IMPACT OF THE INVESTMENT HORIZON ON THE ASSOCIATION BETWEEN SECURITIES' RISK AND RETURN: THEORY AND TESTS

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Abstract

In this paper we develop an analytical model which explains and predicts the following phenomenon: the strength of the association between securities' systematic risk and mean-returns, measured by the explanatory power (R-square) of the estimated Security Market Line, is generally highly sensitive to changes in the length of the investment horizon over which securities' returns are measured. Empirical evidence is presented which supports the model's predictions.

IMPACT OF THE INVESTMENT HORIZON ON THE ASSOCIATION BETWEEN SECURITIES' RISK AND RETURN: THEORY AND TESTS

I Introduction

In this paper we present a theoretical and empirical analysis of the following phenomenon: the strength of the association between securities' systematic risk and their corresponding mean-returns, measured by the explanatory power (R-square) of the estimated Security Market Line (SML) of Sharpe [11] and Lintner [9], is generally highly sensitive to the length of the investment horizon over which securities' returns are measured. For example, the R-square of a monthly SML may significantly differ from the R-square of a daily, a weekly, or a quarterly SML, even though all four lines were estimated over the same calendar period. Evidence of this phenomenon has been reported in this Journal first by Jacob [6] and more recently by Levy [7].[1] It should not be confused with a similar effect exhibited by the explanatory power of a security's characteristic line, the Market Model of Sharpe [12], and reported in this Journal by Schwartz and Whitcomb [10].[2]

In this paper we argue that the sensitivity of the explanatory power of the estimated SML to changes in the length of the investment horizon can be attributed to the presence of serial cross correlations between the returns of securities and the general market movement. Securities' returns, particularly over short differencing intervals, do not more contemporaneously with the market; some may lag behind it while others may lead it[3]. Based on the existence of these lead and lag serial cross dependences, we build a simple model which is powerful enough to explain and to predict the sensitivity of the explanatory power (R-square) of the estimated SML to changes in the investment horizon. Specifically, we show that, as the investment horizon is lengthened, R-square will rise (fall) if the estimated market price of risk (MPR) is positive (negative). R-square will remain constant if the MPR is itself constant as the investment horizon is lengthened.

A quick look at Table 2 will illustrate this phenomenon. For each of eight different calendar periods examined in this study, the first column gives estimates of the MPR over investment horizons of varying lengths. The next column gives the corresponding value of R-square. One can see then when the MPR is positive (negative), R-square falls (rises). When the MPR remains constant, so does R-square. More on the interpretation of Table 2 in section V.

The paper is organized as follows. In the following three sections, we develop our analytical model. Empirical evidence is presented in Section V. The last section is a brief summary.

II Theoretical Background

Consider an investment horizon of T-day length.[4] The SML is usually estimated by running a cross sectional regression between the mean-returns of securities - or portfolios - measured over T-day differencing intervals (denoted $\mu_i(T)$) and their corresponding systematic risk estimated over T-day differencing intervals (denoted b_i (T)) according to:

$$\tilde{\mu}_i (T) = \alpha(T) + \theta(T)\cdot b_i (T) + \tilde{e}_i (T) \quad (1)$$

where $$b_i (T) = \frac{\mathrm{Cov}\ (\tilde{R}_i (T), \tilde{R}_m (T))}{\mathrm{Var}\ (\tilde{R}_m (T))}$$

The tilde indicates a random variable and the hat indicates an estimated value. If the Capital Asset Pricing Model of Sharpe (1964) and Lintner (1965) holds, then the T-day estimated intercept $\hat{\alpha}(T)$ should be equal to the T-day risk free rate and the slope $\hat{\theta}(T)$ is the estimated T-day market price of risk (MPR), a measure of the additional return the financial markets provide investors for bearing one more unit of systematic risk.

The explanatory power of the T-day estimated SML, denoted $R^2(T)$, is:

$$R^2(T) = (\hat{\theta}(T))^2 \frac{\sigma^2(b_i (T))}{\sigma^2(\mu_i (T))} \quad (2)$$

where $\sigma^2(b_i(T))$ is the cross sectional variance of the estimated systematic risks of a sample of securities and $\sigma^2(\mu_i(T))$ is the cross sectional variance of the mean-returns of that same sample of securities.

The purpose of this paper then is to examine analytically and empirically the bahavior of $R^2(T)$ in response to changes in the length T of the investment horizon.

Assume that securities' returns are measured as the logarithm of price relatives (adjusted for cash dividends). Because of the logarithmic form, T-day returns are the sum of one-day returns and the T-day mean-return of of security i can be written[5]:

$$\mu_i\ (T) = T\cdot\mu_i\ (1) \tag{3}$$

where μ_i (1) is the one-day mean-return of security i. Given (3) and recalling that the variance of μ_i (T) in (2) is measured cross-sectionally, that is, with respect to the index i and not with respect to the length T of the investment horizon, $R^2(T)$ can be rewritten as:

$$R^2(T) = (\hat{\theta}(T))^2\frac{\sigma^2(b_i\ (T))}{\sigma^2(T\mu_i(1))} = \left(\frac{\hat{\theta}(T)}{T}\right)^2\frac{\sigma^2(b_i\ (T))}{\sigma^2(\mu_i\ (1))} \tag{4}$$

It is clear from (4) that the relationship between R^2 and T will depend on the relationship between $\hat{\theta}$ and T as well as the relationship between b_i and T. These relationships have been examined analytically and empirically and reported in the literature. It has been shown that[6]:

$$b_i\ (T) = \left[\frac{T + (T-1)\ (\rho_{im}^{-1} + \rho_{im}^{+1})\ /\ \rho_{im}}{T + 2(T-1)\rho_m}\right]b_i(1) = \left[\frac{T + (T-1)q_{im}}{T + 2(T-1)\rho_m}\right]b_i(1) \tag{5a}$$

$$\text{with} \quad 0 < \rho_m < .5 \quad \text{and} \quad 0 < q_{im} < 2 \tag{5b}$$

$$\left.\begin{aligned} &\text{and} \quad \hat{\theta}(T) = \emptyset_{im}\ (T)\cdot\hat{\theta}(1) \\ &\text{with} \quad \emptyset_{im}\ (T) = T \text{ if } q_{im} = \rho_m = 0 \end{aligned}\right\} \tag{6}$$

where ρ_{im}^{-1} is the one-day lag serial cross correlation coefficient between the returns of security i and those on a market-index m, ρ_{im}^{+1} is the one-day lead serial cross correlation coefficient, ρ_{im} is the contemporaneous cross correlation coefficient, and ρ_m is the market-index one-day autocorrelation coefficient. The sum of ρ_{im}^{-1} and ρ_{im}^{+1} divided by ρ_{im} is defined as the q-ratio of security i and denoted q_{im}.

The temporal behavior of $R^2(T)$, that is, the response of R-square to changes in T, can be examined by taking the logarithmic derivative of $R^2(T)$ - see (4) - with respect to the length T of the investment horizon:

$$\frac{1}{R^2(T)} \frac{dR^2(T)}{dT} = \frac{2T}{\hat{\theta}(T)} \frac{d}{dT}\left(\frac{\hat{\theta}(T)}{T}\right) + \frac{1}{\sigma^2(b_i(T))} \frac{d\sigma^2(b_i(T))}{dT} \tag{7}$$

III <u>Temporal Behavior of $R^2(T)$ in the Absence of Correlations</u>

<u>Claim</u>: The absence of correlations ($q_{im} = \rho_m = 0$) is a <u>sufficient</u> condition for the explanatory power of the estimated SML to be invariant to changes in the investment horizon.

<u>Proof</u>: If $q_{im} = \rho_m = 0$, then from (5) and (6) it follows that $\hat{\theta}(T) = T\hat{\theta}(1)$ and $b_i(T) = b_i(1)$. Substituting these expressions into (7) yields:

$$\frac{dR^2(T)}{dT} = \frac{2TR^2(T)}{\hat{\theta}(T)} \frac{d\hat{\theta}(1)}{dT} + \frac{R^2(T)}{\sigma^2(b_i(T))} \frac{d\sigma^2(b_i(T))}{dT} = 0 \tag{8}$$

The derivative of $R^2(T)$ with respect to T being zero, $R^2(T)$ is invariant to T. Q.E.D.

Note that the absence of correlations ($q_{im} = \rho_m = 0$) is a sufficient condition. We show in the next section that R^2 can be invariant to T even in the presence of correlations.

IV Temporal Behavior of $R^2(T)$ in the Presence of Correlations

Claim: In the presence of correlations ($q_{im} \neq 0$, $\rho_m \neq 0$) the explanatory power of the estimated SML will generally rise (fall) in response to an increase in the investment horizon if the estimated market price of risk $\hat{\theta}(T)$ is negative (positive). $R^2(T)$ may be invariant to T, even in the presence of correlations, if $\hat{\theta}(T)$ is itself invariant to T.

Proof: The sign of $dR^2(T)/dT$ depends on that of $d(\hat{\theta}(T)/T)/dT$ and $d\sigma^2(b_i(T)/dT$. Let us first examine the sign of $d\sigma^2(b_i(T))/dT$. Using (5) we can evaluate the sign of this derivative. We have[8]:

$$\frac{d\sigma^2[b_i(T)]}{dT} = \frac{d}{dT}\left\{\sigma^2\left[\frac{(T-1)(1+q_{im})\, b_i(1) + b_i(1)}{T + 2(T-1)\rho_m}\right]\right\}$$

Recalling that the variance is taken with respect to the index i and not with respect to T, we get:

$$\frac{d\sigma^2[b_i(T)]}{dT} = \frac{2\left[(T-1)\sigma^2(b_i(1)\cdot q_{im}) - (1+2\rho_m)\sigma^2(b_i(1)\right]}{\left[T + 2(T-1)\rho_m\right]} \tag{9}$$

The denominator is always positive since $0 < \rho_m < .5$ as pointed out in (5b). The numerator is the difference between two positive terms since $q_{im} > 0$, see (5b). For small values of T, say $T \leqq 3$, the first term in (9) may be larger than the second and the derivative should be negative. When T becomes sufficiently large, the sign of this derivative will turn positive. But, in any case, the value of the derivative will approach zero as the investment horizon T is lengthened. This can be easily seen by noting that the limit of the derivative when T approaches infinity is zero:

$$\lim_{T\to\infty} \frac{d\sigma^2(b_i(T))}{dT} = 0$$

To summarize, for very short investment horizons, the cross sectional variance of a large sample of securities' betas is expected to decrease initially and then rise and remain approximately constant as the investment horizon is lengthened. We will see that this important analytical result is unambiguously supported by the empirical work presented in the next section. Its implication is clear. If $d\sigma^2(b_i(T))/dT$ remains close to zero as T varies, then:

$$\text{Sign}\left\{\frac{dR^2(T)}{dT}\right\} \overset{g}{=} \text{Sign}\left\{\frac{1}{\hat{\theta}(T)}\frac{d}{dT}\left(\frac{\hat{\theta}(T)}{T}\right)\right\} \tag{10}$$

where the letter g above the equality sign means "in general". It has been shown elsewhere that the sign of the term in curly brackets on the right hand side of the equality (10) is negative (positive) when $\hat{\theta}(T)$ is positive (negative). It follows that $R^2(T)$ will generally rise (fall) in response to an increase in T if $\hat{\theta}(T)$ is negative (positive). Furthermore, referring to (10), we can see that when the derivative on the right hand side is zero, so is the one on the left hand side. Thus $R^2(T)$ may be invariant to T, even in the presence of correlations, if $\hat{\theta}(T)$ is itself invariant to T. Q.E.D.

V Empirical Evidence

The data are from the Center for Research in Security Prices. Observations begin on July 3, 1962 and end on December 31, 1976. The sample has 1115 securities; these are all the securities in the file for which "full length" observations were available. The proxy for the market portfolio is a value-weighted index comprising a maximum of 3950 securities with weights in proportion to the total market value of the outstanding securities that day.

Estimates of $\sigma^2(b_i(T))$, $\hat{\theta}(T)/T$ and $R^2(T)$ were obtained over eight calendar periods of varying lengths (see Tables 1 and 2) for differencing intervals of 1 day (T = 1) , 2 days (T = 2), 3 days (T = 3), 4 days (T = 4), 1 week (T = 5), 2 weeks (T = 10), 3 weeks (T = 15), and one month (T = 20).

The time behavior of the sample cross sectional variance is reported in Table 1 for the 8 different calendar periods. As predicted by the model developed in the previous sections, $\sigma^2(b_i(T))$ initially falls then rises and remains approximately constant as the investment horizon is lengthened.

Also reported in Table 1 are the average values of the daily q-ratio (q_{im}) and the value of the first-order daily autocorrelation coefficient. These coefficients are positive and their values are consistent with condition (5b).[10] Note that the number of observations per calendar period depends on the length of the investment horizon. In order to determine the number of observations per calendar period, one should simply divide the number of daily observations given in the lower part of Table 1 by T which is given in the first column of Table 1. For example, for period 4, the number of monthly observations (T = 20) is equal to 900 divided by 20, that is, 45 observations.

The time behavior of $R^2(T)$ is reported in Table 2. As predicted by the model, $R^2(T)$ rises when the MPR is negative. This is the case for the first, third, sixth and eighth period. When MPR is positive, $R^2(T)$

falls as indicated by the results for the second and seventh period. We have also predicted that when the MPR remains constant, so will $R^2(T)$ regardless of the sign of MPR and even if correlations are non-zero. This is (approximately) the case for the fourth and fifth subperiod.

The results reported in Table 2 call for the following additional comments:

1) The estimated values of the MPRs are annualized by multiplying $\hat{\theta}(T)$ by (250/T) under the assumption that the year has 250 trading days. This allows us to interpret the results and make meaningful comparisons without converting the numbers presented in Table 2. For example, for calendar period 2, the estimated daily SML (T = 1) indicates that the daily MPR was 11.82% on an annual basis; this is the compensation received by investors holding a diversified portfolio with a systematic risk of one. However, the estimated monthly SML indicates that the monthly MPR was only 5.18% on an annual basis even though both MPRs were estimated over the same calendar period.

2) The results summarized in Table 2 point out that there are calendar periods over which the estimated SML based on daily returns is statistically more significant than the estimated SML based on monthly returns. Both Jacob [6] and Levy [7, 8] using monthly returns as the shortest interval, have concluded from their work that the significance and the explanatory power of the estimated SML generally increase with the length of the investment horizon. One should be very careful in generalizing these empirical results to submonthly investment horizon. Our work clearly shows the impact of the investment horizon on the MPR and the

SML's R-square are quite complex for shorter interval and do not always increase with the investment horizon.

3) The empirical results presented in Table 2 are, to our knowledge, the the first study of the association between the risk and return of individual common stocks based on submonthly returns.

4) Finally, we should emphasize that when we state that $R^2(T)$ rises or falls, we do not imply that the alternative values of $R^2(T)$ are statistically significantly different from each other. Again, one should be careful on this point and not infer from Table 2 that, for example, in period 2, daily intervals are "better" than monthly intervals because the former provide a better fit between risk and return. Since the various $R^2(T)$ are estimated over the same calendar period, we can hypothesize that they are all calculated from samples (different values of T corresponding to different samples) drawn from the same population. We can then test for the homogeneity of the different values of R-square using a χ^2 test. First, for a given calendar period, we convert the square root of each R-square into Fisher's Z value[11] and calculate the following statistics[12]:

$$\chi^2 = \Sigma_1^{k=8} (n_i - 3) Z_i^2 - \frac{\left[\Sigma_1^{k=8} (n_i - 3) Z_i\right]^2}{\Sigma_1^{k=8} (n_i - 3)}$$

with $k - 1 = 7$ degrees of freedom, where $k = 8$ is the number of R^2 observations for a given calendar period and n_i is the number of observations in each of the $k = 8$ samples. For example, for period one, $n_1 = 1800$, $n_2 = 900$, $n_3 = 600$, $n_4 = 450$, $n_5 = 360$, $n_6 = 180$, $n_7 = 120$, and $n_8 = 90$.

We obtain:

χ^2(period 1)	=	13.61	χ^2(period 5)	=	0.50
χ^2(period 2)	=	7.57	χ^2(period 6)	=	2.71
χ^2(period 3)	=	10.64	χ^2(period 7)	=	1.50
χ^2(period 4)	=	1.23	χ^2(period 8)	=	6.61

At the 5% level of significance and 7 degrees of freedom, the critical value of χ^2 is 14.07, which is above the computed χ^2 values. Therefore, we can conclude that within each of the 8 periods analyzed, the various values of R-square can be considered estimates of the same population value despite the wide differences that may exist between them.

For each calendar period, we can calculate the weighted average value of the Z:

$$\bar{Z} = \frac{\Sigma_{1}^{k=8} (n_i - 3)\, Z_i}{\Sigma_{1}^{k=8} (n_i - 3)}$$

and may consider this value as an estimate of the common population value of R-square based on the combined data from the eight samples. After conversion from $\bar{Z}$ to $\bar{R}^2$, we get:

$\bar{R}^2$(period 1)	=	.0473	$\bar{R}^2$(period 5)	=	.1789
$\bar{R}^2$(period 2)	=	.1452	$\bar{R}^2$(period 6)	=	.0538
$\bar{R}^2$(period 3)	=	.0210	$\bar{R}^2$(period 7)	=	.3169
$\bar{R}^2$(period 4)	=	.1892	$\bar{R}^2$(period 8)	=	.0734

For example, over calendar period 7, R-square varies from 34.59% to 24.89% but we can consider 31.69% as an estimate of the common population of R-square.

VI Conclusion

In this paper we presented an analytical model which explains and predicts the behavior of the explanatory power of the estimated SML in response to changes in the length of the investment horizon over which the returns of securities are measured. Our empirical evidence using investment horizons varying from a day to a month for a sample of 1115 securities over eight different calendar periods is consistent with the predictions of the model.

TABLE 1

Time-behavior of $\sigma^2(b_i(T))$ and estimates of mean (q_{im}) and ρ_m

Investment Horizon (T)	Period 1 10/69-11/76	Period 2 7/62-4/67	Period 3 2/72-11/76	Period 4 10/69-4/73	Period 5 5/65-3/68	Period 6 3/68-3/71	Period 7 11/64-4/67	Period 8 2/72-7/47
1 day (T = 1)	.185	.319	.191	.324	.402	.267	.419	.264
2 days (T = 2)	.168	.252	.170	.265	.328	.271	.332	.257
3 days (T = 3)	.162	.247	.160	.257	.327	.265	.329	.244
4 days (T = 4)	.158	.247	.161	.263	.326	.279	.346	.268
1 week (T = 5)	.159	.235	.163	.257	.316	.288	.326	.272
2 weeks (T = 10)	.173	.233	.175	.256	.312	.338	.342	.309
3 weeks (T = 15)	.162	.261	.171	.221	.315	.372	.376	.331
1 month (T = 20)	.198	.294	.201	.362	.507	.441	.558	.391
No. of daily observations	1800	1200	1200	900	720	720	600	600
Average q_{im}	0.764	0.534	0.729	0.789	0.590	0.884	0.721	0.773
ρ_m	0.300	0.165	0.280	0.356	0.229	0.293	0.279	0.296

Note: The number of observations per period where the investment horizon is longer than a day is obtained by dividing the number of daily observations by T. For example, for period 4, the number of monthly observations is equal to (900/20) = 45.

<u>TABLE 2</u>

Time-behavior of the market price of risk $\hat{\theta}(T)/T$ and the explanatory power $R^2(T)$ of the estimated SML

Investment Horizon (T)	Period 1 10/69-11/76		Period 2 7/62-4/67		Period 3 2/72-11/76		Period 4 10/69-4/73		Period 5 5/65-3/68		Period 6 3/68-3/71		Period 7 11/64-4/67		Period 8 2/72-7/74	
	MPR(T)	R^2(T)	MPR(T)	R^2(T)	MPR(T)	R^2(T)	MPR(T)	R^2(T)	MPR(T)	R^2(T)	MPR(T)	R^2(T)	MPR(T)	R^2(T)	MPR(T)	R^2(T)
1 day	-.0461	.0305	.1182	.1733	-.0309	.0094	-.1365	.1884	.1193	.1834	-.0795	.0416	.1990	.3451	-.1054	.0529
2 days	-.0620	.0500	.1013	.1454	-.0461	.0185	-.1429	.2007	.1323	.1841	-.0949	.0601	.1872	.3065	-.1271	.0748
3 days	-.0655	.0538	.0902	.1394	-.0519	.0225	-.1396	.1925	.1264	.1650	-.0930	.0565	.1831	.2940	-.1245	.0681
4 days	-.0657	.0526	.0880	.1325	-.0627	.0325	-.1415	.1766	.1236	.1594	-.0882	.0533	.1820	.3037	-.1238	.0739
1 week	-.0652	.0525	.0819	.1095	-.0671	.1378	-.1288	.1485	.1426	.1794	-.0886	.0557	.1862	.2994	-.1271	.0862
2 weeks	-.0856	.0982	.0717	.0831	-.0893	.0717	-.1381	.1997	.1341	.1804	-.0901	.0678	.1741	.2766	-.1245	.1310
3 weeks	-.1058	.1404	.0788	.1122	-.1099	.1064	-.1431	.1966	.1340	.1815	-.1815	.1255	.1692	.2844	-.1538	.1416
1 month	-.1055	.1707	.0518	.0546	-.1343	.1347	-.1377	.2292	.1105	.1985	-.1985	.1534	.1370	.2489	-.1623	.1855

Notes:

- MPR(T) are annualized, i.e., MPR(T) = $250\hat{\theta}(T)/T$, assuming the year has 250 daily observations.
- All MPR(T) are statistically significant at the 5% level.
- We do not present the results of 12 other periods of varying calendar lengths because the R-squares and MPRs for the SML in these periods, for all the investment horizons, are not significantly different from zero.

FOOTNOTES

1. For additional evidence of this phenomenon, see also Levy [8].

2. For additional evidence of this phenomenon, see also Hawawini [3].

3. Empirical evidence of the presence of these serial cross correlations as well as an economic justification of the existence can be found in Hawawini [4]. In this respect, see also the paper by Cohen et al. [1].

4. The choice of the shortest interval is irrelevant to the model developed in this paper. Daily returns were selected in order to have a sufficient number of observations when the investment horizon is lengthened by multiples of the shortest horizon.

5. We have $\mu_i(T) = E\left[\sum_T R_i(1)\right] = \sum_T E(R_i(1)) = \sum_T \mu_i(1) = T\mu_i(1)$.

6. For $b_i(T)$ see Hawawini [3]. For $\hat{\theta}(T)$ see Hawawini and Vora [5].

7. It is worth pointing out that ρ_m is a function of q_{im}. In general, if $q_{im} = 0$, then $\rho_m = 0$. For details, see Hawawini [4].

8. For the convenience of mathematical manipulation, the numerator of $b_i(T)$ has been slightly modified by adding and subtracting one.

9. The proof of this statement is in Hawawini and Vora [5]. It is not repeated here for sake of brevity.

10. Note that condition (5b) applies to individual securities whereas the values reported in Table 2 are the averages of the q-ratios of 1115 securities.

11. Fisher Z transformation is given by:

$$Z = \frac{1}{2} \log_e (1+R) - \log_e (1-R)$$

where R is the square root of R-square. For details, see Edwards [2]. R. A. Fisher has shown that the distribution of Z is approximately normal in form and for all practical purposes this distribution is independent of the population value of R-square.

12. See Edwards [2], p. 81.

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