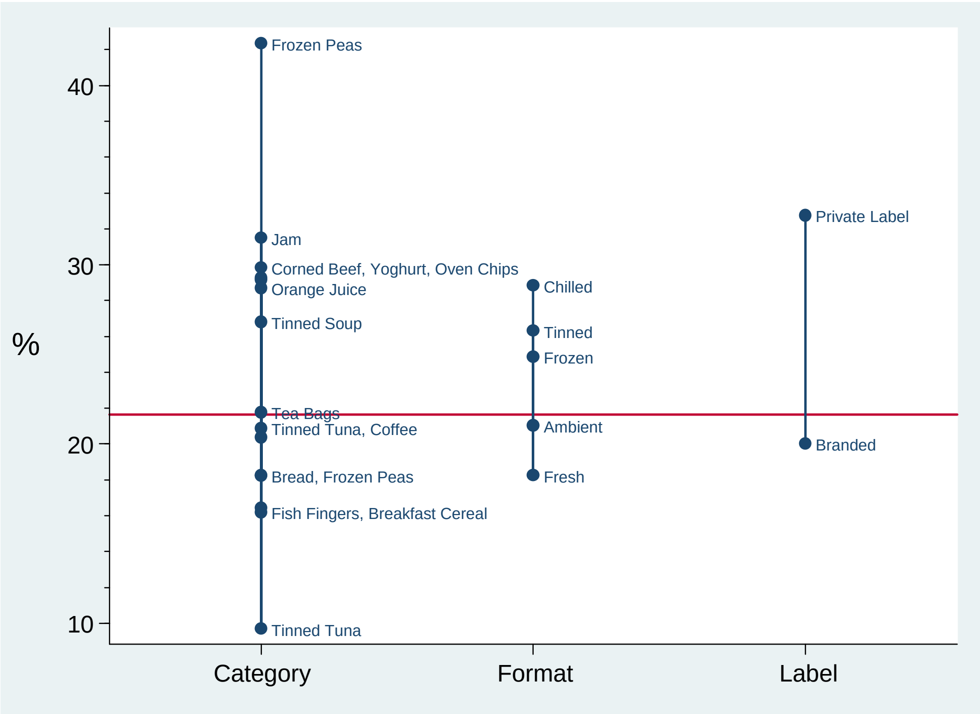


Figure 2: Price Dispersion by Category, Format and Label



Note: Median weekly price range between UPCs of the same product sold in two or more retailers.

Figure 3: The Median Frequency of Price Changes and the Implied Duration of UPC Prices

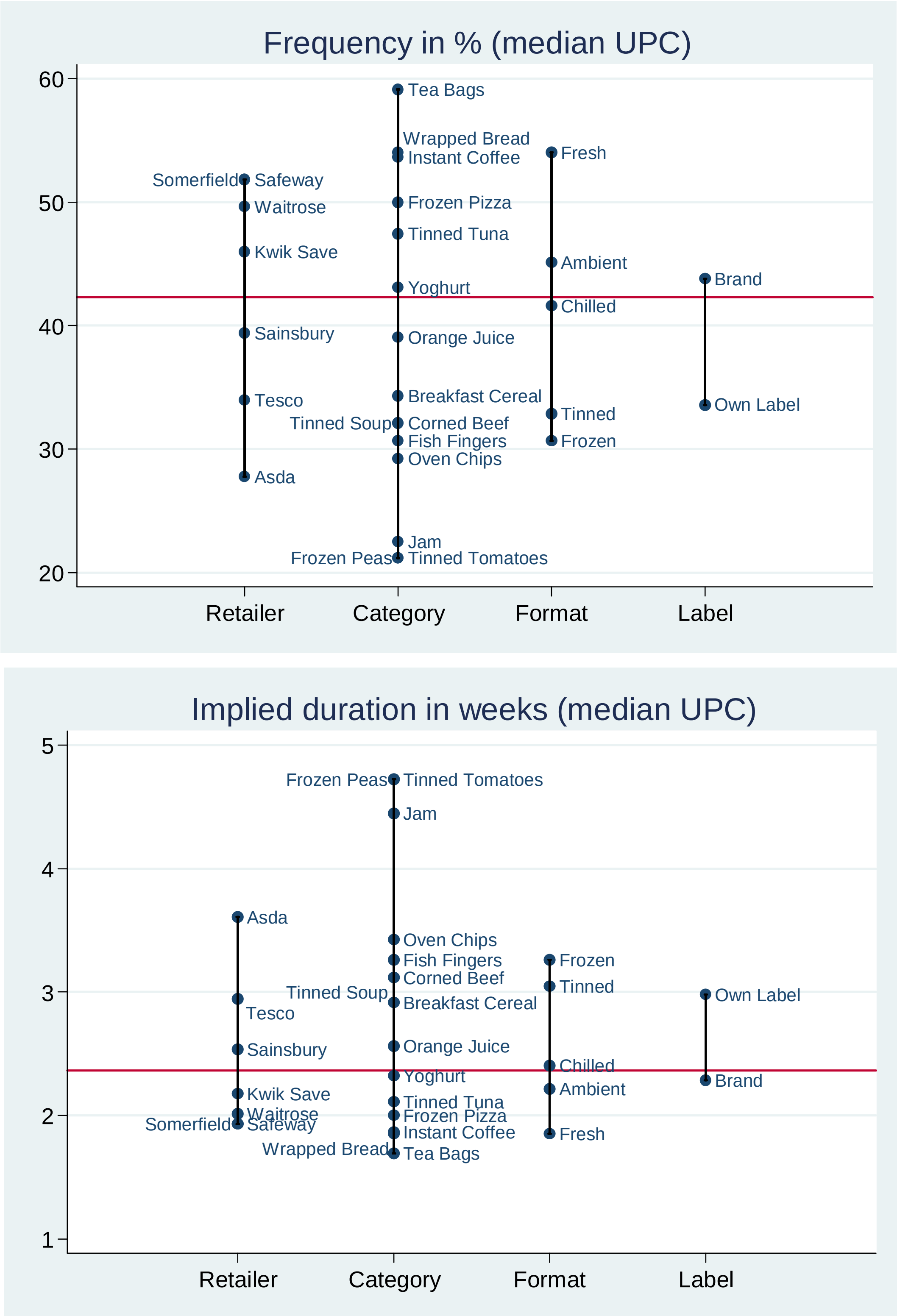


Figure 4: The Prevalence of Sale Prices by Retailer (%)

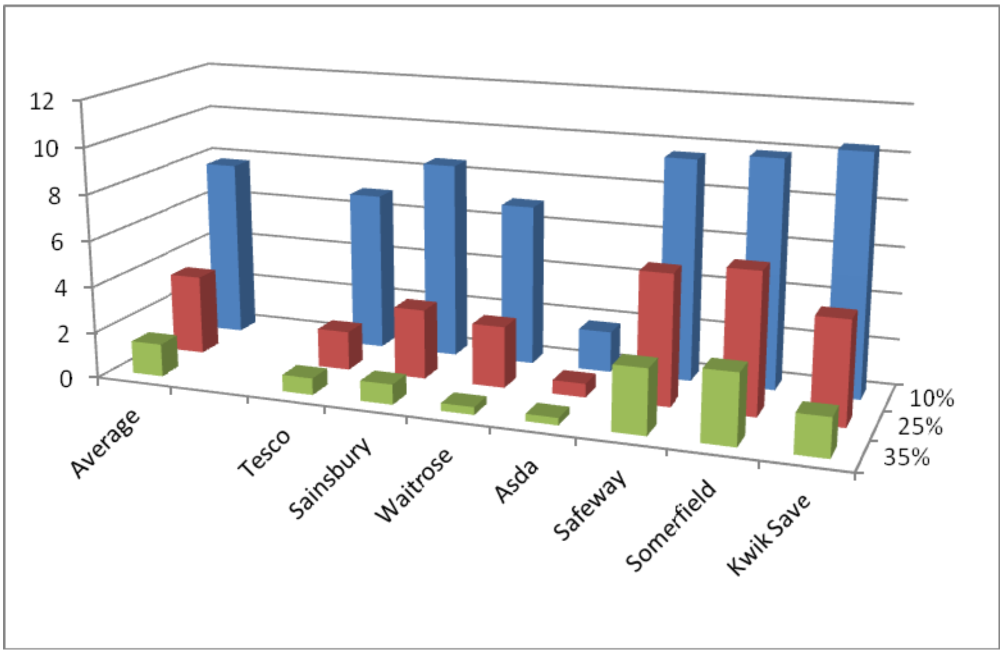
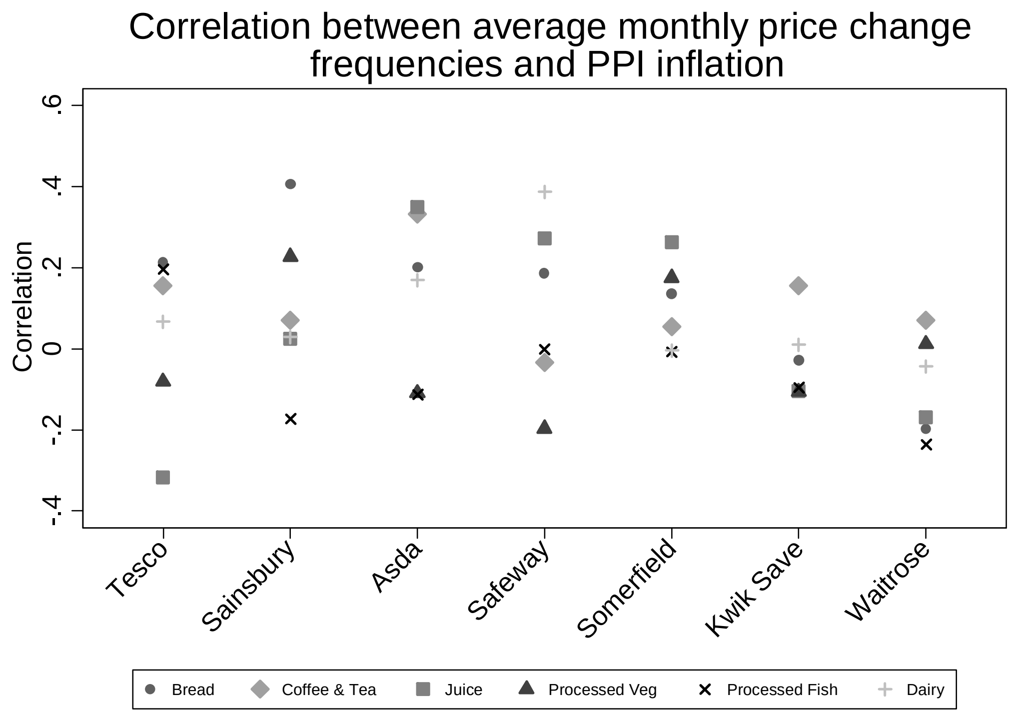


Figure 5: Contribution (R^2) to Price Variation across Retailers and Label

Figure 6: Price Change Frequency by Product and Retailer



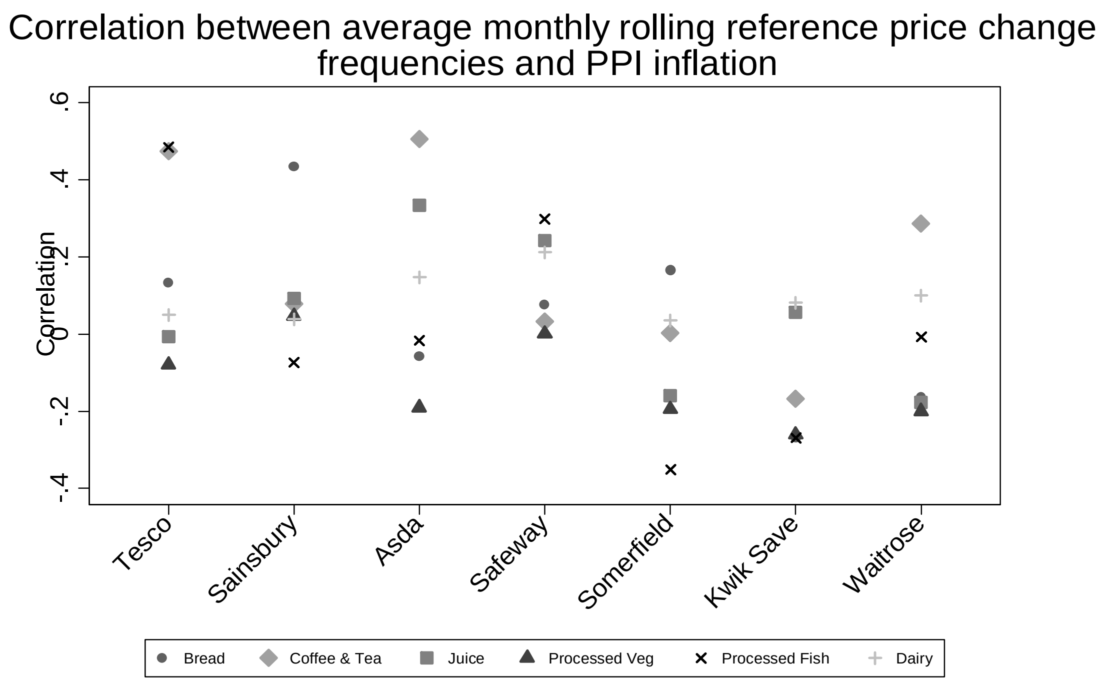


Table 1: Distribution of Unique Product Codes (UPCs) by Category

Category	Brands	Private Label	All	% of total
Orange Juice	57	51	108	6.34
Instant Coffee	111	27	138	8.10
Tinned Tuna	51	0	51	2.99
Tinned Tomatoes	50	0	50	2.93
Tinned Soup	237	71	308	18.08
Oven Chips	83	0	83	4.87
Corned Beef	25	5	30	1.76
Frozen Peas	34	0	34	2.00
Fish Fingers	20	0	20	1.17
Breakfast Cereal	66	0	66	3.87
Tea Bags	59	8	67	3.93
Yoghurt	65	4	69	4.05
Wrapped Bread	488	95	583	34.21
Jam	33	44	77	4.52
Frozen Pizza	20	0	20	1.17
Total	**1,399**	**305**	**1,704**	**100.00**

Table 2: Price Dispersion within Product Code
(average price difference between the highest and lowest price of identically bar-coded products)

Price	Median Price Dispersion (%)	Mean Price Dispersion (%)
Actual	21.63	26.35
Rolling Reference	18.01	22.98
Quarterly Reference	18.99	23.68

Table 3: Implied Duration Statistics for Actual and Reference Price Data (median UPC, in weeks)

	Actual Prices	Rolling Reference Prices	Quarterly Reference Prices
Overall	2.4	13.9	26.0
Retail Chain			
Asda	3.6	20.8	32.5
Tesco	2.9	20.8	32.5
Sainsbury	2.5	15.6	32.5
Kwik Save	2.2	13.9	26.0
Waitrose	2.0	15.6	32.5
Somerfield	1.9	11.4	26.0
Safeway	1.9	8.9	18.6
Brand Status			
Private Label	3.0	17.9	32.5
Brand	2.3	13.8	26.0
Format			
Frozen	3.3	20.8	32.5
Tinned	3.0	20.8	32.5
Chilled	2.4	12.5	21.7
Ambient	2.2	14.6	29.3
Fresh	1.9	10.4	21.7

Table 4: Summary Statistics of the Sales Data

	Sale Threshold								
	10%			25%			35%		
	All	Brands	Private Label	All	Brands	Private Label	All	Brands	Private Label
Frequency (%)	7.8	8.5	4.6	3.5	3.8	1.9	1.4	1.5	0.9
UPCs (%)	63.0	66.9	44.9	36.8	49.6	23.9	20.1	21.4	13.8
Average Duration (weeks)	4.5	4.5	4.4	4.4	4.4	4.5	4.2	4.1	4.7

Table 5: Contribution (R^2) of Reference Prices and Sales in Price Variation

	Model (1)	Model (2)	Model (3)	
	Reference Spell Dummies	Sales Spell Dummies	Reference and Sales Spell Dummies	Residual
Rolling Reference Prices				
All UPCs	0.44	0.43	0.87	0.13
UPCs with at least one sale	0.38	0.49	0.87	0.13
Quarterly Reference Prices				
All UPCs	0.39	0.42	0.82	0.18
UPCs with at least one sale	0.34	0.48	0.82	0.18

Table 6: Correlations between the Frequency of Average Monthly Retail Prices and Manufacturing Inflation: By Product Category

By Product Category	Actual Price Data	Rolling Reference Prices
Bread	0.22	0.13
Tea and Coffee	0.28	0.37
Juice	0.11	0.14
Processed Vegetables	0.00	-0.15
Processed Fish	-0.10	0.12
Dairy	0.18	0.20