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ON ALTERNATIVE METHODS OF TREATING RISK

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On Alternative Methods of Treating Risk

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I. Introduction

Two methods for accounting for risk have been suggested in the literature: the certainty equivalent factor (α) and the risk adjusted discount rate (K) methods. Robichek and Myers [3] have analyzed the relation between α and K and concluded that using K "leads to serious contradiction" [3, p. 80]. Chen [1] re-examined the relations between the two risk methods and correctly pointed out that Robichek and Myers' conclusion is incorrect and stems from their failure to recognize that K_t (where t denotes a time period), unlike α_t, reflects in addition to risk and time value of money, a time factor.

In this paper we first reclarify the relationship between α_t and K_t and emphasize that the time pattern of K_t does not necessarily reflect the time pattern of risk. We, then, suggest an alternative indicator of risk (η) which is closely related to K_t but, unlike K_t, is free of the time factor and is thus directly related to risk and α. As an alternative way for neutralizing the time factor we carry out the analysis in terms of the "marginal" rather than the "average" values[1] of K_t and demonstrate that the time-pattern of the marginal discount rate is (unlike the average one) directly related to the time-pattern of risk.

In section II we introduce our suggested indicator of risk (η) and examine the effect of changes in time pattern of risk on the time pattern values of η as well as of K and α. In section III, we carry on the analysis in terms of the marginal rather than the average values of these risk indicators. Lastly, section IV summarizes the paper.

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[1] The meaning of "marginal" and "average" in this context is discussed later.

II. Alternative Indicators of Risk

Before proceeding let us re-examine briefly the relationship between α_t and K_t.

Notation:

P = the present value of a cash flow.

$\bar{C}_t$ = the expected value of a cash flow at time period t.

i = the risk free rate; assumed to be constant over time.

α_t = the certainty cash equivalent factor at time period t.

K_t = the risk adjusted discount rate applicable to time period t.

θ_t = the risk premium applicable to time period t.

The present value of a cash flow can be expressed either by the certainty equivalent method, or by the risk adjusted discount rate method (equations (1) and (2) below, respectively):

$$(1)\quad P = \sum_{t=1}^{n} [\bar{C}_t/(1+i)^t], \qquad (2)\quad P = \sum_{t=1}^{n} [\bar{C}_t/(1+K_t)^t]$$

where K_t is defined as: (3) $K_t \equiv i + \theta_t$

By equating (1) and (2) above one can derive the following alternative relations between α_t, K_t and θ_t:

$$(4)\quad \alpha_t = (1+i)^t/(1+K_t)^t, \qquad (5)\quad K_t = (1+i)/\alpha_t^{1/t} -1,$$

$$(6)\quad \theta_t = (1+i)(1/\alpha_t^{1/t} -1)$$

---

[1]Expressions (4) and (5) have been derived by [3] and [1] respectively.

In the graphical representation below we express the relation given by equation (4) or (5) by ploting the time pattern of K_t for various time patterns of α_t:

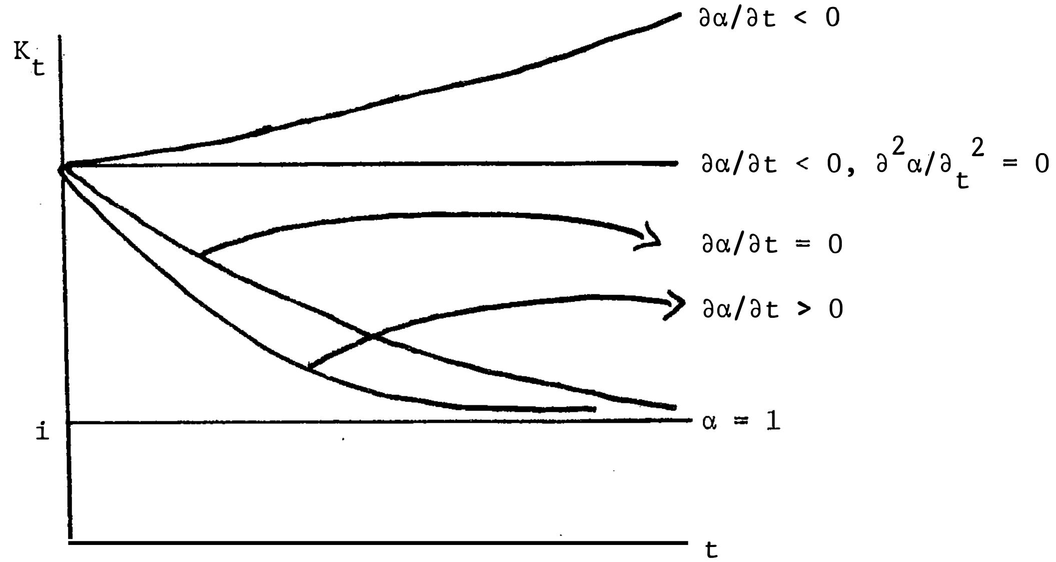

Figure 1. Time pattern of K_t under different time patterns of α_t.

The "deficiency" of K_t to precisely reflect risk is demonstrated particularly in the case where $\partial\alpha/\partial t = 0$. In this case, although risk is constant over time, K_t decreases over time (or in other words θ_t falls over time). Further, when t becomes very large K_t approaches the risk free rate (i.e., $\theta \to 0$) regardless of the degree of risk associated with the cash flow. At first glance this result seems somewhat puzzling. However, it becomes quite clear once one realizes that since K_t (and, hence θ_t) includes a time factor it must fall (when risk is constant over time) in order to offset the increase in the time factor over time. We demonstrate this point more clearly below, by showing that K_t can be decomposed or modified such that the resulting "new" risk indicator is free of the interest rate and time factors and therefore is, unlike K_t and θ_t, directly related to both risk and α.

First, let us express equation (1) by the following form:

$$(7) \quad P = \sum_{t=1}^{n} [\delta_t \alpha_{t-1} \bar{C}_t / (1+i)^t]$$

where α_t is given now by $\delta_t \alpha_{t-1}$ and δ represents the <u>change</u> over time in the risk factor.[1] For simplicity we assume in this analysis that risk changes at a constant rate; i.e., δ is constant over time. α_t is then given by $\alpha_1 \delta^{t-1}$ and equation (7) can be written as:

$$(8) \quad P = \alpha_1 \sum_{t=1}^{n} [\delta^{t-1} \bar{C}_t / (1+i)^t]$$

By equating (2) and (8) (for two time period: t and t+1) and rearranging terms[2] we obtain the following relation between K_t and K_{t+1}:

$$(9) \quad K_{t+1} = (1+K_t)^{t/(t+1)} ((1+i)/\delta)^{1/(t+1)}$$

which shows clearly that (assuming δ is constant) K_{t+1} is not linearly related to K_t just because of the time factor inherent in K_t.

Let us define the new indicator of risk, η, as follows:

$(10) \quad \eta_t \equiv (1+K_t)^t - (1+i)^t$ which implies that $(11) \quad K_t \equiv [(1=i)^t + \eta_t]^{1/t}$

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[1] If risk is constant over time $\delta_t = 1$ and $\alpha_t = \alpha_{t-1}$; if risk increases $0 < \delta_t < 1$ and $\alpha_t < \alpha_{t-1}$; and if risk falls $\delta_t > 1$ and $\alpha_t > \alpha_{t-1}$.

[2] The detailed derivation of equation (9) and other expressions in this paper are available from the author upon request.

Substituting (11) for K_t in equation (2) yields:

$$(12) \quad P = \sum_{t=1}^{n} [\bar{C}_t/(1+i)^t + \eta_t)]$$

Equating (8) and (12) yields the following relation between η_t and α_t:

$$(13) \quad \eta_t = (1+i)^t(1-\alpha_t)/\alpha_t$$

Expressions (10) and (13) demonstrate that η does serve as a measure of risk. To verify this, note that when risk is not present then $\alpha = 1$, $\eta = 0$, $\theta = 0$ and $K = i$; and when risk exists then $0 < \alpha < 1$, $\eta > 0$, $\theta > 0$ and $K > i$.

In order to compare α_t and η_t with respect to a change in the time pattern of risk we first have to derive a relationship between η_t and η_{t+1}. By equating (8) and (12) (for two time periods: t and t+1) and rearranging terms we obtain the following relationship between η_t and η_{t+1}:

$$(14) \quad \eta_{t+1} = \eta_t(1+i)/\delta + (1+i)^{t+1}(1-\delta)/\delta$$

Note that when risk is constant over time (i.e., $\delta = 1$) then $\eta_{t+1} = (1+i)\eta_t$. In other words when risk is unchanged η_{t+1} will differ from η_t by just the interest rate factor. To neutralize this factor we, simply, define a "new" $\hat{\eta}_t$, say $\hat{\eta}_t$, which is given by $(1+i)\eta_t$ so that equation (13) can be written as:

$$(15) \quad \eta_{t+1} = \hat{\eta}_t/\delta + (1+i)^{t+1}(1-\delta)/\delta$$

Since in equation (15) both the time and the interest rate factors are neutralized we must have now a one to one relationship between risk, α_t and η_t. Let us verify this contention:

If risk is constant $\alpha_{t+1} = \alpha_t$ and $\eta_{t+1} = \hat{\eta}_t$.
If risk increases $(0<\delta<1)$, $\alpha_{t+1} < \alpha_t$ and $\eta_{t+1} > \hat{\eta}_t$.
If risk falls $(\delta>1)$ $\alpha_{t+1} > \alpha_t$ and $\eta_{t+1} < \hat{\eta}_t$.

Another method, which is very similar to the certainty equivalent method, is the following: Instead of multiplying the expected value of a cash flow by a factor which is lower than unity (α), one can alternatively multiply the gross risk free discount rate (1+i) by a factor which is greater than unity (denoted below by γ) and varies positively with risk. Using γ, equation (2) can be expressed as follows:

$$(16) \quad P = \sum_{t=1}^{n} [\bar{C}_t/\gamma_t(1+i)^t], \text{ where } (16') \quad \gamma_t \equiv 1/\alpha_t$$

Since γ_t is just the reciprocal[1] of α_t, it is related to K_t by the following relation:

$$(17) \quad K_t = (1+i)\gamma_t^{1/t} - 1 \simeq i + \gamma_t^{1/t} - 1$$

which shows clearly that the reciprocal of the certainty cash equivalent factor (α) is just a (gross) <u>risk premium</u> (γ), but, unlike θ, it is free of the time factor.

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[1]Note also that (16") $\gamma_t = \gamma_1 \delta^{t-1}$.

To demonstrate more explicitly that η_t, like α_t (or γ_t) but unlike K_t, is free of the time effect note that[1]:

(18) $\partial^2\gamma_{t+1}/\partial\gamma_t^{\ 2} = \partial^2\eta_{t+1}/\partial\eta_t^{\ 2} = 0 \neq \partial^2 K_{t+1}/\partial K_t^{\ 2}$

and

(19) $\partial^2\eta_t/\partial\gamma_t^{\ 2} = 0 \neq \partial^2 K_t/\partial\gamma_t^{\ 2}$

which implies that, (assuming δ is constant over time), while η_t is linearly related to η_{t+1} and differs from it just by the risk factor, K_t is not linearly related to K_{t+1} because it reflects a time factor as well as a risk premium. Similarly we find that, for any time period, η is linearly related to γ(or $1/\alpha$) while such a relation does not exist between K and γ.

This brief analysis implies that all the above three models (equations 1, 2 and 12) are correct and equivalent to each other; no one of them is, in theory, superior to the rest. It even seems difficult to argue that one of them has a better economic interpretation than the others. In theory, the time pattern of these alternative indicators of risk can be derived only from the multi-period utility function of the decision maker. Once the time pattern of one of them is derived the others can be easily found since they are closely related to each other. In some cases, for instance stock valuation, we can arrive at only the <u>over-all averages</u> (over time) of these risk indicators, namely α, K and η, by employing a specific stock valuation model.

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[1]Although γ is just the reciprocal of α, it has a better mathematical properties in this context; therefore we use γ, rather than α, in the derivatives above. The reason is that γ, as a measure of a risk premium is (unlike α) positively related to both K and η which include (or serve as a measure of) a risk premium too.

III. Analysis in Terms of Marginal Values

A better understanding of the interrelationship between the various indicators of risk and their relation to the time pattern of risk can be achieved when carrying out the preceeding analysis in terms of the marginal and not the average values of the risk indicators.

Denoting all risk indicators (α, K and η) by, say, F, there are three distinct "types" of F:

1. F^*_t = the marginal risk indicators applicable to time period t only.[1]
2. F_t = the average risk indicator applicable to time period t.
3. F = the overall average (over time) of the risk indicator.

The mathematical relations between the average and the marginal values of each of the risk measures are as follows:

$$(20)\quad \alpha_t = \prod_{j=1}^{t} \alpha^*_t \qquad (20')\quad \alpha^*_t = \alpha_t/\alpha_{t-1} = \delta$$

$$(21)\quad K_t = [\prod_{j=1}^{t} (1+K^*_j)]^{1/t} -1 \qquad (21')\quad K^*_t = [(1+K_t)^t/(1+K_{t-1})^{t-1}] -1$$

$$(22)\quad \eta_t = \sum_{j=1}^{t} \eta^*_j \qquad (22')\quad \eta^*_t = \eta_t - \eta_{t-1}$$

Employing these relations, equations (1), (2) and (12) can be replaced by the following set of equations:

$$(23)\quad P = \sum_{t=1}^{n} [\prod_{j=1}^{t} \alpha^*_j \bar{C}_t/(1+i)^t] \qquad (24)\quad P = \sum_{t=1}^{n} [\bar{C}_t/\prod_{j=1}^{t} (1+K^*_j)]$$

$$(25)\quad P = \sum_{t=1}^{n} [\bar{C}_t/((1+i)^t + \sum_{j=1}^{t} \eta^*_j)]$$

---

[1] It is crucially important to note that F^*_t does not reflect the risk applicable to time period t but only the change in risk from t-1 to t. Thus when risk is, for instance, constant over time, namely, there is no change in risk, all marginal values of α, K and η (i.e., α^*_t, K^*_t and η^*_t) appear as if risk does not exist. This point is made clearer later.

Equating (23), (24) and (25) yields the following relation between the marginal values of the risk indicators:

(26) $K_t^* = (1+i)/\alpha_t^* - 1 \equiv (1+i)\gamma_t^* - 1 = i + \hat{\eta}_t^*/[(1+i)^{t-1} + \eta_{t-1}]$.

From which we can derive[1] the following relationship between the time pattern of risk and the change in the risk measures over time:

I. Risk is constant over time

In terms of marginal value: $\alpha_t^* = \alpha_{t+1}^* = 1$, $K_t^* = K_{t+1}^* = i$ and $\eta_t^* = \eta_t^* = 0$ for $t = 2, 3, \ldots, n$.

In terms of average values: both α_t and $\hat{\eta}_t$ are constant over time, and K_t falls with time due to the time factor <u>only</u>.

II. Risk increases with time[2]

$\alpha_t^* < 1$, $K_t^* > i$ and $\hat{\eta}_t^* > 0$ for $t = 2, 3, \ldots, n$.

In this case α_t decreases, η_t increases, while K_t will increase, decrease or stay constant over time, as risk increases at an increasing, decreasing or constant rate over time, respectively.

III. Risk decreases over time

$\alpha_t^* > 1$, $K_t^* < i$ and $\eta_t^* < 0$ for $t = 2, 3, \ldots, n$.

The average α_t increases, both K_t and η_t decrease with time, and when t becomes very large $\alpha_t \to 1$, $K_t \to i$ and $\eta_t \to 0$.[3]

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[1] Where $\hat{\eta}_t^*$ is given by $\eta_t^* - i\eta_{t-1}$; as before (P. 5) this modification is made in order to neutralize the interest rate factor inherent in η. Using the relevant equations and definitions as above, $\hat{\eta}_t^*$ will be given by: (22") $\hat{\eta}_t^* = [(1+i)(\eta_{t-1} + (1+i)^t)](1-\delta)/\delta$. Note that $\eta_t^* \gtrless 0$ as $\delta \lessgtr 1$, respectively.

[2] In the appendix a neumerical example of this case is contracted.

[3] Footnote (1) P. 8 may help to understand these results.

To demonstrate more explicitly that K_t^*, unlike K_t, is free of the time factor and hence is linearly related to the marginal values of the other risk measures, η_t^* and α_t^* (or γ_t^*), note that by differentiating equation (26) we get the following result:[1]

$$(27)\quad \partial^2 K_t^*/\partial \gamma_t^{2*} = \partial^2 \hat{\eta}_t^*/\partial \gamma_t^{2*} = \partial^2 K_t^*/\partial \eta_t^{2*} = 0$$

Of the three marginal risk measures we choose α_t^* and K_t^* and present below a graphical representation of the time pattern relationship between them as given by equation (26).[2]

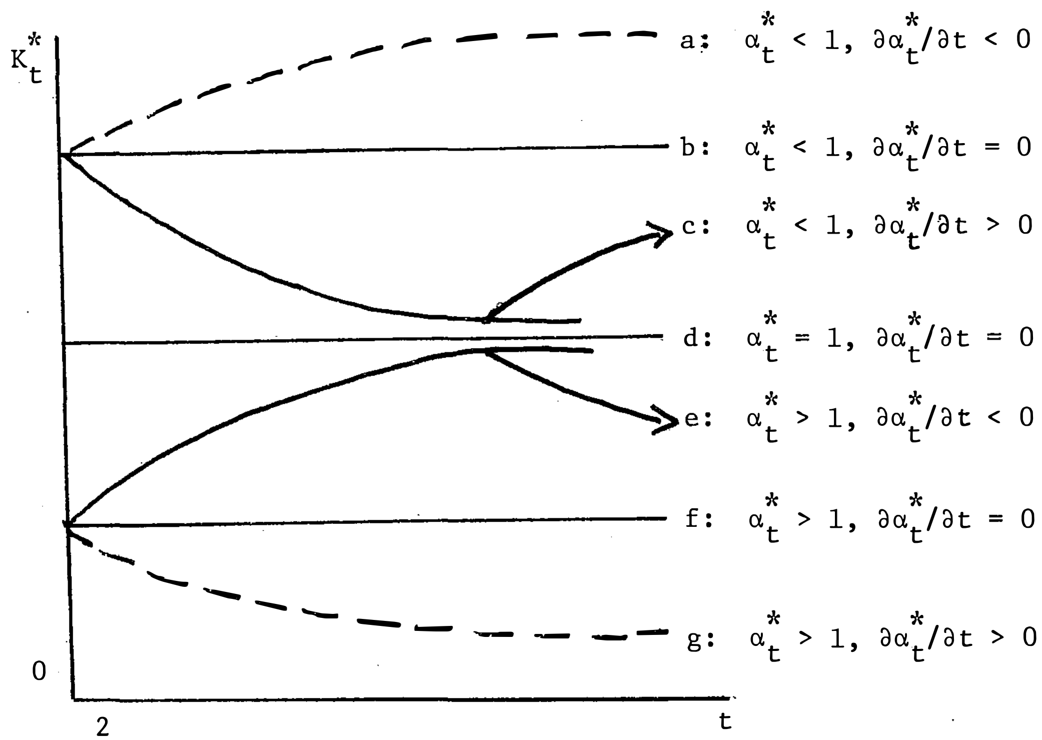

Figure 2. Time pattern of K_t^* under different time pattern of α_t^*.

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[1] Recall footnote (1) P. 7 and compare expressions (19) and (27).

[2] In light of this analysis Robichek and Myers' statement [3 page 80] regarding the marginal discount rate is imprecise; they note that "the greater the over-all risk, the greater the spread between K_τ (our K_t^*) and the riskless rate i_t." However, we have just seen that if risk is constant over time $K_t^* = i$, and if risk decreases over time $K_t^* < i$ regardless of the level of risk associated with the cash flow.

Out of the seven types of time-patterns of risk plotted in Figure (2) we would like to comment on two: (a) and (g) which are denoted by dotted rather than by solid lines. Curve (a) reflects a time pattern of risk that increases at an increasing rate. Depending on the specific rate of increase in risk, K_t^* can behave in one of the following three forms: 1. $\partial^2 K_t^*/\partial t^2 > 0$, 2. $\partial^2 K_t^*/\partial t^2 = 0$, 3. $\partial^2 K_t^*/\partial t^2 < 0$. In figure (2) above we presented only the third form. At the extreme as $t \rightarrow \infty$, both α_t^* and α_t approach 0, and both K_t^* and K_t approach ∞. These extreme mathematical results simply mean that the risk associated with the cash inflow is so high that a risk averse investor will not pay any positive amount to purchase such a cash inflow.

Curve (g), on the other hand, reflects a time pattern of risk that falls at an increasing rate. Equations (26), (20'), (5) and (21') imply, in this case, that as $t \rightarrow \infty$, both α_t^* and α_t approach ∞, and both K_t^* and K_t approach -1.0. These extreme mathematical results are not consistent with the notion of risk aversion since any value of α_t which is greater than a unity means that a risk averse investor is willing to pay for a risky cash inflow a price which is greater than the cash inflow expected value. Therefore, in order to obtain reasonable and consistent results a restriction on the time-pattern behaviour of α_t^* should be incorporated such that both α_t^* and α_t approach a unity and both K_t^* and K_t approach the risk free rate. These values are consistent with the fact that although risk falls at an increasing rate, risk associated with the cash inflow at time period t (regardless of how far t is) still exists (though very small and approaching zero).

V. Summary and Concluding Remarks

Our starting point was the puzzling relationship between change in risk and variation over time in K_t (or θ_t) as given by equations (5), (6) and Figure (1). The most important point that one should be aware of is that the time pattern of K_t (and θ_t) does not necessarily reflect the time pattern of risk. The central reason underlying this result is the fact that K_t reflects, in addition to risk, a time factor; therefore K_t is not directly related to risk. We have shown that once the time factor is neutralized the desired direct relation between risk and the indicator of risk is obtained. The first suggested method for neutralizing the time factor is to decompose or modify K_t such that the "new" resulting reflector of risk (η) is free of the time factor and is therefore perfectly related to risk and α. The second method for neutralizing the time factor is to reformulate the risk-adjusted discount rate formula such that risk is related to the marginal (K_t^*) rather than to the average (K_t) discount rate. K_t^*, as opposed to K_t is free of the time factor and therefore is directly related to both risk and the other "time factor" free indicators of risk.

In conclusion, both the introduction of an alternative indicator of risk (η) and the analysis in terms of the average and marginal values will, hopefully, clarify the effect of changes in the time pattern of risk on the time pattern values of the various measures of risk - an important issue which unfortunately, has not been made clear enough in the literature.[1]

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[1]Various applications of this analysis are presently examined by the author; e.g. see [2].

Appendix

The following neumerical example may help to understand better the interrelationships between the various marginal and average risk indicators.

t	0	1	2	3	4
$\bar{C}_t$	0	1	1	1	1
i	0	.07	.07	.07	.07
α_t	1	.90	.85	.82	.80

This is an example of case (c) in figure (2), namely, risk increases at a decreasing rate. Employing the relevant equations in the preceding analysis we obtain the following results:

t		1	2	3	4
			Marginal values		
$\alpha_t^* = \delta_t$	1	.9000	.9444	.9647	.9756
K_t^*	0	.1889	.1300	.1091	.0968
η_t^*	0	.1189	.0829	.0673	.0587
γ_t^*	0	1.1111	1.0588	1.0366	1.0250
			Average values		
α_t	1	.9000	.8500	.8200	.8000
K_t	0	.1889	.1605	.1432	.1314
η_t	0	.1189	.2018	.2691	.3278
γ_t	0	1.1111	1.1765	1.2195	1.2500

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