An empirical study of supermarket demand and equilibrium pricing

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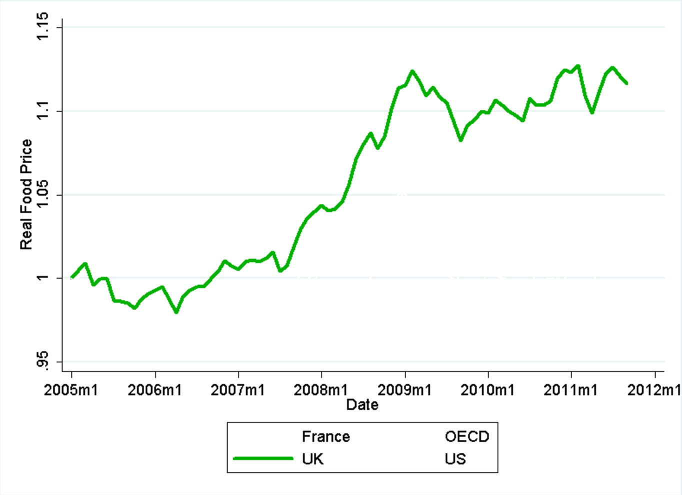
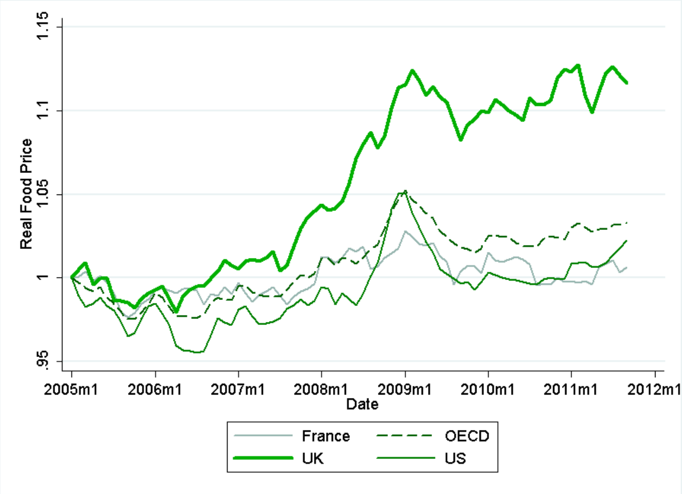
Outline of presentation

1. Background/motivation
   - From Griffith, O'Connell and Smith (2011)
2. Outline a model of grocery demand and supermarket pricing
3. Show some very preliminary results

Recent large increase in UK food price

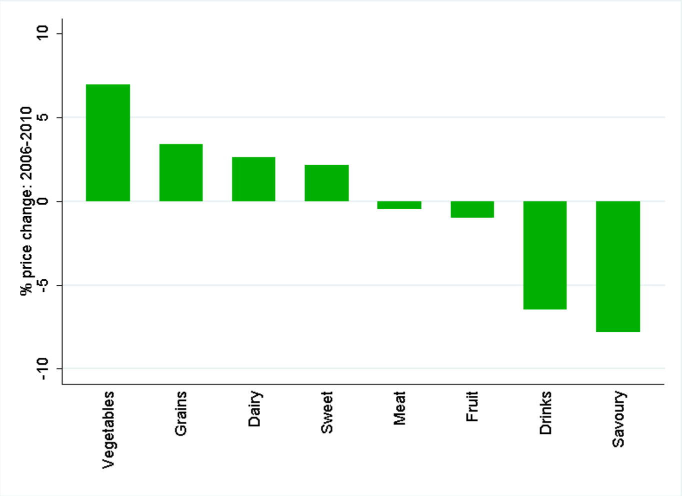


Recent large increase in UK food price



Large change in relative prices of different foods

Change in price of food types relative to change in price of all food: 2006 - 2010



Possible drives of changes in retail food prices

Changes in costs?

- Large depreciation of sterling and global food commodity price boom
- Would expect an increase in retailer costs

Changes in demand?

- Concurrently there's been large shocks to consumers' incomes
- Crossley et al (2011) report 6.6% decline in consumer expenditure on food over recession
- Would expect resultant reallocation of expenditures across different foods

Objective of this work

- Specify and estimate a model that allows for separation of impact of changes in costs and changes in demand conditions on equilibrium food prices
- In common with many empirical IO papers:
  - Estimate demand facing firms
  - Use equilibrium pricing condition to pin down marginal costs
- But in contrast to much of this literature:
  - Model demand for a large class of goods
  - Allow for complementarities between goods
  - Allow for income effects
- Use model to simulate counterfactual market equilibria
  - e.g. Path of retail prices in absence of increases in costs

Overview of demand model

- Focus on modelling the consumer's main weekly supermarket trip
  - Which supermarket they choose
  - How they allocate their main trip grocery expenditure across 9 grocery goods
- Assume one stop shop model - purchase decisions made on main trip are independent of purchase decisions on smaller top up trips
- Consumer makes discrete decision over which retailer to shop with based on:
  - Anticipated utility from optimal shopping within retailer
  - Their valuation of other retailer characteristics
- And a continuous decision over how to allocate expenditure across grocery goods available in chosen retailer
- Model allows for estimation of demand faced by retailers; e.g. demand for meat in retailer Tesco

Utility conditional on retailer choice

Consumer i in week t gets utility from shopping with retailer s given by:

$$\overline{V}_{ist} = \zeta_i \phi(p_{st}, x_{it}, \xi_{it}) + \kappa_i z_{is} + \lambda_i \mu_s + \varepsilon_{ist}$$

where:

- $p_{st} = (p_{s1t}, ..., p_{sJt})'$ are prices for J goods within the retailer
- x_{it} is weekly main shop budget
- $\xi_{it} = (\xi_{i1t}, ..., \xi_{iJt})'$ captures household specific and time specific factors influencing within retailer demand
- z_{is} are observable consumer-retailer characteristics
- μ_s are retailer fixed effects
- $(\zeta_i, \kappa_i, \lambda_i)$ are consumer specific (random) coefficients
- ε_{ist} is an idiosyncratic shock

Within retailer behaviour

- Assume within retailer preferences can be represented by AIDS with consumer specific heterogeneity
- Portion of indirect utility realised from within retailer behaviour is:

$$\phi(p_{st}, x_{it}, \xi_{it}) = \frac{1}{B(p_{st})}[\ln x_{it} - \ln A(p_{st}, \xi_{it})]$$

where

$$\ln A(p_{st}, \xi_{it}) = \alpha_o + \sum_j \alpha_j(\xi_{ijt}) \ln p_{sjt} + \frac{1}{2}\sum_j \sum_k \widetilde{\gamma}_{jk} \ln p_{sjt} \ln p_{skt}$$

$$\ln B(p_{st}) = \sum_j \beta_j \ln p_{sjt}$$

Within retailer behaviour

- Assuming
  1. $\alpha_j(\xi_{ijt}) = \overline{\alpha}_j + \xi_{ijt}$
  2. $\xi_{ijt} = \tau_{jt} + c_{ij}$
- Roy's Identity implies (anticipated) share of trip expenditure allocated to good j is:

$$w_{isjt} = \overline{\alpha}_j + \tau_{jt} + c_{ij} + \sum_k \gamma_{jk} \ln p_{skt} + \beta_j \ln \left(\frac{x_{it}}{A(p_{st}, \xi_{it})} \right)$$

  - τ_{jt} captures unobserved common time factors affecting intercept of budget share demands
  - c_{ij} captures unobserved household specific factors affecting intercept of budget share demands

Within retailer behaviour

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- Consumer makes retailer choice decisions based on expected behaviour captured by w_{isjt}
- Within retailer realised demand, $\widetilde{w}_{isjt}$, may differ; I assume

$$w_{isjt} = E(\widetilde{w}_{isjt} | \tau_{jt}, c_{ij}, p_{st}, x_{it})$$

Choice of supermarket

- Consumer chooses retailer that provides her with most utility

$$V_{it} = \max_s [\overline{V}_{i0t}, ..., \overline{V}_{iSt}]$$

- Assume ε_{ist} is distributed iid extreme value and $(\zeta_i, \kappa_i, \lambda_i)$ are drawn from a multivariate normal distribution F
- Then probability consumer i in week t visits retailer s is:

$$\pi_{ist} = \int \frac{\exp(\zeta_i \phi(p_{st}, x_{it}, \xi_{it}) + \kappa_i z_{is} + \lambda_i \mu_s)}{\sum_r \exp(\zeta_i \phi(p_{rt}, x_{it}, \xi_{it}) + \kappa_i z_{ir} + \lambda_i \mu_r)} dF$$

Substitution patterns

- Consumer i's week t expected demand for good j in retailer s is:

$$q_{isjt} = \pi_{ist}\overline{q}_{isjt}$$

  where $\overline{q}_{isjt}$ is demand conditional on retailer choice

- Ignoring i and t subscripts, price elasticities of demand between goods within a retailer are:

$$\delta_{(sj)(sk)} = \frac{\partial \ln \pi_s}{\partial \ln \phi_s}\frac{\partial \ln \phi_s}{\partial \ln p_{sk}} + \frac{\partial \ln \overline{q}_{sj}}{\partial \ln p_{sk}}$$

- Price elasticities of demand between goods in different retailers are:

$$\delta_{(sj)(rk)} = \frac{\partial \ln \pi_s}{\partial \ln \phi_r}\frac{\partial \ln \phi_r}{\partial \ln p_{rk}}$$

Choice of total grocery expenditure

- Current version of the model conditions on main trip grocery expenditure
- Consumer chooses supermarket based on utility she will get from optimally spending that budget on grocery goods, given prices she'll face in the retailer
- But budget is assume to be fixed across retailers
  - Roughly, consistent with demand for aggregate grocery good having unit price elasticity with respect to total grocery price index
  - Means variation in consumer's grocery expenditure through time is driven by changes in her total non-durable expenditure/income

Consumer's problem

Choice of total grocery expenditure

- Aim is to relax this assumption
- Difficulty is market research data has
  - Very detailed information on consumer's within supermarket expenditures
  - But little information on their non-grocery expenditure or income
- One idea is to:
  - Assume weak separability between grocery and non-grocery demand
  - Use market research data to estimate preference parameters determining grocery demand
  - Use additional data source to estimate preference parameters determining choice of grocery expenditure

Retailer behaviour

- Assume retailers compete in a Nash-Bertrand game
- Retailer s in market t chooses the prices of J goods to maximise profits:

$$\max_{p_{st}} \sum_{j \in \{1,\ldots,J\}} (p_{sjt} - c_{sjt}) Q_{sjt}(p_{01}, \ldots, p_{St}) - C_{sjt}$$

- where:
  - c_{sjt} is market t marginal cost of good j in retailer s
  - C_{sjt} is market t fixed cost of good j in retailer s
  - $Q_{sjt} \equiv \sum_{i \in \Omega_t} q_{isjt}$ is market t demand for good j in retailer s

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- First order condition is:

$$Q_{sjt} + \sum_{k \in \{1,\ldots,J\}} (p_{skt} - c_{skt}) \frac{\partial Q_{skt}}{\partial p_{sjt}} = 0$$

- Inverting system yields implied marginal cost of each good in each retailer and market

Data

- Rolling panel of households, containing
  - All grocery shopping trips households make
  - Including the retailer they visit
  - And within retailer expenditures and transaction prices on very disaggregate products
- Data cover period 2002-2010; 466 weeks/markets
- Households in data for 120 weeks on average

- Weekly main shopping trip is defined as weekly trip on which household spends most
- Small number of weeks where a household's grocery expenditure is less than 50% of its median are dropped
- On average 82% of households' weekly grocery supermarket expenditure is made on main trips

Goods

Good	Expenditure share	Main compenents
Fruit	8.05%	Fresh fruits, canned and dried fruits, frozen fruit and fruit juices
Vegetables	5.08%	Fresh vegetables, canned vegetables and frozen vegetables
Grains	7.95%	Flour, cereals, pasta, rice, breads and potatoes
Dairy	10.73%	Milk, cream, cheese, butter, margarine and yogurt
Meats	14.88%	Beef, pork, lamb, poultry, bacon, ham, sausages, eggs, seafood, seeds and nuts
Drinks	5.52%	Non fruit juice, water, tea and coffee
Sweet	8.23%	Sugar, sweeteners, cakes, biscuit and desserts
Savoury	18.24%	Ready meals and prepared snacks
Non food	21.31%	Alcohol, toiletries, pet foods and cleaning produce

▸ Prices

Retailers

Retailer	Market share
Asda	20.1%
Morrisons	14.8%
Sainsbury's	17.9%
Tesco	35.9%
Other	11.3%

Demand conditional on retailer choice

Variables	Fruit	Vegetables	Grain	Dairy	Meat
Expenditure	-0.0202***	-0.0132***	-0.0230***	-0.0331***	0.0016***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)
PriceFruit	0.0180***	0.0004	-0.0006	-0.0032***	-0.0252***
	(0.0007)	(0.0004)	(0.0006)	(0.0007)	(0.0009)
PriceVegetables	0.0004	0.0277***	0.0021***	0.0026***	-0.0207***
	(0.0004)	(0.0006)	(0.0006)	(0.0007)	(0.0008)
PriceGrain	-0.0006	0.0021***	0.0057***	-0.0148***	-0.0158***
	(0.0006)	(0.0006)	(0.0011)	(0.0010)	(0.0010)
PriceDairy	-0.0032***	0.0026***	-0.0148***	0.0220***	-0.0287***
	(0.0007)	(0.0007)	(0.0010)	(0.0016)	(0.0013)
PriceMeat	-0.0252***	-0.0207***	-0.0158***	-0.0287***	0.1321***
	(0.0009)	(0.0008)	(0.0010)	(0.0013)	(0.0022)
PriceDrink	0.0035***	-0.0003	0.0142***	0.0174***	-0.0189***
	(0.0005)	(0.0004)	(0.0005)	(0.0007)	(0.0008)
PriceSweet	-0.0213***	-0.0046***	-0.0185***	-0.0236***	0.0213***
	(0.0005)	(0.0004)	(0.0005)	(0.0006)	(0.0008)
PriceSavoury	-0.0141***	-0.0128***	-0.0052***	-0.0110***	0.0449***
	(0.0008)	(0.0006)	(0.0008)	(0.0010)	(0.0014)
Time effects	Yes	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes	Yes
No. of observations	2287160	2287160	2287160	2287160	2287160

*Notes: *** $p<0.01$, ** $p<0.05$, * $p<0.1$*

Demand conditional on retailer choice

Variables	Drink	Sweet	Savoury	Non Food
Expenditure	-0.0025***	-0.0108***	-0.0214***	0.1225***
	(0.0001)	(0.0001)	(0.0002)	(0.0002)
PriceFruit	0.0035***	-0.0213***	-0.0141***	0.0424***
	(0.0005)	(0.0005)	(0.0008)	(0.0008)
PriceVegetables	-0.0003	-0.0046***	-0.0128***	0.0056***
	(0.0004)	(0.0004)	(0.0006)	(0.0007)
PriceGrain	0.0142***	-0.0185***	-0.0052***	0.0330***
	(0.0005)	(0.0005)	(0.0008)	(0.0009)
PriceDairy	0.0174***	-0.0236***	-0.0110***	0.0392***
	(0.0007)	(0.0006)	(0.0010)	(0.0011)
PriceMeat	-0.0189***	0.0213***	0.0449***	-0.0890***
	(0.0008)	(0.0008)	(0.0014)	(0.0015)
PriceDrink	-0.0010	-0.0075***	-0.0088***	0.0014*
	(0.0006)	(0.0004)	(0.0007)	(0.0008)
PriceSweet	-0.0075***	0.0448***	0.0140***	-0.0046***
	(0.0004)	(0.0006)	(0.0007)	(0.0008)
PriceSavoury	-0.0088***	0.0140***	0.0151***	-0.0221***
	(0.0007)	(0.0007)	(0.0016)	(0.0013)
Time effects	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes
No. of observations	2287160	2287160	2287160	2287160

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Demand conditional on retailer choice

Conditional elasticities in Tesco

	Fruit	Vegetables	Grain	Dairy	Meat	Drink	Sweet	Savoury	Non Food
Fruit	**-0.74**	0.05	0.04	0.02	-0.17	0.07	-0.25	-0.06	0.10
Vegetables	0.03	**-0.44**	0.05	0.06	-0.14	0.00	-0.04	-0.06	-0.03
Grain	0.03	0.08	**-0.88**	-0.09	-0.11	0.26	-0.21	-0.01	0.06
Dairy	0.01	0.10	-0.13	**-0.72**	-0.20	0.32	-0.27	-0.04	0.06
Meat	-0.27	-0.37	-0.16	-0.23	**-0.09**	-0.33	0.29	0.28	-0.46
Drink	0.06	0.01	0.20	0.19	-0.13	**-1.02**	-0.09	-0.04	-0.03
Sweet	-0.23	-0.06	-0.20	-0.19	0.15	-0.13	**-0.42**	0.10	-0.08
Savoury	-0.11	-0.19	0.01	-0.03	0.31	-0.15	0.21	**-0.88**	-0.23
Non Food	0.47	0.06	0.37	0.32	-0.61	0.02	-0.08	-0.15	**-0.93**
Expenditure	0.76	0.74	0.71	0.70	1.01	0.95	0.86	0.88	1.55

Notes: Number (i, j) gives percent change in demand for product j with respect to a 1 percent increase in price for product i

Demand conditional on retailer choice

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	Fruit	Vegetables	Grain	Dairy	Meat	Drink	Sweet	Savoury	Non Food
Fruit	**-0.74**	0.05	0.04	0.02	-0.17	0.07	-0.25	-0.06	0.10
Vegetables	0.03	**-0.44**	0.05	0.06	-0.14	0.00	-0.04	-0.06	-0.03
Grain	0.03	0.08	**-0.88**	-0.09	-0.11	0.26	-0.21	-0.01	0.06
Dairy	0.01	0.10	-0.13	**-0.72**	-0.20	0.32	-0.27	-0.04	0.06
Meat	-0.27	-0.37	-0.16	-0.23	**-0.09**	-0.33	0.29	0.28	-0.46
Drink	0.06	0.01	0.20	0.19	-0.13	**-1.02**	-0.09	-0.04	-0.03
Sweet	-0.23	-0.06	-0.20	-0.19	0.15	-0.13	**-0.42**	0.10	-0.08
Savoury	-0.11	-0.19	0.01	-0.03	0.31	-0.15	0.21	**-0.88**	-0.23
Non Food	0.47	0.06	0.37	0.32	-0.61	0.02	-0.08	-0.15	**-0.93**
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Vegetables	0.03	**-0.44**	0.05	0.06	-0.14	0.00	-0.04	-0.06	-0.03
Grain	0.03	0.08	**-0.88**	-0.09	-0.11	0.26	-0.21	-0.01	0.06
Dairy	0.01	0.10	-0.13	**-0.72**	-0.20	0.32	-0.27	-0.04	0.06
Meat	-0.27	-0.37	-0.16	-0.23	**-0.09**	-0.33	0.29	0.28	-0.46
Drink	0.06	0.01	0.20	0.19	-0.13	**-1.02**	-0.09	-0.04	-0.03
Sweet	-0.23	-0.06	-0.20	-0.19	0.15	-0.13	**-0.42**	0.10	-0.08
Savoury	-0.11	-0.19	0.01	-0.03	0.31	-0.15	0.21	**-0.88**	-0.23
Non Food	0.47	0.06	0.37	0.32	-0.61	0.02	-0.08	-0.15	**-0.93**
Expenditure	0.76	0.74	0.71	0.70	1.01	0.95	0.86	0.88	1.55

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Retailer demand

Unconditional elasticities in Tesco

	Fruit	Vegetables	Grain	Dairy	Meat	Drink	Sweet	Savoury	Non Food
Fruit	**-0.93**	-0.13	-0.12	-0.14	-0.33	-0.07	-0.40	-0.21	-0.03
Vegetables	-0.08	**-0.55**	-0.04	-0.04	-0.24	-0.09	-0.14	-0.16	-0.12
Grain	-0.12	-0.07	**-1.05**	-0.26	-0.25	0.12	-0.36	-0.16	-0.06
Dairy	-0.19	-0.09	-0.34	**-0.95**	-0.38	0.14	-0.46	-0.23	-0.10
Meat	-0.54	-0.65	-0.43	-0.49	**-0.40**	-0.61	0.02	0.02	-0.74
Drink	-0.04	-0.09	0.10	0.09	-0.23	**-1.14**	-0.20	-0.15	-0.13
Sweet	-0.37	-0.20	-0.35	-0.34	0.00	-0.29	**-0.60**	-0.05	-0.22
Savoury	-0.42	-0.50	-0.33	-0.36	0.01	-0.47	-0.11	**-1.25**	-0.51
Non Food	0.09	-0.34	0.00	-0.04	-1.06	-0.42	-0.50	-0.54	**-1.46**

Notes: Number (i, j) gives percent change in demand for product j with respect to a 1 percent increase in price for product i

Firm own price elasticity

- There are strong complementarities across goods within a supermarket
  - Increasing price of one good, creates a reduction in demand for most goods sold in supermarket
- Can measure strength of this effect through "firm own price elasticity"
  - Percent change in demand for all of a retailer's produce in response to 1% increase in all prices in that retailer

Firm own price elasticity

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  - Increasing price of one good, creates a reduction in demand for most goods sold in supermarket
- Can measure strength of this effect through "firm own price elasticity"
  - Percent change in demand for all of a retailer's produce in response to 1% increase in all prices in that retailer

Retailer	Firm own price elasticity
Asda	-3.13
Morrisons	-3.42
Sainsbury's	-3.27
Tesco	-2.80

Retailer demand

Unconditional meat elasticities

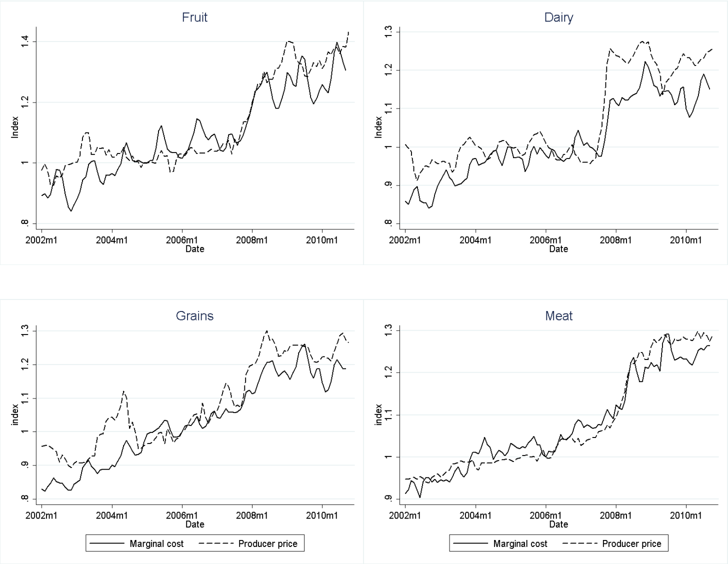
	Asda	Morrisons	Sainsbury's	Tesco
Asda	**-0.48**	0.09	0.07	0.07
Morrisons	0.07	**-0.54**	0.06	0.06
Sainsburys	0.07	0.07	**-0.61**	0.08
Tesco	0.12	0.13	0.14	**-0.40**

Notes: Number (i, j) gives percent change in demand for product j with respect to a 1 percent increase in price for product i

Retailer-good margins

	Asda	Morrisons	Sainsbury's	Tesco
Fruit	0.31	0.30	0.33	0.35
Vegetables	0.31	0.30	0.31	0.33
Grains	0.34	0.30	0.32	0.35
Dairy	0.34	0.31	0.31	0.36
Meat	0.32	0.29	0.33	0.36
Drinks	0.34	0.30	0.31	0.35
Sweet	0.31	0.29	0.29	0.36
Savoury	0.34	0.29	0.32	0.36
Non food	0.32	0.29	0.31	0.36
Profit	0.32	0.29	0.31	0.36

Marginal costs and producer prices over time



Summary

- Aim is to model consumer demand and supermarket pricing in UK food market
- And to use model to gauge relative importance of changes in
  - retailers' costs
  - demand conditions faced by retailers

  on recent large changes in UK food prices
- Next steps include
  - Modelling choice over total grocery expenditure
  - Possibly using producer price information in estimation
  - Conduct counterfactuals

Consumer's problem conditional on retailer choice

Conditional on choosing supermarket s, consumer i in week t solves

$$\max_{(q_{ist}, n_{ist})} U_i(u_i(q_{ist}), n_{ist})$$

$$s.t.\ p_{st} q_{ist} + n_{ist} = X_{it}$$

Where

- $q_{its} = (q_{is1t}, ..., q_{isJt})$ are quantities of supermarket goods
- n_{its} is total quantity of non-supermarket non-durable (numeraire)
- $p_{st} = (p_{s1t}, ..., p_{sJt})'$ are prices for J goods within the supermarket
- X_{it} is weekly non-durable expenditure

Consumer's problem conditional on retailer choice

Conditional on choosing supermarket s, consumer i in week t solves

$$\max_{(q_{ist}, n_{ist})} U_i(u_i(q_{ist}), n_{ist})$$

$$s.t.\ p_{st}q_{ist} + n_{ist} = X_{it}$$

Which implies

- Conditional demands for supermarket goods

$$w_{isjt} \equiv \frac{p_{sjt}q_{isjt}}{x_{ist}} = f_{ij}(p_{st}, x_{ist})\ \forall\ j$$

  where $x_{ist} \equiv p_{st}q_{ist}$ is total supermarket expenditure
- A total supermarket expenditure rule

$$x_{ist} = F_i(p_{st}, X_{it})$$

- And indirect utility

$$\phi_i(p_{st}, X_{it})$$

Back: Expenditure

Prices

- From transaction level prices for 100,000s of different products, need to compute prices for 9 broad goods in each retailer
- Define 43 sub-goods and define market t retailer s price as volume weighted mean transaction price
  - Where weights are time and retailer varying
  - Captures retailer price of narrowingly defined good - e.g. poultry in Tesco
- Aggregate up to market t retailer s price for good j by computing an expenditure weighted mean over relevant sub-goods
  - Where weights are constant across markets and retailers
  - Captures price offering for, e.g. meat in Tesco, allowing for weighting of meat components based on long run average behaviour

Back: Goods