A Three-Stage Experimental Test of Revealed Preference

Peter J. Hammond, with Stefan Traub (Bremen)

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Outline

Parametric Estimates with Aggregate Data

"Klein/Rubin" utility function; actually invented by Gorman (unpublished work as an undergraduate in Dublin) and then Samuelson.

Undergraduate exercise: derive the implied demand functions and show they satisfy the linear expenditure system (LES).

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there was a postwar US representative utility-maximizing consumer
who had spent some 30 years walking up an income expansion path
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with controlled laboratory experiments.
Advantages include:

1. price and income changes needed to test the axioms are easy to implement;
2. changes of taste can largely be ruled out;
3. errors in observation largely avoided.

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The Afriat Test in the Simplest Case

What is the simplest case?

How about two goods and two observations?

Suppose a consumer chooses bundle $\mathbf{x}^1 \in \mathbb{R}^2$
when the price vector is $\mathbf{p}^1 \in \mathbb{R}^2$.

By definition $\mathbf{x}^1$ is revealed preferred
to any $\mathbf{x}^2$ satisfying $\mathbf{p}^1\mathbf{x}^2 < \mathbf{p}^1\mathbf{x}^1$.

But suppose nevertheless that the same consumer,
when the price vector is $\mathbf{p}^2$,
chooses the bundle $\mathbf{x}^2$ where $\mathbf{p}^2\mathbf{x}^2 > \mathbf{p}^2\mathbf{x}^1$.

This would violate GARP,
and the *Afriat efficiency index* is the ratio $\mathbf{p}^1\mathbf{x}^2/\mathbf{p}^1\mathbf{x}^1 < 1$.

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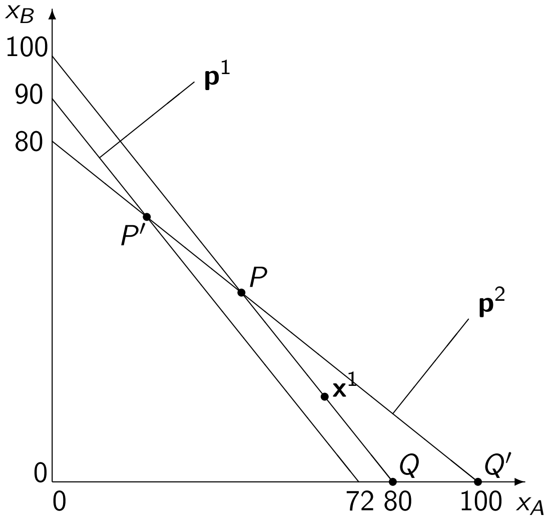
Specific Example

Consider a budget of \$100,
along with two price vectors $\mathbf{p}^1 = (1.25, 1)$ and $\mathbf{p}^2 = (1, 1.25)$.

Suppose the bundle $\mathbf{x}^1 = (x_A^1, x_B^1) = (64, 20)$ is chosen at prices $\mathbf{p}^1$
— or indeed any other bundle
on the line segment joining the end point Q
to the intersection point $P = (44\frac{4}{9}, 44\frac{4}{9}) \approx (44.4, 44.4)$.

At prices $\mathbf{p}^2$ the *supporting set* of bundles satisfying GARP
consists of the line segment joining P
to the end point $Q' = (100, 0)$.

Specific Example



Limited Power of Afriat's Approach

Assuming a uniform distribution along this second budget line, the probability is $\frac{5}{9} \approx 55.6\%$ of satisfying GARP.

Allowing an Afriat efficiency index of 0.9, however, which is equivalent to throwing away \$10 at prices $\mathbf{p}^2$, moves the intersection down to $P' = (22\frac{2}{9}, 62\frac{2}{9}) \approx (22.2, 62.2)$.

The chance that random choice will be classified as rational rises to $\frac{56}{81} \approx 69.1\%$.

Revealed Preference

Revealed Preference, review by Hal R. Varian (2005)
prepared for *Samuelsonian Economics and the 21st Century*.

Given some vectors of prices
and chosen bundles (p^t, x^t) for $t = 1, \ldots, T$,
we say x^t is directly revealed preferred
to a bundle x (written $x^t \; R_D \; x$) if $p^t x^t \geq p^t x$.

We say x^t is revealed preferred to x (written $x^t \; R \; x$)
if there is some sequence $r, s, t, \ldots, u, v$ such that

$$p^r x^r \geq p^r x^s, \; p^s x^s \geq p^s x^t, \ldots, p^u x^u \geq p^u x^v.$$

In this case, we say the relation R
is the transitive closure of the relation R_D.

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Generalized Axiom of Revealed Preference

The data (p^t, x^t) satisfy
the Generalized Axiom of Revealed Preference (GARP)
if $x^t \; R \; x^s$ implies $p^s \, x^s \leq p^s \, x^t$.

GARP . . . is equivalent to what Afriat called "cyclical consistency."

The only difference between GARP and SARP
is that the strong inequality in SARP
becomes a weak inequality in GARP.

This allows for multivalued demand functions
and "flat" indifference curves,
which turns out to be important in empirical work.

Supporting Set

Consider any list $s^n = (\mathbf{p}^i, \mathbf{x}^i)_{i=1}^n$
of n pairs of price and quantity vectors that satisfy
both GARP and the normalization $\mathbf{p}^i \mathbf{x}^i = 1$ $(i = 1, \ldots, n)$.

Let $\mathbf{p}^{n+1}$ be any previously unobserved price vector.

Then Varian (1982, 2006) defines
the supporting set $S(\mathbf{p}^{n+1}; s^n)$ of consumption bundles $\mathbf{x}^{n+1}$
as those for which the extended sequence $(\mathbf{p}^i, \mathbf{x}^i)_{i=1}^{n+1}$
also satisfies both GARP
and the normalization $\mathbf{p}^i \mathbf{x}^i = 1$ $(i = 1, \ldots, n+1)$.

As Varian (1982) notes, the supporting set describes
"what choice a consumer will make
if his choice is to be consistent
with the preferences revealed by his previous behavior" (p. 957).

First and Second Stages

When teaching intermediate microeconomics,
we usually explain the revealed preference axiom
in a two-stage process.

First suppose a consumer chooses
a (two-dimensional) commodity bundle $\mathbf{x}^1$ at the price vector $\mathbf{p}^1$.

Second, consider the consumer's demands
when faced with a new price vector $\mathbf{p}^2$
and a new budget line $\mathbf{p}^2\mathbf{x} = \mathbf{p}^2\mathbf{x}^1$
that passes through the originally chosen bundle $\mathbf{x}^1$.

The usual revealed preference axiom implies that
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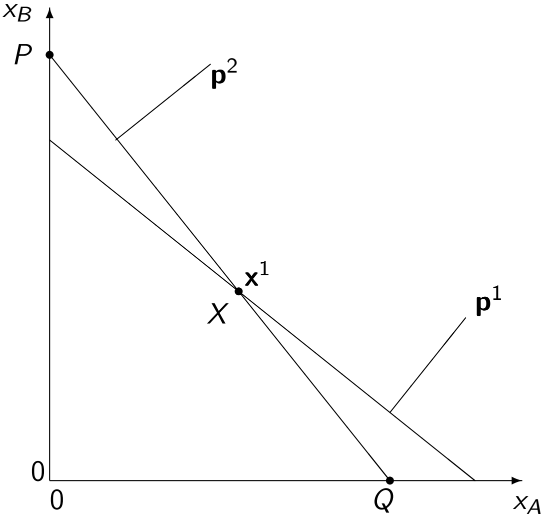
Illustration



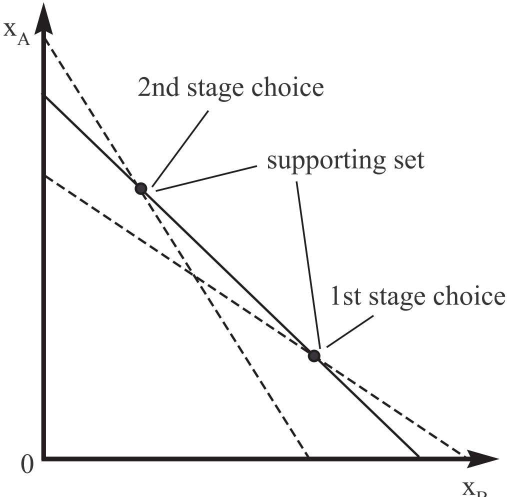
Illustration

Thus GARP implies that $\mathbf{x}^2$ should lie in the line segment PX.

Under the null hypothesis of uniformly random choice
over the budget line segment PQ,
the probability of satisfying GARP is PX/PQ.

This is somewhat over 0.5 in the diagram.

Third Stage



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Random Lottery Incentive System

Following the usual random lottery incentive system, at the end of the experiment one decision problem was selected at random.

Each token won in that decision problem was converted into $0.20 of UK currency.

In each decision problem, subjects had to split an initial endowment of 100 tokens between the two Arrow securities.

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Budget Constraint

Theoretical budget constraint $p_A x_A + p_B x_B = 100$,
where p_s denotes the price and x_s the demand for Arrow security s.

In practice, prices were rounded off to one decimal place, and subjects could only choose nonnegative integer amounts of each security.

In addition to the budget constraint $p_A x_A + p_B x_B \leq 100$, subjects were restricted to pairs (x_A, x_B) of nonnegative integers immediately below the budget line.

Specifically, we allowed any nonnegative integer allocation satisfying

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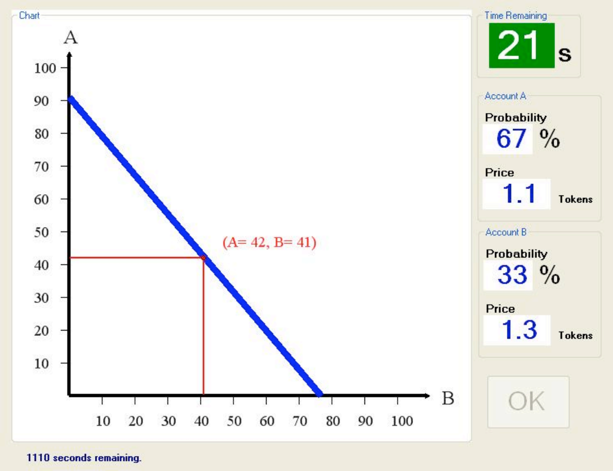


Decision Process

As each new decision problem appeared,
the mouse pointer became visible at its default position
in the upper right-hand corner of the screen.

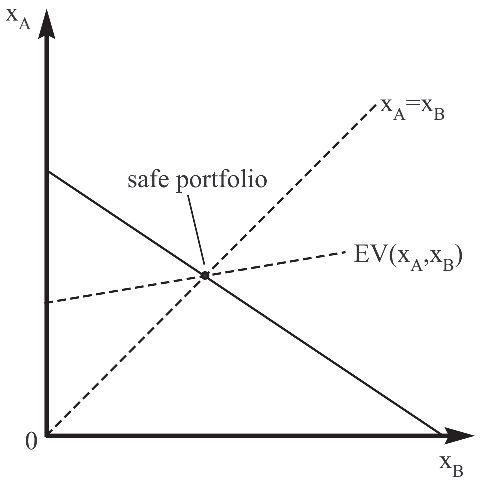
While the mouse pointer was close to a feasible allocation,
that allocation was indicated by two numbers
and by associated reference lines marked in red.

Subjects could also “fix” and later “release” an allocation
by clicking the left mouse button.

Once a portfolio was fixed, even if the mouse pointer was moved,
the numbers and reference lines turned green
and stayed visible on the screen until released.

To choose this portfolio and proceed to the next decision problem,
a subject could simply click the OK button.

Safe Portfolio



Safe Portfolio

The figure illustrates a scenario where $p_A = 1.5$, $p_B = 1$, and both states are equally likely.

The solid line represents the budget constraint with slope $-p_B/p_A = -1.5$.

The dashed 45°-line marks all portfolios for which $x_A = x_B$.

It intersects the budget line at the indicated safe portfolio, where $x_A = x_B = 40$.

Stochastically Dominated Choices

The second dashed line is the graph of the expected value

$$\mathbb{E}V(x_B) = \pi x_A + (1-\pi)x_B = \frac{\pi}{p_A}(100 - p_B x_B) + (1-\pi)x_B$$

of each portfolio as a function of x_B,
as one moves along the budget line.

Its slope in the figure is $1/6$.

Hence, portfolios to the left of the safe portfolio
are stochastically dominated.

First Stage

Each subject faced 16 rounds of successive grouped choice problems in up to three stages.

At each first stage, the budget constraint was $\mathbf{p}^1\mathbf{x} = 100$, where $\mathbf{p}^1 = (p_A^1, p_B^1)$ and $\mathbf{x} = (x_A, x_B)$.

The price vector $\mathbf{p}^1$ was taken from the eight-point set

$$\{(1, 1.5), (2, 1), (1, 2.5), (3, 1), (1.5, 2), (2.5, 1.5), (3, 1.5), (2, 3)\}$$

of price vectors in $\mathbb{R}^2$.

Furthermore, a pseudo-random number generator would select state A with probability π either 0.5 or 0.67.

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At each first stage, the budget constraint was $\mathbf{p}^1\mathbf{x} = 100$, where $\mathbf{p}^1 = (p^1_A, p^1_B)$ and $\mathbf{x} = (x_A, x_B)$.

The price vector $\mathbf{p}^1$ was taken from the eight-point set

$$\{(1, 1.5), (2, 1), (1, 2.5), (3, 1), (1.5, 2), (2.5, 1.5), (3, 1.5), (2, 3)\}$$

of price vectors in $\mathbb{R}^2$.

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Second Stage

Each subject's first-stage choice was used
to construct the second-stage budget line $\mathbf{p}^2\mathbf{x} = 100$.

This was determined in principle by:

1. interchanging the two components of the first-stage price vector $\mathbf{p}^1$;
2. replacing the new higher component with one chosen at random.

Specifically, in case $p_B^1 < p_A^1$, then p_B^2 was chosen at random from a uniform distribution on the closed interval $[100/x_B^1, 200/x_B^1]$,
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Exceptions

In several cases, however, subjects chose dominated portfolios close to the extreme where the whole budget is allocated to the more costly security!

In these cases the budget line would be very steep (or flat).

Our software did not allow the subject beyond the first stage in case the second-stage choice problem would have involved a price ratio greater than 10 (or smaller than 0.1).

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If a subject's second-stage choice
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the third-stage budget constraint was constructed
by first taking the unique line passing
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The experiment was conducted at the University of Warwick on 20th May, 2008.

To avoid "expert" bias,
the subjects were 41 non-economics undergraduates
— 26 male and 15 female students
who had responded to our invitation in time.

Everyone attending and completing the experiment
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Payout

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Choice "Consistency"

Three notions of choice consistency,
different for each round:

1. on round 1, choice far enough away from the stochastically dominated extreme so that we could progress to round 2;
2. on round 2, choice away from the dominated "half" of the budget line segment, so that we could progress to round 3;
3. on round 3, GARP consistent choices.

Choice "Consistency": Aggregate Data

	Outset	Stage		
		1st	2nd	3rd
maximum number of choices	16	16	16	16
number of consistent choices	16	14.6	8.1	6.3
consistent choices (%)	100	91	51	39
% of previous column	—	91	55	78

Consistency: Gender Differences

	Gender				Significance level
	female		male		
	mean	s.e.	mean	s.e.	
share of dominated portfolios					
1st stage	0.324	(0.049)	0.153	(0.032)	0.004*
2nd stage	0.354	(0.056)	0.138	(0.039)	0.002*
3rd stage	0.267	(0.087)	0.078	(0.029)	0.056*
share of GARP consistent choices					
3rd stage	0.474	(0.078)	0.764	(0.046)	0.001*

p-values based on a two-tailed independent-sample *t* test (checked for equality of variances).

Logit Regressions

Variable	All Choices	1st Stage	2nd Stage	3rd Stage
Intercept	-2.089***	-1.805***	-2.102***	-2.693***
	0.203	0.296	0.331	0.542
Gender	1.585***	1.251***	1.914***	1.027
($Female = 1$)	0.276	0.405	0.434	0.849
Round	0.017	0.010	0.030	0.000
	0.021	0.030	0.033	0.056
Gender	-0.051*	-0.032	-0.085*	0.017
$\times$ Round	0.029	0.042	0.045	0.085
n	1589	656	598	335
LL	-734.206	-331.757	-291.980	-98.771
Pseudo-R^2	0.053	0.039	0.064	0.044

Notes

Independent variable: Dominated portfolio chosen.

Binary logit with robust covariance matrix estimation.

First line: coefficients; second line: standard errors.

*$p \leq 0.10$, **$p \leq 0.05$, ***$p \leq 0.01$.

Summary of Aggregate Data

1. on round 1, 91% of choices (16 per participant) were far enough away from the stochastically dominated extreme to allow progress to round 2;
2. on round 2, only 55% of survivors chose away from the dominated "half" of the budget line segment; to allow progress to round 3;
3. on round 3, 78% of survivors made GARP consistent choices.
4. females more likely to make dominated choices than males, but effect declines in later rounds of the 16.

Null Hypothesis

Our null hypothesis is that each choice is made at random from a uniform distribution over the budget line interval
— or more precisely,
over our discrete approximation to this interval.

Given survival to the third-stage, let $F(z)$ denote the conditional probability that a random subject makes fewer than ℓ GARP consistent choices.

Let z_s denote the smallest possible integer satisfying $1 - F(z_s) \leq s$.

Then we reject the null hypothesis of uniform randomness at the significance level s provided that the subject's choice pattern satisfies GARP on at least z_s occasions.

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Significance Levels

We used an obvious Monte Carlo simulation procedure, with 1000 rounds, to estimate $F(z_s)$ for each of the 11 particular values

$$s \in \{0.01, 0.05, 0.1, 0.2, 0.3, \ldots, 0.8, 0.9\}.$$

Rounding implies that the exact probability P_s of $F(\ell) \geq s$ satisifies $P_s = s$ only when $s = F(z)$ for some $z \in \{0, 1, \ldots, I\}$.

Hence, the curve lies below the 45° line except at the end points $s = 0$ and $s = 1$.

For this reason, our test slightly favours the null hypothesis of random choice.

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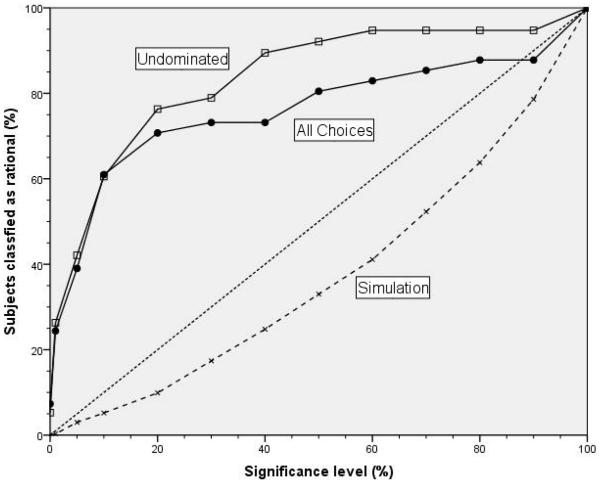
Test Statistics



More Conclusions

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