THE THEORY OF RISK AVERSION AND LIQUIDITY PREFERENCE: A GEOMETRIC EXPOSITION

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Abstract

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This paper introduces the Arrow-Pratt concept of Absolute Risk Aversion into the mean-variance framework and provides a geometric generalization of the theory of liquidity preference under condition of risk aversion which removes the ambiguities existing in Tobin's seminal paper (1958) concerning the direction of the relationship between the rate of interest and the demand for cash. An opportunity locus is derived in terms of the investor's wealth and is subjected to a comparative static analysis that explains the portfolio behavior of risk adverse investors according to the type of absolute risk aversion they display.

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I. INTRODUCTION

In his seminal paper, Tobin [10] has examined liquidity preference under condition of risk aversion within the mean-variance framework first introduced by Markowitz [6] and shown that, under some restrictive conditions, the individual's liquidity preference curve is downward sloping. Introducing the concept of Absolute Risk Aversion, Arrow [3] has generalized analytically some of Tobin's results and removed some of the ambiguities existing in Tobin's paper concerning the direction of the relationship between the rate of interest and the demand for cash.

The purpose of this paper is to introduce the concept of Absolute Risk Aversion into the geometric framework developed by Tobin and to provide a generalization of Tobin's results. In section II the locus of investment opportunities is derived in terms of expected wealth and risk measured as standard deviation of wealth.[1] In section III the geometry of Absolute Risk Aversion and optimal equilibrium is developed within the Tobin framework. In section IV the model is subjected to a comparative static analysis which provides a generalization of Tobin's results and removes the ambiguities existing in Tobin's paper. In this section we also examine the effect of a proportional tax on wealth or income.

II. THE OPPORTUNITY LOCUS

Investors are assumed to allocate their initial wealth W_0 between a safe asset yielding a return R_f with certainty and a risky asset with random end-of-period returns $\tilde{R}_r$ with an expected return of $E(\tilde{R}_r)$ and a standard deviation of the distribution of random returns $\sigma(\tilde{R}_r)$. The tilde above a variable indicates a random variable. If W_r represents wealth invested in the risky asset and $\tilde{W}$ the random end-of-period wealth, then:

$$\tilde{W} = (W_0 - W_r)\,(1 + R_f) + W_r(1 + \tilde{R}_r)$$

or

$$\tilde{W} = W_0(1+R_f) + W_r(\tilde{R}_r - R_f) \tag{1}$$

The expected wealth and, respectively, the standard deviation of wealth are:

$$E(\tilde{W}) = W_0(1 + R_f) + W_r \left[E(\tilde{R}_r) - R_f\right] \tag{2}$$

$$\sigma(\tilde{W}) = W_r \, \sigma(\tilde{R}_r) \tag{3}$$

Eliminating W_r between eq. (2) and eq. (3) yields the locus of investment opportunities for expected wealth and risk measured by the standard deviation of wealth:

$$E(\tilde{W}) = W_0 \,(1 + R_f) + \left[\frac{E(\tilde{R}_r) - R_f}{\sigma(\tilde{R}_r)}\right] \cdot \sigma(\tilde{W}) \tag{4}$$

In the expected wealth-risk plane, the opportunity locus is a straight line with a positive intercept $W_0(1 + R_f)$ and a positive slope $(E(\tilde{R}_r) - R_f)/\sigma(\tilde{R}_r)$ as shown in the upper part of figure 3. If the safe asset is cash with no nominal yield, the opportunity locus becomes:

$$E(\tilde{W}) = W_0 + \left[E(\tilde{R}_r)/\sigma(\tilde{R}_r)\right] \cdot \sigma(\tilde{W}) \tag{5}$$

III. THE GEOMETRY OF RISK AVERSION AND EQUILIBRIUM

<u>1. Global Measures of Risk Aversion and the Shape of Indifference Curves</u> (figure 1)

Investors are assumed to be risk averse. They will always prefer more wealth to less, with a decreasing preference for incremental units of wealth. Introducing a von-Neumann Morgenstern utility function of wealth, the risk averse investor will display a positive and decreasing marginal utility of wealth:

$$U'(W) > 0 \quad \text{and} \quad U''(W) < 0 \,, \tag{6}$$

and will select the particular combination (portfolio) of safe and risky assets which will maximize his expected utility of wealth.

In order to determine geometrically the optimal portfolio in the (E,σ)-plane, the concept of risk aversion must be represented by Indifference Curves. In this plane, an indifference curve is defined as the locus of points along which an investor's expected utility of wealth remains constant. This assumes that the expected utility of wealth can be written as a function of expected wealth and the standard deviation of wealth only which, in turn, implies that the investor's utility function is either quadratic or that wealth is normally distributed. In this respect see Feldstein [4]. In this paper, wealth is assumed to be normally distributed in order to permit an examination of various shapes of the utility function.

The slope of an indifference curve for a risk averse investor will be positive and will increase with risk. This slope measures the investor's marginal rate of substition (MRS hereinafter) of expected wealth for risk. Being risk averse, the investor will require increasing increments of expected wealth to move to riskier portfolio opportunities along the same indifference curve. Mathematically we have:

$$MRS = \frac{dE(W)}{d\sigma(W)} > 0 \quad \text{and} \quad \frac{dMRS}{d\sigma(W)} > 0 \tag{7}$$

and the MRS can be used as a global measure of an investor's risk aversion.

An indifference field is generated by assuming varying values for the investor's expected utility. Curves further removed from the origin indicate successively higher levels of expected utility as illustrated in figure 1.

2. Local Measures of Risk Aversion and the shape of Indifference Fields (figure 1)

The concept of global risk aversion alone is not sufficient to derive unambiguously individual liquidity preference curves and to interpret the various shifts in these curves resulting from changes in the model's parameters. This has been shown analytically by Arrow [3] who, with Pratt [9], introduced various measures of local risk aversion to explain and interpret liquidity preference and the demand for risky assets. Of particular interest is the Absolute Risk Aversion function defined by Arrow and Pratt as

$$R_A(W) = -\left[U''(W)/U'(W)\right] \tag{8}$$

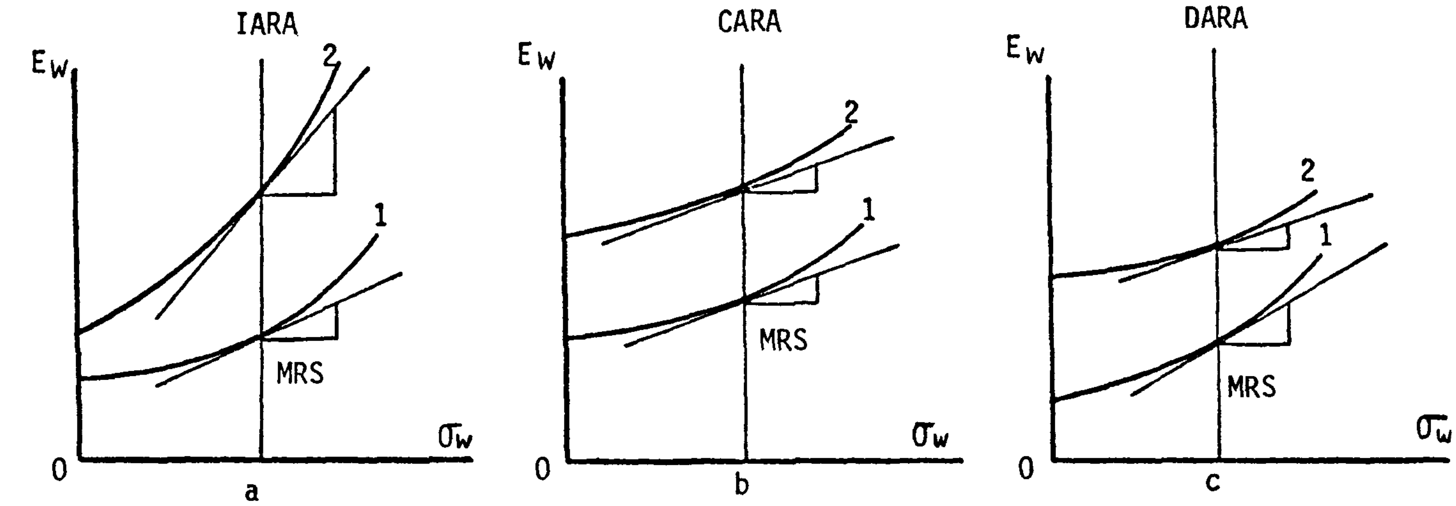

FIGURE 1

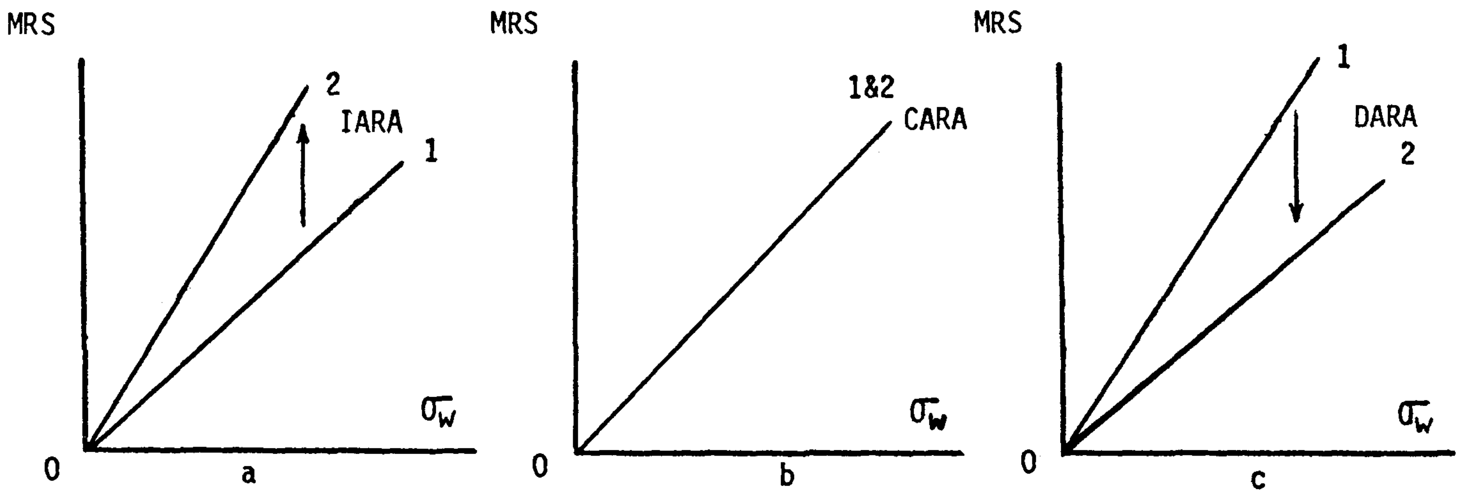

FIGURE 2

From conditions (6) it follows that all risk averse investors exhibit positive absolute risk aversion. A risk averse investor is said to display decreasing absolute risk aversion (DARA hereinafter) if $R_A(W)$ decreases with increasing wealth, i.e. $R'_A(W) < 0$, constant absolute risk aversion (CARA hereinafter) if $R_A(W)$ remains constant when wealth changes, i.e. $R'_A(W) = 0$, and increasing absolute risk aversion (IARA hereinafter) if $R_A(W)$ increases with increasing wealth, i.e. $R'_A(W) > 0$.

Absolute risk aversion can be represented geometrically in the (E,σ)-plane by indifference fields. Unlike global risk aversion which involves movements along an indifference curve,[2] absolute risk aversion involves movements between indifference curves. The three types of absolute risk aversion can be interpreted geometrically by the variation in the investor's MRS (his global measure of risk aversion) while holding the level of risk constant. This consists of a move to a higher indifference curve with the same level of risk but higher expected wealth.[3] It follows that absolute risk aversion can be measured in the (E,σ)-plane by the sign of the partial derivative $\left[\partial \, MRS/\partial E(W)\right]$. It has been shown by Amihud [2] that, for normally distributed wealth, we have:

$$\left[\frac{\partial \, MRS}{\partial \, E(W)}\right] \begin{matrix} > \\ = \\ < \end{matrix} 0 \iff R'_A(W) \begin{matrix} > \\ = \\ < \end{matrix} 0 \qquad (9)$$

The Arrow-Pratt measure of absolute risk aversion and the one introduced here are equivalent for <u>normally</u> distributed wealth. An investor displays IARA, respectively, CARA, or DARA if, for a constant risk, a move to a <u>higher</u> indifference curve increases, leaves constant, or decreases his MRS as illustrated in figure 1a, figure 1b, and figure 1c.

<u>3. The Shape of the MRS Curves</u> (figure 2)

To facilitate the analysis of the equilibrium, it is convenient to draw MRS curves instead of indifference curves.[4] Assuming risk aversion, the MRS is positive and increases with risk along a given indifference curve. Although it is not the case for all indifference curves, we can assume for the sake of exposition and without loss of generality that the MRS increases at a constant rate. This is illustrated in figure 2b.[5]

If an investor displays CARA, all his indifference curves have the same MRS for any level of risk. It follows that his indifference field is summarized by a unique MRS curve as illustrated in figure 1b and figure 2b. If the investor displays either IARA or DARA, then, to each of his indifference curves there exists a unique MRS curve and a field of MRS curves can be generated that corresponds to his indifference field. However, one should observe that for the increasingly risk averse investor, higher indifference curves correspond to higher MRS curves since the MRS increases with a move to a higher indifference curve while holding risk constant, as illustrated in figure 1a and figure 2a. The opposite holds true for the decreasingly risk averse investor. For this investor, higher indifference curves correspond to lower MRS curves since the MRS decreases with a move to higher indifference curves, holding risk constant, as illustrated in figure 1c and figure 2c.

4. Equilibrium and Optimal Investment in the Risky Asset (figure 3)

Equilibrium is determined at the tangency point between the opportunity locus (OL hereinafter) and the investor's highest attainable indifference curve. At this point the investor's MRS of expected wealth for risk is equal to the slope of the opportunity locus (SOL hereinafter) and the investor's expected utility of wealth is maximized for the given constraints.

The constant slope of the OL can be represented by a straight line SOL parallel to the risk axis on the same plane as the MRS curves. This is shown in the upper quadrant in figure 3. The intersection between SOL and a MRS curve is the equilibrium point. Note that in the case of IARA and DARA there exist more than one intersection point, only one of which is the equilibrium point.[6]

From this equilibrium point the optimal investment in the risky asset is found in the lower right quadrant in figure 3. It is read along the W_r axis with the amount of wealth W_r invested in the risky asset increasing with a move away from the origin

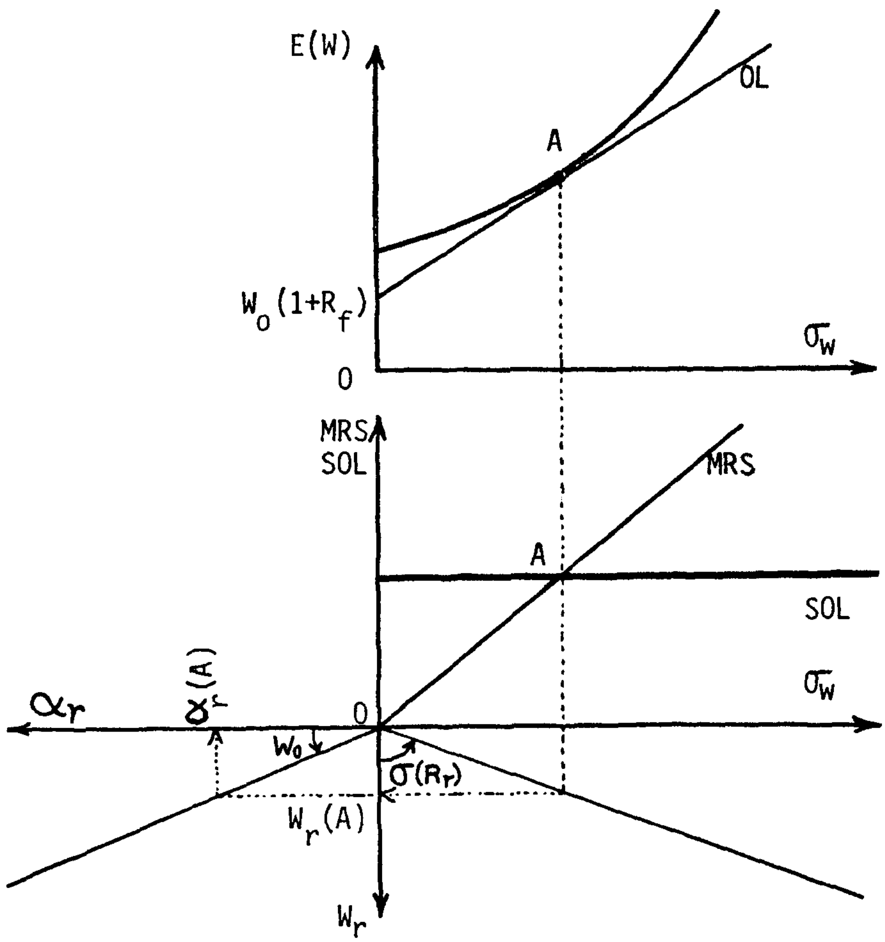

FIGURE 3

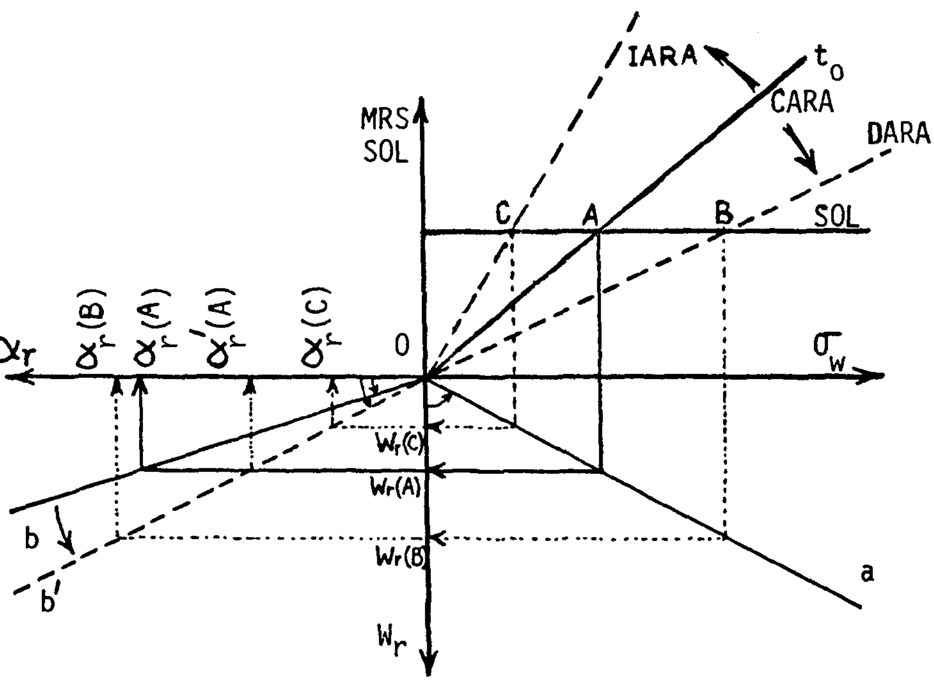

FIGURE 4

toward the bottom of the diagram. The proportion of wealth invested in the risky asset, $\alpha_r = W_r/W_o$, is found in the lower left quadrant in figure 3 by noting that $W_r = W_o\alpha_r$ with α_r read along the horizontal axis moving away from the origin toward the left of the diagram.

IV. COMPARATIVE STATIC ANALYSIS

The model specified in the previous sections can be subjected to a comparative static analysis by varying the parameters of the OL. These are the initial wealth, the expected return on the risky asset, the risk (standard deviation of the risky asset)an the riskless rate of return on the safe asset. Also examined is the effect of a change in a proportional tax on wealth or income. A comparison of the original and final equilibria will allow us to derive individual liquidity preference curves and to explain the portfolio behavior of risk averse investors according to the type of absolute risk aversion they display.

1. The Effect of a Change in Initial Wealth (figure 4)

Assume an increase in initial wealth W_o. The OL will shift upward in a parallel fashion since its intercept increases but its slope (SOL) remains the same. (See eq. (4) and eq. (5)). It follows that the SOL curve is unaffected by the change in initial wealth. Assume t_o to be the original equilibrium indifference curve. Referring to figure 4, observe that in the case of CARA the original equilibrium point is A, but so is the final equilibrium point since SOL is fixed and t_o summarized the complete indifference field under CARA. Consequently, the investor does not alter his optimal investment $W_r(A)$ in the risky asset. However, since initial wealth has increased, the proportion of wealth invested in the risky asset is reduced from $\alpha_r(A)$ to $\alpha'_r(A)$ because of the swing in line ob. In the case of IARA (DARA) the equilibrium point will shift from A to C (from A to B) and the investment in the risky asset will be reduced (increased) from $W_r(A)$ to $W_r(C)$ (from $W_r(A)$ to $W_r(B)$). This is so because a move to a higher indifference curve corresponds to a higher (lower) MRS curve for the increasing (decreasing) absolute risk averse investor. The proportion of wealth invested in the risky asset decreases in the case of IARA. However, it is indeterminate in the case of DARA; it may or may not increase depending upon the magnitude of the increase in initial wealth and the relative steepness of the slope of the MRS curve, i.e. the investor's degree of global risk aversion. This can be easily inferred from figure 4.

The wealth effect, then, can be represented by a movement from point A to point B under DARA, a movement from point A to point C under IARA or no movement under CARA. However, one should differentiate between an absolute wealth effect as defined by the wealth invested in the risky asset W_r and a relative wealth effect as defined by the proportion of wealth invested in the risky asset α_r. It follows that:

> Proposition I. "Under increasing absolute risk aversion both the absolute and the relative wealth effects are negative. Under constant absolute risk aversion the absolute wealth effect is neutral and the relative wealth effect is negative. Under decreasing absolute risk aversion the absolute wealth effect is positive and the relative wealth effect is indeterminate."

Note that decreasing absolute risk aversion is a necessary and sufficient condition for a positive absolute wealth effect.

2 The Effect of a Change in the Expected Return (figure 5)

Assume an increase in the expected return on the risky asset. SOL will shift upward in a parallel fashion from SOL_1 to SOL_2 as shown in figure 5 since the OL will have a steeper slope value. Lines oa and ob in figure 5 are not affected. Referring to figure 5, observe that the equilibrium point will shift from A to D under CARA, from A to C under IARA and from A to B under DARA. It is clear that under CARA and DARA both the wealth invested in the risky asset W_r and the proportion of wealth invested in the risky asset α_r will increase. In the case of IARA it is indeterminate for both W_r and α_r. It depends upon the magnitude of the increase in $E(\tilde{R}_r)$ and the slope of the MRS curve. Therefore:

> Proposition II. "Nonincreasing absolute risk aversion is a sufficient condition for the demand for the risky asset to vary directly with expected return and for the existence of a downward sloping liquidity preference curve."

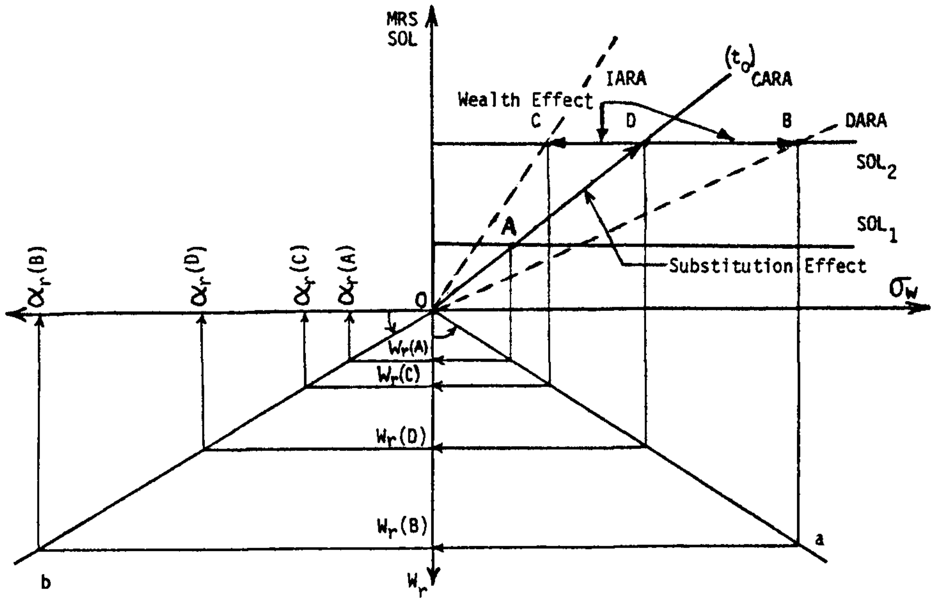

FIGURE 5

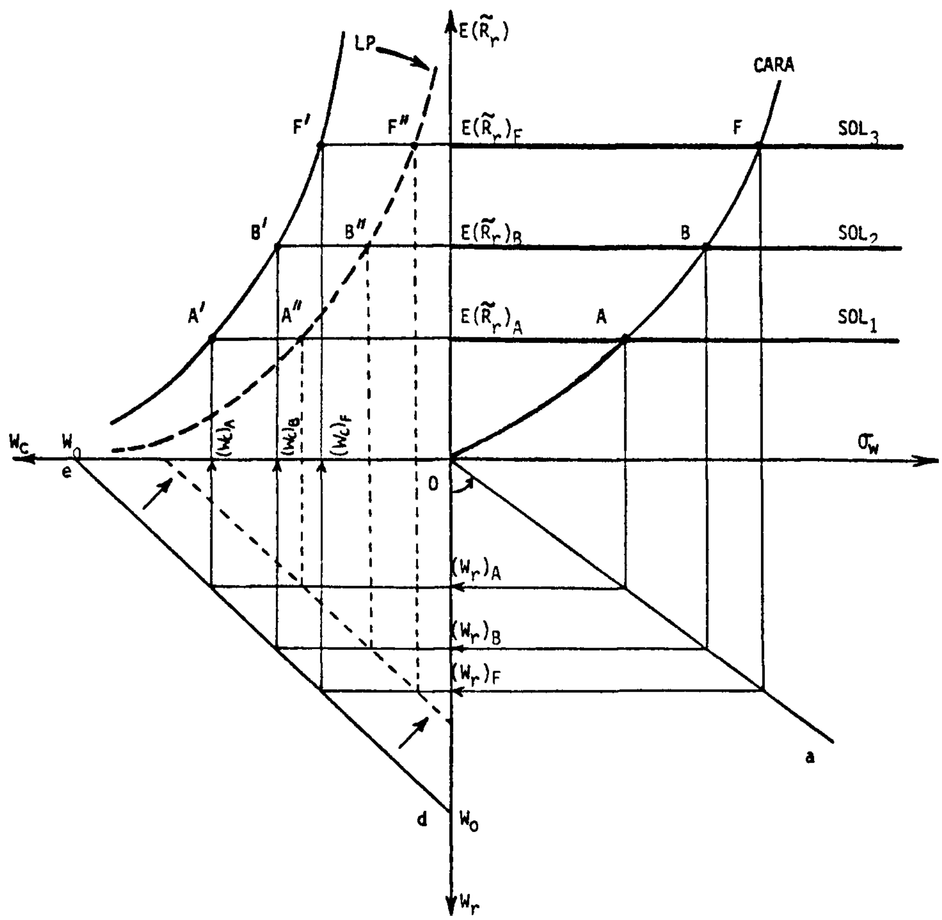

FIGURE 6

The demand for the risky or the safe asset can be expressed either in terms of wealth invested or in terms of proportion of wealth invested. Proposition II holds in either case.

3. Substitution and Wealth Effects (figure 5)

The response to an increase in the expected return can be decomposed into a substitution effect and a wealth effect as in the case of traditional demand theory.[7]

The substitution effect (Slutsky-type) can be defined as a movement along the original equilibrium indifference curve, i.e. holding expected utility constant, from the initial equilibrium point to an intermediate point at which the OL is parallel to its final position. The wealth effect is defined as the movement from that intermediate point to the final equilibrium point as discussed in the previous subsection.

Referring to figure 5, the substitution effect is represented by the movement from the initial equilibrium point A to the intermediate point D since both points are on the same original indifference curve t_0 and SOL_2 is parallel to its final position. In this case the intermediate SOL curve is identical to the final SOL curve because their corresponding opportunity loci are parallel. It follows that:

> Proposition III. "Global risk aversion is a necessary and sufficient condition for the substitution effect to be positive."

Holding expected utility of wealth constant, more wealth in absolute and relative terms is invested in the risky asset in response to an increase in expected return, regardless of the type of absolute risk aversion.

The wealth effect was discussed in the previous subsection. Contrary to the substitution effect, it is a function of the type of absolute risk aversion and is represented geometrically by a movement from point D to either point C under IARA or point B under DARA or no movement under CARA.

4. Derivation of the Individual Liquidity Preference Curve (figure 6)

An individual's liquidity preference curve can be derived geometrically by modifying figure 5. Assume that R_f is zero and $\sigma(\tilde{R}_r)$ is equal to one, then the slope of the OL (SOL) is equal to the expected return and is read on the vertical axis from the origin upward. In this case, changes in expected return are represented by parallel shifts in the SOL curves. In the lower left quadrant in figure 6 the straight line ed allows us to transform wealth invested in the risky asset W_r into wealth held in cash[8] W_c using the equality $W_r = W_0 - W_c$. Wealth held in cash is read on the horizontal axis moving away from the origin to the left. Assume CARA for simplicity.[9] At the equilibrium point A, the expected return is $E(\tilde{R}_r)_A$ and wealth held in cash is $(W_c)_A$ yielding point A' on the liquidity preference curve. Similiarly, to equilibrium point B (point F) there is a corresponding point B' (point F') on the downward sloping liquidity preference (LP) curve. The same derivation can be obtained under DARA. However, according to proposition II, the liquidity preference curve is indeterminate under IARA.

One can examine shifts in the LP curve resulting from changes in initial wealth. Under CARA a reduction in initial wealth will cause an inward shift in the LP curve[10] as shown in figure 6. Under DARA the shift is indeterminate since the absolute wealth effect is positive.

The preceding analysis yields an individual LP curve. If the vast, weighted majority of investors display DARA then the aggregate LP curve will also be downward sloping.

5. The Effect of a Change in Risk (figure 7)

Assume that risk, as measured by the standard deviation of the returns on the risky asset, is revised downwards. The slope of the OL will increase from SOL_1 to SOL_2 and the line oa will rotate to oa' as shown in figure 7. The initial equilibrium point A will move to point B under CARA, to point D under DARA and to point C under IARA. Referring to figure 7 observe that both the wealth invested in the risky asset W_r and the proportion wealth invested in the risky asset α_r increase under CARA and DARA. In the case of IARA the change is indeterminate. It follows that :

Proposition IV. "Nonincreasing absolute risk aversion is a sufficient condition for the demand for the risky asset (for cash) to be inversely (directly) related to changes in the level of risk".

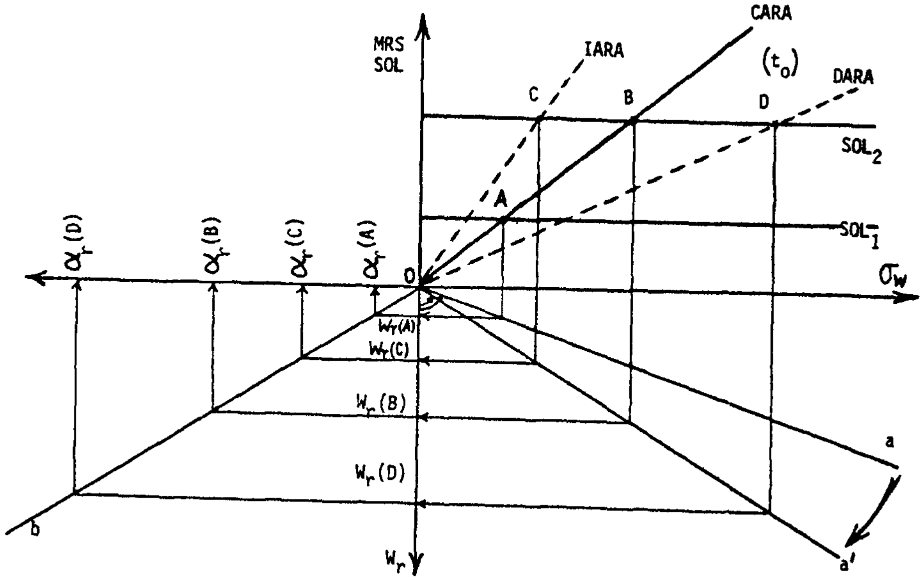

FIGURE 7

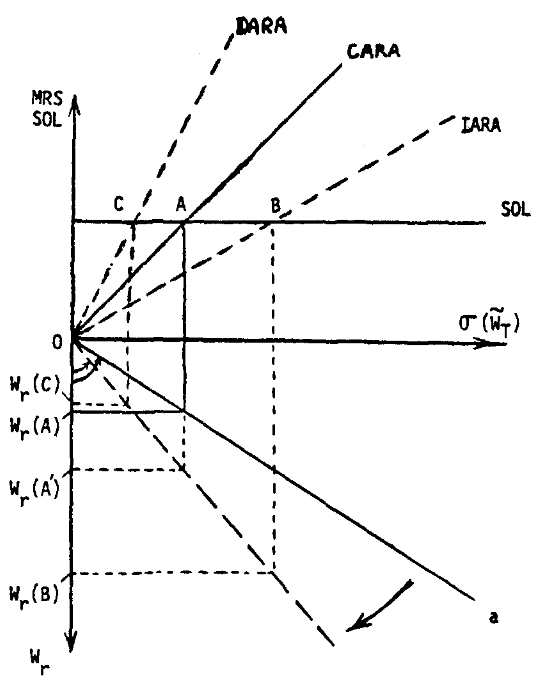

FIGURE 8

The demand for assets can be expressed either in absolute or relative wealth invested. Proposition IV holds in both cases.

6. The Effect of a Change in the Riskless Rate (figure 5)

The effect of a change in the riskless rate on the safe asset can be analyzed with the help of figure 5. A reduction in the riskless rate R_f will shift SOL upwards. This is similar to an increase in the expressed return on the risky asset. It follows that:

> Proposition V. "Nonincreasing absolute risk aversion is a sufficient condition for the demand for the risky asset (cash) to be inversely (directly) related to changes in the riskless rate."

7. The Effect of a Change in a Proportional Tax on Wealth (figure 8)

Assume that a proportional tax on wealth is introduced; In this case investors maximize the expected utility of their after-tax-terminal wealth ($\tilde{W}_T$). Given a tax rate equal to t, eq. (2) and (3) become:

$$E(\tilde{W}_T) = W_o(1 + R_f)(1 - t) + W_r\left[E(\tilde{R}_r) - R_f\right](1 - t) \quad \text{and} \tag{10}$$

$$\sigma(\tilde{W}_T) = W_r(1 - t) \ \sigma(\tilde{R}_r) \tag{11}$$

and the wealth tax OL can be written as:

$$E(\tilde{W}_T) = W_o(1 + R_f)(1 - t) + \left[\frac{E(\tilde{R}_r) - R_f}{\sigma(\tilde{R}_r)}\right] \cdot \ \sigma(\tilde{W}_T) \tag{12}$$

a proportional tax on wealth will only affect the intercept of the OL leaving its slope unchanged. It will also affect the slope of the line oa in the lower quadrant as indicated by eq. (11) and illustrated in figure (8).

Assume an increase in the proportional tax rate on wealth. The wealth tax OL will shift down in a parallel fashion leaving the SOL unaffected. The line oa will rotate clockwise. Note that the equilibrium point will move from A to B under IARA because a downward shift in the OL will move the equilibrium point to a lower indifference curve. The movement is from point A to point C under DARA with no movement under

CARA. It is clear from figure 8 that investors displaying either CARA or IARA will increase their holding of the risky asset in absolute and relative terms. The behavior of investors with DARA is in this case indeterminate. Therefore:

> Proposition VI. "Nondecreasing absolute risk aversion is a sufficient condition for the demand for the risky asset to be directly related to a change in a proportional tax on wealth."

8. The Effect of a Change in a Proportional Tax on Income (figure 8)

Assume that a proportional tax on income is introduced with income $\tilde{Y}$ defined as $(\tilde{W} - W_0)$. The after tax income $\tilde{Y}_T$ can be written:

$$\tilde{Y}_T = \tilde{Y}(1 - t) = (\tilde{W} - W_0)(1 - t), \text{ and} \tag{13}$$

$$\tilde{W}_T = \tilde{Y}_T + W_0 (1 - t). \tag{14}$$

It follows from eq. (14) that:

$$E(\tilde{W}_T) = E(\tilde{Y}_T) + W_0(1 - t), \text{ and} \tag{15}$$

$$\sigma(\tilde{W}_T) = \sigma(\tilde{Y}_T) \tag{16}$$

The income tax OL becomes:

$$E(\tilde{Y}_T) = W_0(1 - t)R_f + \left[\frac{E(\tilde{R}_r) - R_f}{\sigma(\tilde{R}_r)}\right] \sigma(\tilde{Y}_T), \text{ with} \tag{17}$$

$$\sigma(\tilde{Y}_T) = W_r(1 - t) \, \sigma(\tilde{R}_r) \tag{18}$$

As long as the return on the safe asset is positive, an increase in a proportional tax on income will have a similar effect on the income tax OL and the line oa as in the case of a proportional tax on wealth. Therefore:[11]

> Proposition VII(a) "If the return on the safe asset is positive, then nondecreasing absolute risk aversion is a sufficient condition for the demand for the risky asset to be directly related to a change in a proportional tax on income."

If the return on the safe asset is zero (cash), then the intercept of the income tax OL is also equal to zero but its slope is the same. Consequently, a proportional income tax does not alter the OL when the return on the safe asset is zero and the equilibrium point A in figure (8) will not move. Note, however, that equation (18) still holds and the line oa will rotate clockwise when the income tax is increased resulting in an increase in the demand for the risky asset regardless of the type of local risk aversion.[12] It follows that:

> <u>Proposition VII(b)</u> "If the return on the safe asset is zero, then global risk aversion is a necessary and sufficient condition for the demand for the risky asset to be directly related to a change in a proportional tax on income."

FOOTNOTES

1
See Laidler (5) for a similar derivation in terms of wealth instead of returns. Tobin's derivation (10) is in terms of returns.

2
In this respect see Adler (1) who also points out this difference between global and local risk aversion. Adler examines optimum equilibria for a set of three specific utility functions.

3
For a discussion of the relationship between the Arrow-Pratt absolute risk aversion function and the shape of indifference curve, see Miller (7).

4
This is so because equilibrium determined with indifference curves and the opportunity locus is found at a tangency point which is often difficult to determine whereas equilibrium determined with MRS curves is found at an intersection point (as it will be shown) which is easily determined.

5
Note that the MRS curves pass through the origin. This happens because the slope of the indifference curves is zero when risk is zero as shown by Tobin (11).

6
Since we are interested in building a framework for a comparative static analysis it is only necessary that we be able to determine a final equilibrium point given the original equilibrium point whichever this point is.

7
This decomposition has been suggested by both Tobin (10) and Arrow (3).

8
One can derive the liquidity preference curve in terms of proportion of wealth held in cash as did Tobin. However, because the relative wealth effect is indeterminate under DARA, shifts in the liquidity preference curve in response to changes in initial wealth cannot be examined.

9
Note that we relaxed the assumption of a constant rate of increase for the MRS curve in order to be able to derive "curved" rather than straight liquidity preference curves.

10
Since under CARA the absolute wealth effect is neutral, a reduction in initial wealth will cause a decrease in cash balances thus shifting the liquidity preference curve inwards.

11
Näslund (8) has examined this case but could not make a definite statement as to the effect of a change in tax since his paper does not introduce the absolute risk aversion function.

12
This is the case discussed by Tobin (10).

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