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Risk Preference and Indirect Utility in Portfolio Choice Problems

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Abstract

We consider a portfolio choice problem with one risky and one safe asset, where the utility function exhibits decreasing absolute risk aversion (DARA). We show that the indirect utility function of the portfolio choice problem need not exhibit DARA. However, if the (optimal) marginal propensity to invest is positive for both assets, which is true when the utility function exhibits non-decreasing relative risk aversion, then the DARA property is carried over from the direct to the indirect utility function.

Key words: Portfolio Choice, Absolute Risk Aversion, Relative Risk Aversion, Indirect Utility.

JEL Classification: D81, D92.

I. Introduction

One of the basic models that brings out the relationship between risk preference of agents and allocation of resources is the risk portfolio choice problem. The simplest static version of this problem is one where an agent decides on how to allocate his total wealth between investment in an asset with stochastic return (the risky asset) and an asset with deterministic return (the safe asset) so as to maximize the expected utility of return[1]. The von Neumann-Morgenstern utility function is assumed to be concave in wealth or, equivalently, the agent is assumed to be risk-averse. Furthermore, short sales or borrowing are not allowed.

If the mean return on the risky asset is less than that of the safe asset, the agent concentrates all his investment in the safe asset. On the other hand, if the mean return on the risky asset is greater than the safe return, then the agent invests a positive fraction of his wealth in the risky asset. Given the asset return structure, the absolute or relative (to total wealth) investment in the risky asset depends on the degree of risk aversion of the agent embodied in the utility function. The Arrow-Pratt measures of absolute and relative risk aversion (see Pratt (1964) and Arrow (1965)) provide a precise characterization of the risk-taking behaviour of agents in such situations. These measures depend on the curvature and slope of the utility function. In particular, if the utility function exhibits decreasing, increasing or constant absolute risk aversion, then the optimal investment in the risky asset is, respectively, increasing, decreasing or constant in the level of current wealth. Similarly, whether the relative risk aversion is decreasing, increasing or constant determines whether the fraction of total investment going to the risky asset is, respectively, increasing, decreasing or constant in the level of current wealth.

[1]The agent's preferences on the space of lotteries over wealth are assumed to satisfy the expected utility hypothesis.

Consider a simple two-period model of successive risk taking. In each period, the agent chooses a risk portfolio allocation of his current wealth between a risky and a risk-less asset. The wealth return from the first period's portfolio choice determines the current wealth in period 2. At the end of period two, total wealth is consumed. It is easy to see that the return from the portfolio chosen in the first period will be evaluated according to the indirect utility the agent obtains when he invests this wealth optimally in period 2. For the portfolio decision in the first period, the risk preference as embodied in the utility function of the agent is not very relevant. It is the behaviour of the Arrow-Pratt measures of risk aversion corresponding to the indirect utility from one-period portfolio choice, which determines the optimal risk choice policy of the agent in period 1.[2] One might therefore ask the following questions: under what conditions on the utility function and other primitives of the model does the indirect utility function display a certain kind of risk preference. In particular, if the (primitive or direct) utility function is assumed to exhibit DARA, does the indirect utility inherit this property?

Nachman (1982) showed that risk aversion properties of utility functions are preserved under expectations operations. For a finite horizon consumption-investment model with a linear production function (single asset), Neave (1971) showed that the value function (the indirect utility for multi-period decision problems) exhibited DARA if the one-period utility function was assumed to do so. More relevantly, in a multi-period consumption, investment and portfolio choice problem, Hakansson (1970) shows that if the one-period utility function exhibits constant absolute or

[2]This is true for a general class of dynamic models where agents decide on investment portfolio choice in every period and might, in some cases, decide on consumption in every period. It is the value function which determines the optimal portfolio policy in such models.

relative risk aversion, then the indirect utility or value function inherits this property. Incidentally, for this class of utility functions the optimal portfolio allocation rule is wealth independent. To allow for interesting wealth effects, one should look at multi-period portfolio choice models where the utility function exhibits variable risk aversion.

Our results indicate that the DARA property is not necessarily carried over from the (direct) utility function to the indirect utility function for a one-period portfolio choice problem. In Section IV, we provide an example to demonstrate this point. The implication is that even if the (one-period) utility function of an agent satisfies the DARA property, in a multi-period investment portfolio choice problem (with or without consumption possibility in every period) the agent's optimal portfolio policy in all but the last period can be such that he invests less in the risky asset when his total wealth increases. The latter behaviour is associated with strictly increasing absolute risk aversion in static portfolio models.

In Section III, we show that if in the static portfolio choice problem, the marginal propensity to invest is positive for both assets then the DARA property is carried over to the indirect utility function. This is always true when the utility function exhibits increasing relative risk aversion (in the weak sense), in addition to DARA. In the literature, there appears to be considerable support for the hypotheses of decreasing absolute risk aversion and increasing relative risk aversion as being "reasonable" and, to some extent, consistent with empirical observation.[3] Risky investment is often observed to be a normal good. Arrow (1965) remarks that the hypothesis of increasing relative risk aversion gives a wealth elasticity of demand for cash balances of at least one, which is supported by empirical evidence. The

[3]Levy (1994) conduct an experimental study to test these two hypotheses. From analyzing investment strategies of MBA students empirical evidence is found on DARA but the hypothesis of increasing relative risk aversion is rejected.

appendix contains examples of different utility functions which satisfy both DARA and increasing relative risk aversion.

In the next section, i.e. Section II, we outline the problem formally and state the preliminary results.

II. The One-Period Portfolio Choice Problem

To begin, the agent's preferences on the space of lotteries over wealth are assumed to satisfy the expected utility property. Let L denote the real line augmented by the point $\{-\infty\}$ and let $u: \mathbb{R}_+ \to L$ be the (von Neumann-Morgenstern) utility function of the agent. We make the following assumptions on u:

(U.1) u is continuous on $\mathbb{R}_+$ and thrice continuously differentiable on $\mathbb{R}_{++}$;

(U.2) $u'(y) > 0$ for all $y > 0$;

(U.3) $u''(y) < 0$ for all $y > 0$;

(U.4) $\lim_{y \downarrow 0} u'(y) = +\infty$.

(U.1) through (U.3) are fairly standard. (U.4) is assumed in order to ensure an interior solution to the portfolio choice problem.

There are two assets, one risky and the other safe. Both assets mature in one period. The risky asset yields stochastic return ρ and the safe asset has return r. The following assumptions are imposed on the return structure of the assets:

(T.1) The support of ρ is a finite set contained in $\mathbb{R}_+$ and Probability $\{\rho = 0\} > 0$;

(T.2) $\mu = E(\rho) > r > 0$.

Let w denote the level of initial wealth and q the amount of wealth invested in the risky asset. We shall assume that only non-negative quantities can be invested and total investment cannot exceed total wealth, i.e. no short sales or borrowing are allowed. Assumption (T.2) ensures that the risky asset is not mean variance dominated and so a positive fraction of wealth is always invested in the risky asset. Assumption (T.1) is a simplifying assumption whose only role is to ensure, along with (U.4), that a positive quantity of wealth is always invested in the safe asset. This allows us to use the first order necessary conditions as equalities and the method of comparative statics.

Let V(w) denote the indirect utility function. Then V(w) and the maximization problem faced by the agent are given by:

$$V(w) = \max_{0 \le q \le w} E[u(\rho q + r(w-q))] \qquad (1)$$

The next two lemmas summarize smoothness properties of the optimal solution and the indirect utility as functions of wealth.

Lemma 1: There exists an unique interior optimal solution q(w) to the portfolio choice problem (1).

Proof: The existence of an optimal solution is assured by the Weierstrass theorem. The strict concavity of the utility function implies an unique optimal solution. The assumption $E[\rho] > r$ ensures $q(w) \neq 0$ and assumptions (T.1) and (U.4) ensure $q(w) < w$ (see also Arrow (1965), pp. 155-157). //

Lemma 2: V(w) is thrice continuously differentiable and q(w), the optimal solution to the maximization problem (1), is twice continuously differentiable on $\mathbb{R}_{++}$.

Proof: Lemma 2 is shown by successive use of the implicit function theorem, assumption (U.2) and the fact that $0 < q(w) < w$ for all $w > 0$. //

Next, we state the result that the indirect utility function exhibits risk aversion. The proof follows directly from the definition of V(w) and assumption (U.3).

Lemma 3: V is strictly increasing on $\mathbb{R}_{+}$; V(w) is strictly concave on $\mathbb{R}_{++}$; $V'(w) > 0$ and $V''(w) < 0$ on $\mathbb{R}_{++}$.

The Arrow-Pratt measure of absolute risk aversion R_u is defined by $R_u \equiv \frac{-u''(y)}{u'(y)}$ and the Arrow-Pratt measure of relative risk aversion r_u is defined by $r_u \equiv \frac{-yu''(y)}{u'(y)}$. We shall define a function f: $\mathbb{R} \rightarrow \mathbb{R}$ to be increasing (decreasing) if x > y implies f(x) ≥ (≤) f(y); f is said to be strictly increasing (strictly decreasing) if x > y implies f(x) > (<) f(y). u is said to exhibit decreasing or increasing absolute risk aversion (DARA or IARA) if R_u is, respectively, decreasing or increasing in y. Similarly, u exhibits decreasing or increasing relative risk aversion (DRRA or IRRA) if r_u is, respectively, decreasing or increasing in y. If, in particular, r_u is constant in y, then u is said to exhibit constant relative risk aversion (CRRA). Recall the results in Pratt (1964) and Arrow (1965). If u exhibits DARA on $\mathbb{R}_{++}$, then the optimal investment in the risky asset is increasing in the level of wealth. If u exhibits IRRA on $\mathbb{R}$, then $\frac{q(w)}{w}$ is decreasing in w.

III. Positive Results on Inheritance of DARA Property by Indirect Utility

The important question to address is under what conditions on the utility function and other primitives of the model does the indirect utility function inherit the DARA property of the utility function. In proposition 1 we show that if the optimal investment policy is such that the marginal propensity to invest is positive for both assets, i.e. both risky and safe investment are normal goods, then the DARA property is preserved. More precisely, the first derivative of the optimal investment rule q(w) with respect to w must lie between zero and one. To understand the intuition behind the result, suppose to the contrary that an increase in wealth would lower the optimal investment in the safe asset. In this case an increase in wealth would sharply increase the riskiness of the optimal portfolio and therefore the indirect utility function can not display the DARA property because a risk averse agent would ask for a higher risk premium to meet this higher portfolio risk. Note that indirect utility is directly determined by the optimal portfolio.

Proposition 1: Suppose q(w) is the optimal solution to (1). If $0 \leq q'(w) \leq 1$ and u(y) exhibits DARA on $\mathbb{R}_{++}$, then V(w) exhibits DARA on $\mathbb{R}_{++}$.

Proof: We shall show that $R_V = \frac{-V''(w)}{V'(w)}$ is decreasing in w on $\mathbb{R}_{++}$. Note that from Lemma 3, R_V is well-defined. The first order necessary condition for an interior maximum in optimization problem (1) can be written as:

$$E[u'(\rho q(w)+r(w-q(w)))(\rho-r)] = 0. \tag{2}$$

Using Lemma 2 and differentiating (2) with respect to w results:

$$E[u''(\rho q(w)+r(w-q(w)))(\rho-r)(r+(\rho-r)q'(w))] = 0. \tag{3}$$

Differentiating (3) with respect to w:

$$E[u'''(\rho q(w)+r(w-q(w)))(\rho-r)(r+(\rho-r)q'(w))^2] + E[u''(\rho q(w)+r(w-q(w)))(\rho-r)^2]q''(w) = 0. \tag{4}$$

Now, $V(w) = E[u(\rho q(w)+r(w-q(w)))]$ so

$$V'(w) = E[u'(\rho q(w) + r(w - q(w)))(r+(\rho-r)q'(w))]. \tag{5}$$

Using (2) in (5) we have

$$V'(w) = E[u'(\rho q(w)+r(w-q(w)))r], \tag{6}$$

so

$$V''(w) = E[u''(\rho q(w)+r(w-q(w)))(r+(\rho-r)q'(w))r] \tag{7}$$

and

$$V'''(w) = E[u'''(\rho q(w)+r(w-q(w)))(r+(\rho-r)q'(w))^2 r] + E[u''(\rho q(w)+r(w-q(w)))r(\rho-r)q''(w)]. \quad (8)$$

Substituting for $q''(w)$ from (4) in (8):

$$V'''(w) = E[u'''(\rho q(w)+r(w-q(w)))(r+(\rho-r)q'(w))^2 r] + h(w)E[u'''(\rho q(w)+r(w-q(w)))(\rho-r)(r+(\rho-r)q'(w))^2] \quad (9)$$

where $h(w) = -\frac{E[u''(\rho q+r(w-q))(\rho-r)r]}{E[u''(\rho q+r(w-q))(\rho-r)^2]}$.

From (3) we have $h(w) = q'(w)$. So, $V'''(w)$ can be written as:

$$V'''(w) = E[u'''(\rho q(w)+r(w-q(w)))(r+(\rho-r)q'(w))^3]. \quad (10)$$

Further $V''(w)$ can be written as:

$$\begin{aligned} V''(w) &= E[u''(\rho q(w)+r(w-q(w)))(r+(\rho-r)q'(w))r] + \\ &\quad E[u''(\rho q(w)+r(w-q(w)))(r+(\rho-r)q'(w))(\rho-r)q'(w)] \text{ (using (3))} \\ &= E[u''(\rho q(w)+r(w-q(w)))(r+(\rho-r)q'(w))^2]. \quad (11) \end{aligned}$$

Using (5), (10), the Cauchy-Schwarz inequality, $0 \leq q'(w) \leq 1$ (so that $(r+(\rho-r)q'(w))$ assumes only non-negative values) and the fact that R_u is decreasing (or equivalently $u'''(y)u'(y) \geq [u''(y)]^2$) we have:

$$\begin{aligned} V'''(w)V'(w) &\geq \{E[(u'''(\rho q(w)+r(w-q(w)))u'(\rho q(w)+r(w-q(w))))^{1/2}(r+(\rho-r)q'(w))^2]\}^2 \\ &\geq \{E[u''(\rho q(w)+r(w-q(w)))(r+(\rho-r)q'(w))^2]\}^2 \\ &= \{V''(w)\}^2 \text{ (using (11))}. \end{aligned}$$

Thus, $V'''(w)V'(w) \geq [V''(w)]^2$, that is, the measure of absolute risk aversion R_V associated with the indirect utility function V, is decreasing on $\mathbb{R}_{++}$. //

If the risk preference of the agent as revealed by the utility function is one of DARA and IRRA[4], then it is easy to check that investment in both the risky and the safe assets is increasing in wealth and therefore $q'(w)$ lies in [0,1]. Using Proposition 1, we have then:

Corollary 1: If u(y) exhibits DARA and IRRA on $\mathbb{R}_{++}$, then V(w) exhibits DARA on $\mathbb{R}_{++}$.

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[4]See Appendix.

IV. An Example to Show that the DARA Property need not be Inherited by the Indirect Utility Function

Suppose the utility function is given by $u(y)=-\frac{1}{2}y^{-2}+y$. It is easy to check that u exhibits DARA on $\mathbb{R}_{++}$. However, (contrary to the assumption of Corollary 1) u does not exhibit IRRA, in fact r_u is a strictly decreasing function. We find that the measure of absolute risk aversion as revealed by the indirect utility function corresponding to optimization problem (1) is strictly increasing in wealth for a sub-interval of the real line. We choose the following parameter values: r=0.1, P[ρ=0]=0.04, P[ρ=0.01]=0.86 and P[ρ=1]=0.1. One can check that assumptions (U.1) to (U.4) and (T.1) to (T.2) hold. Lemma 1 ensures the existence of an unique interior optimal solution q(w) to (1). The first order condition of the maximization problem (1) can be written as:

$$-0.004\left[1+\frac{1}{(0.1(w-q))^3}\right]-0.0774\left[1+\frac{1}{(0.01q+0.1(w-q))^3}\right]+$$

$$0.09\left[1+\frac{1}{(q+0.1(w-q))^3}\right]=0 \qquad (12)$$

Differentiating (12) with respect to w and solving for q′(w) results:

$$q'(w)=\frac{\frac{12}{(w-q)^4}+\frac{0.02322}{(0.01q+0.1(w-q))^4}-\frac{0.027}{(q+0.1(w-q))^4}}{\frac{12}{(w-q)^4}+\frac{0.020898}{(0.01q+0.1(w-q))^4}+\frac{0.243}{(q+0.1(w-q))^4}} \qquad (13)$$

The Newton-Raphson algorithm is used to calculate q(w) from (12) for the configuration w=100.[5] This results q(100)=86.378201. Evaluating (13) at w=100 using q(100)=86.378201 returns q′(100)=1.0788284. Inserting w=100, q(100)=86.378201 and q′(100)=1.0788284 in (10) and computing the expected value results a negative value for V‴(w), i.e. $V'''(100)=-4.5217275*10^{-8}$. Note from lemma 3 that V′(w) > 0 on $\mathbb{R}_{++}$. Therefore, $V'''(w)V'(w) \ngeq [V''(w)]^2 \geq 0$ for all $w \in \mathbb{R}_{++}$, thus the measure of absolute risk aversion R_V associated with the indirect utility V(w) is strictly increasing for some sub-intervals of $\mathbb{R}_{++}$.

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[5] The calculations were carried out using GAUSS which has as default about 19 digits of precision.

V. Conclusion

We conclude that in multi-period portfolio choice problems, the nature of optimal portfolio choice is not necessarily determined by the risk aversion measures associated with the one-period utility function. In particular, if the one period utility function satisfies decreasing absolute risk aversion, this property may not be carried over to the indirect utility or value function so that the optimal portfolio policy in early periods can exhibit features only associated with increasing absolute risk aversion in static models. However, for simple two period models, if the one period utility function exhibits both decreasing absolute risk aversion as well as increasing relative risk aversion, then the indirect utility function which determines the nature of risk portfolio choice in period 1, will exhibit decreasing absolute risk aversion. The optimal investment in the risky asset will be non-decreasing in current wealth in both periods. However, we have not been able to show that the indirect utility function also inherits the increasing *relative* risk aversion property. Unless one can show this, it is not possible to extend the DARA property to models with more than two periods. We leave this as an open question.

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Appendix:

Table 1 contains examples of different utility functions which satisfy both decreasing absolute risk aversion and increasing (or constant) relative risk aversion.

Table 1. **Examples of Utility Functions which exhibit DARA and IRRA (or CRRA)**[*]

1	$u(y)=y^c$ $0<c<1$	DARA	CRRA
2	$u(y)=-y^{-c}$ $c>0$	DARA	CRRA
3	$u(y)=\log(y)$	DARA	CRRA
4	$u(y)=(y+a)^c$ $a>0,\ 0<c<1$	DARA	IRRA
5	$u(y)=-(y+a)^{-c}$ $a>0,\ c>0$	DARA	IRRA
6	$u(y)=\log(y+a)$ $a>0$	DARA	IRRA

[*]DARA = decreasing absolute risk aversion,
CRRA = constant relative risk aversion,
IRRA = increasing relative risk aversion.

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