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TWO-MOMENTS-DECISION MODELS AND UTILITY-REPRESENTABLE PREFERENCES

by
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Rehovot, Israel, P.O.B. 12

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If a decision problem satisfies Meyer's location-scale condition, then any utility-representable preferences are also representable by a mean standard deviation utility function. The properties of this function are inferred from common assumptions concerning the individual's risk preferences, without relying on the expected utility model or any of its substitutes.

Introduction

Beginning with James Tobin's (1958) pioneering work, several studies have investigated the conditions under which expected utility (EU) and mean standard deviation (MS) utility yield consistent ranking. Hans-Werner Sinn (1989) and, later, Jack Meyer (1987) provided new important insights into this question, by suggesting the location-scale (LS) condition. Unlike previous characterizations, the LS condition does not imply restrictions on either the class of utility functions or the risks under consideration. Rather, it hinges on the structure of the decision problem, requiring the payoff to be a linear function of a single risk source. Meyer showed that many economic decision problems under uncertainty, including the liquidity preferences model, fulfill this requirement.[1] Indeed, over the last few years this result has been applied to study a variety of decision problems under risk (*e.g.* Meyer and Lindon Robison (1988), Howard Leathers and John Quiggin (1991)). Recently, Michael Ormiston and Quiggin (1993) extended Meyer's work to the case of rank-dependent EU (RDEU).

Studies thus far have investigated the compatibility of the MS criterion with alternative criteria such as EU or RDEU. In light of the accumulating evidence against the EU theory and the lack of consensus concerning a particular substitute, this note proposes an alternative line of investigation. The essence of the proposed approach is to identify circumstances under which the risk preferences of any rational decision-maker are representable by a MS utility function (MS-representable). To accomplish this, the Sinn-Meyer argument is taken a step further, by showing that the LS condition creates such circumstances. Namely, any preference relation which is utility-representable (U-representable)[2] over some choice set, is MS-representable over any sub-choice set that satisfies the LS condition. Moreover, the properties of this MS utility function are easily inferred from a set of

[1] Of course not all ecnomic decision models result in a location scale family, the most familar example is the portfolio choice problem.

[2] A preference relation is U-representable over some choice set if there exists a utility functional which ranks the elements in the choice set at the same order as the preference relation.

intuitive and commonly assumed axioms concerning preferences over a set of cumulative distribution functions (CDFs).

Definitions and Notations

A choice set consisting of an arbitrary collection of CDFs is denoted $\mathcal{F}$. A particular member of $\mathcal{F}$ is denoted F, where $F\colon \mathcal{R} \to [0,1]$, with subscripts denoting the CDF of a particular random variable. The discussion below focuses on a subset of the above choice set, $\mathcal{D} \subset \mathcal{F}$, that satisfies the LS condition. That is:

$$\mathcal{D} = \{F_x \in \mathcal{F} \mid x = \mu_x + \sigma_x \epsilon,\ \epsilon \sim_d (0,1),\ \mu_x \in \mathcal{R},\ \sigma_x \in \mathcal{R}_+\},$$

where $\epsilon \sim_d (0,1)$ indicates that the first and second moments of ϵ equal 0 and 1, respectively.

An immediate question is whether the choice sets corresponding to real-life decision problems satisfy the LS condition. Sinn and Meyer provided affirmative answers by noting that in many economic decision problems the economic agent's payoff function $Q\colon \mathcal{R}_M \times \mathcal{R} \to \mathcal{R}$ takes the form

$$x = Q(z,\epsilon) \equiv \mu_x(z) + \sigma_x(z)\epsilon,$$

where $\epsilon \sim_d (0,1)$, $\mu_x\colon \mathcal{R}_M \to \mathcal{R}$ and $\sigma_x\colon \mathcal{R}_M \to \mathcal{R}_+$, and $z \in \mathcal{R}_M$ is a choice vector. In short, the payoff is an upward-sloping linear function of a random variable, where both the slope and the intercept are functions of the vector z. In such decision problems, the distribution of the random variable and all possible choices of the control vector z induce a choice set that consists of a LS family. This is true regardless of the particular distribution of the random variable, ϵ. Thus, the LS condition is ensured by the nature of the economic model rather than by restriction on distribution of the randomness source. It is also worth noting that the above payoff function includes models in which there is more than one source of risk if all random variables are comonotonic. This generalization was first pointed out by Ormiston and Quiggin for the case of RDEU.

Continuing with our list of notations, two stochastic order relations will be useful below. F_i represents a "greater payoff" than F_j, in a stochastic sense, if F_i first-order stochastically dominates F_j (Josef Hadar and William Russell (1969)). The associated notation is $F_i \geq^1 F_j$. The definition of a riskier payoff follows Michael Rothscild and Joseph Stiglitz (1970): $F_i \geq^2 F_j$ indicates that F_i second-order stochastically dominates F_j and that both have the same mean.

The decision-maker is assumed to be endowed with a symmetric-complete-continuous binary preference relation over $\mathcal{F}$, denoted by $\succeq$. These assumptions assure that $\succeq$ is U-representable. The asymmetric counterpart of $\succeq$ is denoted by $\succ$, while $\sim$ denotes indifference. The preference relation $\succeq$ is said to be convex when the set $\{F_i \in \mathcal{F} | F_i \succeq F_j\}$ is a convex set $\forall F_j \in \mathcal{F}$.

A few more behavioral hypotheses with regard to $\succeq$, such as decreasing/increasing absolute risk aversion (DARA/IARA) and increasing/decreasing relative risk aversion (IRRA/DRRA), will be used. Following Menahem Yaari (1969), the preference relation $\succeq$ exhibits DARA if $F_{x+y} \succeq F_x \Rightarrow F_{w+x+y} \succ F_{w+x}$ $\forall w > 0$ and comonotone x and y whose CDFs $F_x, F_y \in \mathcal{F}$. Similarly, we say that $\succeq$ exhibits IRRA if $F_x \succeq F_{x+y} \Rightarrow F_{wx} \succ F_{w(x+y)}$ $\forall w > 1$ and comonotone x and y whose CDFs $F_x, F_y \in \mathcal{F}$. Finally, $\succeq^2$ exhibits greater risk aversion than $\succeq^1$ if $F_x \succeq^1 F_{x+y} \Rightarrow F_x \succ^2 F_{x+y}$ $\forall$ comonotone x and y whose CDFs $F_x, F_y \in \mathcal{F}$.

For the sake of ease of presentation, the indifference curves in the (μ, σ) plane are assumed to be differentiable.[3] The slope of an indifference curve at a point (μ, σ) is denoted by $S(\mu, \sigma)$.

The Main Result

Given a choice set that satisfies the LS condition, the representation theorem and the derived properties of the representing MS utility constitute a MS decision theory which is actually more general than the EU theory, yet tractable and intuitive. The increased

[3] This assumption is further discussed in the opening section of the appendix.

generality stems from the fact that the class of decision-makers whose risk preferences are representable by a MS utility function is broader than the corresponding class of individuals whose risk preferences are representable by an EU function. This is because the MS decision theory is capable of accommodating various nonlinearities in the probabilities, including the RDEU theory.

A Theorem: *Let $\succeq$ be a binary preference relation defined over a choice set $\mathcal{F}$. Then, if $\succeq$ is U-representable over $\mathcal{F}$, it is also MS-representable over $\mathcal{D}$ by a utility function, $V(\mu, \sigma)$, with the following properties:*

Property 1: $V(\mu, \sigma) \uparrow \mu$ *if* $\forall\ F_i$ *and* $F_j \in \mathcal{F},\ F_i \geq^1 F_j \Longrightarrow F_i \succ F_j$.

Property 2: $V(\mu, \sigma) \downarrow \sigma$ *if* $\forall\ F_i$ *and* $F_j \in \mathcal{F}\ F_i \geq^2 F_j \Longrightarrow F_i \succ F_j$.

Property 3: $V(\mu, \sigma)$ *is quasiconcave if* $\succeq$ *is convex.*

Property 4: $S(\mu, \sigma) > 0$ *if* $V(\mu, \sigma) \uparrow \mu \downarrow \sigma$.

Property 5: $S(\mu, \sigma) \downarrow (\uparrow)\ \mu \quad \forall \mu$ *and* $\sigma > 0$ *if* $V \uparrow \mu$ *and* $\succeq$ *displays DARA (IARA).*

Property 6: $S(\mu, \sigma) \uparrow (\downarrow)\ \sigma \quad \forall \mu$ *and* $\sigma > 0$ *if* $V \uparrow \mu$ *and* $\succeq$ *displays DARA (IARA).*

Property 7: $S(w\mu, w\sigma) \uparrow (\downarrow)\ w \quad \forall \mu,$ *and* $\sigma > 0$ *if* $V \uparrow \mu$ *and* $\succeq$ *displays DRRA (IRRA).*

Property 8: $S^2(\mu, \sigma) > S^1(\mu, \sigma) \quad \forall \mu$ *and* $\sigma > 0$ *if* $V \uparrow \mu$ *and* $\succeq^2$ *displays greater risk aversion than* $\succeq^1$.

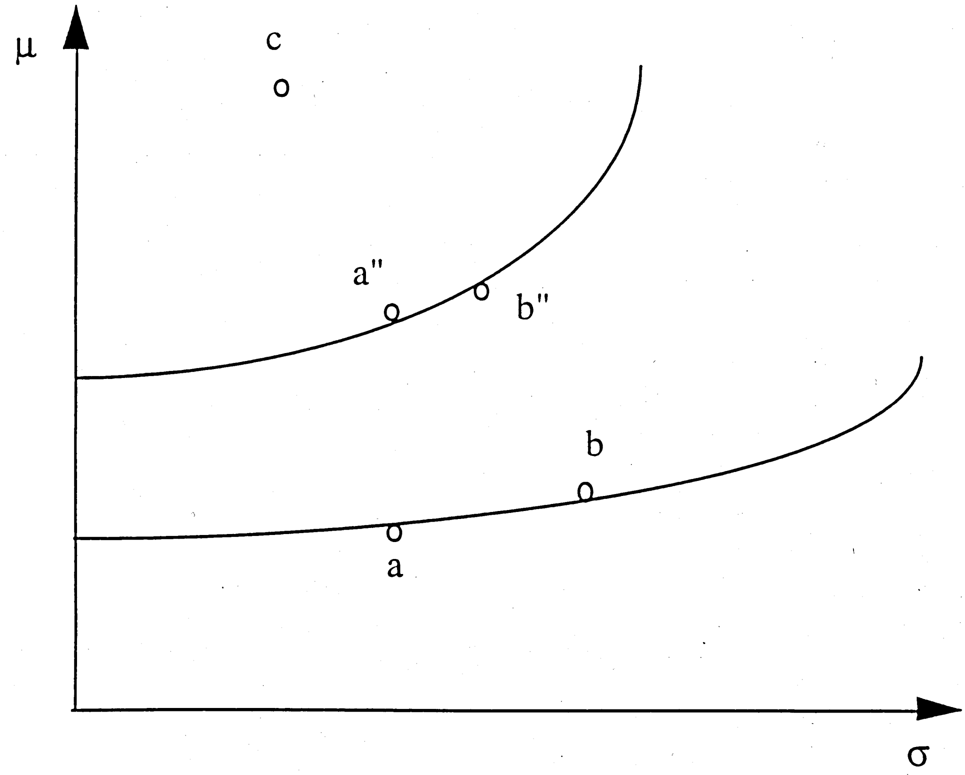
The theorem is proven in the appendix.

Discussion

The above properties of the MS utility function are similar, in their economic implications and graphical presentations, to the properties presented by Meyer, and Ormiston and Quiggin. However, the differences that do exist warrant a discussion.

The assumptions, employed in this note to infer the properties of V are, usually, weaker than the corresponding assumptions used by Meyer, and Ormiston and Quiggin. A significant difference is that our set of assumptions does not rely on a "representation axiom", such as the independence axiom or its substitutes. Indeed, a binary preference relation can be MS-representable, satisfy properties 1-8 and violate the independence axiom, simultaneously. This is illustrated in Figure 1. Although the decision-maker prefers prospect b to a, a lottery between a and c, a'', is preferred to the same lottery between b and c, b''.[4]

Figure 1: Violation of The Independence Axiom



Thus, Theorem 1 generalizes the results shown by Sinn, Meyer, and Ormiston and Quiggin. Furthermore, the assumptions used here to infer the properties of the MS utility function coincide with the assumptions used by those authors when a particular representation axiom is added. For example, nonsatiated preferences is the sufficient condition for monotonicity of V in μ in the current framework as well as in Meyer's study, even though in the current context nonsatiation is expressed by preferences for first-order stochastic dom-

[4] The prospect a'' is a lottery which gives the prospect a with probability p and the prospect c with probability $1-p$. It follows that $E(a'') = pE(a) + (1-p)E(c)$ and $V(a'') = pV(a) + (1-p)V(c) + p(1-p)(E(a) - E(c))^2$.

inance whereas in Meyer's analysis, it is expressed by positive marginal utility of income. However, preferences for first-order stochastic dominance and positive marginal utility are equivalent under the EU hypothesis.

Bypassing the need for a representation axiom allows one to show compatibility of the MS theory with general rational decision-making under uncertainty. In addition to overcoming the inability of the EU theory to rationalize paradoxical behaviors such as in the Alias paradox and the common ratio effect, some others deficiencies of the EU theory are eliminated. One example is the risk-aversion axiom that yields the monotonicity of V in σ. Proof of this property under the EU hypothesis requires an assumption of diminishing marginal utility of income. This assumption deals with the preference for bundles of commodities and there is no a priori reason why it should be required in the analysis of preferences for lotteries. As Yaari (1987) stated, risk-aversion means that "increased uncertainty hurts," whereas diminishing marginal utility tells us that "a loss of a sheep hurts more when the agent is poor than when the agent is rich." Our approach, similar to Yaari's dual approach, allows separation of these two properties.

It is worth noting that several of the properties of V could be inferred from even weaker assumptions concerning the binary preferences relation. For example, preferences for a smaller standard deviation would be sufficient for property 2. Our purpose was not, however, to find the weakest possible axiom that yields a certain property of the MS function. Rather, we attempted to show that basic, commonly assumed axioms concerning the decision-makers' risk preferences suffice for deriving properties of the MS function that facilitate tractable intuitive MS analysis.

Finally, it is interesting to note that property 6 establishes the implications of "horizontal movement" on the slope of the indifference curves, under the IARA and DARA assumptions. The result regarding IARA has not been shown previously and could be useful in comparative static exercises.

Appendix

Before we turn to the proofs, note that the assumption of differentiable indifference curves, as can be seen below, is non-redundant only for the proofs of properties 6 and 7. One could also avoid the differentiability assumption for properties 6 and 7, by including two more primitive axioms regarding $\succeq$. Assuming $F_x \succeq F_{x+y} \Rightarrow F_{x+\epsilon} \succ F_{x+y+\epsilon}$ $\forall$ comonotone x and y, and $F_x \succeq F_{x+y} \Rightarrow F_{wx} \succ F_{wx+y}$ $\forall w > 1$ and comonotone x and y, would eliminate the need for the differentiability assumption for proofing properties 6-7, respectively. Since these axioms do not have clear economic meanings and/or they are not commonly assumed, they were not employed in the analysis.

Proof of the Representation: Let the preference relation, $\succeq$, over $\mathcal{F}$ be U-representable, in the sense that $U(F_i) \geq U(F_j) \Longleftrightarrow F_i \succeq F_j$, $\forall F_i, F_j \in \mathcal{F}$. Since $\mathcal{D} \subseteq \mathcal{F}$, the latter holds also $\forall F_i, F_j \in \mathcal{D}$. But, $\forall F_i \in \mathcal{D}$

$$U(F_i) = U(P(x_i \leq x)) = U\left(P\left(\epsilon \leq \frac{x-\mu_i}{\sigma_i}\right)\right) = U\left(F\left(\frac{x-\mu_i}{\sigma_i}\right)\right) \equiv V(\mu_i, \sigma_i)$$

where $F(\cdot)$ denotes the CDF of ϵ. Thus, $\succeq$ is MS-representable over $\mathcal{D}$ in the sense that $V(\mu_i, \sigma_i) \geq V(\mu_j, \sigma_j) \Longleftrightarrow F_i \succeq F_j$, $\forall F_i, F_j \in \mathcal{D}$.

Proof of Properties 1-8:

Property 1: Let $\mu_i > \mu_j$ and $\sigma_i = \sigma_j$. Clearly, $F_i \geq^1 F_j$ which implies $F_i \succ F_j$. The latter, combined with the MS representation, establishes the property. ■

Property 2: Let $\mu_i = \mu_j$ and $\sigma_i < \sigma_j$. Clearly, $F_i \geq^2 F_j$ which implies $F_i \succ F_j$. The latter, combined with the representation, establishes the property. ■

Property 3: Given the MS-representation, convexity of $\succeq \Longleftrightarrow$ convexity of the upper counter set of $V \Longleftrightarrow$ quasiconcavity of $V(\mu, \sigma)$. ■

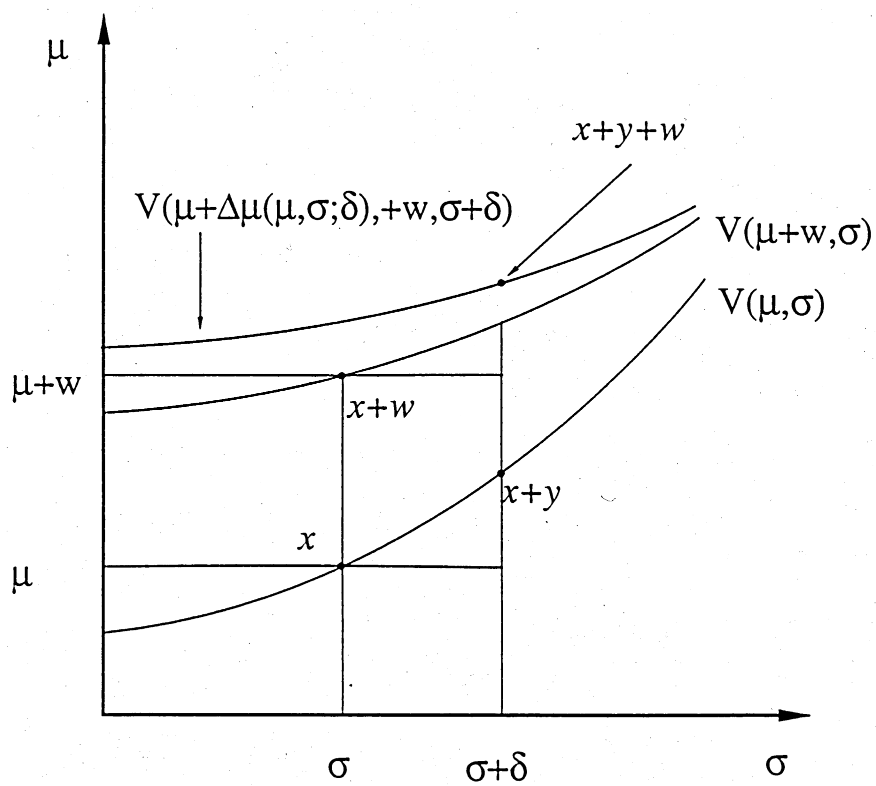
In the following proofs we will use the notation $\triangle\mu(\mu, \sigma; \delta)$ which is defined implicitly by $(\mu + \triangle\mu, \sigma + \delta) \in I(\mu, \sigma)$, where $I(\mu, \sigma)$ denotes the indifference set containing the point (μ, σ). Obviously, nonsatiation of $\succeq$ guarantees that $\triangle\mu$ is well-defined and uniqe, and $\triangle\mu(\mu, \sigma; \delta)/\delta \longrightarrow S(\mu, \sigma)$ as $\delta \longrightarrow 0^+$.

Property 4: We show that $\triangle\mu(\mu, \sigma; \delta) > 0$, given the MS representation $V(\mu, \sigma) = V(\mu + \triangle\mu(\mu, \sigma; \delta), \sigma + \delta)$. Thus, this property is a direct consequence of properties 1 and 2. ■

Property 5: We show that $\triangle\mu(\mu, \sigma; \delta) > \triangle\mu(\mu + w, \sigma; \delta)\ \forall w > 0$. Let $x = \mu + \sigma\epsilon$ and $y = \triangle\mu(\mu, \sigma; \delta) + \epsilon$ where $\epsilon \sim_d (0, 1)$. Since x and y are comonotone and since $F_{x+y} \sim F_x$, DARA implies $F_{x+y+w} \succ F_{x+w}$, or equivalently, $V(\mu + \triangle\mu(\mu, \sigma; \delta) + w, \sigma + \delta) > V(\mu + w, \sigma)$. Considerations of the equality $V(\mu + w, \sigma) = V(\mu + \triangle\mu(\mu + w, \sigma; \delta) + w, \sigma + \delta)$ and of property 1 conclude the proof. ■

This proof is illustrated in Figure 2, where the lower indifference curve passes through the prospects x and $x+y$, the middle indifference curve passes through the prospect $x+w$, and the upper one passes through the prospect $x + y + w$. Similar figures can be constructed for the rest of the proofs.

Figure 2: Indifference Curves Under DARA



Property 6: We show that $\triangle\mu(\mu,\sigma;\delta) < \triangle\mu(\mu,\sigma+\delta;\delta)$ as $\delta \longrightarrow 0^+$. By property 4, we know that DARA implies $\triangle\mu(\mu,\sigma;\delta) > \triangle\mu(\mu+\triangle\mu(\mu,\sigma;\delta),\sigma;\delta)$. But, as $\delta \longrightarrow 0^+$, $\triangle\mu(\mu,\sigma;\delta) \longrightarrow \triangle\mu(\mu+\triangle\mu(\mu,\sigma;\delta),\sigma+\delta;\delta)$. ∎

Property 7: First we will show that $\triangle\mu(w\mu,w\sigma;w\delta) > w\triangle\mu(\mu,\sigma;\delta)\ \forall w > 1$ as $\delta \longrightarrow 0^+$. Let x and y be as in property 5. Since x and y are comonotone and since $F_x \sim F_{x+y}$, IRRA implies $F_{wx} \succ F_{w(x+y)}$, or equivalently, $V(w\mu,w\sigma) > V(w(\mu+\triangle\mu(\mu,\sigma;\delta)),w(\sigma+\delta))$. Considerations of the equality $V(w\mu,w\sigma) = V(w\mu+\triangle\mu(w\mu,w\sigma;w\delta),w(\sigma+\delta))$ and of property 1 establish the opening statement. Dividing by $w\delta$ and taking the limit as $\delta \longrightarrow 0^+$ completes the proof. ∎

Property 8: We show that $\triangle\mu^2(\mu,\sigma;\delta) > \triangle\mu^1(\mu,\sigma;\delta)$. Let $x = \mu+\sigma\epsilon$ and $y = \triangle\mu^1(\mu,\sigma)+\epsilon$ where $\epsilon \sim_d (0,1)$. Since x and y are comonotone and since $F_x \sim^1 F_{x+y}$, the greater risk aversion of $\succeq^2$ implies $F_x \succ^2 F_{x+y}$, or equivalently, $V^2(\mu,\sigma) > V^2(\mu+\triangle\mu^1(\mu,\sigma;\delta),\sigma+\delta)$. Considerations of the equality $V^2(\mu,\sigma) = V^2(\mu+\triangle\mu^2(\mu,\sigma;\delta),\sigma+\delta)$ and of property 1 conclude the proof. ∎

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