Appendix III
Testing rationality

An allocation π is *directly revealed preferred* to an allocation π', denoted $\pi R^D \pi'$, if $p \cdot \pi \geq p \cdot \pi'$. An allocation π is *revealed preferred* to an allocation π', denoted $\pi R \pi'$, if there exists a sequence of allocations $\left\{\pi^k\right\}_{k=1}^K$ with $\pi^1 = \pi$ and $\pi^K = \pi'$, such that $\pi^k R^D \pi^{k+1}$ for every $k = 1, ..., K-1$. The Generalized Axiom of Revealed Preference (GARP) requires that if $\pi R \pi'$ then $p^j \cdot \pi' \leq p^j \cdot \pi$ (if π is revealed preferred to π', then π must cost at least as much as π' at the prices prevailing when π' is chosen). Afriat (1967) tells us that if a *finite* data set generated by an individual's choices satisfies GARP, then there exists a continuous, concave, monotonic utility function $u(\pi)$ such that for each observation

$$u(x) \leq u(\pi) \text{ for any } \pi \text{ such that } p \cdot x \leq p \cdot \pi.$$

Hence, in order to show that the data are consistent with utility-maximizing behavior we must check whether it satisfies GARP. Since GARP offers an exact test, it is desirable to measure the *extent* of GARP violations.

We report measures of GARP violations based on three indices: Afriat (1972) (CCEI), Varian (1991), and Houtman and Maks (1985) (HM). The CCEI measures the amount by which each budget constraint must be adjusted in order to remove all violations of GARP. For any number $0 \leq e \leq 1$, define the direct revealed preference relation $R^D(e)$ as $\pi R^D(e) \pi'$ if $ep \cdot \pi \geq p \cdot \pi'$, and define $R(e)$ to be the transitive closure of $R^D(e)$. Let e^* be the largest value of e such that the relation $R(e)$ satisfies GARP. Afriat's CCEI is the value of e^* associated with the data set $\{(p, \pi)\}$. It is bounded between zero and one and can be interpreted as saying that the consumer is 'wasting' as much as $1 - e^*$ of his income by making inefficient choices. The closer the CCEI is to one, the smaller the perturbation of the budget constraints required to remove all violations and thus the closer the data are to satisfying GARP.

Although the CCEI provides a summary statistic of the overall consistency of the data with GARP, it does not give any information about which of the observations are causing the most severe violations. Varian (1991) refined Afriat's CCEI to provide a measure that reflects the minimum adjustment required to eliminate the violations of GARP associated with each observation π. In particular, fix an observation π and find the largest value of e such that $R(e)$ has no violations of GARP within the set of allocations

π' such that $\pi R(e)\pi'$. The value e measures the efficiency of the choices when compared to the allocation π'. Varian (1991) provides an algorithm that will select the least costly method of removing all violations by changing each budget set by a different amount which allows us to say where the inefficiency is greatest or least. To describe efficiency, Varian (1991) uses $e^* = \min\{e\}$. Thus, Varian's (1991) index is a lower bound on the Afriat's CCEI.

Houtman and Maks (1985) (HM), finds the largest subset of choices that is consistent with GARP. This method has a couple of drawbacks. First, observations may be discarded even if the associated GARP violations could be removed by small perturbations of the budget constraint. Further, it is computationally very intensive and thus impractical if, roughly speaking, violations often overlap. As a result, we were unable to calculate this measure for a small number of subjects who often violated GARP, and we therefore report only lower bounds on the consistent set.

Table AIII1 reports, by subject, the values of the CCEI scores in the two- and three-person budget set experiments. The results presented in Table AIII1 allow for a narrow confidence interval of one token (for any π, π' if $|\pi, \pi'| \leq 1$ then π and π' are treated as the same allocation). Figure AIII1A compares the distributions of the CCEI scores generated by a sample of 25,000 hypothetical random subjects and the distributions of the scores for the actual subjects in the three-person experiment. The histograms show that also in the three-person case actual subject behavior has high consistency measures compared to the behavior of the random subjects. Figure AIII1B compares the distributions of the Varian efficiency index in the two- and three-person experiments and Figure AIII1C compares the distributions of the HM index.

[Table AIII1 here]
[Figure AIII1 here]

Finally, we note that there is a very high probability that random behavior will pass the GARP test if the number of individual decisions is as low as it usually has been in experiments. To illustrate this point, we calibrated the choices of random 25,000 subjects over 10, 25 and 50 two-person budgets. The results are listed in the diagram below, which reports the fractions of high CCEI scores. Bronars' (1987) test (the probability that a random subject violates GARP) has also been applied to other experimental data. Our study has the highest Bronars power of one (all random subjects had violations). Hence, our experiment is sufficiently powerful to exclude the possibility that consistency is the accidental result of random behavior. Therefore, the consistency of our subjects' behavior under these conditions is not accidental.

CCEI	10	25	50
$0.95 - 1.0$	0.202	0.043	0.001
$0.9 - 0.95$	0.171	0.100	0.007
$0.85 - 0.9$	0.133	0.146	0.026

To make this more precise, we also generate a random sample of 25,000 hypothetical subjects who implement the CES utility function

$$U_s = [\alpha(\pi_s)^\rho + (1-\alpha)(\pi_o)^\rho]^{1/\rho}$$

with an idiosyncratic preference shock that has a logistic distribution

$$\Pr(\pi^*) = \frac{e^{\gamma \cdot u(\pi^*)}}{\int\limits_{\pi : p \cdot \pi = m} e^{\gamma \cdot u(\pi)}},$$

where the parameter γ reflects sensitivity to differences in utility. The choice of allocation becomes purely random as γ goes to zero, whereas the probability of the allocation yielding the highest utility approaches one as γ goes to infinity. Figure AIII2 summarizes the distributions of CCEI scores generated by samples of hypothetical subjects with $\alpha = 0.75$ and $\rho = 0.25$, which is in the range of our estimates, and various levels of precision γ. Each of the 25,000 hypothetical subjects makes 50 choices from randomly generated two-person budget sets in the same way as the human subjects do. The data clearly show that our experiment is sufficiently powerful to detect whether utility maximization is in fact the correct model.

[Figure AIII2 here]

Table AIII1: The number of violations of GARP and the values of the three indices

Two-person

ID	GARP	CCEI	Varian	HM	ID	GARP	CCEI	Varian	HM
1	376	0.844	0.464	39	39	76	0.948	0.822	41
2	1089	0.517	0.244	42	40	4	0.998	0.978	46
3	332	0.817	0.390	35	41	5	0.990	0.984	47
4	0	1.000	1.000	50	42	0	1.000	1.000	50
5	20	0.965	0.901	44	43	248	0.811	0.510	37
6	16	0.946	0.832	47	44	15	0.972	0.938	42
7	70	0.928	0.754	34	45	191	0.931	0.707	39
8	1	0.977	0.971	49	46	57	0.902	0.802	41
9	2	0.989	0.960	48	47	359	0.798	0.533	30
10	55	0.966	0.836	42	48	1037	0.500	0.069	43
11	209	0.834	0.658	42	49	19	0.965	0.911	42
12	22	0.935	0.593	48	50	9	0.990	0.916	42
13	20	0.954	0.828	40	51	54	0.926	0.774	42
14	19	0.806	0.741	42	52	60	0.933	0.789	35
15	9	0.983	0.965	45	53	942	0.619	0.196	42
16	1005	0.606	0.205	42	54	2	0.975	0.952	48
17	0	1.000	1.000	50	55	58	0.970	0.896	39
18	7	0.978	0.937	44	56	9	0.968	0.894	45
19	497	0.710	0.256	33	57	0	1.000	1.000	50
20	2	0.996	0.974	48	58	0	1.000	1.000	50
21	539	0.845	0.486	41	59	30	0.959	0.909	43
22	2	0.998	0.980	49	60	0	1.000	1.000	50
23	3	0.978	0.931	49	61	89	0.957	0.889	38
24	5	0.985	0.967	46	62	41	0.956	0.905	45
25	3	0.981	0.963	47	63	73	0.716	0.507	47
26	797	0.272	0.185	42	64	132	0.848	0.693	36
27	2	0.989	0.969	48	65	0	1.000	1.000	50
28	34	0.957	0.886	41	66	541	0.865	0.518	40
29	63	0.900	0.812	43	67	3	0.983	0.960	47
30	15	0.971	0.933	43	68	9	0.980	0.948	46
31	0	1.000	1.000	50	69	100	0.939	0.824	40
32	4	0.991	0.982	47	70	24	0.892	0.877	42
33	3	0.990	0.973	49	71	528	0.582	0.364	38
34	26	0.928	0.716	43	72	14	0.952	0.884	45
35	3	0.985	0.948	49	73	221	0.899	0.676	34
36	181	0.916	0.795	42	74	521	0.697	0.402	40
37	480	0.930	0.590	38	75	446	0.792	0.540	38
38	14	0.977	0.947	47	76	1216	0.211	0.066	43

Three-person

ID	GARP	CCEI	Varian	HM
135	0	1.000	1.000	50
136	57	0.982	0.822	44
137	608	0.699	0.273	32
138	0	1.000	1.000	50
139	0	1.000	1.000	50
140	1033	0.393	0.127	43
141	250	0.723	0.449	39
142	0	1.000	1.000	50
143	65	0.669	0.620	47
144	88	0.696	0.586	43
145	2	0.998	0.989	49
146	9	0.996	0.967	47
147	12	0.986	0.960	46
148	21	0.989	0.926	45
149	0	1.000	1.000	50
150	0	1.000	1.000	50
151	81	0.848	0.636	41
152	95	0.928	0.671	42
153	277	0.683	0.467	38
154	0	1.000	1.000	50
155	2	0.996	0.971	49
156	103	0.862	0.769	39
157	4	0.985	0.980	48
158	0	1.000	1.000	50
159	26	0.972	0.917	46
160	0	1.000	1.000	50
161	21	0.933	0.793	44
162	2	0.991	0.990	49
163	92	0.906	0.554	45
164	561	0.689	0.435	35
165	189	0.902	0.766	41
166	373	0.894	0.539	25
167	5	0.994	0.969	49
168	337	0.789	0.427	30
169	0	1.000	1.000	50
170	8	0.969	0.929	47
171	0	1.000	1.000	50
172	87	0.949	0.843	47
173	51	0.878	0.789	46
174	23	0.926	0.900	46
175	43	0.886	0.803	44
176	6	0.989	0.932	48
177	84	0.946	0.764	42
178	0	1.000	1.000	50
179	6	0.995	0.977	48
180	0	1.000	1.000	50
181	0	1.000	1.000	50
182	44	0.970	0.900	45
183	7	0.969	0.948	48
184	6	0.994	0.978	47
185	375	0.824	0.379	40
186	12	0.971	0.963	44
187	53	0.958	0.858	40
188	0	1.000	1.000	50
189	2	0.989	0.987	49
190	8	0.992	0.982	48
191	94	0.932	0.851	44
192	85	0.864	0.681	44
193	131	0.884	0.713	39
194	336	0.837	0.603	19
195	0	1.000	1.000	50
196	4	0.991	0.961	48
197	48	0.926	0.901	44
198	8	0.976	0.971	48
199	6	0.960	0.776	48

Figure AIII1A: The distributions of Afriat's (1972) critical cost efficiency index (CCEI
in the three-person budget set experiment

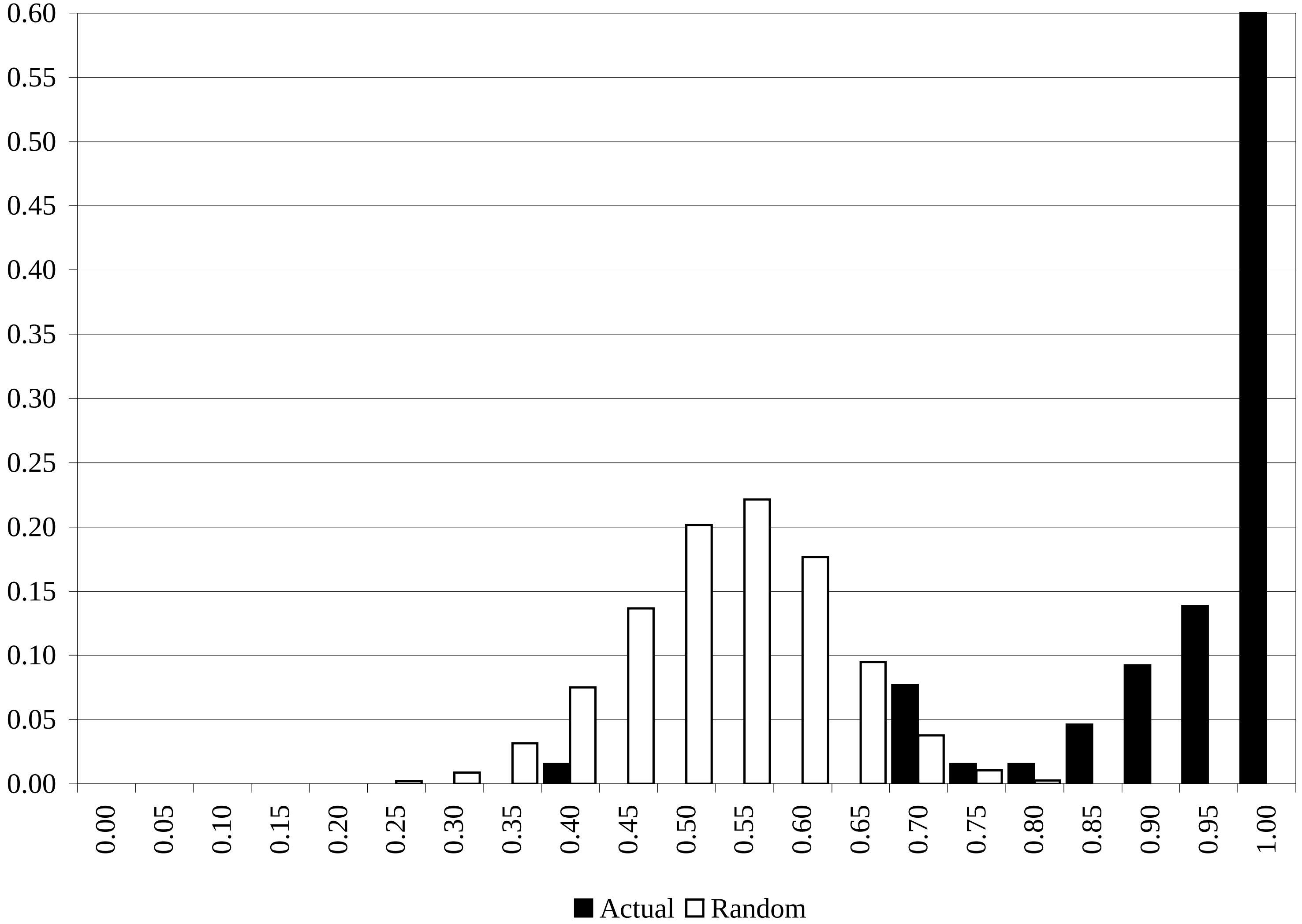

Figure AIII1B: The distributions of Varian (1991) index in the two- and three-person budget set experiments

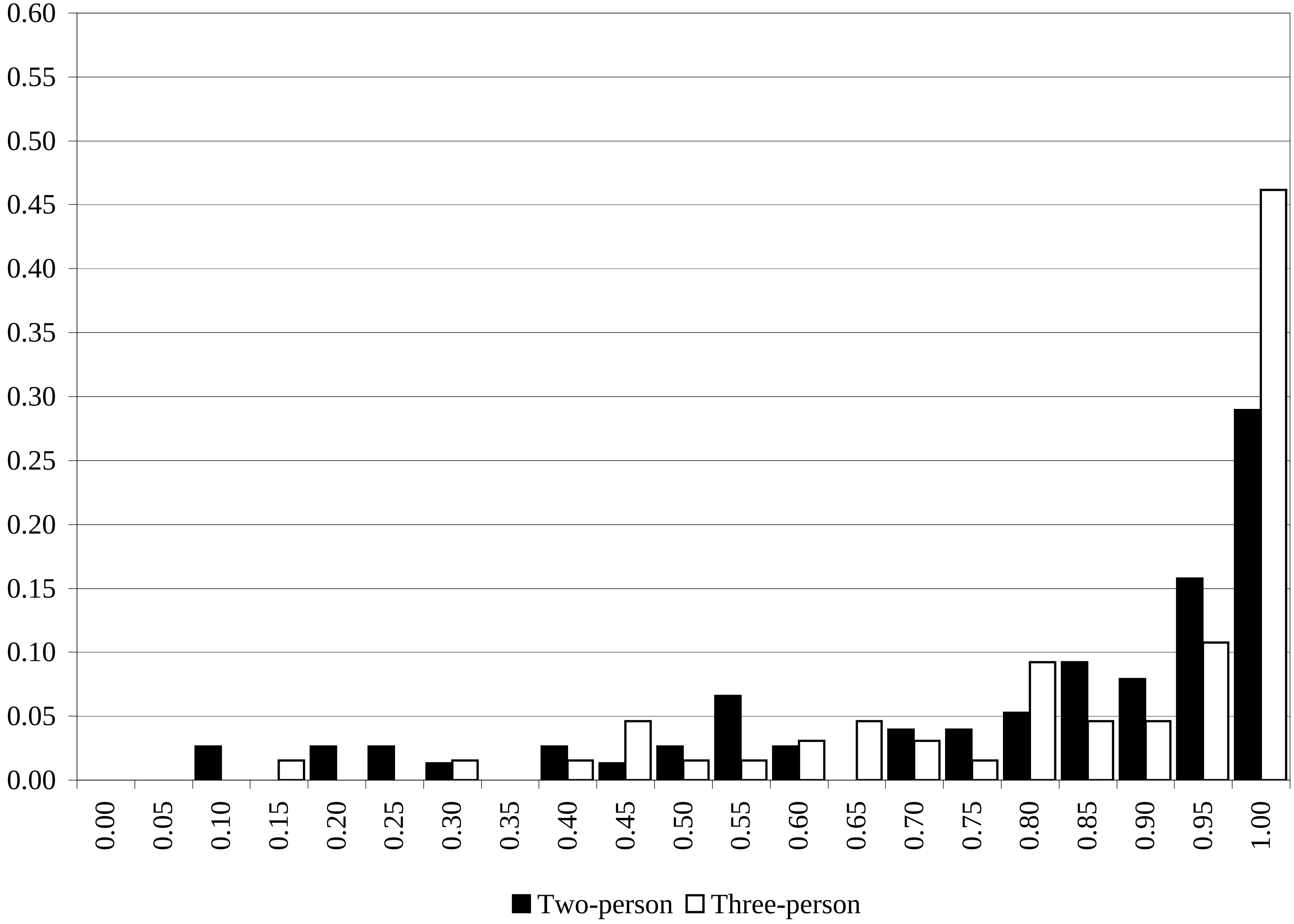

Figure AIII1C: The distributions of HM index
in the two- and three-person budget set experiments

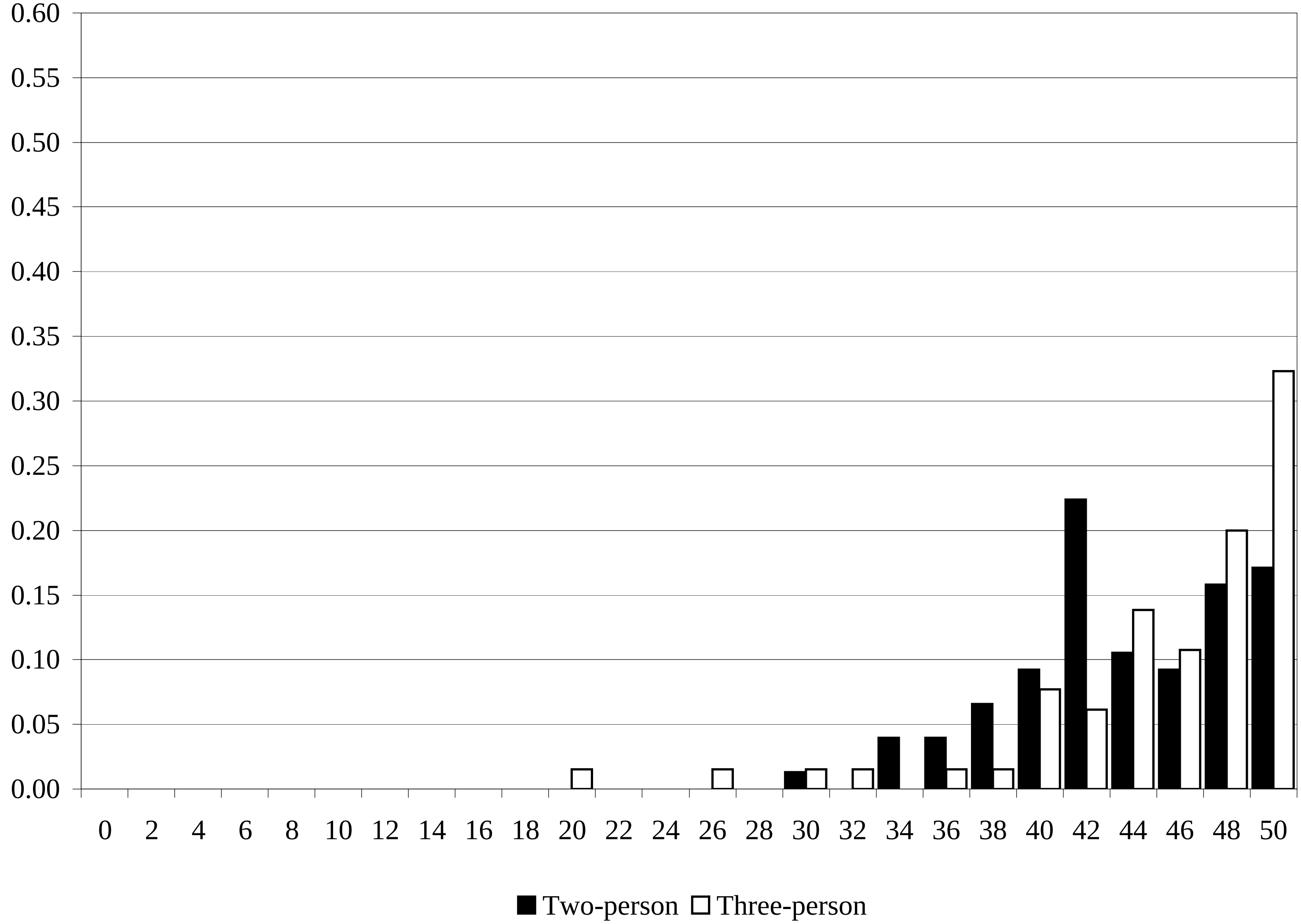

Figure AIII2: The distributions of Afriat's (1972) critical cost efficiency index (CCEI
of samples of 25,000 hypothetical subjects