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Decision-making under uncertainty – A field study of cumulative prospect theory ☆

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ABSTRACT

The presented research tests cumulative prospect theory (CPT, [Kahneman, D., Tversky, A., 1979. Prospect theory: An analysis of decision under risk. Econometrica 47, 263–291; Tversky, A., Kahneman, D., 1981. The framing of decisions and the psychology of choice. Science 211, 453–480]) in the financial market, using US stock option data. Option prices possess information about actual investors' preferences in such a way that an exploitation of conventional option analysis, along with theoretical relationships, makes it possible to elicit investor preferences. The option data in this study serve for estimating the two essential elements of the CPT, namely, the value function and the probability weighting function. The main part of the work focuses on the functions' simultaneous estimation under CPT original parametric specification. The shape of the estimated functions is found to be in line with theory. Comparing to results of laboratory experiments, the estimated functions are closer to linearity and loss aversion is less pronounced.
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1. Introduction

The solution of various problems in economics, as well as in other social sciences, requires understanding of agents' behavior under risk and uncertainty. Expected utility theory (EUT) served for this purpose for a long time as a normative model of rational choice. However, actual choices often exhibit systematic deviations from this widely accepted theory, as has been reported by a range of studies.[1] To resolve this discrepancy, an alternative model, cumulative prospect theory (CPT), was developed by Kahneman and Tversky (1979) and Tversky and Kahneman (1992). The purpose of this descriptive model is to explain agents' behavior in uncertain environments, which remained unexplained by EUT.[2]

Laboratory experiments and field studies are two possible ways to check the explanatory power of CPT. The laboratory provides the experimenter with a controlled environment for measuring agents' utility and event probabilities, the two essential elements at issue. Laboratory results, however, may have limited applicability to real life situations, being based either on decisions regarding imaginary choices, or on small-scale artificial gambling situations. The problem was clearly pointed out by Kahneman and Tversky in their pioneering paper on prospect theory (Kahneman and Tversky, 1979, p. 265): "The reliance on hypothetical choices raises obvious questions regarding the validity of the method and the generalizability of the results... Laboratory experiments have been designed to obtain precise measures of utility and probability from actual choices, but these experimental studies typically involve contrived gambles for small stakes, and a large number of repetitions of very similar problems. These features of laboratory gambling complicate the interpretation of the results and restrict their generality". So, while accumulated laboratory results generally support CPT (cf. Edwards, 1996), the question of the model's validity out of the lab remains open. The purpose of the present research is to fill this gap by conducting a field study of the theory.

CPT may be viewed as a modification of EUT which keeps the model's bilinear form. One modification regards the weights assigned to the possible outcomes. CPT replaces the expectation principle with a more general rule, according to which the utility of each possible outcome is multiplied by a corresponding decision weight obtained by a specific probability weighting function (PWF), which represents a non-linear transformation of the physical probabilities. The PWF has the following characteristic features: it is regressive, i.e., it overweights low probabilities and underweights high probabilities; it is inverse-S-shaped, exhibiting

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[1] The question of investor behavior and its market-wide implications has long been and remains a source of much controversy; for a recent example, see Deng (2006).

[2] Assessing investors' behavioral features currently comprises an area of intensive research; e.g., Venezia and Shapira (2007) analyze widely observed "weekend effect" and its extent among professional and amateur investors.

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diminishing marginal sensitivity when moving away from the boundary probability levels of 0 and 1; and it is asymmetric, having a fixed point at a probability level of about 1/3. The theory allows for different PWFs for gains and losses with the above-mentioned basic properties.

Another modification is the definition of the utility function on wealth changes, rather than on wealth levels. According to CPT, the value (utility) function has a reference point, representing a status quo point such as a current wealth level. Outcomes are recorded as either losses or gains relatively to the reference point, and serve as arguments for the value function (VF), an S-shaped curve, exhibiting diminishing marginal sensitivity when moving away from the reference point, and manifesting "loss aversion", by having a higher slope for losses than for gains. The VF and the PWFs rely on a range of empirical examinations of agents' behavior in uncertain environments (see, e.g., Tversky and Kahneman 1992; Camerer and Ho, 1994; Wu and Gonzalez, 1996; Bleichrodt and Pinto 2000). For instance, the two functions described above yield a fourfold pattern of risk attitudes: risk seeking for gains and risk aversion for losses of low probabilities, and risk aversion for gains and risk seeking for losses of high probabilities.[3]

The presented research tests CPT in the financial market, using US stock option data. Option data enable us to access implicit investor preferences by applying established theoretical relationships to the observed market prices. Similarly to other studies using option prices to shed light on investors' preferences, we extract aggregate functions.[4] The options data in current study serve for estimating the two essential elements of the CPT, namely, the VF and the PWF. The technique employed here was also used in Kliger and Levy(2007, forthcoming) in S&P500-based tests of CPT which yielded results qualitatively close to those achieved in the current work; moreover, a technique similar to the one described below was applied by Kliger and Levy (2002) in S&P500-based elicitation of investors' risk aversion functions.[5] A number of related studies, such as those above-mentioned, were performed using index options. Our work sheds light on investors' behavior using options written on individual stocks, rather than on the index. Our analysis requires the elicitation of risk-neutral and physical probabilities. In the next Section, the former are derived using option prices, and the latter are reconstructed from historical return data. The main part of the work focuses on the VF and the PWF simultaneous estimation under the original parametric specifications. The obtained results are then analyzed. Qualitatively, the results support the central principles of the model: the shapes and the properties of the estimated functions are in line with the theory. Quantitatively, the estimated functions are both more linear in comparison to those acquired in laboratory experiments and the utility function exhibits less loss aversion than was obtained in the laboratory. Overall, the empirical results suggest confirmative evidence for the effects predicted by CPT, while the strength of the effects may be lower than that reported by lab experiments.

The rest of the paper is organized as follows: Section 2 introduces theoretical relations that are used to test CPT and describes our method for arriving at estimation equations, Section 3 presents the raw data and the method for extracting the information required for model estimation, Section 4 presents the results obtained by the empirical testing of the CPT, and Section 5 concludes.

2. A field study of CPT – Method and application

In this section we introduce theoretical relations required to test the CPT and describe our method for arriving at estimation equations.[6] In addition, we present an econometric procedure for estimation of parameters that cannot be directly observed and measured.

2.1. A theoretical relation between marginal utilities and stochastic discount factors

The subjective stochastic discount factor (SDF) between times t and $t+\tau$ is defined (see, e.g., Ait-Sahalia and Lo, 2000; also cf. Rubinstein, 1976) as follows:

$$M_{t,t+\tau} \equiv U'(W_{t+\tau})/U'(W_t), \quad (1)$$

where W_t is the wealth level at time t and $U'(W_t)$ is the marginal utility. According to this definition, the SDF is the marginal rate of substitution of time t and $t+\tau$ utility.

According to one of the results achieved by Ait-Sahalia and Lo (2000), the marginal utilities are cross-sectionally proportional to the SDFs, i.e.:

$$U'_{t+\tau,s} = A_t M_{t+\tau,s}, \quad s = 1,\ldots,S, \quad (2)$$

where $U'_{t+\tau,s}$ is the marginal utility at time $t+\tau$ under state of nature s, $A_t > 0$ is a state-independent constant and S is the total number of possible states of nature.

2.2. A relation between state prices and marginal utilities

The state price, $Q_{t,s}$, is defined as the price of a contract that guaranties its owner one \$US if state s occurs and nothing otherwise. The subjective SDF of state s can be represented (see Kliger and Levy, 2002) as a ratio of the state s price and the decision weight (DW) assigned by the subject to that state:

$$M_{t+\tau,s} = Q_{t,s}/DW(s;p_t), \quad s = 1,\ldots,S, \quad (3)$$

where $DW(s;p_t)$ is the subjective decision weight of state s and p_t is the physical probability distribution function (i.e., $p_t \equiv (p_{t;1}, \ldots, p_{t;S})$, where $p_{t,s}$ is the physical probability of state s).[7]

Substituting $M_{t+\tau,s}$ from (3) into (2), the following relation between state prices and marginal utilities is established:

$$U'_{t+\tau,s} = A_t Q_{t,s}/DW(s;p_t), \quad s = 1,\ldots,S. \quad (4)$$

2.3. A relation between option prices and state prices

We employ the option-pricing model developed by Cox and Ross (1976). According to their risk-neutrality argument, the call option price is determined as follows:

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[3] An extensive psychological foundation explaining the characteristic features of the utility function and the PWFs may be found in Tversky and Kahneman (1981).

[4] The empirical analysis in Jackwerth (2000), for instance, employs a model of the economy implying the existence of a representative investor Constantinides (1982) to derive risk aversion functions across wealth. Note that in a reference dependent model, such as CPT, the wealth distribution problem raised by Constantinides is of less concern.

[5] However, in contrast with Kliger and Levy (2002, 2007, forthcoming), our paper implicitly tests the relevance of the narrow framing assumption at the firm level, an assumption consistent with results obtained by, e.g., Abbink and Rockenbach (2006) and Kroll et al. (1988). The former study compared performance of students and professional traders in an option pricing experiment and found, inter alia, that investors overlook arbitrage considerations; the latter study experimentally tested basic assumptions underlying the capital asset pricing model and found that investors disregard return covariances. Both results corroborate the narrow framing assumption by showing that investors actually focus on individual assets' performance in forming their decisions.

[6] Leland (1980) presents a closely related model linking physical and risk-neutral probabilities. However, as the present work considers a more general case, for instance requiring conversion of probabilities into decision weights, the derivation of the appropriate model is outlined below.

[7] Recall that in CPT framework the decision weights are determined by the PWF, while according to EUT they are equal to the physical probabilities of the relevant states of nature.

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