How Revealing is Revealed Preference?
The Stone Legacy and the Analysis of Consumer Behaviour

Sir Richard Stone Annual Lecture 2009
CReMic

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References and Figures are at the end of the slides.

This Lecture draws on work with Martin Browning, Xiaohong Chen, Ian Crawford and Rosa Matzkin.

Background motivation

■ The aim of this Lecture is to address the following two key criticisms of the empirical application of revealed preference theory to consumer behaviour:

► when it does not reject, it doesn't provide precise predictions; and

► when it does reject, it doesn't help us characterise the nature of irrationality or the degree/direction of changing tastes.

■ I will argue that recent developments in the application of revealed preference have rendered these criticisms unfounded**.**

■ I'm going to take a nonparametric approach. To quote Dan McFadden: "parametric models interpose an untidy veil between econometric analysis and the propositions of economic theory", ■ The idea of the lecture is to "lift the untidy veil"!

It all began with Richard Stone....

- With his great 1954 *CUP* monograph (with D.A.Rowe) "The Measurement of Consumers' Expenditure and Behaviour in the United Kingdom, 1920-1938", (CE)
- the classic 1954 *Economic Journal* paper "Linear Expenditure Systems and Demand Analysis: An Application to the Pattern of British Demand" (LES)
- and the wonderful 1956 OEEC monograph "Quantity and Price Indices in the National Accounts" (PI).

.... with a little help from Samuelson

- The individual through his consumer behaviour reveals his preference pattern

...he originally called this **'selected over'** rather than revealed preferred.

... and Afriat's Theorem **the 'world according to GARP'**

- remember Sydney Afriat was working with Stone in Cambridge in the 1950s.

► Data $(\mathbf{p}^t, \mathbf{q}^t)$ satisfy **GARP** if $\mathbf{q}^t R \mathbf{q}^s$ implies $\mathbf{p}^s\mathbf{q}^s \leq \mathbf{p}^s\mathbf{q}^t$

$\equiv$ if $\mathbf{q}^t$ is indirectly revealed preferred to $\mathbf{q}^s$ then $\mathbf{q}^s$ is not strictly preferred to $\mathbf{q}^t$

► **Afriat's theorem**: $\exists$ a well behaved concave utility function $\equiv$ the data satisfy GARP

Stone's ideas and data....

■ **Ideas**

► Systematic treatment of expenditures across commodities and across time (CE).

► First coherent treatment across commodities (LES)

► Cost of Living indices (PI)

► Quality differences and characteristics (PI)

■ **Data**

► Expenditure Survey Data (CE)

► Consistent measures of prices (PI)

■ **In this lecture I am going to take a similar problem to the one that Stone was addressing in these three volumes - namely:**

► understanding consumer responses to relative price and income changes

► seeing how well observations accord with (some) basic theoretical predictions

► using the structure of an estimated model to predict consumer behaviour in circumstances not previously observed - a new price vector and a new (distribution of) income.

► examine the welfare consequences of prices changes - and price rationing!

■ **But doing so with 50 years of hindsight......**

The problem

Our initial interest is in consumer behaviour described by

$$\mathbf{q} = \mathbf{d}(\mathbf{p}, x, \mathbf{h}, \boldsymbol{\varepsilon})$$

where

- $\mathbf{q}$ is a $J-1$ vector of demands, x is total budget or income,
- $\mathbf{h}$ is a vector characterising observed individual types, and
- $\boldsymbol{\varepsilon}$ is a $J-1$ vector of unobservable heterogeneity.

The environment is described by a continuous distribution of $\mathbf{q}$, x and $\boldsymbol{\varepsilon}$, some discrete types $\mathbf{h}$ and a finite set of price regimes $\mathbf{p}_s$, $s = 1, ..., T$.

For the **demands**

$$\mathbf{q} = \mathbf{d}(\mathbf{p}, x, \mathbf{h}, \boldsymbol{\varepsilon})$$

- we often refer to $\mathbf{q}_s(x)$ as an **expansion path** for the given prices $\mathbf{p}_s$ and type $(\mathbf{h}, \boldsymbol{\varepsilon})$.
- when ε is **nonseparable** we will assume **invertibility** in ε (monotonicity for $J = 2$).

Questions to address here:

- **How do we devise a powerful test of RP conditions in this environment?**
- **How do we estimate demands for some new price point $\mathbf{p}_0$?**
- We will see that revealed preference conditions, in general, only allow **set identification** of demands.

Stone's Solution - The LES

Stone suggested a simple (parametric) form for demands

$$p_i q_i = p_i \gamma_i + \beta_i (x - \sum_{k=1}^{n} p_k \gamma_k) + \varepsilon_i \text{ with } \sum_{j=1}^{n} \beta_j = 1 \text{ and } \sum_{j=1}^{n} \varepsilon_j = 0.$$

This accorded with four key points:

- ► in Stone's data analysis (CE) he had found that including **all** relative prices resulted in imprecision, especially with a large number of goods
- ► a reasonable fit required some 'necessary expenditure' γ_k that varied across commodities - non-homothetic Engel curves
- ► allowed welfare analysis - direct utility function $U(\mathbf{q}) = \prod (q_k - \gamma_k)^{\beta_k}$
- ► although nonlinear, still computationally easy ('computers' were people!)
  - ► note, only 2n parameters and only 2n-1 to be chosen independently

But remember McFadden's untidy veil....

Take the LES:

$$p_i q_i = p_i \gamma_i + \beta_i (x - \sum_{j=1}^{n} p_k \gamma_k) + \varepsilon_i$$

► Stone's estimated price and income elasticities do not conflict greatly with prior expectations from theory - but Deaton noted one curious feature:

■ The ordering of commodities in terms of price elasticities is identical to that by income elasticities (price elasticities close to - 1/2 expenditure elasticities)

■ These restrictions are fixed by functional form and not data,

- and not by any economic theory either.

■ Moreover, they are strong restrictions,

- especially when we look across households with different income levels.

Back to the future ....

- I want to step back and look at the same problem - but with a leap of 50 years,

  - you may think we haven't come very far at all!

- To improve the power of tests of rationality

  - ► for both experimental and observational data.

- to consider rationality over periods of time - to characterise changing tastes.

- to provide tight bounds on demand responses and on the *distribution* of demands (quantiles).

- to provide tight bounds on welfare costs of relative price and tax changes.

The RP analysis described here extends to....

- ► Collective choice
- ► Habits
- ► Characteristics models
- ► Unobserved heterogeneity

And **'Beyond'** Revealed Preference... How are preferences revealed? -

- ► Altruism
- ► Choice under uncertainty
- ► Frame-sensitive choice...

Data: Observational or Experimental - Is there a best design for experimental data?

Blundell, Browning and Crawford (Ecta, 2003) develop a method for choosing a sequence of total expenditures that maximise the power of tests of RP (GARP).

Define sequential maximum power (SMP) path

$$\{\tilde{x}_s, \tilde{x}_t, \tilde{x}_u, ...\tilde{x}_v, x_w\} = \{\mathbf{p}_s'\mathbf{q}_t(\tilde{x}_t), \mathbf{p}_t'\mathbf{q}_u(\tilde{x}_u), \mathbf{p}_v'\mathbf{q}_w(\tilde{x}_w), x_w\}$$

Proposition 1: (BBC, 2003) Suppose that the sequence

$$\{\mathbf{q}_s(x_s), \mathbf{q}_t(x_t), \mathbf{q}_u(x_u)..., \mathbf{q}_v(x_v), \mathbf{q}_w(x_w)\}$$

rejects RP. Then SMP path also rejects RP. ■

to get behind this result - think through a simple RP rejection: **Figure 1a:**

- great for experimental design but we have

Observational Data

■ continuous micro-data on incomes and expenditures

■ finite set of observed price and/or tax regimes (across time and markets)

■ discrete demographic differences across households

■ use this information alone, together with revealed preference theory to assess consumer rationality and to place 'tight' bounds on demand responses and welfare measures.

- great for experimental design but we have

Observational Data

- continuous micro-data on incomes and expenditures
- finite set of observed price and/or tax regimes
- discrete demographic differences across households
- use this information alone, together with revealed preference theory to assess consumer rationality and to place 'tight' bounds on demand responses and welfare measures.

So, is there a best design for observational data?

- use nonparametric expansion paths to **mimic the experimental design,** derive a most powerful test, and construct best bounds on demand responses, **Fig 1b**

Good for testing GARP, but can these expansion paths help in identifying demand responses?

Support Sets and Bounds on Demand Responses:

Suppose we observe a set of demand vectors $\{\mathbf{q}_1, \mathbf{q}_2, ...\mathbf{q}_T\}$ which record the choices made by a consumer when faced by the set of prices $\{\mathbf{p}_1, \mathbf{p}_2, ...\mathbf{p}_T\}$.

- new price vector $\mathbf{p}_0$ with total outlay x_0.
- best *support set* $S^V(\mathbf{p}_0, x_0)$ for $q(\mathbf{p}_0, x_0)$ is given by:

$$\left\{ \mathbf{q}_0 : \begin{array}{c} \mathbf{p}_0'\mathbf{q}_0 = x_0,\ \mathbf{q}_0 \geq \mathbf{0} \text{ and} \\ \{\mathbf{p}_t, \mathbf{q}_t\}_{t=0...T} \text{ satisfies RP} \end{array} \right\}$$

Figure 2a here

E-Bounds on Demand Responses

■ Given the expansion paths $\{\mathbf{p}_t, \mathbf{q}_t(x)\}_{t=1,..T}$, define intersection demands $\mathbf{q}_t(\tilde{x}_t)$ by $\mathbf{p}_0'\mathbf{q}_t(\tilde{x}_t) = \mathbf{x}_0$

The set of points that are consistent with observed expansion paths and utility maximisation is given by the *support set*:

$$S(\mathbf{p}_0, x_0) = \left\{ \mathbf{q}_0 : \begin{array}{c} \mathbf{q}_0 \geq \mathbf{0},\ \mathbf{p}_0'\mathbf{q}_0 = \mathbf{x}_0 \\ \{\mathbf{p}_0, \mathbf{p}_t; \mathbf{q}_0, \mathbf{q}_t(\tilde{x}_t)\}_{t=1,...,T} \text{ satisfy RP} \end{array} \right\}$$

The support set $S(\mathbf{p}_0, x_0)$ that uses expansion paths and RP defines *E-bounds* on demand responses

Figure 2b,c here

$S(\mathbf{p}_0, x_0)$ is the identified *set* for the parameter $q(\mathbf{p}_0, x_0)$.

Proposition 2 (BBC, Ecta 2008) : (best support set)

If demands are weakly normal, $S(\mathbf{p}_0, x_0) \subseteq S'(\mathbf{p}_0, x_0)$ *where* $S'(\mathbf{p}_0, x_0) = \{\mathbf{q}_0 : \mathbf{p}_0'\mathbf{q}_0 = x_0, \mathbf{q}_0 \geq \mathbf{0}$ *and* $\{\mathbf{p}_0, \mathbf{p}_t; \mathbf{q}_0, \mathbf{q}_t(x_t)\}_{t=1,...,T}$ *satisfies RP, and* $x_t \neq \tilde{x}_t$ *for some* $t\}$.

■ Thus there do not exist alternative bounds (derived from the same data) which are tighter than the *E-bounds*.

■ The *E-bounds* therefore make maximal use of the data and the basic nonparametric choice theory in predicting in a new situation.

Proposition 3 (BBC, Ecta 2008) : (properties of the support set)

(1) $S(\mathbf{p}_0, x_0)$ *is non-empty iff the data set* $\{\mathbf{p}_t, \mathbf{q}_t(\tilde{x}_t)_{t=1,...T}\}$ *satisfies RP.*

(2) *If the data set* $\{\mathbf{p}_t, \mathbf{q}_t(\tilde{x}_t)\}_{t=1...T}$ *satisfies RP* and $\mathbf{p}_0 = \mathbf{p}_t$ for some t then $S(\mathbf{p}_0, x_0)$ is the singleton $\{\mathbf{q}_t(\tilde{x}_t)\}$.

(3) $S(\mathbf{p}_0, x_0)$ *is convex.*

■ The first statement establishes that there are some predicted demands for $\{\mathbf{p}_0, x_0\}$ if and only if the intersection demands satisfy RP.

■ The second statement shows that the support set is a single point if the new price vector is one that has been observed.

The 'local' nature of the analysis

■ Note the support sets for demand responses are **local** to each point in the income distribution.

■ Allowing the **distribution of demand responses** to vary across the income distribution in a unrestricted way - except for the RP conditions.

► e.g. analysis here on extending Stone's work on **food demand** across the income distribution

► e.g. recent work on **petrol (gasoline) demand** across the income distribution

Some Extensions

■ **Habits** - something close to Stone's heart

- Today's preferences $U(\mathbf{q}_t, \mathbf{q}_{t-1})$ depend directly on $\mathbf{q}_{t-1}$.

► Using panel data on consumer demands for tobacco, Ian Crawford has produced a beautiful extension.

► Transform the RP conditions for a habits model in to those for the case above by defining suitable shadow discounted prices. There exist shadow discounted prices $\boldsymbol{\rho}_t$ and a discount rate β, such that a set of inequalities are satisfied.

► Not all prices are now directly observed so a harder identification problem results. But otherwise identical approach.

■ **Characteristics and quality differences.**

Again close to Stone's heart, introduced formally in his 1956 OEEC monograph (PI). Great discussion of beer and wine....also cars, anticipating the recent IO literature on differentiated products.

► Consumer choice model is extended to

$$\max_{\mathbf{q}} V(\mathbf{z}) \text{ subject to } \mathbf{z} = \mathbf{F}(\mathbf{q}) \text{ and } p'q \leq x, q \geq 0.$$

► Blow, Browning and Crawford (ReStud, 2006), extend the set of RP inequalities in BBC to the linear characteristics model, where $\mathbf{z} = \mathbf{A}'\mathbf{q}$.

► Underlying characteristics are not necessarily observed so a harder identification problem results. Use scanner panel data. But otherwise identical approach.

■ **Collective models** - families versus individuals.

Data which records some assignable goods. Cherchye et at (Ecta, recent) extends what we have here.

A pair of utility functions U^1 and U^2 satisfy collective rationalisation (CARP) if inequalities hold over personalised quantities. Not all personalised quantities are observed so a harder identification problem results. But otherwise identical approach.

■ **Models of Altruism** - 'rational' altruistic preferences. Andreoni and Miller (Ecta). Adapt measures in an experimental design to include payments to self and payments to others, $U(\pi_s, \pi_o; \gamma)$, where γ are the observable attributes of the game. Extended set of RP inequalities.

■ **Choice under uncertainty, and Frame-sensitive choice.....**

Some Data and Some Estimated Sets

Begin by assuming that unobservables are **separable and independent** of $x, \mathbf{h}$.

In any particular price regime $\mathbf{p}_s$ demands are identified by the moment condition

$$E[\mathbf{q}|\mathbf{p}_s, x, \mathbf{h}] = \mathbf{q}_s(x, \mathbf{h})$$

this characterises the set of expansion paths.

$E[\mathbf{q}|\mathbf{p}_s, x, \mathbf{h}]$ will be recovered empirically by nonparametric regression.

What does the **observational** data look like?

Figure 3a, b

■ require empirically acceptable and theoretically sound method for pooling over types $\mathbf{h}$

- ▸ shape invariant or shape similar specification

Estimation of semiparametric expansion paths

Let $\mathbf{h}_i$ represent a vector of demographic variables relating to household i.

Proposition BBC (Ecta 2003) *Suppose that budget shares have the following form that is additive in functions of* $\ln x$ *and demographics* $\mathbf{h}$

$$w_j(\ln \mathbf{p}, \ln x, \mathbf{h}) = m_j(\ln \mathbf{p}, \mathbf{h}) + g_j(\ln \mathbf{p}, \ln x)$$

If Slutsky symmetry holds and if the effects of demographics on budget shares are unrestricted, then $g_j(.)$ *is linear in* $\ln x$.

* Thus, if the simple partially linear form is used then, to make it generally consistent with RP, preferences are restricted to the semi-log budget share class know as Piglog - underlying the Almost Ideal and Translog systems. Ruling out quadratic models, for example.

The specification we use takes the shape invariant form

$$w_j^i = g_j(\ln x_i - \phi(\mathbf{h}_i'\boldsymbol{\alpha})) + \mathbf{h}_i'\boldsymbol{\gamma}_j + \varepsilon_j^i$$

where w_j^i is the expenditure share for household i on good j. **Figure 3c, d**

■ To account for the endogeneity of $\ln x$ we specify

$$\ln x_i = \pi(\mathbf{z}_i, v_i)$$

where π is monotonic in v, $\mathbf{z}$ are a set of variables which include the demographic variables $\mathbf{h}$ and an excluded instrument. Control function assumptions

$$E(\varepsilon_j^i | \ln x_i, \mathbf{z}_i, v_i) = 0$$

■ Also semiparametric IV regression (**BCK Ecta 2007**) - **Figure 3e**

Estimating Bounds on Local Consumer Responses

► For each household defined by $(x, \mathbf{h}, \varepsilon)$, the parameter of interest is the consumer response at some new relative price $\mathbf{p}_0$ and income x or at some sequence of relative prices. The later defines the demand curve for $(x, \mathbf{h}, \varepsilon)$.

► We may be interested in the average demand over $(\mathbf{h}, \varepsilon)$, the average demand for some specific $\mathbf{h}$, or the complete distribution of demands according to the distribution of $\mathbf{h}$ and ε.

■ A typical sequence of relative prices in the UK, as in Stone's analysis:

Figure 4a **Relative prices in the UK and a 'typical' relative price path $\mathbf{p}_0$.**

Figure 4b **Corresponding convex hull.**

Figure 4c **Corresponding convex hull of non-GARP rejections.**

E-Bounds

The aim is to construct E-bounds on demands $\mathbf{q}(\mathbf{p}_0, x, \mathbf{h})$ at the sequence of new relative prices $\mathbf{p}_0$

This can be carried out at any particular (expenditure) income level x and for any specific household type $\mathbf{h}$

Figure 5. **Estimated demand response sets for a given relative price path and some given income (median, for example) $\mathbf{q}(\mathbf{p}_0, x_0)$**

* Own and cross demands.

Estimation subject to RP restrictions

- Suppose we want to find the support set for $\mathbf{p}_0, x_0$. Let Σ denote the set of demands which satisfy the RP inequalities for prices $\{\mathbf{p}_t\}_{t=1,\ldots,T}, \mathbf{p}_0$.
- We want to find the intersection demands that satisfy the RP inequalities. Consider the solution to following the minimum distance problem

$$\min_{\{q_t^{j*}\}_t^j} \{L\left(\left\{q_t^{j*}\right\}_t^j\right) = \sum_{j=1}^{j=J}\sum_{i=1}^{i=J}\sum_{t=1}^{t=T}\left(q_t^{j*} - q_t^j\left(\tilde{x}_t\right)\right)\left(\Omega_t^{-1}\right)^{ij}\left(q_t^{i*} - q_t^i\left(\tilde{x}_t\right)\right)\}$$

$$\text{subject to:} \qquad \{\mathbf{q}_t^*\}_t \in \Sigma$$

$$q_t^{j*} \geq 0,\ \mathbf{p}_0'\mathbf{q}_t^* = x_0 \ \forall\, t.$$

- **Use this minimum distance function to:**
- **Estimate subject to the RP restrictions. Fig 6, constrained.**
- **Perform inference on the RP restrictions.**
- **Construct a larger 'not rejected' region, Fig 4d and Fig 7.**

Can also investigate demand responses in a fully nonparametric way:

- **Demand responses differ by income in a very interesting way too, Fig 8.**
- **What about changing tastes?**

Changing Tastes

These restricted demands can be interpreted as *perturbed intersection demands*

$$q_t^{j*} = e_t^j q_t^j$$

where e_t^j is a (multiplicative) perturbation to the intersection demand for the j'th good in the t'th period. The e_t^j can be interpreted as a **tilting of the marginal rate of substitution** U_j/U_l local to x.

For example, the marginal conditions between good j and good l are tilted by e_t^j/e_t^l and become

$$\frac{U_j}{U_l}\frac{e_t^j}{e_t^l} = \frac{p_j}{p_l}.$$

Provides a characterisation of changing tastes: **Figure 9** . Differing by income.

Improving Bounds with Separability

Consider separating the set of goods q_t into a single good q_t^1 and a separable subset of all other goods labeled $\mathbf{q}_t^2$ for convenience. In this case we can write direct utility as

$$u = u\left(q_t^1, U^2\left(\mathbf{q}_t^2\right)\right)$$

This is the case of weak separability, if $\mathbf{q}_t^2$ is homothetically separable then $U^2\left(\mathbf{q}_t^2\right)$ is a homothetic function. We define the total outlay on $\mathbf{q}_t^2$ to be x_t^2.

* In this case choices over q_t^1 will simply depend on q_t^1, total budget x_t and a single price index p_t^2. The price index is independent of x and p^1. This is close to the approach taken by Stone.

E-Bounds with Separability (**BBC 2007 IER**) **Figures 10a,b.**

Bounds on Indifference Curves and Welfare Costs

In addition to bounding demand responses, it can also be shown that using non-parametric expansion paths provides the *best nonparametric bounds* on welfare costs of price regulation or tax reforms.

Tightest possible bounds on indifference curves, generalising Varian's result.

The intuition can be seen from **Figure 11**.

* The upper and lower E-bounds on the indifference surface passing through $\mathbf{q}_1$ describe the revealed better and revealed worse sets relative to $\mathbf{q}_1$ - the revealed better set is the convex monotonic hull of allocations revealed preferred to $\mathbf{q}_1$.

* The dashed lines marked 'upper' and 'lower' shows the bounds on the cost function for some new set of relative prices $\mathbf{p}_z$.

The application of these bounds will be important in welfare economics and can be illustrated in the analysis of cost of living bounds.

Figure 12 provides such an analysis using the British FES data.

* In this graph the E-bounds on cost of living are represented by the solid lines and the classical revealed preference bounds by the dashed line.

* The bounds from classical revealed preference restrictions of the type used by Varian (1982), confirming the classical non-parametric/revealed preference bounds give little additional information on the curvature of the indifference curve through commodity space, and hence the bounds on the true index are wide.

* But **a Divisia index, which generalises Stone's idea, fits within the bounds.**

Nonseparable unobserved heterogeneity and the distribution of demands

Recall that for any household, defined by (x, ε), (ignore observable heterogeneity $\mathbf{h}$), demands $\mathbf{q}$ are written:

$$\mathbf{q} = \mathbf{d}(\mathbf{p}, x, \varepsilon)$$

Assume sufficient conditions for $\mathbf{d}(.)$ to be **invertible** in ε and write

$$\varepsilon = \mathbf{r}\left(\mathbf{p}, x, \mathbf{q}\right)$$

► **Aim**: to bound demand responses local to points in the distribution of ε and x.

- impose RP **across the distribution of demands, the** quantiles of x and ε.

► In order for unambiguous revelation of stochastic preferences from stochastic demands, global invertibility of $\mathbf{q}_{-J} = d(\mathbf{p}, x, \varepsilon)$ is required.

What conditions on heterogeneous preferences enable global invertibility?

MRS-Separable Heterogeneity

Assumption A4: $MRS(\mathbf{q}, \varepsilon)$ is multiplicatively separable with respect to ε:

$$MRS(\mathbf{q}, \varepsilon) = v(\mathbf{q}) + K(\mathbf{q})\psi(\varepsilon),$$

where $v(\mathbf{q})$ is a $(J-1) \times 1$ vector of nonnegative functions, $K(\mathbf{q})$ is a $(J-1) \times (J-1)$ matrix with full rank, and $\psi : \mathbf{R}^{J-1} \rightarrow \mathbf{R}^{J-1}$.

.

Lemma: (Beckert-Blundell, 2008 RESTud) *Suppose A1, A2, A3, and A4 hold. Then, for any* ***p*** *and* x, $\mathbf{d}(\mathbf{p}, x, \varepsilon)$ *is globally invertible for all* $\mathbf{q}_{-J} \in B_{-J}(\mathbf{p}, x)$*, and, hence,* $\mathbf{q}_{-J}$ *has a non-degenerate distribution on budget set* $B_{-J}(\mathbf{p}, x)$*, given any* ***p*** *and* x*.*

Estimation

Consider the case where $J = 2$

$$q = d(p, x, \varepsilon)$$

- The expansion paths for each regime p local to any ε are identified through the invertibility assumption, implying monotonicity of d in ε, and estimated via **quantile regression**.
- Endogeneity of x can be dealt with using the **control function approach** adapted for quantiles
  - Expansion paths are local to x and ε
  - Support sets are defined at the quantiles of x and ε

Estimation

- sequential conditional quantile splines - 3rd order pol. spline with 5 knots
- RP restrictions imposed at 40 x-points over the empirical support x

Figures 13, 14: Distribution of demands.

Summary

- Improve power of test of rationality

  - for both experimental and observational data.

- to allow responses to vary nonparametrically with income and relative prices.
- to consider rationality over periods of time - to characterise changing tastes.
- to provide tight bounds on welfare costs of relative price and tax changes.
- to provide tight bounds on demand responses (and elasticities) and on the distribution of demands.
- **take Stone's analysis and ask what 50 years can do** – *lifting the untidy veil* - remember: *'[parametric regression] interposes an untidy veil between econometric analysis and the propositions of economic theory'* Dan McFadden

Some References

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Figure 1a:

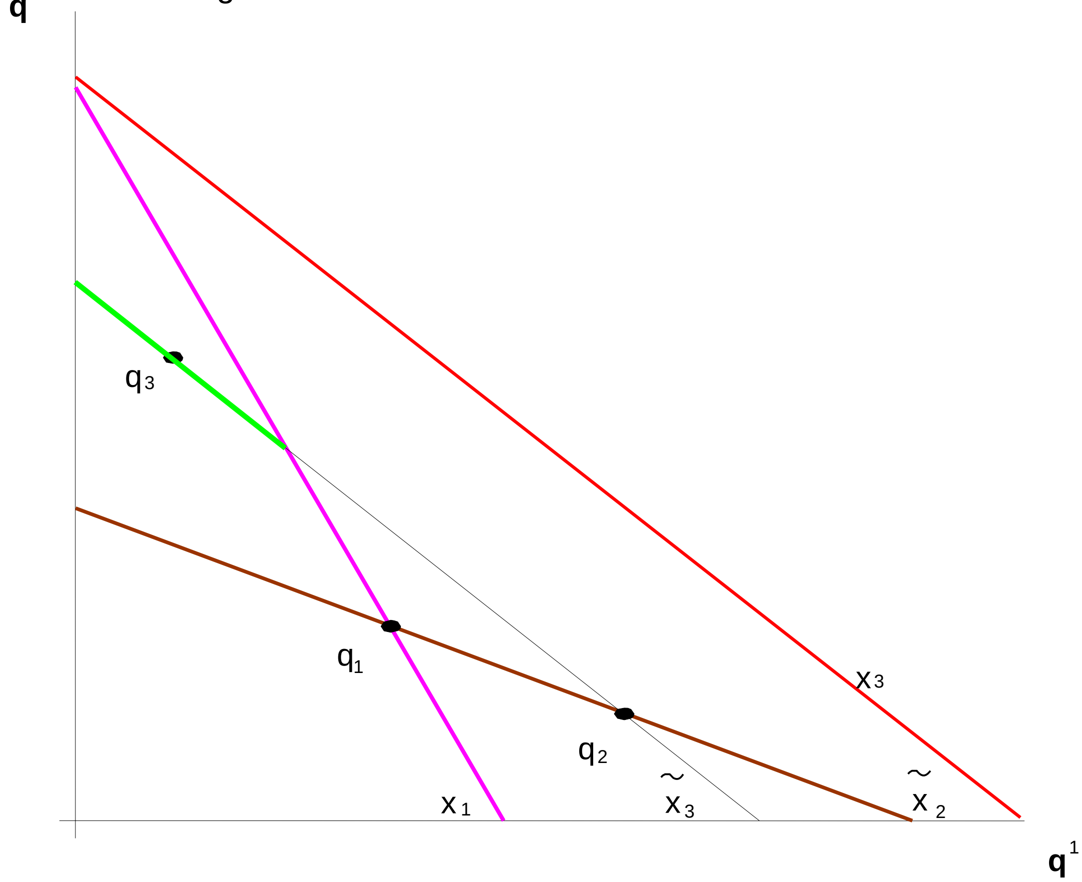

Figure 1b: Expansion Paths

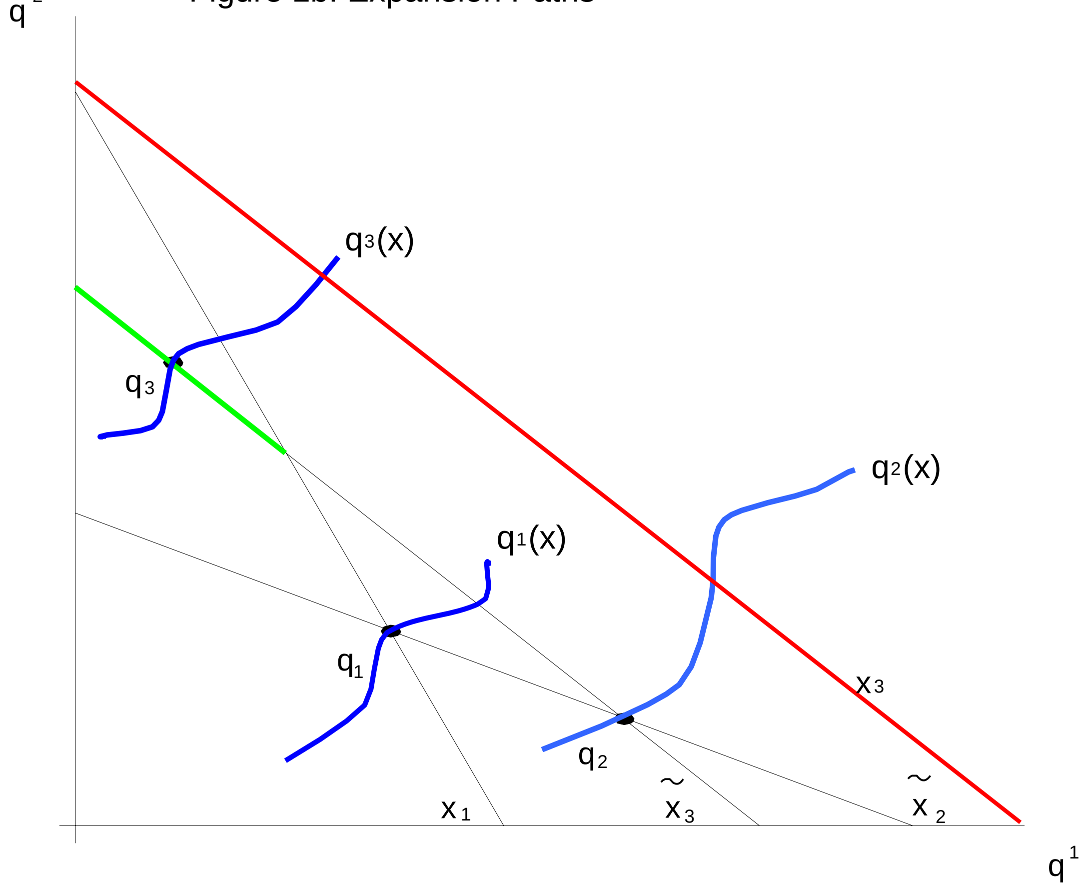

Figure 2a: The 'Varian' Support Set with RP

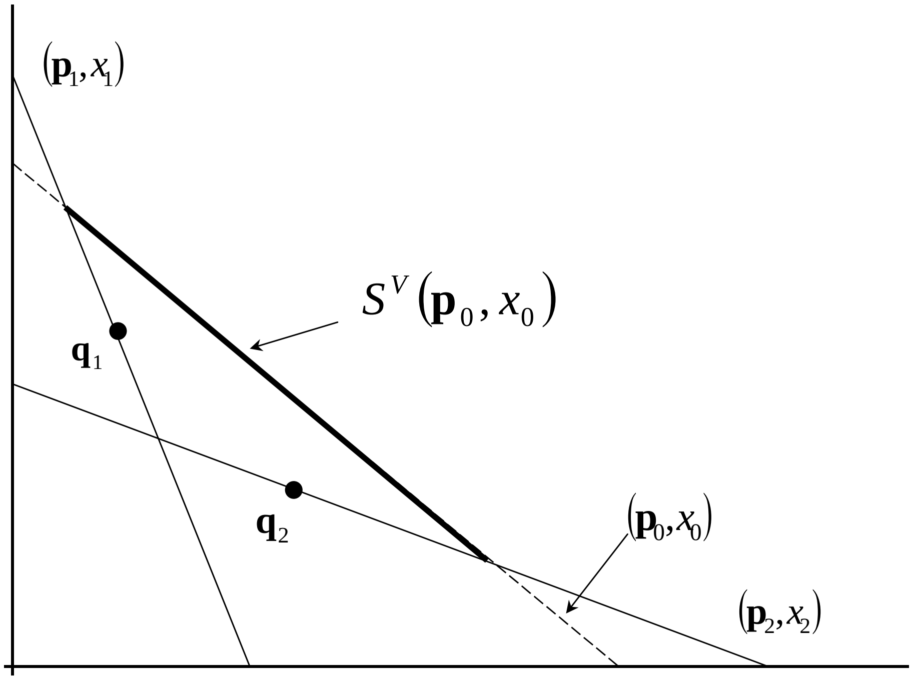

Figure 2b. Defining the support set with *E-bounds*

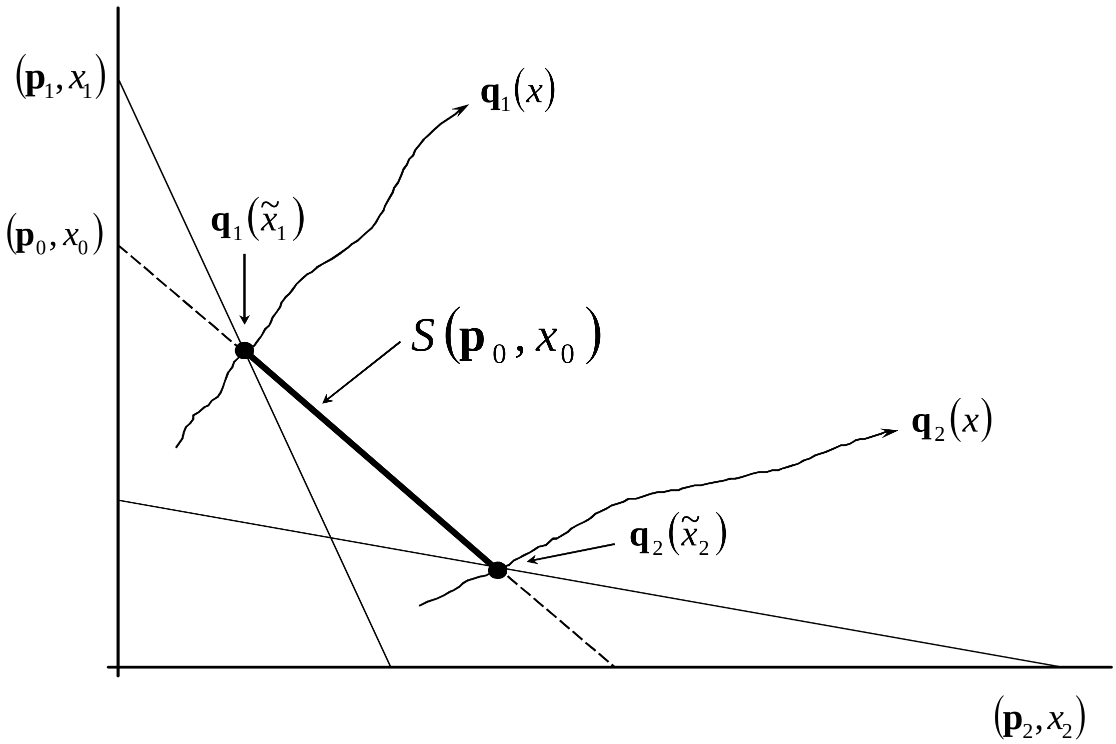

Figure 2c: Support Set with RP and Many Prices

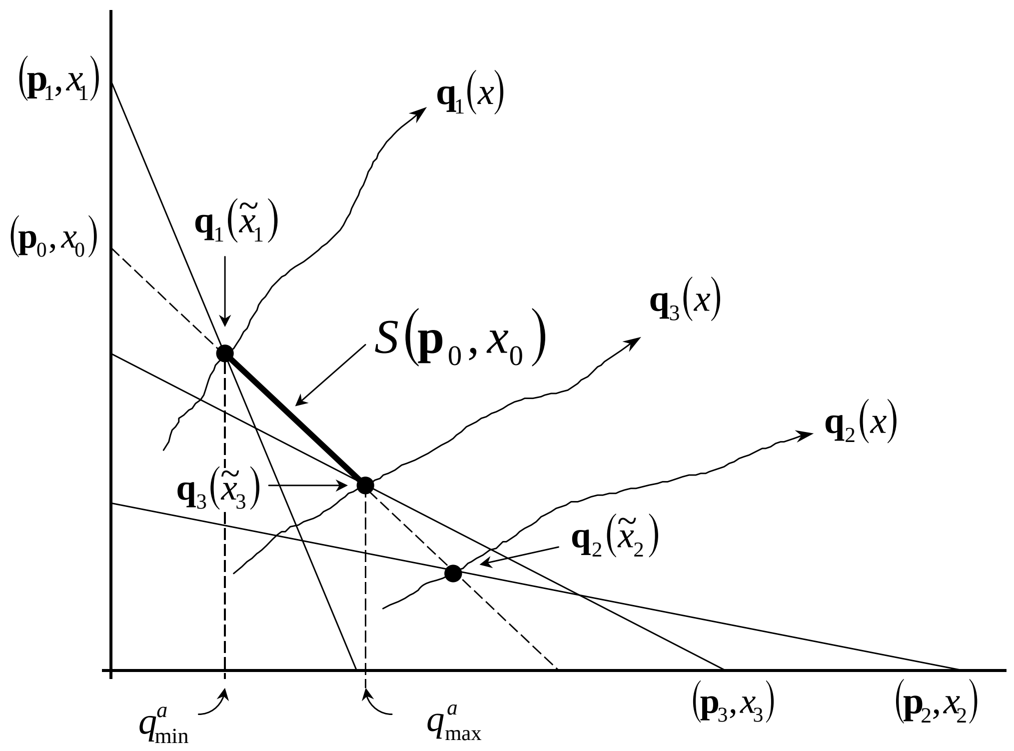

Fig 3a: The Density of Log Consumption: FES

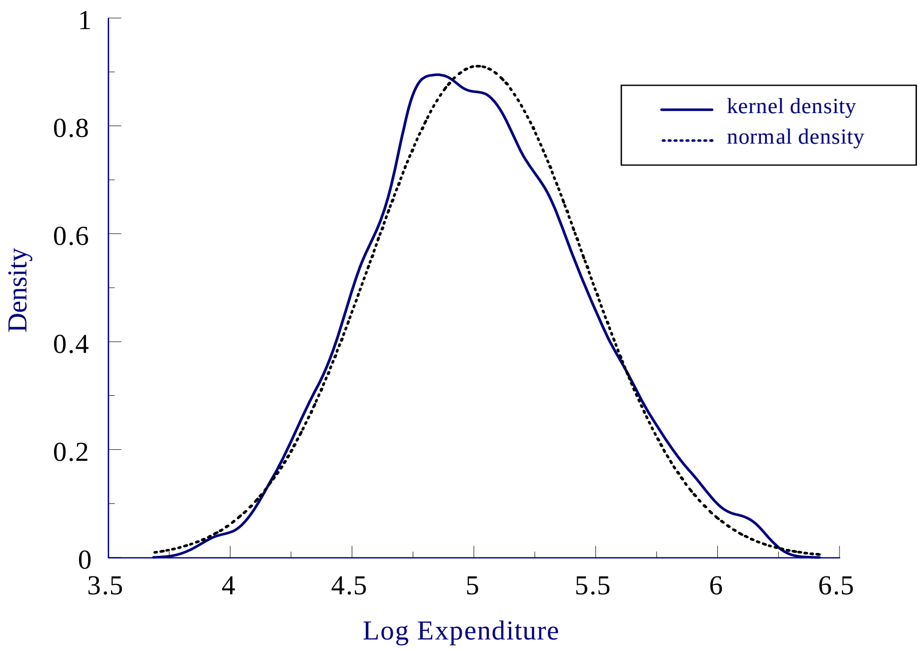

Figure 3b: Typical Joint Distribution in Micro-Data

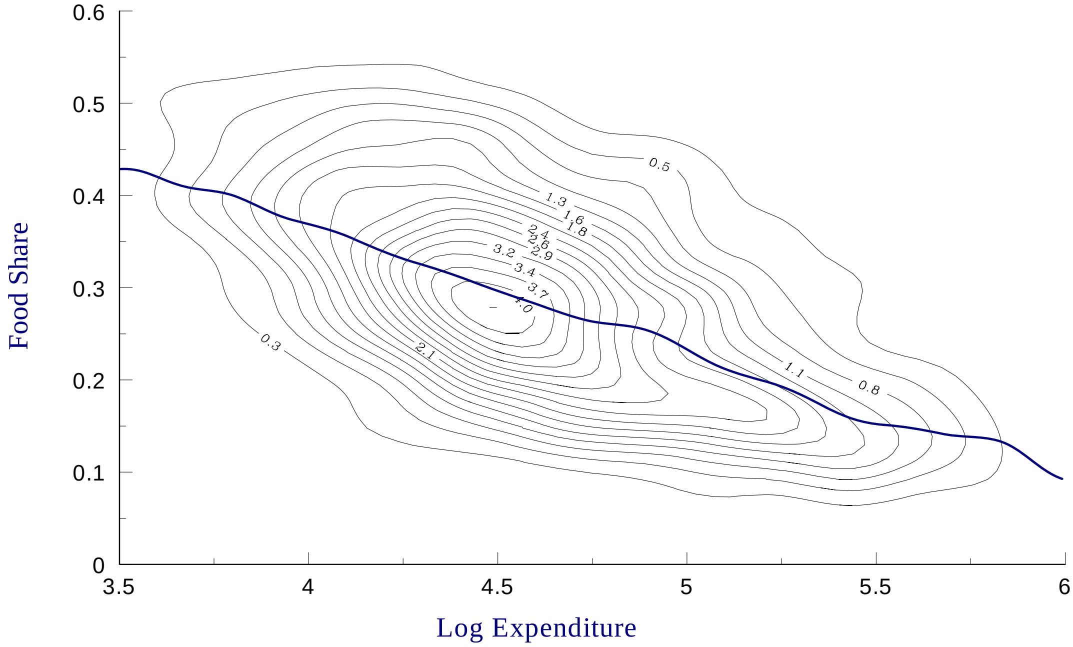

Fig 3c: Shape Invariant Engel Curve: Food Share

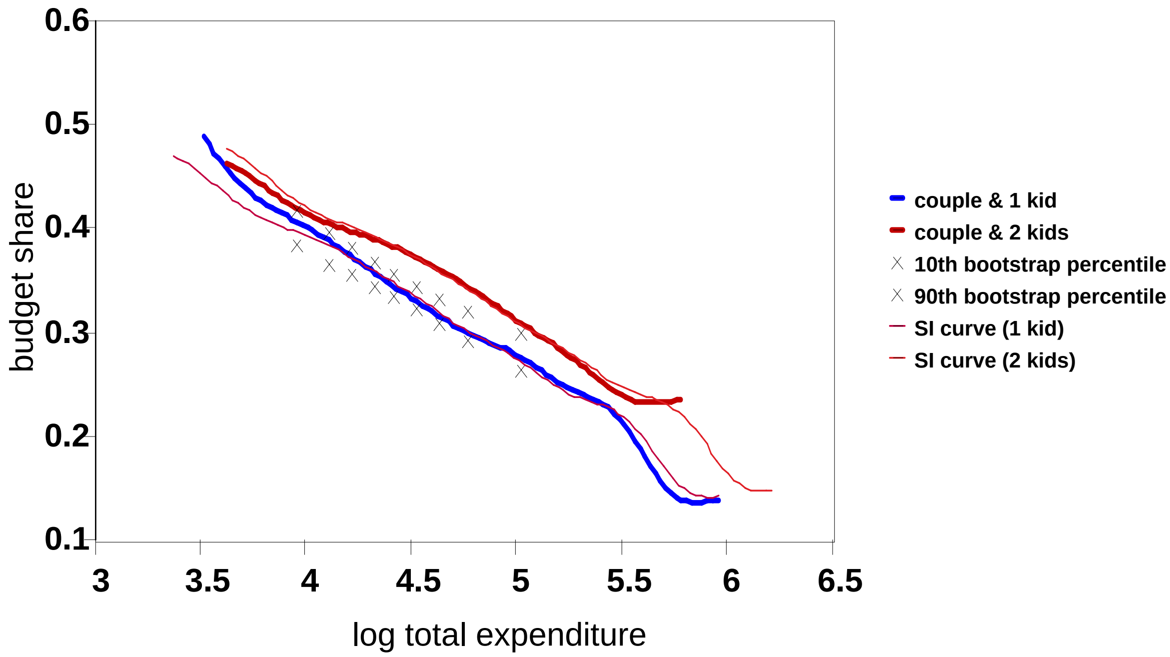

Fig 3d: Shape Invariant Engel Curve: Alcohol Share

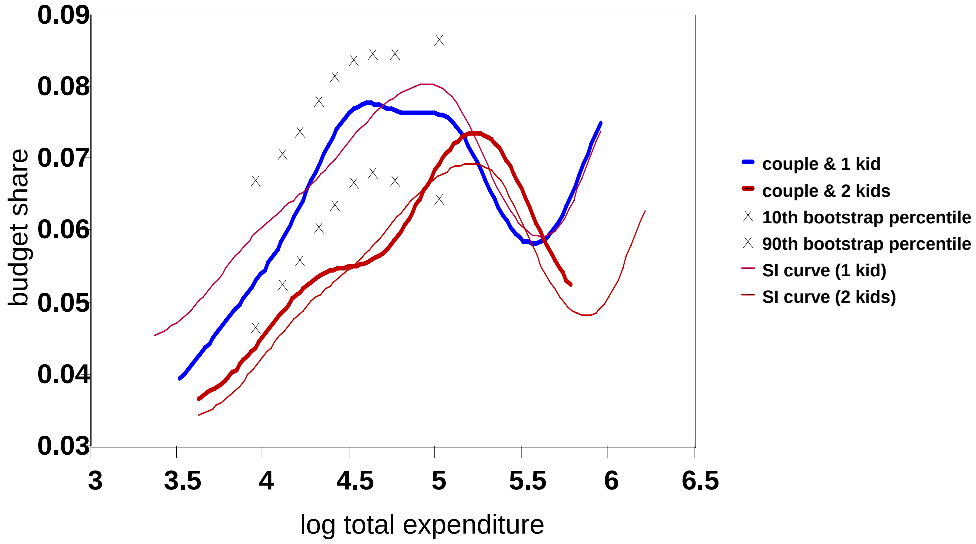

Figure 3e: Semiparametric IV estimates of Engel curves

Figure 4a. Relative price data: 1975 to 1999 and price path

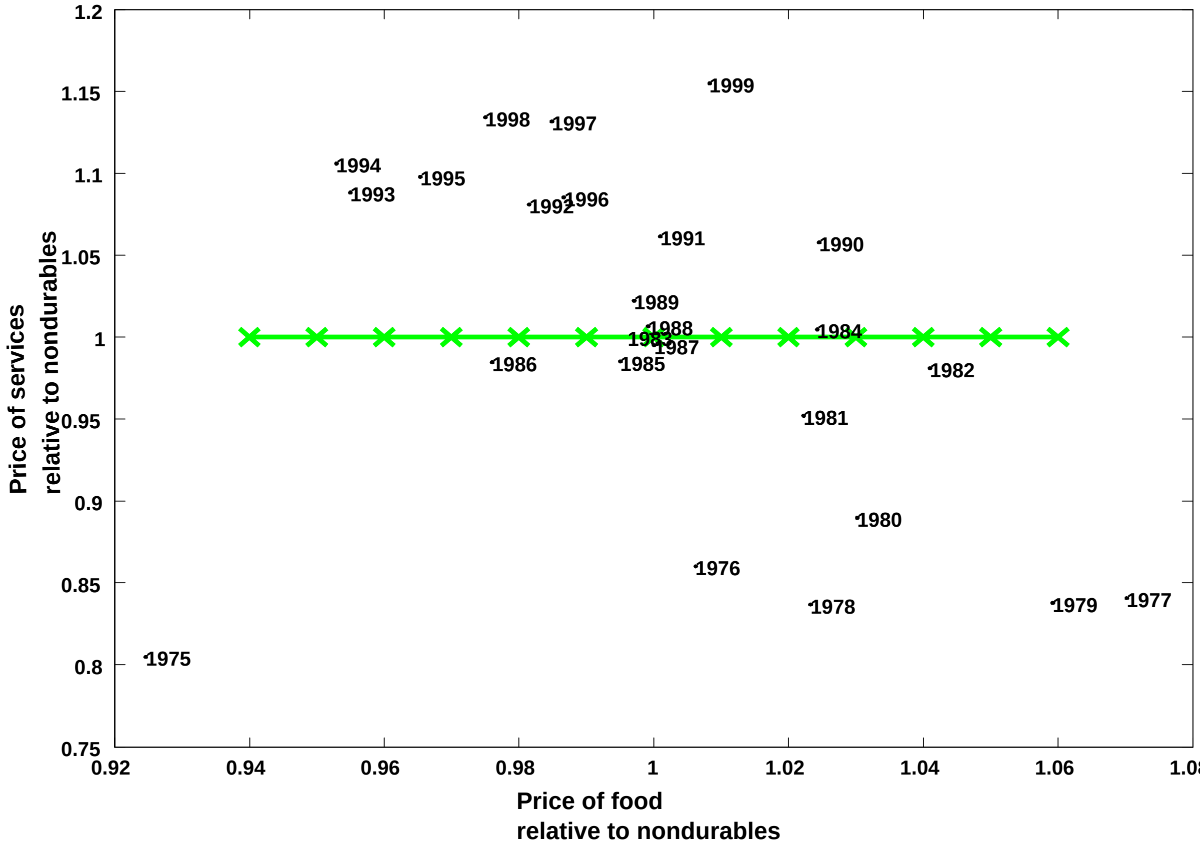

Figure 4b. Scatter plot of the relative price data: 1975 to 1999

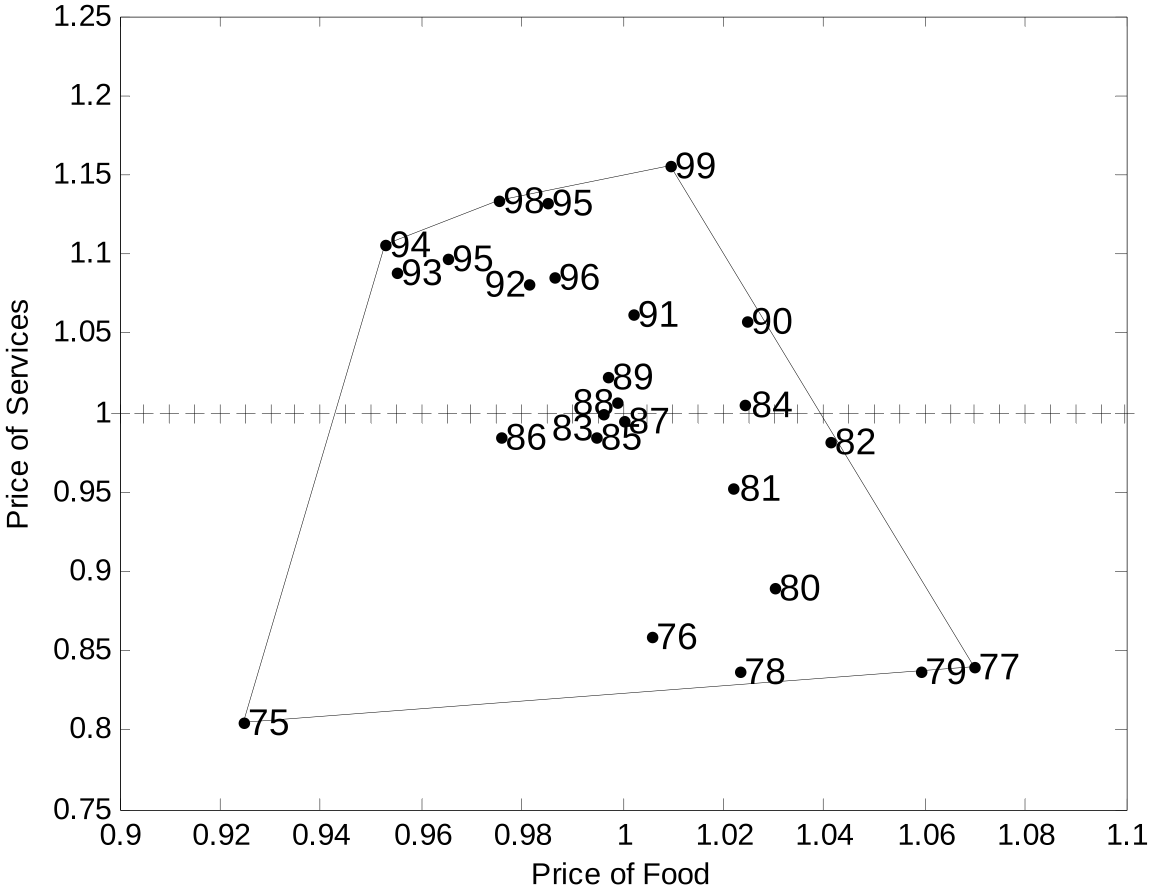

Figure 4c. A sequence of relative prices that don't reject GARP exactly

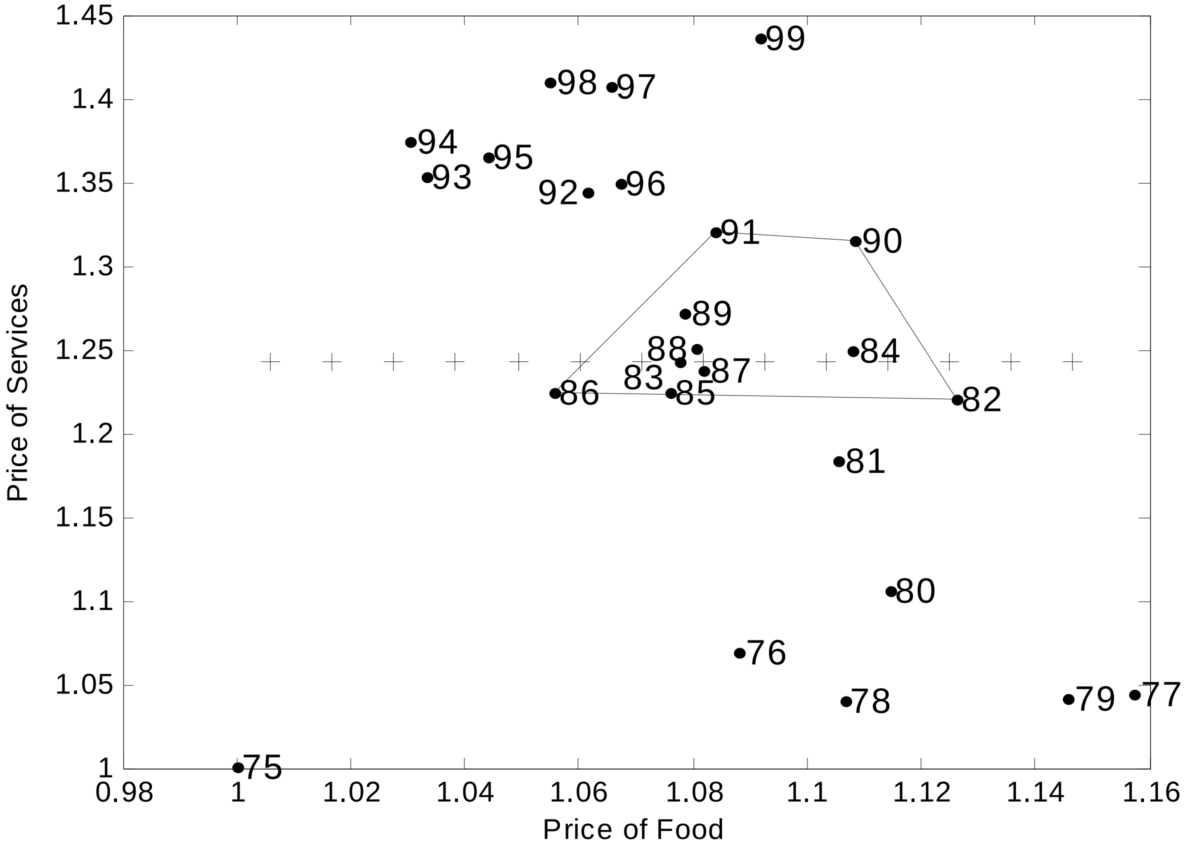

Figure 5. Own price demand bounds for Food
(at median income)

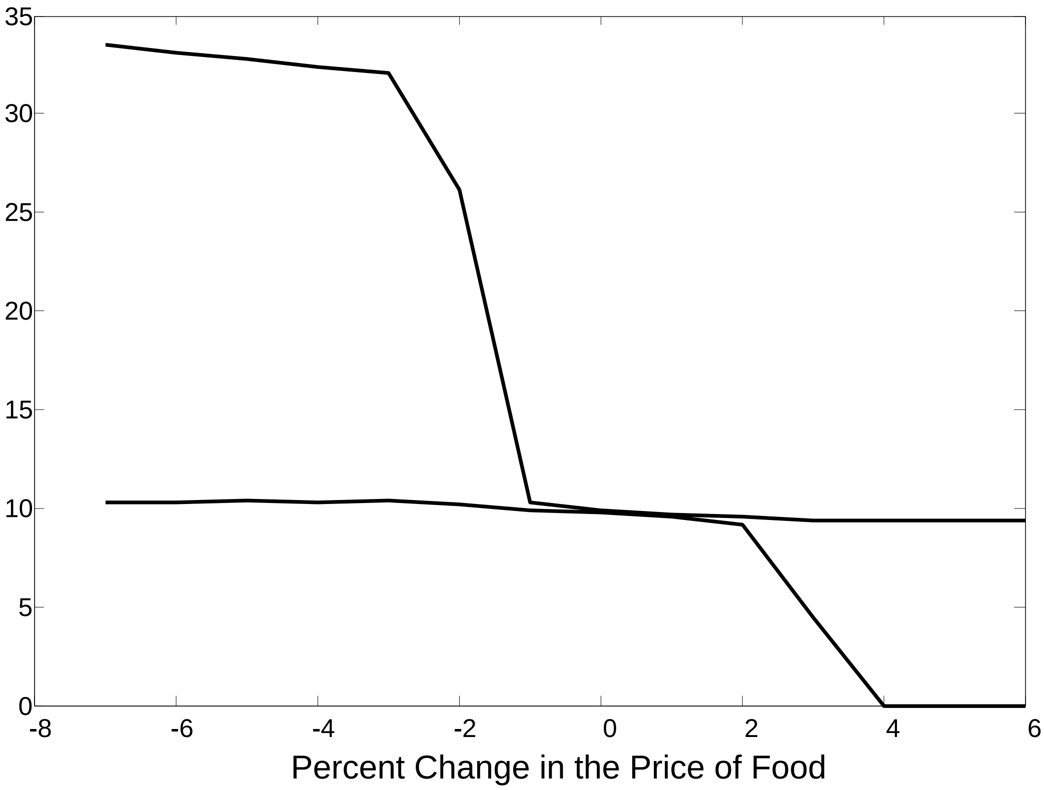

Figure 6. Constrained E-Bounds for Food
(at median income)

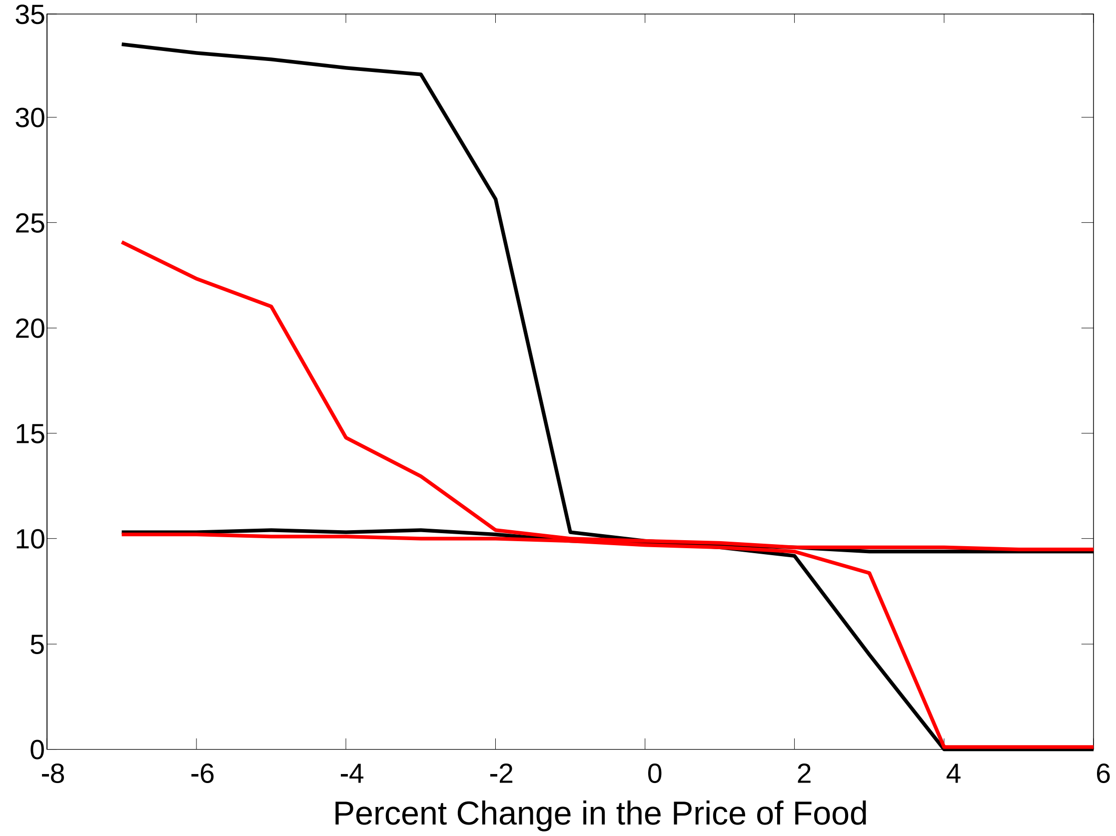

Figure 4d. A sequence of relative prices that don't reject GARP (statistically)

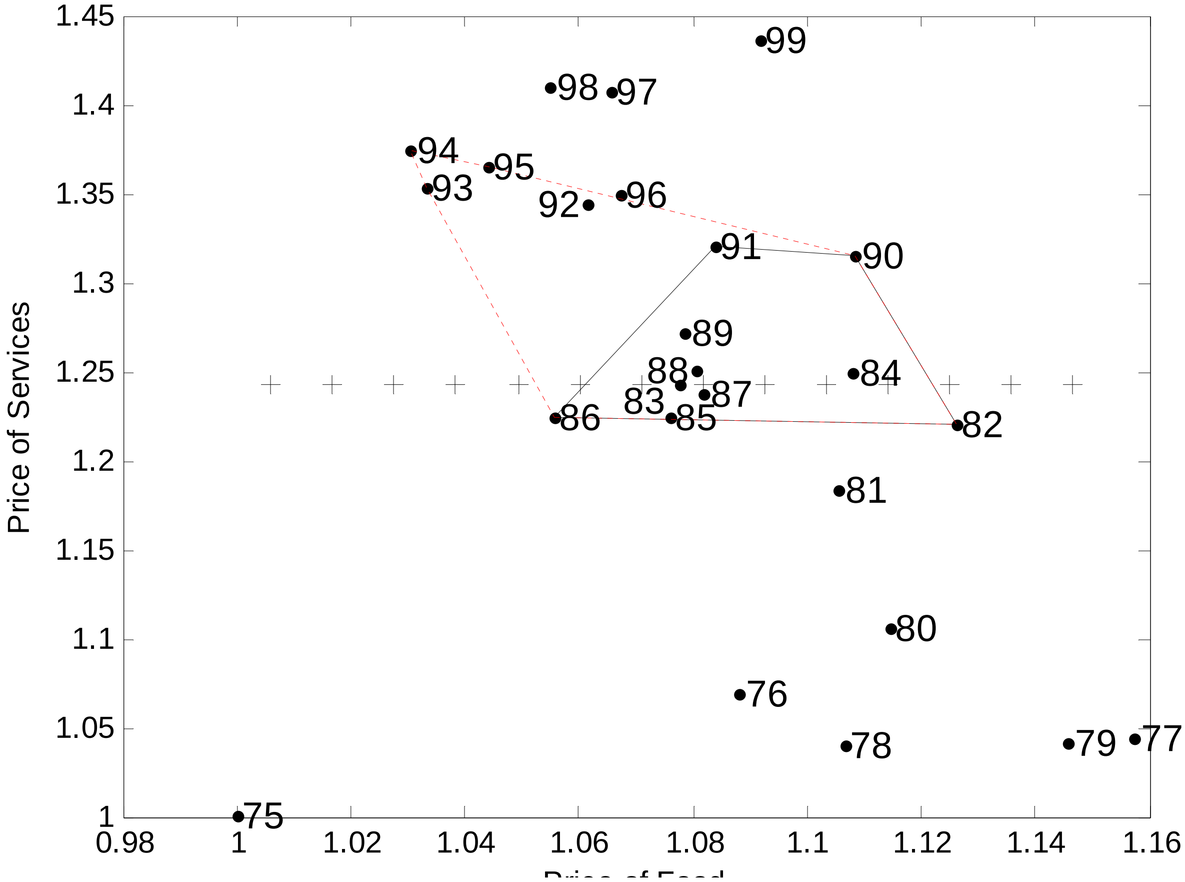

Figure 7. RP Consistent E-Bounds for Food (at median income)

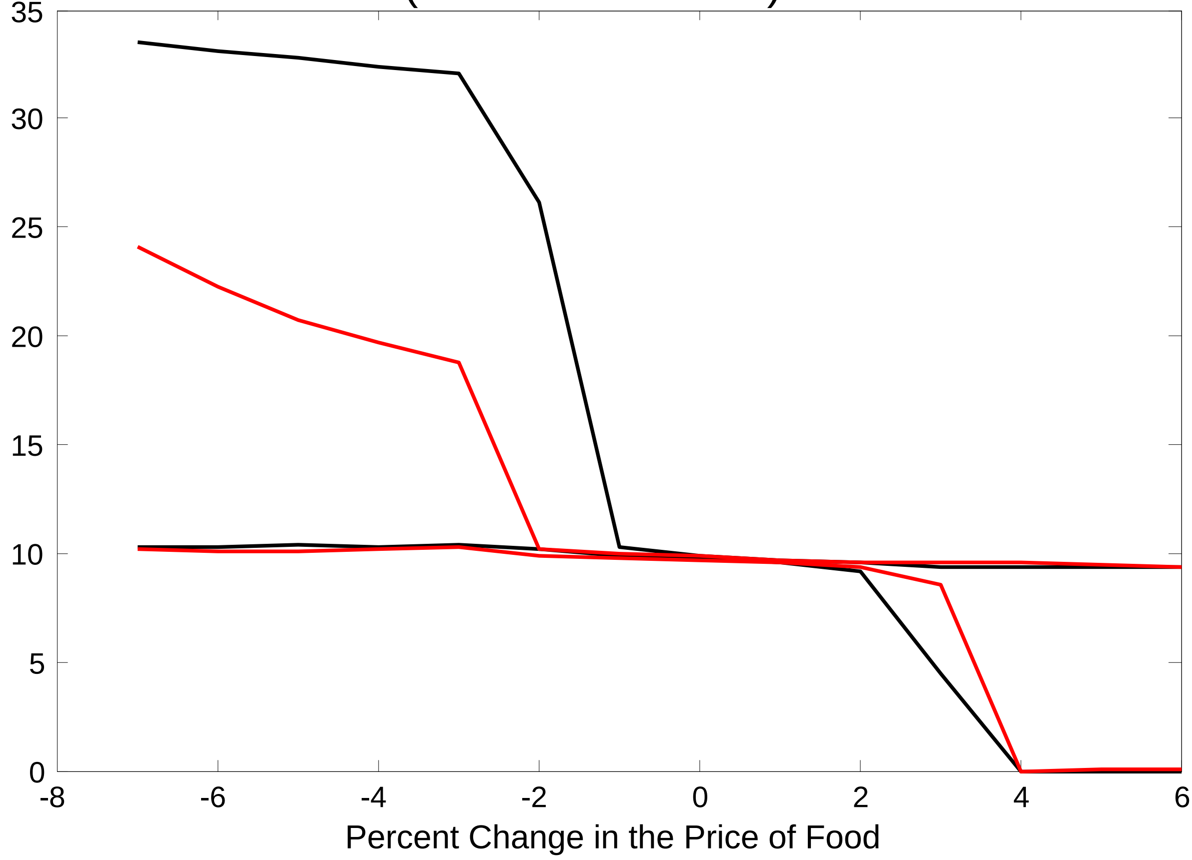

Figure 8. Demand Bounds for Food (log-log) by **Income Quartiles**

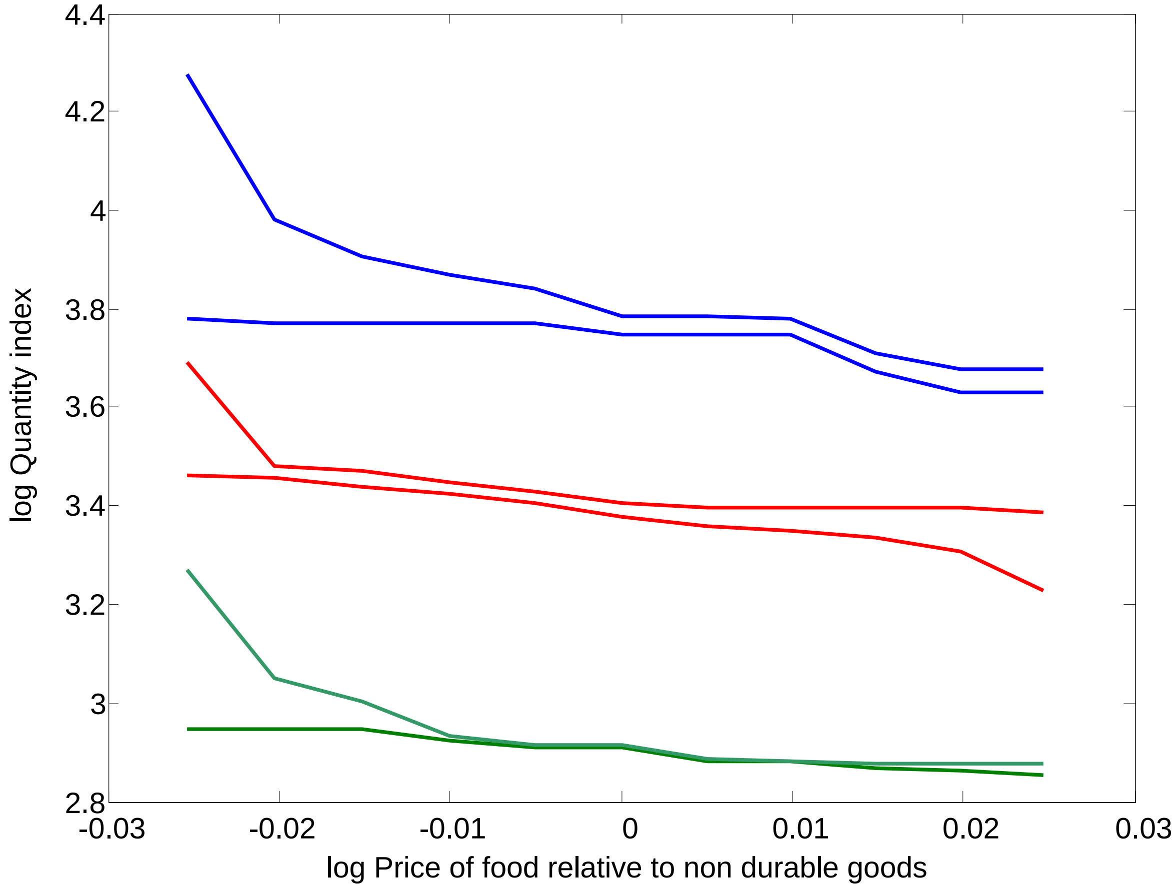

Figure 9. RP Perturbations

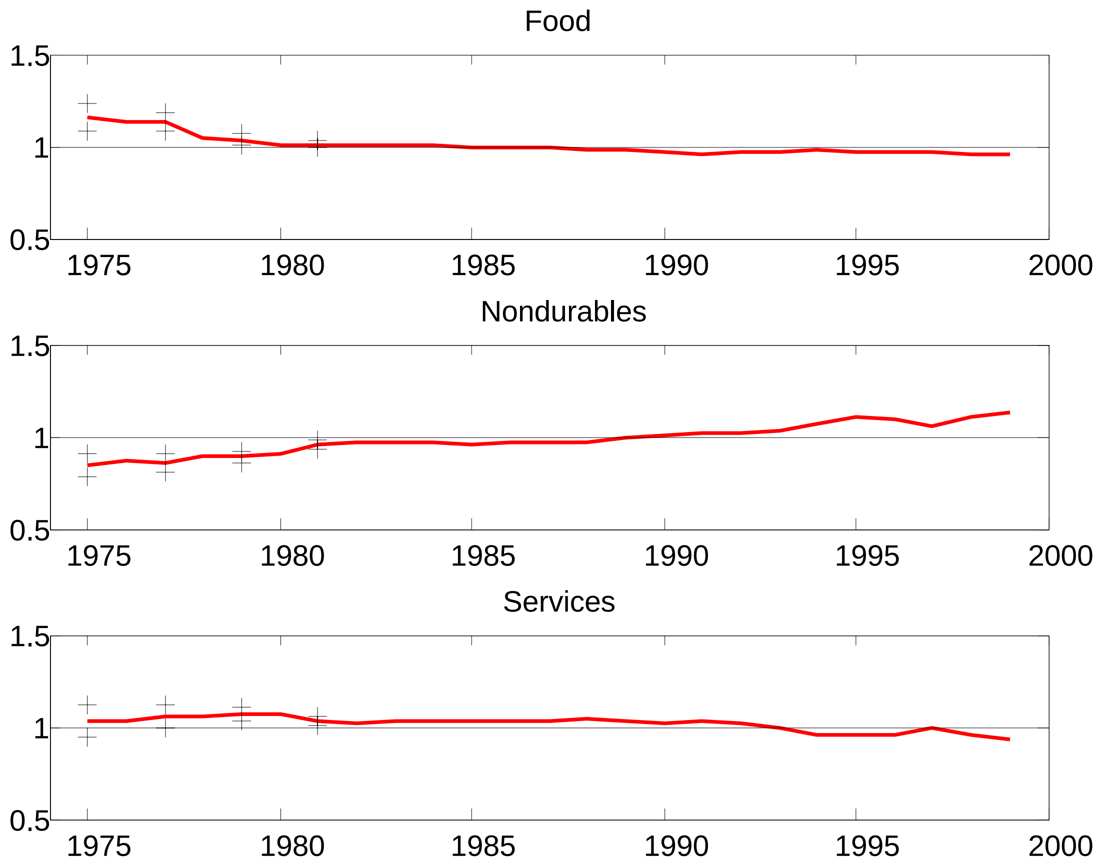

Figure 10a. Separability restricted E-Bounds

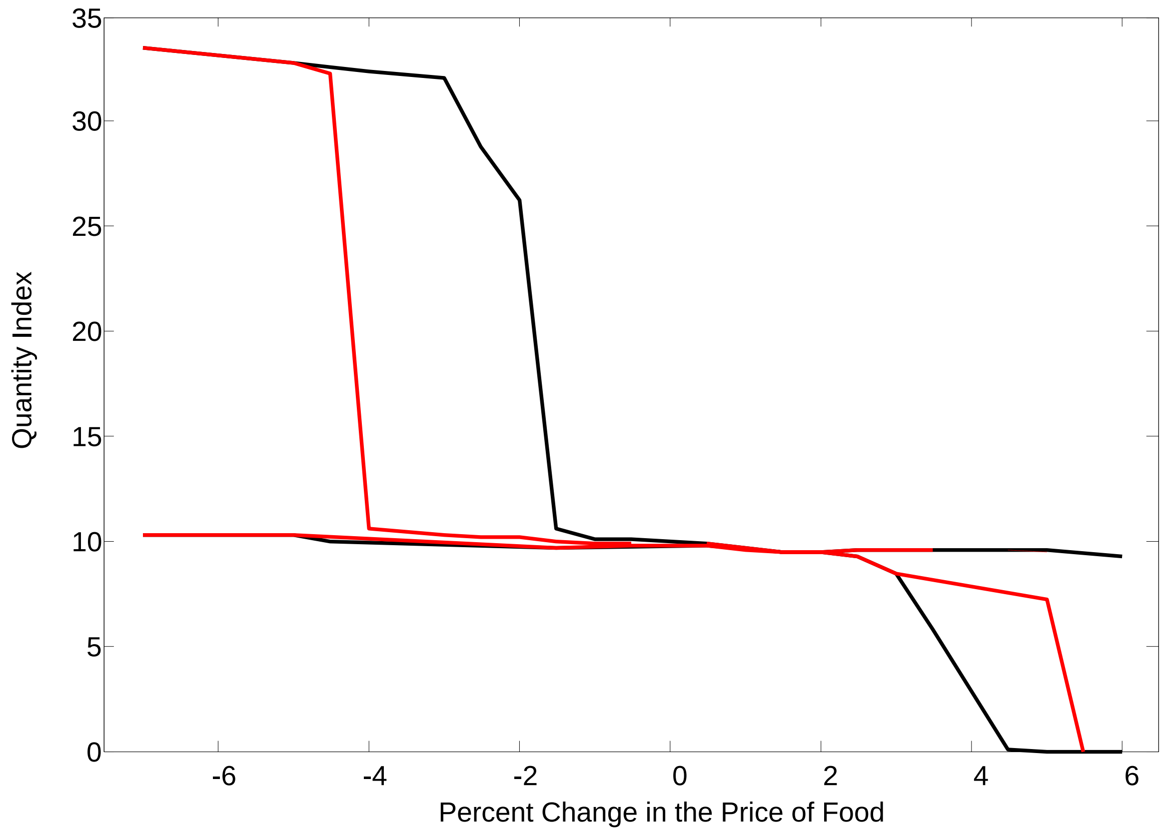

Figure 10b. Separability restricted E-Bounds: many goods

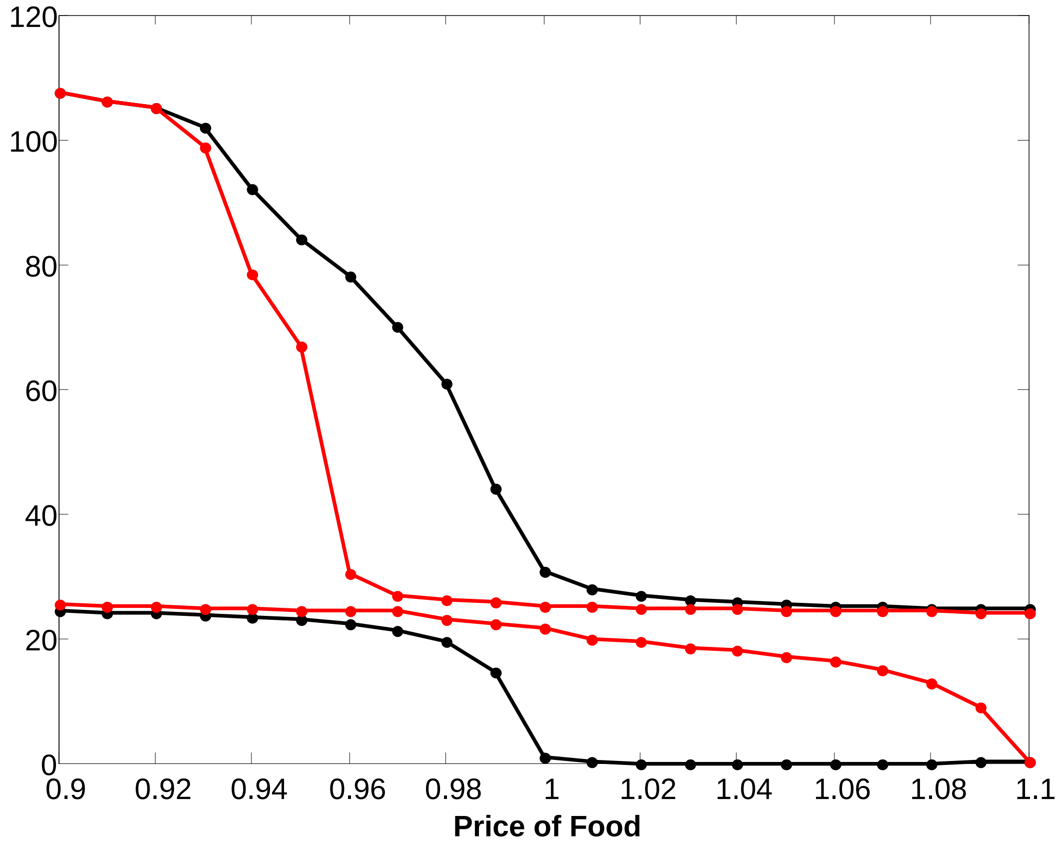

Figure 11: Best Bounds on the Indifference Curve Using Expansion Paths

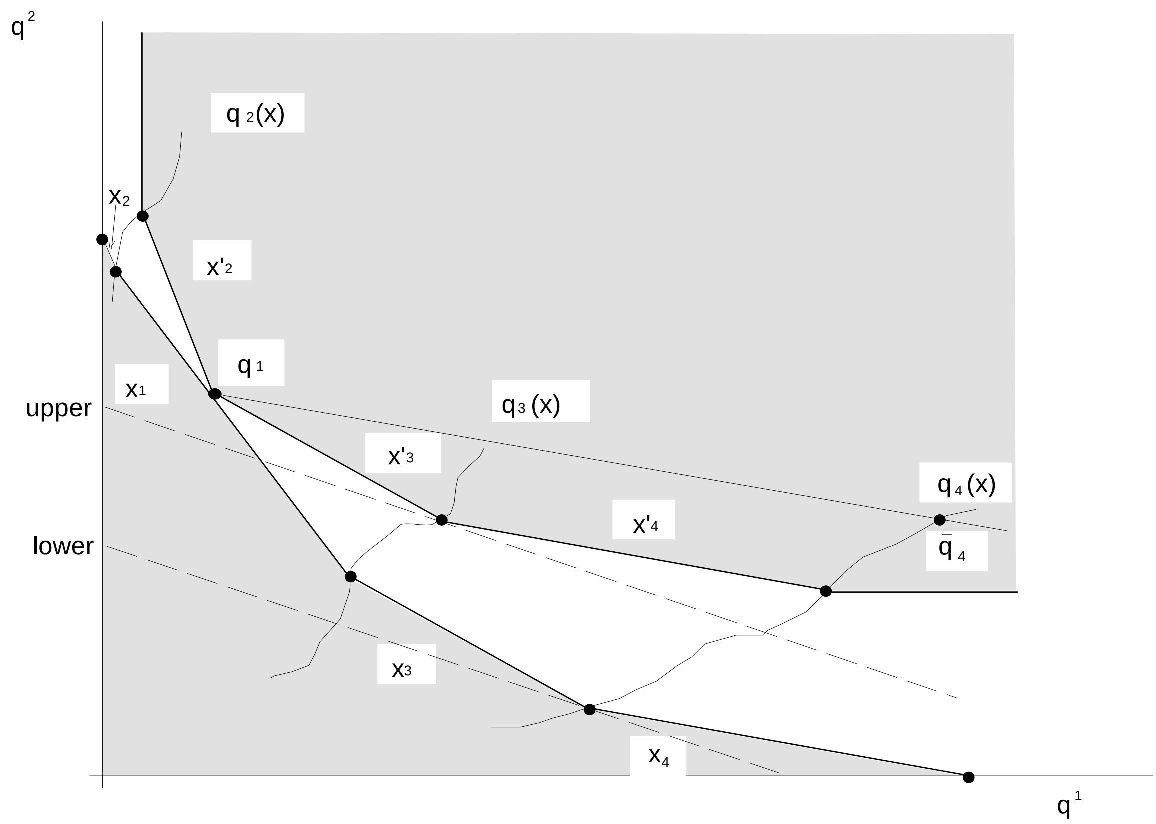

Figure 12: GARP Bounds and classical RP Bounds: 1974-1993

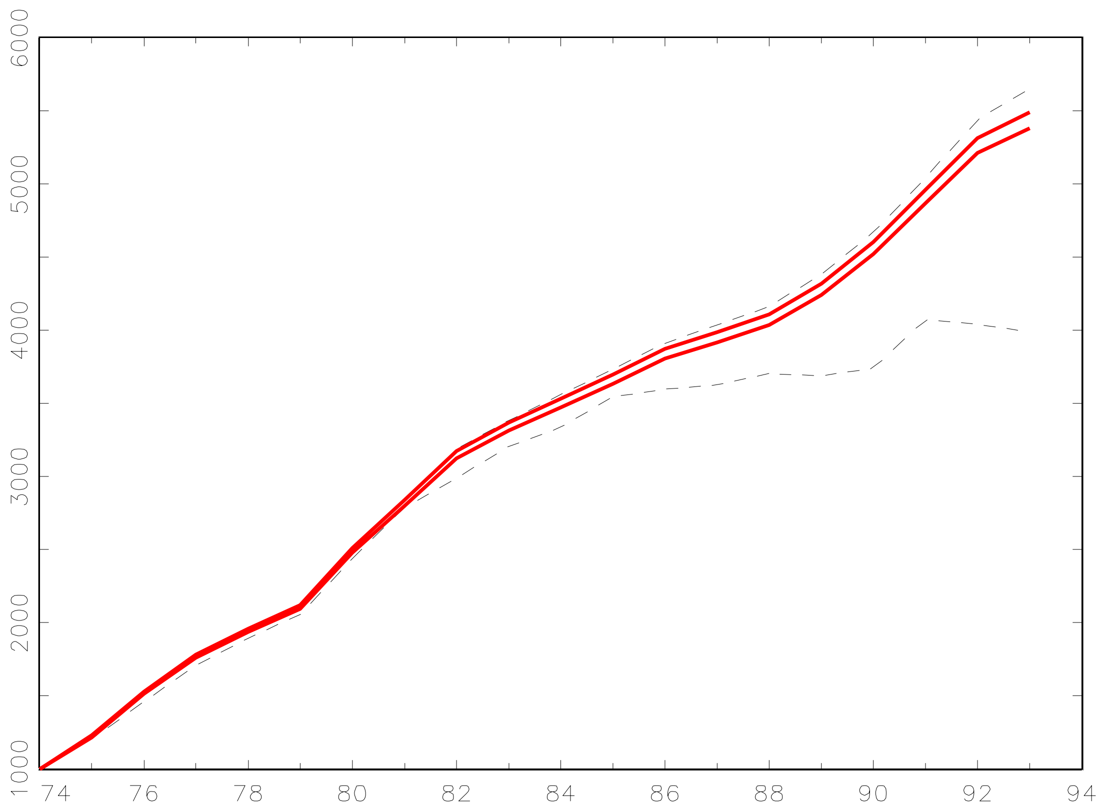

Figure 13. Quantile Expansion Paths: Food Shares

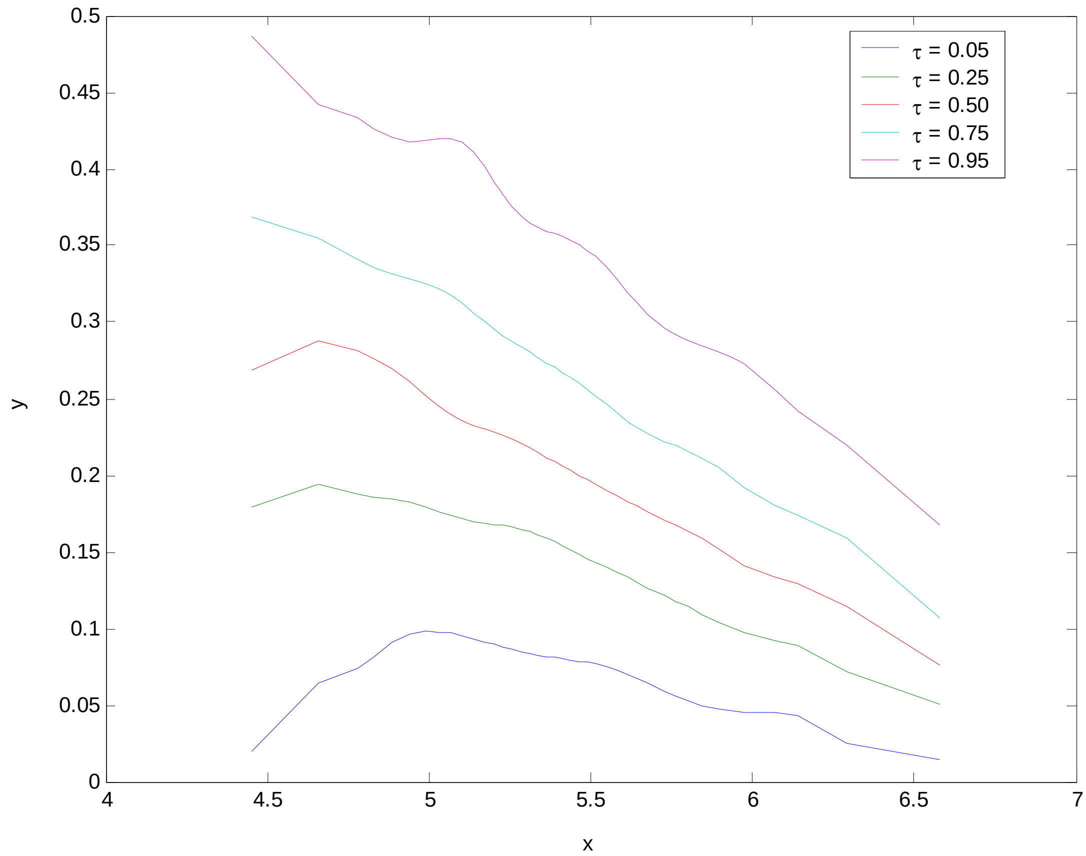

Figure 14a. Demand Bounds at Income Percentiles

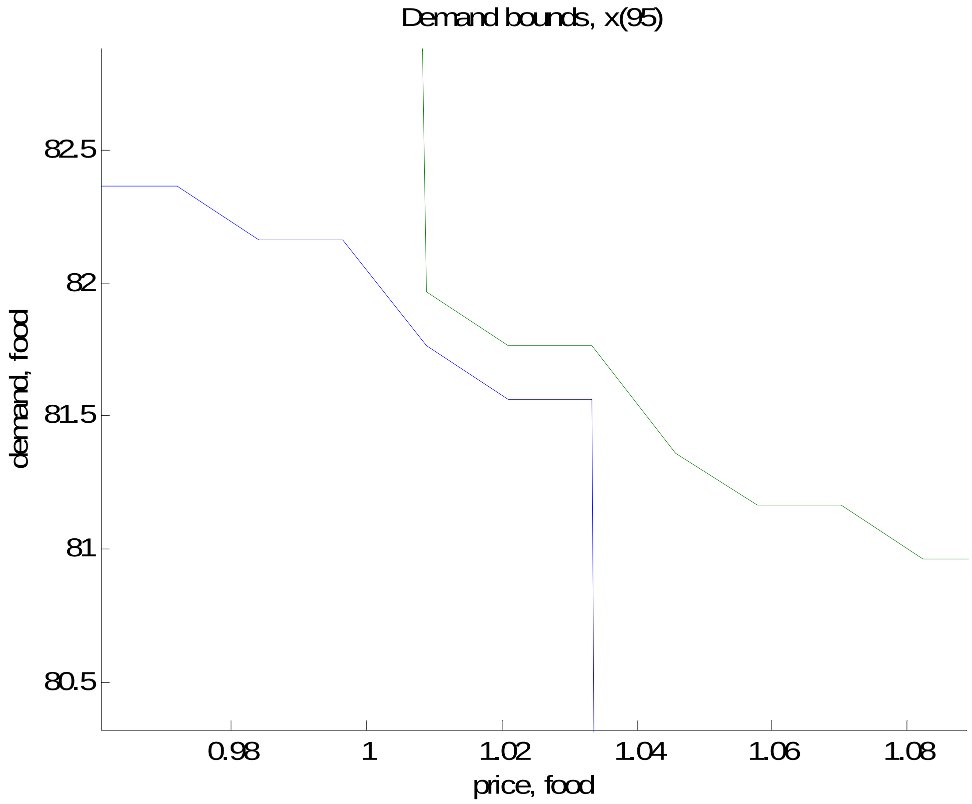

Figure 14b. Demand Bounds at Income Percentiles

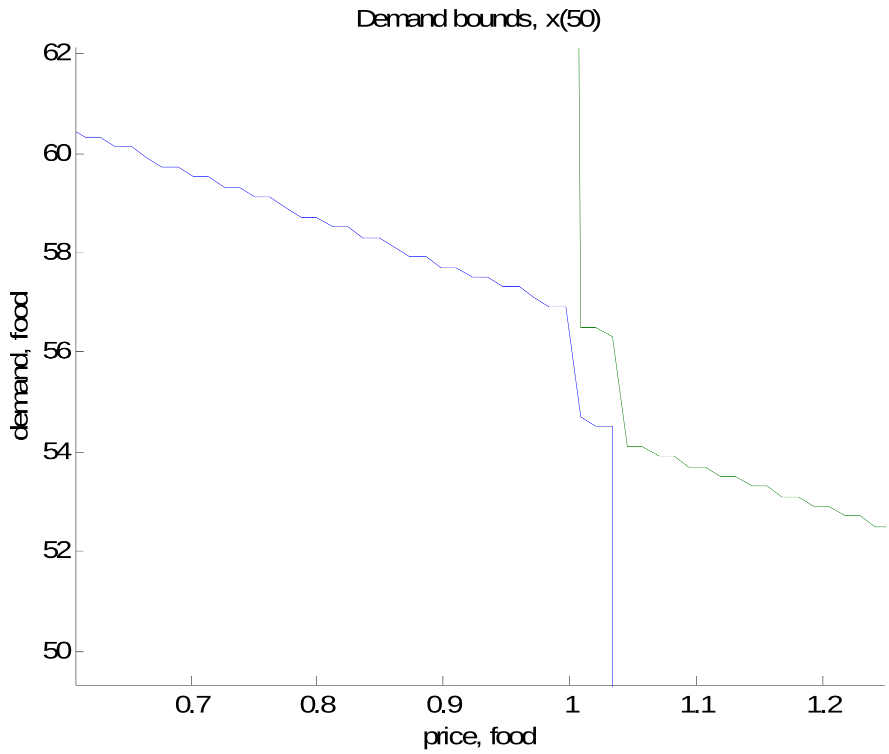

Figure 14c. Demand Bounds at Income Percentiles