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Framing the Allais paradox as a daily farm decision problem: tests and explanations

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Abstract

The well-known Allais paradox is reformulated as a daily farm decision problem. Only 26% of the farmers exhibit violations of the expected utility hypothesis. Moreover, the tendency for violation decreases with the farm operator's education, experience and family size. No effects of the farm main crop or its scale were detected. Finally, when taking into account the possibility of choice errors, we find that the violation rate is statistically insignificant.

1. Introduction

Over the last 2 decades, a growing number of studies published in the economic and psychological literature have exhibited evidence against the EU (expected utility) hypothesis (a comprehensive survey of this literature is provided by Schoemaker, 1982; Machina, 1987). For many agricultural economists, whose interests lie in researching farmers' behavior under risk, this literature presents a serious dilemma. Should the large body of theoretical and empirical results concerning farmers' behavior, which has been derived using the vehicle of expected utility (EU), be abandoned or do other possibilities perhaps exist?

Two main alternatives for coping with such a problem come to mind: (1) examining which classes of previous results generalize to new alternative theories and redriving other results with one of the many theories comprising alternatives to EU (e.g. Machina, 1989; Finkelshtain and Hewitt, 1989); (2) searching for additional empirical evidence concerning EU violations, specifically regarding farmers' behavior, in the hope that these violations would prove less significant than those found in laboratory experiments.

A recently published paper (Bar-Shira, 1992) pioneered the econometric approach. Utilizing a non-parametric econometric analysis, Bar-Shira found no violation of the EU hypothesis among Israeli farmers from the Arava region, which suggests that this approach has promise. Econometric analysis in this area requires large amounts of information and is based on many restrictive assumptions (the difficulties are elaborated in Section 3). These problems motivate additional research, oriented to collect further evidence of EU violations among the farming community, which are based on non-econometric methods.

Adopting this approach, we presented the Allais (1953) decision problem to 180 farmers and con-

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structed a formal statistical model for testing the EU hypothesis among these farmers. Unlike previous experimental studies, the questionnaire in the current study is framed as a daily decision problem, customized to each farm type. This is an important feature, if the test results are to be used as a recommendation for the future employment of the EU model in conducting risk analysis among farmers. Indeed, the violation rate of 26%, which we found among the farmers, is low in comparison with the findings of laboratory experiments with students as subjects (see Conlisk, 1989).

The statistical analysis constitutes two parts. First, we assumed sampling error only, or in other words, that by answering the questionnaire, farmers exhibited their true preferences. Under this assumption the violation rate, reported above, differs significantly from zero. The paper adds to the existing literature by employing probit and discriminate analyses in an attempt to find socioeconomic characteristics (SECs) that explain the tendency for violation.

In the second stage of the statistical analysis, we explicitly recognized the difficulties associated with answers to hypothetical questions and took into consideration the possibility of choice errors. A procedure proposed by Conlisk to test for EU violation, in the presence of choice errors, was employed and showed that the rate of violation is statistically insignificant. The main advantage of this procedure is that it does not require information regarding the actual probabilities of choice errors by farmers. Its disadvantage is, however, that under some circumstances, it may suffer from low power. These circumstances are identified, and an alternative procedure that dominates Conlisk's test (on the grounds that its power is higher) is proposed.

This procedure requires prior information about the probability of choice errors, estimated by utilizing complementary information about the farmers' risk attitudes. We infer that a lower bound for the probability that a farmer will make a choice error is 19.5%. This estimate is consistent with the results of previous studies (Bushina and Zilberman, 1993). Given this level of a choice error probability, our sample results indicate that the violations are not statistically significant. We, therefore, conclude that our findings provide additional evidence in support of the EU model among farmers.

2. The Allais paradox: description and evidence

We commence the formal analysis by the introduction of several conventions and presentation of the most well-known example of systematic violations of the EU hypothesis – the paradox proposed by Allais.

Let

$$L = (P_1, P_2, P_3; \pi_1, \pi_2, \pi_3)$$

represent a lottery L offering three possible prizes π_1, π_2, π_3 with corresponding probabilities P_1, P_2, P_3. Thus, (1/3, 1/3, 1/3; 0, 9, 27) stands for an equal probabilities lottery with a probability of one third of receiving each 0, 9 or 27.

We can now present the Allais example. An individual is offered the choice of a gamble from each of the two pairs given by:

Pair I:

$$L_1 = (0,1,0;0,1M,5M)$$

$$L_2 = (0.01,0.89,0.1;0,1M,5M)$$

Pair II:

$$\hat{L}_1 = (0.9,0,0.1;0,1M,5M)$$

$$\hat{L}_2(0.89,0.11,0;0,1M,5M)$$

where M stands for millions of American dollars (or in the original study of Allais, 1953, millions of French francs).

There are four possible choices $(L_1, \hat{L}_1)$, $(L_1, \hat{L}_2)$, $(L_2, \hat{L}_1)$, $(L_2, \hat{L}_2)$, from which the first and the last are consistent with expected utility theory, whereas the other two are not. The reason is that the two choices, $(L_1, \hat{L}_2)$, $(L_2, \hat{L}_1)$, violate the independence axiom.

To illustrate the violation we define the lotteries

$$I_1 = (1;1M), \quad I_2 = (1/11, 10/11; 0, 5M)$$

and note that

$$L_1 = (11/100, 89/100; I_1, 1M),$$

$$L_2 = (11/100, 89/100; I_2, 1M)$$

Thus, L_1 is a weighted average (the weights being 11/100 and 89/100) of I_1 and $1M$, while L_2 is a weighted average with the same weights of I_2 and $1M$. From the independence axiom it follows that individuals who prefer L_1 to L_2 reveal that they also prefer I_1 to I_2 (and vice versa). Turning to $\hat{L}_1$ and $\hat{L}_2$ one observes that

$$\hat{L}_1 = (11/100, 89/100; I_2, 0)$$

$$\hat{L}_2 = (11/100, 89/100; I_1, 0)$$

Thus, $\hat{L}_1$ is simply a mixture of I_1 and 0 (with weights being, as before, 11/100 and 89/100), while $\hat{L}_2$ is a mixture of I_2 and 0 with the same weights. By the independence axiom, one's preferences over a pair of lotteries should be invariant to mixtures with some third lottery. Clearly, choices such as L_1, $\hat{L}_2$ and L_2, $\hat{L}_1$ violate this axiom.

3. Testing the EU hypothesis: a methodological review

The literature that reports various tests of the EU hypothesis is enormous and we make no attempt to provide a comprehensive review of it. Instead the reader is directed to several excellent surveys: Robison (1982), Schoemaker (1982) and Machina (1987). The purpose of this review is confined to a brief discussion of the various methodologies that were used to examine the EU hypothesis.

3.1. Field studies based on stylized facts

The important advantage of field studies is that the analysis is based on actual decisions. Most field studies are based on stylized facts, such as low demand for insurance against low probability events. In particular, Kunreuther et al. (1978) report that in spite of Federal subsidies of up to 90% of the cost of flood and crime insurance programs, participation by the public is poor. On the face of it, this behavior contradicts the prediction of the EU model that risk averters will purchase full actuarially fair insurance. One may, therefore, conclude that people violate the EU hypothesis.

However, one encounters serious difficulties with the above studies in that, in many cases, one can offer plausible explanations that rationalize the observed behavior as consistent with EU. For example, people may abstain from purchasing flood insurance, because they expect government assistance in the case of a disaster. Also, they may be misinformed about the possibility of purchasing subsidized insurance or about the actual probability of a disaster. Another problem with this approach is that many real-world decisions are qualitatively the same under the EU model and competitive models, such as rank-dependent expected utility. In such cases, only a quantitative analysis can distinguish between the alternative choice criteria. This motivates econometric studies.

3.2. Econometric studies

As with studies, which are based on stylized facts, the important advantage of econometric studies is the reliance on actual decisions. Unfortunately econometric analysis in this area requires a large amount of information. In particular one must know or estimate the: (1) agricultural technology; (2) producer preferences; (3) joint probability distribution of profits from the various farm crops, and the changes of the distribution over time and finally (4) information about the value of the farmer's total assets and property. To handle this huge amount of information, researchers must incorporate many simplifying assumptions. These assumptions call into doubt the validity and accuracy of the results.

For example, in Bar-Shira's pioneering work, it is assumed that each year the family farm land can be allocated freely among crops without any technological, financial or environmental constraints (such as the scarcity of labor during certain periods or imperfect markets for investment capital). In addition, the technology is assumed to exhibit constant return to scale and fixed proportions and farmers' expectations are presumed adaptive. Finally, future realizations of profits can only take the historically observed values and the farmers' subjective probabilities for these realizations coincide with the historical observed frequencies.

Bar-Shira avoids the need to assume a functional form for the utility function by employing a nonparametric test. However, currently, non-parametric tests lack a formal statistical framework. Therefore, it is not possible to evaluate the test power, which in turn implies that the failure to reject the EU hypothesis might be a result of relatively low power.

3.3. Questionnaire-based studies

The independence axiom and other axioms and predictions of the EU model have been studied in laboratories by many authors (e.g. Kahneman and Tversky, 1979; MacCrimmon and Larsson, 1979; Conlisk, 1989). A variety of alternative experiments have been reported with one major conclusion: individuals tend to violate the independence axiom, although the proportion of violators is crucially dependent on the exact formulation of the experiment.

The advantage of such studies lies in the possibility to conduct controlled experiments. The disadvantage is the reliance on behavior that does not necessarily reflect a subjects's real-life behavior. Moreover, many studies are criticized on the grounds that they use hypothetical lotteries without monetary prizes. The problem with monetary prizes is that conducting experiments with sums of money that are close to real-life earning is too expensive. Thus, one cannot imitate real-life decision problems, since they involve much higher prizes than those the researcher can afford.

3.4. The current approach: a customized questionnaire

In the current study, farmers were presented with hypothetical lotteries, as in the above literature. However, in contrast to most questionnaire-based studies, the questions were customized to suit each farmer's area of expertise. That is, the lotteries were framed as actual decisions with which the farmers were faced on a daily basis and the prizes were of the same order of magnitude as those appearing in the farmer's real-life decision problems.

By taking this approach, we attempt to exploit the advantages of a controlled experiment, while avoiding the problems associated with artificial lotteries. Obviously, if monetary prizes were used, the analysis could be more convincing. Unfortunately, it is not possible to give western farmers prizes at levels that compare with actual farming earning.

4. The experiment

We surveyed 180 family farms, which were chosen from 20 cooperative villages (moshavim) located in four geographical regions of Israel. [1] These included the Hefer valley, the Jezreel valley, the Galil and the Golan Heights. Thus, the sample is a fairly good representation of the sector of the Israeli moshavim members.

Each farm was visited by a graduate student who presented the farm's operator with a questionnaire. The opening statement of the questionnaire was: "Decision making by farmers is, usually, done under conditions of uncertainty regarding weather conditions, pest risks, unknown prices, etc. As part of a research which is, currently, being undertaken at the department of agr. econ. at ..., we are trying to study how farmers respond to risk and how they make decisions in the presence of such uncertainties. For this purpose we have prepared the attached questionnaire which presents a hypothetical example of an uncertain condition which you may face. Please devote 10 min of your valuable time and complete the questionnaire. The questionnaire is anonymous and we guarantee the secrecy of your identity and answers."

After this opening statement, the farmer was presented with a variant of the Allais paradox. The first notable difference between our version and the original paradox was the prize values. While in the original paradox the lottery prizes are either $1 million (1M) or 5M, in the current version the prizes were fixed at $10000 (10k) and 50k. Thus, we intentionally chose amounts which are more probable to appear in farmers' daily decision problems.

The second difference was the customization of the paradox questions to each farm type. We had three versions of the questionnaire, designed for: livestock farms, plantation plus greenhouse farms and field crop farms. Here we present the questionnaire for livestock farmers. Questionnaires for other farm types are available from the authors upon request.

Each livestock farmer was told that he could either apply a genetically based treatment to increase the female proportion among new-born calves or choose not to apply it. In the first case, the dairy

[1] A moshav is an agricultural community in which all farms are family-owned and operated and all members are organized in a village-level cooperative.

income distribution is given by \$50k, \$10k or \$0k with probabilities 10%, 89% and 1%, respectively. Using the lottery notation it is denoted as $L_1 = (0.01, 0.89, 0.10; 0, 10k, 50k)$. In the second case, the dairy income is certain and equals \$10k, $L_2 = (0, 1, 0; 0, 10k, 50k)$ in lottery notation. Knowing the above information, each farmer had to choose whether or not to apply the new treatment. [2]

Upon completion of this first question, the farmer was given a second version of the story, by which the dairy income was subject to risk in both cases (with and without the new treatment). The risk was related to the natural rate of female birth in the farm. Without the new treatment, there was an 11% chance of an excellent birth rate, yielding \$10k income from the dairy, and an 89% chance of a bad birth rate, yielding \$0k income from the dairy. We denote this lottery $\hat{L}_1 = (0.89, 0.11, 0; 0, 10k, 50k)$. With the treatment the farmer had a 10% chance to make \$50k and a 90% chance to make no money from the dairy. This lottery is denoted by $\hat{L}_2 = (0.9, 0, 0.1; 0, 10k, 50k)$. Again the farmer was asked to choose whether to treat or not.

In addition, we attempted to study the farmers' risk preferences and to obtain some information about the consistency of their answers. For this purpose, each farm operator was asked to choose the minimal probability for success, or probability of winning demanded (PWD), at which he would adopt a new agricultural technology in his area of specialization. The areas of specialization were defined as above. Moreover, the new technologies were identical to those of the Allais example. Adoption of the new technology was presented as a two-prize lottery in which the farmer may win or lose a fixed amount of dollars.

Four alternative prizes were considered: (1) $h = \$1000$, (2) $h = \$10000$, (3) $h = 1\%W^0$, (4) $h = 10\%W^0$, where W^0 denotes the farmer's wealth. The PWD was determined as the minimal probability for winning which triggered adoption. Note that the second prize level is of the same order of magnitude as the prizes in the Allais example. Formally, employing our lottery notations, the PWD, p, is defined by

$$(1-\hat{p},\hat{p};-h,h) \simeq (1;0)$$

where $\simeq$ marks indifference. [3]

The process was supervised by a graduate student, who, in addition to the above questions, collected an array of socioeconomic variables, describing the farmer, his family and his farm. These socioeconomic variables are described below.

Table 1
Descriptive statistics of recorded variables

Variable	Minimum	Maximum	Mean	SD
Farm size (1000 m^2)	3	600	49.9	57.9
Water quota (1000 m^3)	6	100	22.5	12.8
Milk quota (l)	60000	550000	301075	85478
Egg quota	28000	500000	388095	76591
Family members	1	10	5.2	1.5
Schooling years	4	18	12.0	2.1
Age	23	73	43.8	9.6

Farm type	Number
Green house	14
Plantation	57
Cattle	22
Dairy	53
Poultry	21
Others (field crops)	13
Part-time farming	52
Full-time farming	123
Few-hours farming	5
Agency settlement	91
New settlement	36
Established settlement	53

5. Description of the data set

The data set contained panel data regarding farmers' choices of lottery corresponding to the Allais example, choices of PWD and an array of characteristics of the farm and its operator. The following

[2] Note that a farmer that prefers L_1 to L_2 reveals himself as risk averse.

[3] A formal derivation of the relationships between the PWD and conventional measures of risk aversion and SECs is presented in Feinerman and Finkelshtain (1996).

characteristics are included: farm size/acreage (dunams, where 1 dunam = 0.1 ha) and annual water quota (m^3); herd inventory and annual milk quota (l) for farms specializing in livestock; broiler and/or layer inventory and annual egg quota for farms specializing in poultry; qualitative dummy variables for the above-mentioned major areas of specialization; age, education level (years of schooling) and family size of the farm operator. Additional qualitative dummy variables included: part-time farming vs full-time farming; period of the cooperative's establishment (before vs after the Six Days War in 1967); cooperatives that are under the supervision of the Jewish Agency vs cooperatives that are not. Table 1 reports descriptive statistics of the data set.

6. The results

Table 2 presents the experiment results required for testing the EU hypothesis. It shows that the vast majority (73%) of the farmers prefer lottery L_1 over L_2, revealing themselves as risk averters. The distribution of votes between lotteries $\hat{L}_1$ and $\hat{L}_2$ was similar, where the vast majority (77%) of the farmers prefer the less risky prospect lottery $\hat{L}_1$. Detecting risk aversion is consistent with one's prior expectations regarding the population of small family farm operators.

If one's interest lies in testing the EU hypothesis, then the information contained in the interior cells, rather than the margin cells of Table 2, is important. This information with its implications for the EU hypothesis and risk attitudes is summarized in Table 3.

Thus, the choices of the vast majority of the farmers (74.4%) were consistent with the EU hypothesis. Still, there is a considerable proportion (25.6%) of farmers that violate the hypothesis. These findings raise several questions: (1) Is the above proportion of violators statistically significant or could it be the result of a statistical error? (2) If the proportion of violations is found to be non-significant, is it due to low test power or perhaps to the fact that farmers really fulfil the von Neumann and Morgenstern (1953) axioms? (3) Can one identify socioeconomic characteristics (SECs) that differentiate farmers who violate the EU axioms from those who do not. Below, these questions are addressed under two alternative assumptions regarding the data-generating model.

Table 2
Farmers' choice of lottery

	Lottery L_1	Lottery L_2	Total
Lottery $\hat{L}_1$	112	26	138
Lottery $\hat{L}_2$	20	22	42
Total	132	48	180

Table 3
Violators versus non-violators of EU

	Non-violators	Violators
Risk averters	112	–
Risk seekers	22	–
Indeterminate		46
Total	134	46

7. The data-generation process

The results reported in the previous section are sample results. Sample results are of interest, however, additional merit can be gained by attempting to generalize the conclusions to the population level. In this case it is reasonable to presume that the survey population is a good representation of the Israeli family farms which are members of moshavim. This population consists of some 23 000 farms, each owned and operated by a single family. Looking for the violation rate of the EU hypothesis among this population, we begin, in this section, with a description of a plausible data-generation model. Based on this model we then develop, in the next section, a methodology to evaluate the statistical significance of EU violations and to generalize the sample results to the population level.

7.1. The distribution of actual preferences among farmers

We assume that each farmer's true preferences are drawn randomly and independently from a distribu-

Table 4
Farmers' preference distribution

	Lottery L_1	Lottery L_2	Total
Lottery $\hat{L}_1$	$P^{1\hat{1}}$	$P^{2\hat{1}}$	$P^{\hat{1}}$
Lottery $\hat{L}_2$	$P^{1\hat{2}}$	$P^{2\hat{2}}$	$P^{\hat{2}}$
Total	P^1	P^2	1

tion of preferences. Thus, the preferences of a particular subject over the four alternatives, $(L_1, \hat{L}_1)$, $(L_1, \hat{L}_2)$, $(L_2, \hat{L}_1)$, $(L_2, \hat{L}_2)$, are described by the multinomial distribution rule shown in Table 4, where P^{ij} denotes the share in the population of farmers who prefer the pair L_i, L_j $(i, j = 1, 2)$ over three other pairs. Namely, the interior cells of Table 4 describe the joint probability distribution of preferences. For example, if all of the farmers are EU maximizers, then $p^{1\hat{2}} = p^{2\hat{1}} = 0$.

7.2. Choice errors and observed probabilities

Suppose now that when farmers choose a lottery from each pair, (L_1, L_2) and $(L_1, \hat{L^2})$, a choice error with a probability ρ may occur due to misinterpretation of the question or bad instructions of the questioner. Following previous studies (Conlisk, 1989) we employ the simplifying assumption that error probabilities are identical among all farmers and choices. Moreover, the various error events are independent of each other.

Under the above assumptions, the probabilities of the observed choices are given by:

$$Pr(L_1,\hat{L}_1) = P^{1\hat{1}}\rho^2 + P^{2\hat{1}}\rho(1-\rho) + P^{1\hat{2}}\rho(1-\rho) + P^{2\hat{2}}(1-\rho)^2$$

$$Pr(L_1,\hat{L}_2) = P^{1\hat{2}}\rho^2 + P^{1\hat{1}}\rho(1-\rho) + P^{2\hat{2}}\rho(1-\rho) + P^{2\hat{1}}(1-\rho)^2$$

$$Pr(L_2,\hat{L}_2) = P^{2\hat{2}}\rho^2 + P^{2\hat{1}}\rho(1-\rho) + P^{1\hat{2}}\rho(1-\rho) + P^{1\hat{1}}(1-\rho)^2$$

$$Pr(L_2,\hat{L}_1) = P^{2\hat{1}}\rho^2 + P^{2\hat{2}}\rho(1-\rho) + P^{1\hat{1}}\rho(1-\rho) + P^{1\hat{2}}(1-\rho)^2$$

The events in the first and third equations represent choices which are consistent with EU; the second and the last represent violations. The above statistical model sets the basis for statistical tests of the various violation hypotheses.

8. Statistical analysis with no choice errors

In this section it is assumed that errors in the data are only due to sampling error. Under this assumption $\rho = 0$, namely, in answering the questionnaire individuals reveal their true preferences. In this case, a generalization to the population level is achieved by the usual statistical procedure for proportion interval estimation based on the sample statistics.

8.1. Confidence interval

Let $P^V = P^{1\hat{2}} + P^{2\hat{1}}$ denote the share of EU violators in the population. A confidence interval for P^V is given by

$$\bar{x} \pm z_\alpha/2[\bar{x}(1-\bar{x})]^{1/2}N^{-1/2}$$

where $\bar{x}$ is the sample rate of violation and $Z_{\alpha/2}$ is the number with an area of $\alpha/2$ to its right under the standard normal curve.

In our case we get

$$Pr[P^V \in 0.26 \pm 0.064] = 0.95$$

i.e. there is a 95% probability that the interval [0.196, 0.324] covers the population violation rate. Therefore, assuming only sampling errors, our results suggest that although the proportion of violations among Israeli farmers is small, it significantly differs from zero. The vast majority of the farmers seem to rank risky prospects according to the EU criterion, while a significant minority violate the EU hypothesis. It is, therefore, interesting to search for those SECs that differentiate these two groups of farmers and to examine the qualitative effect of each SEC on the tendency for violation. This analysis is conducted in the next two subsections.

8.2. Explaining the violations: a probit analysis

In this subsection we continue to consider the case of no measurement error and turn to a regression analysis, in an attempt to explain the tendency

Table 5
The effects of socioeconomic factors on EU violation

Variable	Regression coefficient	Elasticity of $E(y)$
Acreage	−0.005 **	29
Water quota	0.006	0.19
Family size	0.883 *	6.45
Family-size-squared	−0.087 *	−4.00
Milk quota	0.00	0.31
Eggs quota	0.00	0.12
Green house (d)	1.065 **	0.47
Plantation (d)	0.823	0.14
Cattle (d)	0.598	−0.07
Other (d)	1.152 **	0.12
Schooling years	−0.675 *	−11.33
Schooling-years-squared	0.026 *	5.53
Operator's age	−0.044 *	−2.68
Part-time farming (d)	−0.398	−0.16
Full-time farming (d)	−0.120	−0.11
Village average farm value	−0.002	0.48
Agency settlement (d)	−0.010	−0.00
New settlement (d)	−0.125	−0.04
Type of violation (d)	1.20 *	2.12
Constant	1.05	1.46

* Significant at the 5% level.
** Significant at the 10% level.
(d) Dummy variable.
Chow R-square $R^2 = 0.26$.
Percentage of right predictions = 79%.

for violation by means of socioeconomic variables. Our dependent variable is a dummy variable which equals either 0 if the farmer's choices agree with EU or 1 if they do not. Accordingly we used a probit procedure to analyze the data. Several models were tried and the best model on the ground of explanatory power was selected.

The results are reported in Table 5 and show that a fairly significant share of the variations among the farmers' decision criteria are explained by SECs ($R^2 = 0.26$). [4] Closer review of the regression coefficients and their corresponding statistical significance leads to several interesting findings.

First, it is notable that at the 5% level no significant effects of the farm's main crop or type of settlement are found. Thus, we fail to reject the hypothesis that characteristics of the farm have no effect on the operator's decision criterion under risk. Second, the coefficients of farm size (acreage), water quota and the average value of a farm in the village are all insignificant (at the 5% level). These variables can be thought of as fairly reasonable proxies of the farmer's level of wealth. Thus, we may conclude that neither the farm size nor other measures of the farm wealth explain why some farmers exhibit violation of EU, while others do not.

Third, as oppose to the farm characteristics, most of the operator's characteristics seem to affect the decision criterion under risk. Three major characteristics are found to be related to the violation tendency: education (measured by years of schooling); operator's age; the size of the operator's family. Education enters into the explanatory equation as a second-degree polynomial. The t ratios for both education and its square are larger than 2, indicating that each of these variables is significant at the 5% level. However, since there is a very high correlation between education and its square (the partial correlation coefficient equals 0.85) we also performed an asymptotic Wald test for the simultaneous hypothesis that both are zero. This hypothesis was rejected at 5% as well.

As one may expect, the coefficient on the education variable is negative, meaning that the tendency for violation of EU decreases with education. It should be noted, however, that since education-square has a positive coefficient, it means that the 'marginal productivity' of education in reducing violation is decreasing. The sign of the derivative of the tendency for violation with respect to education is determined by the partial derivatives of the sum of education and education-square. This derivative equals $-0.675 + 0.052 \cdot \text{education}$. Thus, for any education level less than or equal to 13 school years, education reduces the tendency towards violation. Only at the very high levels (college and up), education increases the violation tendency. We do not have an explanation for this latter phenomenon, which may be the result of statistical error.

[4] Of course, if one does suspect a choice error, then the interpretation of the probit analysis may change. In such a case, information about both the effects of SECs on the violation tendency and that of making a choice error are embodied in the regression coefficients. The analysis is still useful for prediction of the proportion of EU maximizers in a certain population, based on observed SECs.

For families below the average size, an increase in the number of children (i.e. in family size) leads to a behavior that is less consistent with EU. However, the marginal contribution of this effect is decreasing and for families above the average size (three children), an increase in number of children leads to behavior which is more consistent with EU. Finally, the lottery-type dummy variable is significant. This dummy receives the value of 1 whenever the farmer's choice among the first pair of lotteries is L_1. Since the choice of L_1 represents higher risk aversion, the regression model controlling for many factors other than the type of violation reveals that the less risk-averse farmers have a higher tendency to violate the EU hypothesis.

While more work (probably interdisciplinary studies) is necessary to understand the mechanisms behind these effects, these findings are important. When considering policies aimed at assisting farmers to cope with risk, it is important to know whether the particular group of farmers are EU maximizers or not. In the latter case, one ought to employ one of the many decision models comprising alternatives to EU.

The above findings suggest that SECs may be useful for predicting whether certain groups of farmers are EU maximizers. The application of this latter idea is the subject of the next subsection.

8.3. SEC-based differentiation: a discriminate analysis

Consider individuals who are in the business of advising farmers regarding management strategies for their farms. Moreover think about policy designers, especially of risk-related policies, such as price stabilization and subsidized crop insurance programs. For such individuals it would be useful to possess a 'measurement device' which could indicate whether an observed individual farmer is an EU maximizer or not. Obviously, one can always directly test, for maximization of EU, each farmer who belongs to the target population. However, this is a costly procedure and more efficient ones, which are statistically based, exist.

One such procedure, which is based on a discrimination analysis, is proposed and illustrated in this subsection. We continue to consider the case of no choice error and apply a discriminate analysis via the SAS subroutine Proc-Discrim. This enables us to differentiate between two farmers' groups, EU maximizers and EU violators, by means of SECs.

SAS, Proc-Discrim is endowed with a procedure that incorporates the researcher's prior beliefs about the proportions of the various groups in the population into the analysis. We utilize the proportions reported by Conlisk: 68% non-violators and 32% violators. Conlisk examined several variations of the Allais example. In one of these experiments he eliminated the so-called certainty effect. This effect means that individuals prefer L_1 over L_2 only because L_1 represents perfect certainty. If one changes L_1 very slightly, such that no prize is given with a probability 1, then the choices of many individuals are shifted away from L_1 and towards L_2. In our experiment, the prizes were much smaller than the prizes in the original Allais example. This change is expected to remove much of the certainty effect. We therefore think that the priors based on these particular results of Conlisk are most reasonable to use.

The coefficients of the discriminate function are reported in Table 6. The overall significance level of the discrimination is 4%. Turning to the perfor-

Table 6
The discriminant function coefficients

Variable	0	1
Acreage	−0.0010	−0.0012
Water quota	0.3262	0.3197
Family size	16.4111	17.3735
Family-size-squared	−1.2701	−1.3800
Milk quota	0.0000	0.0000
Egg quota	−0.0000	−0.0000
Green house (d)	−11.5596	−9.9287
Plantation (d)	3.4126	11.1053
Cattle (d)	10.6186	11.1052
Schooling years	46.1095	45.2223
Schooling-years-squared	−1.7667	−1.7354
Operator's age	1.4781	1.3823
Part-time farming (d)	26.8081	26.4673
Full-time farming (d)	25.5096	25.2580
Village average farm value	−0.0139	−0.0119
Agency settlement (d)	20.7808	20.3428
New settlement (d)	7.7022	7.2682
Constant	−239.2703	−231.8542

(d) Dummy variable.
Percentage of right predictions 79%.

mances of the 'measurement device', we find that the discriminate function indicates that 87% of the farmers are non-violators, while 13% are violators. The proportions of the predicted violators are significantly smaller than the sample results. Indeed, it is found that 94% of the non-violators were classified as such, but only 65% of the violators are classified as violators. Thus, the discriminate procedure is found to be a conservative device which is not powerful enough to reject the EU hypothesis. This subject requires additional research.

9. Introduction of choice errors

Up to this point our results are based on the assumption of no choice error. However, questionnaire-based information is known to suffer from measurement errors (e.g. Smith et al., 1986 and references therein). This section analyzes this issue.

9.1. Testing for pattern II

Testing for EU violations in the presence of choice errors requires an alternative procedure. Such a procedure, which takes into account the sampling errors as before, and in addition the choice errors, was proposed by Conlisk and is based on the following idea: if the proportion of farmers who are truly violators of EU is very small, then the observed violations are due only to choice errors. In this case, the sample proportions of the two types of violations, $(L_1, \hat{L}_2)$ and $(\hat{L}_2, \hat{L}_1)$, should be similar. Thus, if the observed proportion of one type of violation is significantly larger than the other, then it is highly probable that the violations are systematic, rather than the result of choice errors.

The most commonly observed violations of EU are of the type $(L_1, \hat{L}_2)$, which are known in the literature as pattern-II violations (e.g. Conlisk). Thus, a priori, one expects to observe a larger proportion of violations of the type $(L_1, \hat{L}_2)$. Accordingly, Conlisk interpreted his procedure as testing the EU criterion against the 'one-sided' hypothesis of pattern-II violations.

Recall that our results, reported in Tables 2 and 3, suggest that the sample share of violations of the type L_1, $\hat{L}_2$ is smaller that of the type L_2, $\hat{L}_1$. Thus, no formal test is required to conclude that in the current case one cannot reject the EU hypothesis in favor of the pattern-II hypothesis. But, what about testing the EU hypothesis against the pattern-I hypothesis L_2, $\hat{L}_1$, or the 'two-sided' hypothesis of violations of any type?

In the sequel we follow Conlisk's procedure for testing the EU hypothesis against pattern-I and 'two-sided' alternatives. That is, we examine: (1) whether the proportion of farmers exhibiting pattern I is significantly larger than the proportion of those exhibiting type-II violations; (2) whether the proportion of farmers exhibiting violations of any type differs significantly from zero.

Let the random variable x_i, $i \in \{1, ..., N\}$, be defined through:

$$x_i = \begin{cases} 1, \text{ if the } i\text{th farmer chose } \left(L_2, \hat{L}_1\right) \\ -1, \text{ if the } i\text{th farmer chose } \left(L_1 \hat{L}_2\right) \\ 0, \text{ if the } i\text{th farmer does not violate EU} \end{cases}$$

One can use the probabilities of the observed choice, reported above, to calculate the probability distribution of x_i, under the various hypotheses regarding the distribution of the true preferences among the farmers population. Under the null hypothesis of no systematic violations, $p^{1\hat{2}} = p^{2\hat{1}} = 0$ and the distribution of x_i is as shown in Table 7.

Thus, under the null hypothesis, x_i is distributed according to a multinomial rule with expected value 0. Denoting, the sample standard deviation by s, the asymptotic distribution of the statistic

$$T^1 = \frac{\bar{x}N^{1/2}}{s}$$

is $N(0, 1)$. Thus, large (small) values of T^1 (as compared with the standard normal distribution) are evidence against (for) the EU hypothesis and in favor of (against) non-random violations of the type $(L2, \hat{L}_1)$.

Table 7
Distribution of x_i under the null hypothesis

Value	1	−1	0	Total
Probability	$\rho(1-\rho)$	$\rho(1-\rho)$	$1-2\rho(1-\rho)$	1

Conlisk shows that T^1 can be rewritten as

$$T^1 = (N-1)^{1/2}(S-0.5) \times \left[0.25V^{-1} - (S-0.5)\right]^{-1/2}$$

where S is the proportion of type $(L_2, \hat{L}_1)$ violations out of the total number of violations and V is the proportion of total number of violations in the population. Substituting the results of our sample,

$$T^1 = (179)^{1/2}(0.57-0.5) \times \left[0.250 \cdot 0.256^{-1} - (0.57-0.5)\right]^{-1/2} = 0.892$$

The above calculation implies a 'P-value' of 18.67% for the one-sided alternative of systematic violations of the type $(L_2, \hat{L}_1)$. Therefore, contrary to the results of the 'sampling-error-only' test, taking into account choice errors and utilizing Conlisk's test, it is suggested that the EU hypothesis cannot be rejected against either the one-sided alternative or the two-sided alternative. The conclusion of this test is that farmers exhibit no systematic violations of EU.

Are the results of the above test satisfactory? To answer this question, one needs to examine the issue of the test power more carefully. That is, we should investigate whether the above test is powerful enough to test the EU hypothesis against various alternatives. It is not hard to see that Conlisk's test suffers from a major weakness. Suppose that the population consists of only EU violators. The mean of T^1 is then given by $(p^{1\hat{2}} - p^{2\hat{1}})(1-2\rho)$. Thus if the proportions of the two types of violators in the population are similar, then its power is low. In fact, if the population is evenly divided between the two types of violators, the power of Conlisk's test reduces to 'α', the probability of type-1 error. This brings us to suggest an alternative test procedure.

9.2. The tradeoff between type-1 and choice errors

As was explained in the above sections, choices of both type $(\hat{L}_1, \hat{L}_2)$ and $(L_2, \hat{L}_1)$ represent violations. Accordingly, in the sequel we suggest a procedure for testing the hypothesis of no violations of EU versus violation of any type. That is, we examine whether the proportion of the farmers that violate EU differs significantly from zero, when taking into account the possibility of choice errors.

Table 8
Distribution of x_i under the null hypothesis

Value	1	0	Total
Probability	$2\rho(1-\rho)$	$1-2\rho(1-\rho)$	1

A natural test statistic for the above test is the average of the random variables, x_i, $i \in \{1, ..., N\}$, each defined through:

$$x_i = \begin{cases} 1, & \text{if the } i\text{th farmer violates EU} \\ 0, & \text{if the } i\text{th farmer does not violate EU} \end{cases}$$

Recalling the above probabilities of the observed choices, it follows that under the null hypothesis of no systematic violations the distribution of x_i is as shown in Table 8.

Thus, under the null hypothesis, x_i is distributed according to a binomial rule with expected value $\epsilon = 2\rho(1-\rho)$. Denoting, the sample standard deviation by s, the asymptotic distribution of the statistic

$$T^2 = \frac{(\bar{x} - \epsilon)N^{1/2}}{s}$$

is $N(0, 1)$. Thus, large values of T^2 (as compared with the standard normal distribution) are evidence against the EU hypothesis and in favor of non-random violations from the type $(L_1, \hat{L}_2)$ $(L_2, \hat{L}_1)t$.

Although this test does not suffer from the problem of low power for an evenly distributed population, it poses a new problem, namely, that information is needed about the value of ρ, which is not directly observable in the Allais experiment. To overcome this problem we propose a three-stage procedure. First, just as one reports a P-value in usual statistical tests, we report a whole frontier in the (α, ρ) space (where α is a desired significance level), which describes the border of EU rejection. In the second stage, we compare the farmers' answers to the questionnaire and their choice of PWD to calculate an estimated lower bound to ρ. We then combine the two to calculate a lower bound to our test P-value. Below, the three-stage procedure is elaborated.

Fig. 1 describes the border between the rejection and acceptances areas of the EU hypothesis. The

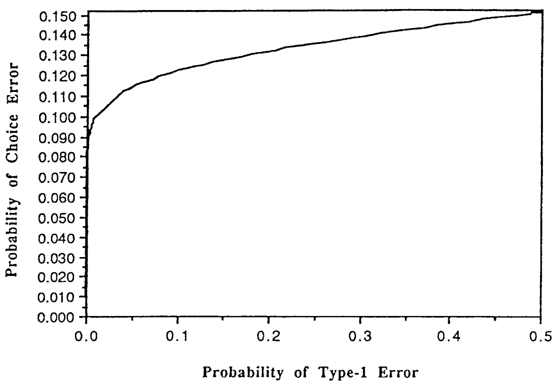

Fig. 1. EU rejection frontier.

horizontal axis measures the size of the probability for type-1 error. The vertical one indicates the size of the probability for a choice error. The area below the frontier defines the rejection area of EU, while any point above the frontier indicates acceptances of EU.

Fig. 1 demonstrates that there is a tradeoff between the significance level of the test and the probability for a choice error in terms of their effects on the rejection of the EU hypothesis. The smaller the probability for a choice error, the larger the significance level under which the EU hypothesis is rejected. The figure shows that at very low levels of probability for a choice error, the EU hypothesis is rejected with almost no risk of type-1 error. Moreover, as long as the probability of a choice error is less than 11.5%, the EU hypothesis is rejected with a significance level of no less than 95%. However, as the probability for a choice error becomes larger, the significance level that implies rejection falls dramatically. For example at a probability for a choice error of 12.3%, the significance level decreases to 90%. The decision of whether to accept or reject the EU hypothesis depends on one's beliefs of how likely people are to make errors when answering the questionnaire.

9.3. Inferring the probability for a choice error

In this subsection we use additional information about farmers' risk attitudes to infer a lower bound for the probability of a choice error in the farmers' population. As mentioned above, in addition to the Allais example, farmers were asked to choose a PWD for several binomial lotteries. The stories behind the lotteries that were used to elicit the PWD are identical to those that were used to present the Allais lotteries. For example, in livestock farms in both cases the lottery had to do with adoption of a new genetic treatment to increase the female proportion among new-born calves. Moreover, in one of lotteries that was presented to elicit the PWD, the prize levels were of the same order of magnitude as in the Allais example, \$10k.

Therefore, one would think that farmers should exhibit similar risk attitudes in both cases. Moreover, it is reasonable to conclude that a farmer who exhibits risk aversion in the one case, while risk seeking in the other, made a choice error in one of these cases. To be on the safe side and not to overestimate the probability of a choice error, we were conservative and counted a farmer as making a choice error only in extreme cases. A farmer, who asks for PWD at a level of 50% or less, reveals himself as indifferent to risk or even as a risk seeker. Such a farmer is expected to prefer L_2 over L_1, since the opposite choice unambiguously indicates risk aversion. On the other hand, a farmer who asks for PWD at a level higher than 95% is clearly extremely risk averse and he is expected to choose the non-risky alternative L_1. When the observed behavior was inconsistent with these requirements it was interpreted as a choice error. Table 9 presents the results.

Examining Tables 3 and 9, it appears that almost 37% (17 out of 46), of those farmers who exhibit violations of EU, also exhibit an inconsistent behavior. Only 13% (18 out of 134) of the farmers with choices which are consistent with EU exhibit inconsistent behavior. The overall percentage of farmers whose behavior is inconsistent is 19.5%. These findings are consistent with the results of Bushina and Zilberman (1993) who report that 20% of experiment participants chose one lottery over another in the beginning of the experiment, only to switch their choices at the end. The sample proportion, 19.5%,

Table 9
Occurrences of choice errors

Group	EU violators	Non-violators	Total
No. of choice error	17	18	35

makes an unbiased estimate for the probability of a choice error in the population. Since we identify as choice-error-cases only the real extreme ones, we interpret the value 19.5% as a lower bound for the real probability of a choice error.

As said above, the last stage in our proposed procedure is to check the implication of the estimated probability of a choice error of the test significance level. Using Fig. 1, one can see that $\rho = 19.5\%$ implies $\alpha > 0.5$ and failure to reject the EU hypothesis. We therefore conclude that it is highly probable that the observed violations of the EU hypothesis in our sample are due to choice errors and are not systematic.

10. Conclusions

The framework developed in this paper enables a statistical testing of the EU hypothesis and examination of the role of SECs in determining the choice criterion of farmers under risk. In addition to the usual sampling error our approach accommodates choice errors among the examined population. Our findings suggest that the observed violations of the EU hypothesis among Israeli family farm operators are mainly due to choice errors, rather than systematic violation of the EU hypothesis. That is, we provide additional evidence in support of employment of the EU model for analysis of farm-related policies.

Nevertheless, in cases where violations are statistically significant, the proposed probit and discrimination methodologies can be employed to predict the proportion of EU maximizers in a certain population of farmers, based on observed socioeconomic variables. Thus, the paper delineates a clear avenue for further research: the development of a 'measurement device', such as the discrimination function, which would be powerful enough to differentiate between EU maximizers and EU violators. In the latter case, one should adopt one of the many theories comprising alternatives to EU (e.g. Kahneman and Tversky, 1979; Machina, 1989; Finkelshtain and Hewitt, 1989) to conduct analysis of risk-related policies.

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