財團法人中華經濟研究院
CHUNG-HUA INSTITUTION FOR ECONOMIC RESEARCH
75 Chang-Hsing St., Taipei, Taiwan, 106
Republic of China
TEL : 886-2-735-6006
FAX : 886-2-735-6035

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THE DYNAMIC SELF-HEDGED BEHAVIOR DURING THE PERIOD OF 1987 CRASH: EVIDENCE FROM THE U.S. STOCK MARKET

ANTHONY H. TU

DISCUSSION PAPER SERIES No.9405
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by
Anthony H. Tu

Associate Research Fellow
Chung-Hua Institution for Economic Research

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75 Chang-Hsing St., Taipei, Taiwan 106

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ANTHONY H. TU*

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Abstract

The paper examines the investors' dynamic self-hedged behavior in a market where information is transmitted across sequential trading periods. In a two-period economy, the signal which aggregates the information revealed from the period that trades earlier is transmitted to the period that trades later. Facing the observable probability distributions of asset returns, the distribution of the signal, as well as the linear relationship between asset returns and signal, investors, who allocate their investment funds over two periods, have to hold a dynamic self-hedged portfolio in the earlier period. The self-hedged portfolio is defined as the one that can be used to hedge against the possible risk resulting from information transmission and can minimize the investors' risk. The Security Market Line (SML) in the earlier period is also modified to reflect the hedged behavior. In the modified SML, the expected excess return and risk premium in the earlier period contain not only the expected excess return and variance from the earlier period, but also those from the later period. The empirical evidence is found in the U.S. stock market during the period of 1987 crash.

*Associate Research Fellow, The Chung-Hua Institution for Economic Research.

I. Introduction

In a financial market, information in the period that trades earlier is always transmitted to the period that trades later. Stock prices in the later period will exhibit volatilities in response to the information revealed from the earlier period. In a market with information transmission, investors, who allocate their investment funds over two periods and seek for mean-variance efficiency, have to modify their portfolio combinations in each period in order to hedge against the possible risk arising from information transmission. In the later period, the modified portfolio holding is only the original portfolio conditional on the information revealed from the earlier period. In the earlier period, we found in this paper that investors, facing the observable probability distributions of asset returns, the distribution of the signal, as well as the linear relationship between asset returns and signal, will hold a ''dynamic self-hedged portfolio''. This modified portfolio can minimize invertors' risk in the market with information transmission. The optimal holdings of assets in the dynamic self-hedged portfolio are determined not only by the expected return and variance from the earlier period, but also by those from the later period.

With the hedged behavior, the usual asset pricing model (such as CAPM) fails to correctly interpret the linear relationship between expected return and risk. A modification of asset pricing model reflecting the hedged behavior is needed. Our results indicate that the expected excess return and risk premium in the modified CAPM contain the expected excess return and variance from the earlier period, as well as those from the later period. This modified CAPM can be roughly treated as a three-factor model. Besides the usual factors of riskless rate and market return in the earlier period, the extra factor appeared in the model is the expected excess return from the later period. Our empirical result indicates that the dynamic self-hedged behavior is obviously present in the U.S. stock market during the period of stock market crash in October 1987.

Our model proposes a new challenge of using typical Security

Market Line (SML) as a performance measurement. To use the SML as a performance measurement, a proper modification of the SML reflecting such information effects is needed.

This paper is organized as follows: In Section II, we derive the investor's optimal asset holding in a two-period market with information transmission. The discrete-time backward dynamic programming is employed. Section III examines the properties of the hedged portfolio. The modified SML is also derived. In Section IV, a set of data is adopted to test the modified SML. The Generalized Method of Moments is employed. Finally, section V summarizes the main conclusions in the paper.

II. Basic Model and Assumptions

The model, as shown in Figure 1, contains two periods and three times 0, 1, and 2 in a market. Period 1 begins at time 0 and ends at time 1. Period 2 begins at time 1 and ends at time 2. The two-period model represents two consecutive trading periods in a particular stock market. The market contains m risky assets, whose return vectors are $\tilde{\underline{R}}_t - \underline{l}$, t=1, 2 (where $\underline{l}$ denotes the vector containing all ones) for period 1 and 2, respectively, and a riskless asset, whose return is r_t-1, t=1, 2 for period 1 and 2, respectively.

The vector, $\tilde{\underline{\theta}}$, representing the signal released from period 1, is transmitted to period 2 at time 1. The signal is assumed to follow the multivariate normal distribution (MN) with expected value $\underline{\mu}_\theta$ and

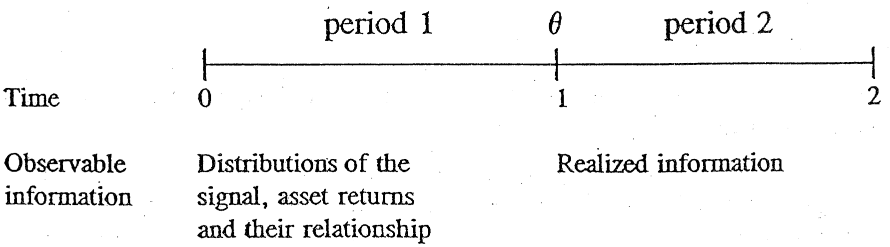

Figure 1

variance Σ_θ[1]. That is

Assumption 1 (A1): $\underline{\theta} \sim MN(\mu_\theta, \Sigma_\theta)$

The relationship between asset returns and the signal can be described as follows:

A2: The asset returns have the following linear relationship with the signal:

$$\underline{\tilde{R}}_1 = \underline{a}_1 + B_1 \underline{\tilde{\theta}} + \underline{\tilde{u}}$$

$$\underline{\tilde{R}}_2 = \underline{a}_2 + B_2 \underline{\tilde{\theta}} + \underline{\tilde{v}}$$

and

$$cov(\underline{\tilde{u}}, \underline{\tilde{v}}) = 0, \quad cov(\underline{\tilde{\theta}}, \underline{\tilde{u}}) = 0 \quad and \quad cov(\underline{\tilde{\theta}}, \underline{\tilde{v}}) = 0$$

where

$\underline{a}_1$ ($\underline{a}_2$) is the regression intercept vector for period 1 (2)

B_1 (B_2) is the regression coefficient matrix for period 1 (2)

$\underline{\tilde{u}} \sim MN(\underline{o}, \Sigma_u)$ and $\underline{\tilde{v}} \sim MN(\underline{o}, \Sigma_v)$ denote the error vectors that are assumed to be multivariate normally distributed.

In the model, we assumed that there exists a unique investor in the market. The representative investor in the model is assumed to have the constant absolute risk aversion (CARA). Further,

A3: The investor has an exponential utility function, which is defined as follows[2]:

$$U(\tilde{W}) = -\exp(-\delta \tilde{W}) \qquad \delta > 0 \tag{1}$$

where

δ is the coefficient of risk aversion for the investor

[1] In this paper, the variable with the low bar denotes the vector and the capital letter denotes the matrix.

[2] The use of an exponential utility function is important to the analysis in the paper, because it has the well-known property that demand correspondences for risky assets depend upon a trader's beliefs, but not directly on his wealth. Further, without assuming an exponential utility function, the equilibrium distribution of prices would be difficult to characterize, and it is highly unlikely that a closed-form expression could be obtained.

$\tilde{W}$ is the investor's final wealth at the end of his (or her) investment.

Further, the investor is assumed to be able to observe the distribution of asset returns, the distribution of the signal, and the linear relationship between asset returns and the signal when the market opens. He (or she) also knows the information content when the signal is realized. That is

A4: At time 0, the distributions of asset returns in both periods, the distribution of the signal, and the linear relationship between asset returns and the signal can be observed by the investor. At time 1, the signal is realized and its content becomes common knowledge.

The basic structure of the above model can be illustrated by the following example. Suppose that the market denotes, respectively, the New York and American Stock Exchange together. While $\underline{R}_1$ denotes the stock return in the market at day t, $\underline{R}_2$ denotes the stock return in the market at day t+1. The signal, which aggregates the information generated from day t, is transmitted to day t+1. The elements in signal vector can be, for instance, the S&P 500 index, unexpected change of the U.S. interest rate, etc.

From A2, the following results can be obtained directly.

$\underline{\mu}_1 \equiv E(\tilde{\underline{R}}_1) = \underline{a}_1 + B_1 \underline{\mu}_\theta$ denotes the mean of return vector $\tilde{\underline{R}}_1$

$\underline{\mu}_2 \equiv E(\tilde{\underline{R}}_2) = \underline{a}_2 + B_2 \underline{\mu}_\theta$ denotes the mean of return vector $\tilde{\underline{R}}_2$

$\Sigma_1 \equiv VAR(\tilde{\underline{R}}_1) = B_1 \Sigma_\theta B_1' + \Sigma_u$ denotes the variance of return vector $\tilde{\underline{R}}_1$

$\Sigma_2 \equiv VAR(\tilde{\underline{R}}_1) = B_2 \Sigma_\theta B_2' + \Sigma_v$ denotes the variance of return vector $\tilde{\underline{R}}_2$

$\Sigma_{12} \equiv COV(\tilde{\underline{R}}_1, \tilde{\underline{R}}_2) = B_1 \Sigma_\theta B_2'$ denotes the return covariance between the two periods.

$\underline{\mu}_{2|\theta} \equiv E(\tilde{\underline{R}}_2 | \underline{\theta}) = \underline{a}_2 + B_2 \underline{\theta}$ denotes the mean of $\tilde{\underline{R}}_2$ conditional on the signal.

$\Sigma_{2|\theta} \equiv VAR(\tilde{\underline{R}}_2 | \underline{\theta}) = \Sigma_2 - B_2 \Sigma_\theta B_2'$ denotes the variance of $\tilde{\underline{R}}_2$ conditional on the signal.

A5: The market is completely competitive. The investor is only a naive price taker.

In order to focus on the financial security market, we examine only a pure exchange economy and take the consumption decision of the investor as given. The investor, facing observable information, will allocate his investment fund over riskless and risky assets in two periods to obtain the maximization of his expected utility. As shown in Figure 2, the investor invests his initial wealth (W_0) in the first period at time 0. At time 1, when the return $\underline{\tilde{R}}_1$ and r_1 are realized, he keeps all of his realized wealth (W_1) in the market for the second period. His goal is to maximize his expected utility of final wealth at the end of the second period (W_2), subject to his budget constraint.

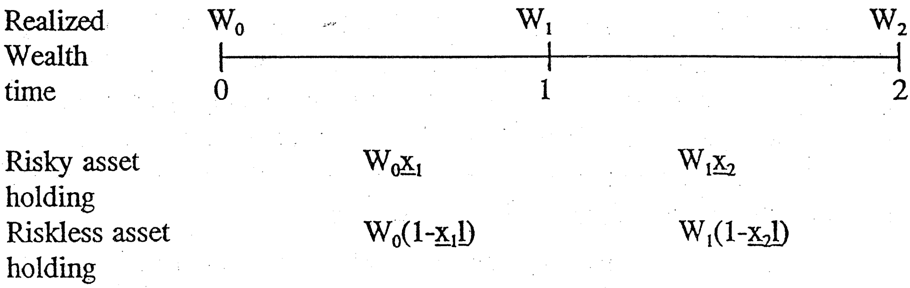

Figure 2

The expected utility maximization problem for the investor can be expressed as follows:

$$\underset{\underline{x}_1,\underline{x}_2}{Max} E_0[U(\tilde{W}_2)] \tag{2}$$

Where

E_t denotes the expectation conditional on the information available at time t.

$\underline{x}_1$ and $\underline{x}_2$ denote, respectively, the investor's optimal holdings of risky assets on period 1 and 2.

In the maximization problem (2), the investor's final wealth at the end of period 2 is

$$\tilde{W}_2 = W_1 \; [\underline{x}_2^{\prime}\underline{\tilde{R}}_2 + r_2(1 - \underline{x}_2^{\prime}\underline{I})] \\ = W_1[r_2 + \underline{x}_2^{\prime}(\underline{\tilde{R}}_2 - r_2\underline{I})] \tag{3}$$

and the investor's wealth at the end of period 1 is

$$\tilde{W}_1 = W_0[r_1 + \underline{x}_1^{\prime}(\underline{\tilde{R}}_1 - r_1\underline{I})] \tag{4}$$

To find the investor's optimal asset holdings in the first and second periods, a backward discrete-time dynamic programming is employed. Its first task is to solve the second-period maximization problem to find its investor's optimal asset holding $\underline{x}_2$, and then to compute the realized maximization in the second period. Together with the realized maximization in the second period, the programming then solves the first-period maximization problem to obtain its investor's optimal asset holding $\underline{x}_1$.

As derived in Appendix, the investor's optimal holdings of risky assets in the second and first periods are, respectively,

$$W_1\underline{x}_2 = \frac{1}{\delta}\Sigma_{2|\theta}^{-1}(\underline{\mu}_{2|\theta} - r_2\underline{I}) \tag{5}$$

and

$$W_0\underline{x}_1 = \frac{1}{\delta r_2}[\Sigma_1 - \Sigma_{12}\Sigma_2^{-1}\Sigma_{21}]^{-1}\{(\underline{a}_1 + B_1\underline{\mu}_\theta - r_1\underline{I}) - \Sigma_{12}\Sigma_2^{-1}(\underline{a}_2 + B_2\underline{\mu}_\theta - r_2\underline{I})\} \tag{6}$$

The newly derived optimal asset holdings ((5) and (6)) are unambiguously distinct from those in an economy without information transmission. In a period, the investor's optimal asset holding in an economy[3] without information transmission is equal to the product of expected excess return vector and the inverse of variance matrix in that period, divided by the investor's coefficient of risk aversion. No factors from other trading periods affect the determination of the investor's optimal asset holding in that period.

As shown in (5), the investor's optimal asset holding in the second period is determined by the expected return and the variance in the second period conditional on the information revealed from the first period. The relationship can be explained by the fact that the investor in the second period, whose trading occurs later, can observe the realized information revealed from the first period.

In the first period, the investor's optimal asset holding is, as shown in (6), to hold a "dynamic self-hedged portfolio" (or hedged portfolio, hereafter). The expected excess return of the hedged portfolio is a linear combination of expected excess returns from both periods. The variance of the hedged portfolio is equal to the variance in the first period with a deduction, which includes the covariance and the inverse of variance from the second period. (The properties of the hedged portfolio will be further described in the next section.) Thus, the investor's optimal asset holding in the first period is equal to the product of the hedged portfolio's expected excess return and the inverse of the hedged portfolio's variance, divided by the

[3] The investor's optimal asset holding in an economy without information transmission can be obtained by solving the same investor's expected utility maximization problem (2) with relaxation of the linear relationship between asset returns and the signal in Assumption 2. Those for the second and first periods are, respectively,

$$W_1 \underline{x}_2 = \frac{1}{\delta} \Sigma_2^{-1} (\underline{a}_2 - r_2 \underline{l})$$

where $\Sigma_2 = \Sigma_v$, and

$$W_0 \underline{x}_1 = \frac{1}{\delta} \Sigma_1^{-1} (\underline{a}_1 - r_1 \underline{l})$$

where $\Sigma_1 = \Sigma_u$

investor's coefficient of risk aversion and the interest rate in the second period. In other words, the investor's optimal asset holding in the first period is determined by the expected return and variance from the first period, as well as by those from the second period.

The form of investor's asset holding in (6) is quite important. It implies that the investor in the first period, facing the observable probability distributions of asset returns, the distribution of the signal, as well as the linear relationship between asset returns and signal, will hold a hedged portfolio. With the hedged portfolio, the investor can hedge against the risk arising from the information transmission and can, as shown in the next section, minimize his risk.

The conditional form of optimal asset holding in the second period has been long and widely recognized. However, the hedged portfolio, held by the investor in the first period has not received any attention. In the remainder of this paper, we will concentrate on the examination of the investor's hedged behavior.

III. Economic Implications and Modified Security Market Line

A. The Properties of the Dynamic Self-Hedged Portfolio

As shown in the last section, the investor's optimal asset holding in a market with information transmission across trading periods is to hold a hedged portfolio in the first period. The hedged portfolio is designed such that its return is equal to $\underline{\tilde{R}}_1^* = \underline{\tilde{R}}_1 - \Sigma_{12}\Sigma_2^{-1}\underline{\tilde{R}}_2$. Its probability distribution is $MN(\underline{\mu}_1^*, \Sigma_1^*)$, where

$$\underline{\mu}_1^* \equiv E(\underline{\tilde{R}}_1^*) = \underline{a}_1 + B_1\underline{\mu}_\theta - \Sigma_{12}\Sigma_2^{-1}(\underline{a}_2 + B_2\underline{\mu}_\theta - r_2\underline{I})$$

and

$$\Sigma_1^* \equiv VAR(\tilde{R}_1^*) = \Sigma_1 - \Sigma_{12}\Sigma_2^{-1}\Sigma_{21}$$

which are, respectively, the expected return and the variance that appeared in (6).

The holding of the hedged portfolio, as previously shown, represents the investor's expected utility maximization. The achievement of expected utility maximization is based on the sense that investor's risk is minimized given expected asset return. The following properties show why the holding of the hedged portfolio can drive the investor into such a position.

Property 1: The return of the hedged portfolio, $\underline{\tilde{R}}_1^{\star}$ is independent of the return to be in the second period $\underline{\tilde{R}}_2$.

The above property can be directly obtained by examining the covariance between $\underline{\tilde{R}}_1^{\star}$ and $\underline{\tilde{R}}_2$. The property implies that the investor's holding of hedged portfolio in the prior period will lead to such a situation that asset return in the prior period is independent of that in the later period. As we know, the total risk position for the investor holding risky assets in two periods will be minimized when asset return processes in the two periods are independent. Thus, the investor's risk minimization is arrived. The other property explaining why the hedged portfolio can minimize the investor's risk, is that the variance of the hedged portfolio is minimized relative to those for the portfolios with any other combinations. This is shown in the next property.

Property 2: For any matrix Ω

$$Var(\underline{\tilde{R}}_1 - \Sigma_{12}\Sigma_2^{-1}\underline{\tilde{R}}_2) \leq Var(\underline{\tilde{R}}_1 - \Omega\underline{\tilde{R}}_2) \tag{7}$$

The above property indicates that the risk for the investor who holds the hedged portfolio is smallest relative to those for the investor who holds portfolios with any other combinations. The special case

Ω =0 means that the risk for the investor who holds the hedged portfolio is smaller than that for the investor who holds only the first-period portfolio.

B. Modified Security Market Line

As described previously, the optimal asset holding in an economy without information transmission becomes invalid if information transmission and hedged behavior exist. Similarly, the usual asset pricing model fails to correctly interpret the linear relationship between expected return and risk. In this subsection, we will modify the SML to reflect the hedged behavior.

As previously shown, the investor's optimal asset holding in the first period is to hold a hedged portfolio. The corresponding SML is modified as follows:

Proposition : In a market with the conditions described in section II, the modified SML in the first peiod can be written in the following form:

$$\underline{\mu}_{1\cdot 2} - r_1 \underline{l} = \underline{\beta}_{1\cdot 2}(\alpha_{1\cdot 2} - r_1) \tag{8}$$

where

$\underline{\mu}_{1\cdot 2} = \underline{a}_1 + B_1\underline{\mu}_\theta - \Sigma_{12}\Sigma_2^{-1}(\underline{a}_2 + B_2\underline{\mu}_\theta - r_2\underline{l})$ denotes the expected return of the hedged portfolio.

$\underline{\beta}_{1\cdot 2} = \dfrac{[\Sigma_1 - \Sigma_{12}\Sigma_2^{-1}\Sigma_{21}]\underline{x}_1}{\underline{x}_1'[\Sigma_1 - \Sigma_{12}\Sigma_2^{-1}\Sigma_{21}]\underline{x}}$ denotes the beta coefficient. The beta coefficient is defined as the covariance between hedged portfolio and market hedged portfolio divided by the variance of market hedged portfolio.

$\alpha_{1\cdot 2} = \underline{x}_1'[\underline{a}_1 + B_1\underline{\mu}_\theta - \Sigma_{12}\Sigma_2^{-1}(\underline{a}_2 + B_2\underline{\mu}_\theta - r_2\underline{l})]$ denotes the expected return of market hedged portfolio.

The expected excess return and risk premium in the modified SML contain not only the expected excess return and variance from the first period, but also those from the second period. A direct implication of the above result is that the use of typical SML in testing the market performance faces a severe challenge. Traditional tests of security market performance seems incorrect when the market has information transmission and hedged behavior. The adequate SML must be able to reflect the information effects. Our modified SML provides an appropriate model in testing the market performance[4].

IV. Empirical Test

The modified SML (8) can be reexpressed as

$$\underline{\mu}_1 - r_1 \underline{l} = \underline{\beta}(\alpha_1 - r_1) + \Gamma(\underline{\mu}_2 - r_2 \underline{l}) \tag{9}$$

where

$\underline{\beta} \equiv \underline{\beta}_{1.2}$

$\Gamma = [I - \underline{\beta}_{1.2} \underline{x}_1'] \Sigma_{12} \Sigma_2^{-1}$ is a (m x m) coefficients matrix

The equation (9) can be roughly treated as a three-factor CAPM. Besides the usual factors of riskless rate and market return in the first period, the extra factor appeared in the equation is the expected excess return from the second period.

The ex post form of (9) is[5]

[4] Other related issues about the inappropriate use of SML as a performance measurement have previously been investigated in a number of studies. For instance, a group of studies related to information issue were made by Dybvig and Ross (1985) and Mayers and Rice (1979). They show that the use of SML as measure of performance is inadequate when differential information exists among traders. The traders who are informed can have superior performance.

[5] The first step necessary to empirically test the theoretical CAPM is to transform it from ex ante form (expectations cannot be measured)into ex post form that uses observed data. This can be done by simply assuming that returns are normally distributed and that capital markets are efficient in a fair game sense.

$$\tilde{\underline{q}}_t = \underline{\beta}(\tilde{R}_{mt}-r) + \Gamma\tilde{\underline{k}}_{t+1} + \tilde{\underline{\eta}}_t \qquad (10)$$

where[6]

$\underline{q}_t = \tilde{\underline{R}}_t - r\underline{l}$

$\underline{k}_{t+1} = \tilde{\underline{R}}_{t+1} - r\underline{l}$

R_{mt} denotes the market return in the first period

$\underline{\eta}_t$ denotes the disturbance

Equation (10) can be reexpressed as a form for the individual asset i with T observations[7]

$$\tilde{q}_{it} = \beta_i(\tilde{R}_{mt}-r) + \underline{\delta}_i'\tilde{\underline{k}}_{t+1} + \tilde{\eta}_{it} \qquad i=1,2,\ldots,m \qquad t=1,2,\ldots,T \quad (11)$$

where

$$\Gamma = [\underline{\delta}_1, \underline{\delta}_2, \ldots, \underline{\delta}_m]'$$
$$\underline{\eta}_t = [\eta_{1t}, \eta_{2t}, \ldots, \eta_{mt}]'$$

We propose to test the following restriction on the data

$$\tilde{q}_{it} = \lambda_{it} + \beta_i(\tilde{R}_{mt}-r) + \underline{\delta}_i'\tilde{\underline{k}}_{t+1} + \tilde{\eta}_{it} \qquad (12)$$

$$H_0:\ \lambda_{it}=0 \qquad all \quad i,t$$

The constraint was also utilized by Mackinlay and Richardson (1991) in developing a GMM-based test of whether a portfolio is

[6] Due to the adoption of daily observations in the later test, we drop all the subscripts from interest rates without loss of generality.

[7] Without the use of GMM, the disturbance term η_{it} is required to have the following properties: $E(\tilde{\eta}_{it})=0$, $E[(\tilde{R}_{mt}-r)\tilde{\eta}_{it}]=0$ *and* $E(k_{it}\eta_{it})=0$. Using the GMM, this strong assumption can be avoided. The disturbance term can be both serially dependent and conditionally heteroskedastic. The required assumptions for the GMM are only the stationarity and ergodicity of $\tilde{q}_{it}$, $\tilde{R}_{mt}-r$ and $\tilde{\underline{k}}_{t+1}$ and the existence of fourth moments for excess returns.

unconditionally mean-variance efficient. The above restriction tests the joint hypothesis that information is transmitted across trading periods and investor's hedged behavior exists.

The GMM procedure first proposed by Hansen (1982) and Hansen and Singleton (1982) is used here for two reasons. First, the GMM is a broad class of estimators that allow the disturbance term to be both serially dependent and conditionally heteroskedastic. Second, the GMM is capable of providing us with tests that are robust to departures from the assumption of normality and constancy of expected returns.

The basic idea of GMM is to use the orthogonality conditions to construct a criterion function whose minimizer is a vector of the estimators of the parameters in the model. The criterion function is constructed so that the parameter estimator is ensured to be consistent, asymptotically normal, and to have an asymptotic covariance matrix that can be estimated consistently. The estimators are then used in the computation of a test statistic that converges in distribution to chi-squares, where the number of degrees of freedom is equal to the number of overidentifying restrictions.

For the subsequent analysis, $\underline{\lambda}$ is defined as the (mx1) vector $[\lambda_1, \lambda_2, ..., \lambda_m]'$, and $\underline{b}$ is defined as the m(m+2)x1 vector $[\lambda_1, \beta_1, \underline{\delta}'_1, \lambda_2, \beta_2, \underline{\delta}'_2, ..., \lambda_m, \beta_m, \underline{\delta}'_m]$. The parameter vector to be estimated is $\underline{b}_j$, for j=1,2,...m, and its true value is $\underline{b}_j^0$.

Define a m×(m+2) vector function

$$f_t(\underline{b}^{\circ}) = \underline{\eta}_t(\underline{\lambda}=0, \underline{\beta}, \Gamma) \otimes [1, R_{mt}-r, \underline{k}_{t+1}] \tag{13}$$

where ⊗ is the Kronecker product operator.

Since $\underline{\eta}$ is a vector of forecast errors, it follows that $E[f_t(\underline{b}^0)] = 0$. Also, define the following sample estimate for the mean of the function as

$$g_T(\underline{b}) = \frac{1}{T}\sum_{t=1}^{T} f_t(\underline{b}) \tag{14}$$

Thus, the GMM consistent estimator $\underline{b}^T$ of $\underline{b}^0$ can be obtained by minimizing the following quadratic function

$$\phi(\underline{b}^T) = g_T(\underline{b})' W_T \, g_T(\underline{b}) \tag{15}$$

where W_T is a $m(m+2) \times m(m+2)$ symmetric, positive definite weighting matrix.

Hansen (1982) shows that the optimal GMM weighting matrix is given by

$$W_T = \frac{1}{T}\sum_{t=1}^{T} f_t(\underline{b}^T) f_t(\underline{b}^T)' \tag{16}$$

and a consistent estimate of the $\underline{b}^T$ covariance matrix is given by $\frac{1}{T}(D_T' W_T \, D_T)^{-1}$ where $D_T = \frac{\partial}{\partial \underline{b}^T} g_T(\underline{b}^T)$

He also shows that $T\,[\min \phi(\underline{b}^T)]$ is asymptotically (central) chi-square distributed with degrees of freedom equal to the number of overidentifying restrictions[8], which is equal to m in our model, under the null hypothesis that the model is correctly specified. The two-step procedure suggested by Hansen and Singleton (1982) can be used to obtain our estimates.

While we formally perform the GMM tests, the following problems concerning data should be noticed:

1. To effectively capture the information effects, daily observations of the equity returns must be adopted. Any other observations, such as monthly or weekly, will obscure the findings.
2. Since the GMM model can be highly nonlinear, the computational burden involved in estimation is potentially quite high. The

[8] The number of overidentifying restriction is defined as the dimension of orthogonality conditions minus the number of parameters to be estimated.

securities can be categorized into a reasonable number of portfolios, according to industry code, firm size, or other grouping schemes.

Data Description

The study uses daily returns on all common stocks traded in the markets of New York Stock Exchange (NYSE) and American Stock Exchange (AMEX) during the period January 2 through December 31 in 1987. The data are obtained from the NYSE/AMEX file in the Center for Research in Security Prices (CRSP) at the University of Chicago. Stocks in the market are grouped into twelve (equally-weighted) portfolios according to their industry codes (SIC codes). The SIC codes for the industry-based portfolios are described in Table 1.

Instrumental Variables

Testing the hypothesis (12) in the three-factor modified CAPM, we employ the excess return of the equally-weighted market portfolio as the proxy of market return. In other words, the instrumental variables used here consist of a constant, the equally-weighted market excess return, and twelve portfolios' one-day ahead returns.

Results

We first test the hypothesis (12) by adopting all the observations in 1987. The result is reported in table 2. The very small p-value (0.00066) shows that the data appear to be inconsistent with the three-factor model. To further investigate the difference of information transmission and hedged behavior between the period of pre-October and the period of October crash, we divide the whole year into two subperiods. The first subperiod is from 1/2/87 to 9/30/87 (the first three quarters in 1987) and the second subperiod is from 10/1/87 to 12/31/87 (the last quarter in 1987). We perform the same GMM test in each subperiod. The results are presented in Table 3. The p-value 0.11 in the second subperiod supports the hypothesis (12) in the three-factor model during the period of the October crash. It implies that the hedged behavior is obviously present over the period of crash. The p-value (0.00067) in the first subperiod is still so small that the mean-variance efficiency of three-factor model is still rejected.

Therefore, we can conclude that the investor's hedged behavior as a result of the information transmission seems nonexistent during the period of normal economic condition. The behavior, however, becomes very active during the period of economic crisis, such as the stock market crash in October 1987.

Table 1

Portfolio	Industry	S.I.C
1	Basic Industries	10,12,14,24,26,28,33
2	Capital Goods	34,35,38
3	Consumer Durables	25,30,36,37,50,55,57
4	Construction	15-17,32,52
5	Finance / Real Estate	60-69
6	Food / Tobacco	1,20,21,54
7	Leisure	27,58,70,78,79
8	Petroleum	13,29
9	Services	72,73,75,80,82,89
10	Textiles / Trade	22,23,31,51,53,56,59
11	Transportation	40-42,44,45,47
12	Utilities	46,48,49

Table 2

Chi-Square Values and Significance Levels for GMM Tests of Modified Asset Pricing Models				
Period	Number of Observations	Chi-Square	Degree of Freedom	p-Value
1/2/87-12/31/87	252	34.07	12	**0.00066**

Table 3

Chi-Square Values and Significance Levels for GMM Tests of Modified Asset Pricing Models over the two subperiods				
Period	Number of Observations	Chi-Square	Degree of Freedom	p-Value
1/2/87 - 9/30/87	188	34.03	12	**0.00067**
10/1/87 -12/31/87	63	18.17	12	0.11

V. Summary

In a two-period economy, the signal, which aggregates the information revealed from the period that trades earlier, is transmitted to the period that trades later. When the investor can observe distributions of asset returns, the distribution of the signal, and the linear relationship between asset returns and the signal, the optimal asset holding for the investor is to hold a dynamic self-hedged portfolio in the first period. The holding of the hedged portfolio can minimize the investor's risk. This is because the hedged portfolio can be used to hedge against the risk resulting from the information transmission.

The SML is also modified to reflect the hedged behavior. In the modified SML, the expected excess return and risk premium in the period trades earlier are influenced by the expected excess return and the variance from the period that trades later. The modified SML can be roughly regarded as a three-factor model. The model is supported by the empirical finding that the investor's hedged behavior is present during the period of economic crisis, such as the crash in October 1987.

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Appendix

Derivation of (5) and (6):

The investor's expected utility maximization problem in the second period is given by

$$\underset{\underline{x}_2}{Max} E_1[U(\tilde{W}_2)] \tag{A1}$$

where

$$\begin{aligned}\tilde{W}_2 &= W_1 \ [\underline{x}_2'\underline{\tilde{R}}_2 + r_2(1-\underline{x}_2'\underline{l})] \\ &= W_1[r_2 + \underline{x}_2'(\underline{\tilde{R}}_2 - r_2\underline{l})]\end{aligned} \tag{A2}$$

and $\underline{1}$ denotes the vector containing all ones.

Since $\tilde{W}_2$ is normally distributed and the investor's utility function is characterized by the constant absolute risk aversion, the problem of expected utility maximization in (A1) and (A2) is equivalent to the maximization of the Certainty Equivalent of Wealth (CEQ), which is defined as follows:

$$\underset{\underline{x}_2}{Max} CEQ_2 = \delta E[\tilde{W}_2 | \underline{\theta}, W_1] - \frac{\delta^2}{2} VAR[\tilde{W}_2 | \underline{\theta}, W_1] \tag{A3}$$

where

$$E[\tilde{W}_2 | \underline{\theta}, W_1] = W_1[r_2 + \underline{x}_2'(\underline{\mu}_{2|\theta} - r_2\underline{l})] \tag{A4a}$$

$$VAR[\tilde{W}_2 | \underline{\theta}, W_1] = W_1^2 \ \underline{x}_2'\Sigma_{2|\theta}\underline{x}_2 \tag{A4b}$$

To solve (A3), we differentiate CEQ_2, with respect to $\underline{x}_2$, and let the first-derivative be zero. The optiomal asset holding for the investor in the second period is then obtained. That is

$$W_1\underline{x}_2=\frac{1}{\delta}\Sigma_{2|\theta}^{-1}(\mu_{2|\theta}-r_2\underline{I}) \tag{A5a}$$

$$=\frac{1}{\delta}[\Sigma_2-B_2\Sigma_\theta B_2']^{-1}(\underline{a}_2+B_2\underline{\theta}-r_2\underline{I}) \tag{A5b}$$

which is (5).

To find the optimal asset holding for the investor in the first period, the realized Certainty Equivalent of Wealth ($\overline{CEQ}$) is computed. Substituting (A5) into (A3), we obtain the realized Certainty Equivalent of Wealth in the second period, which is

$$\begin{aligned}\overline{CEQ_2}&=\delta W_1 r_2+\frac{1}{2}(\mu_{2|\theta}-r_2\underline{I})'\ \Sigma_{2|\theta}^{-1}\ (\mu_{2|\theta}-r_2\underline{I})\\&=\delta W_1 r_2+\frac{1}{2}(\underline{a}_2+B_2\underline{\theta}-r_2\underline{I})'[\Sigma_2-B_2\Sigma_\theta B_2']^{-1}\ (\underline{a}_2+B_2\underline{\theta}-r_2\underline{I})\end{aligned} \tag{A6}$$

Thus, in the first period, the expected utility maximization for the investor is

$$\underset{\underline{x}_1}{Max}\, E_0[U(\overline{CEQ_2})] \tag{A7}$$

It is equivalent to the following maximization problem

$$\underset{\underline{x}_1}{Max}\, E_{(W_1,\underline{\theta})}[-e^{-\delta \tilde{W}_1 r_2-\frac{1}{2}(\mu_{2|\theta}-r_2\underline{I})'\ \Sigma_{2|\theta}^{-1}(\mu_{2|\theta}-r_2\underline{I})}] \tag{A8}$$

where $E_{(W_1,\underline{\theta})}$ denotes the expectation operator of the joint distribution of W_1 and $\underline{\theta}$.

From Assumption 2, (A8) is equivalent to the following maximization problem

$$\underset{\underline{x}_1}{Max}\, E_{(\underline{u},\underline{\theta})}[-e^{-\delta W_0[r_1+\underline{x}_1'(\underline{a}_1+B_1\tilde{\underline{\theta}}+\tilde{\underline{u}}-r_1\underline{I})]r_2-\frac{1}{2}(\mu_{2|\theta}-r_2\underline{I})'\ \Sigma_{2|\theta}^{-1}(\mu_{2|\theta}-r_2\underline{I})}] \tag{A9}$$

Since $\tilde{\underline{u}}$ and $\tilde{\underline{\theta}}$ are uncorrelated, then (A9) can be expressed as follows:

$$\underset{\underline{x}_1}{Max}\, E_{\underline{\theta}}[-e^{-\delta W_0[r_1+\underline{x}_1'(\underline{a}_1+B_1\tilde{\underline{\theta}}-r_1\underline{l})]r_2-\frac{1}{2}(\underline{\mu}_{2|\theta}-r_2\underline{l})'\Sigma_{2|\theta}^{-1}(\underline{\mu}_{2|\theta}-r_2\underline{l})}] \tag{A10}$$

$$\bullet\; E_{\underline{u}}[-e^{-\delta W_0 r_2 \underline{x}_1' \tilde{\underline{u}}}]$$

To solve (A10), it is convenient to solve the two expectations separately. Since the second expectation in (A10) is only the moment generating function of u̲, it is equal to

$$e^{\frac{\delta^2}{2}W_0^2 r_2^2 \underline{x}_1'\Sigma_u \underline{x}_1}$$

To solve the first expectation, it can be simplified to be the following form:

$$E_{\underline{\theta}}\{-e^{-\frac{1}{2}[\alpha+\underline{\beta}'\underline{\theta}+\underline{\theta}'\Gamma\underline{\theta}]}\} \tag{A11}$$

where

$$\alpha=2\delta\pi w_0[r_1+\underline{x}_1'(\underline{a}_1-r_1\underline{l})]r_2+(\underline{a}_2-r_2\underline{l})'\Sigma_{2/\theta}^{-1}(\underline{a}_2-r_2\underline{l}) \tag{A12a}$$

$$\underline{\beta}'=2\delta\pi w_0 r_2 \underline{x}_1' B_1+(\underline{a}_2-r_2\underline{l})'\Sigma_{2|\theta}^{-1}B_2 \tag{A12b}$$

$$\Gamma=B_2'\Sigma_{2|\theta}B_2 \tag{A12c}$$

Since θ is normally distributed, (A11) can be expressed as follows:

$$E_{\underline{\theta}}\{-e^{-\frac{1}{2}[\alpha+\underline{\beta}'\underline{\theta}+\underline{\theta}'\Gamma\underline{\theta}]}\}=|\Sigma_\theta|^{-\frac{1}{2}}|\Gamma+\Sigma_\theta^{-1}|^{\frac{1}{2}}\exp\{-\frac{1}{2}[\alpha+\underline{\mu}_\theta'\Sigma_\theta^{-1}\underline{\mu}_\theta- \tag{A13}$$

$$(\Sigma_\theta^{-1}\underline{\mu}_\theta-\frac{1}{2}\underline{\beta})'(\Gamma+\Sigma_\theta^{-1})^{-1}(\Sigma_\theta^{-1}\underline{\mu}_\theta-\frac{1}{2}\underline{\beta})]\}$$

Thus the maximization problem of (A10) is equivalent to the following problem:

$$\underset{\underline{x}_1}{Max}\ |\Sigma_\theta|^{-\frac{1}{2}}|\Gamma+\Sigma_\theta^{-1}|^{\frac{1}{2}}\exp\{-\frac{1}{2}[\alpha+\underline{\mu}_\theta^{\prime}\Sigma_\theta^{-1}\underline{\mu}_\theta-(\Sigma_\theta^{-1}\underline{\mu}_\theta-\frac{1}{2}\underline{\beta})^{\prime}$$
$$(\Gamma+\Sigma_\theta^{-1})^{-1}(\Sigma_\theta^{-1}\underline{\mu}_\theta-\frac{1}{2}\underline{\beta})]\}\ \bullet\ \exp\{\frac{\delta^2}{2}W_0^2r_2^2\underline{x}_1^{\prime}\Sigma_u\underline{x}_1\} \tag{A14}$$

To simplify the maximization problem, (A14) can be rewritten as a quadratic form of $\underline{x}_1$. That is

$$\underset{\underline{x}_1}{Max}\ |\Sigma_\theta|^{-\frac{1}{2}}|B_2^{\prime}\Sigma_{2|\theta}^{-1}B_2+\Sigma_\theta^{-1}|^{\frac{1}{2}}\exp\{-\frac{1}{2}[\underline{x}_1^{\prime}R\underline{x}_1+\underline{q}^{\prime}\underline{x}_1+P]\} \tag{A15}$$

where

$$R=\delta^2W_0^2r_2^2[B_1(B_2^{\prime}\Sigma_{2|\theta}^{-1}B_2+\Sigma_\theta^{-1})^{-1}B_1^{\prime}+\Sigma_u] \tag{A16a}$$

$$\underline{q}^{\prime}=-2[\underline{\mu}_\theta^{\prime}\Sigma_\theta^{-1}-(\underline{a}_2-r_2\underline{l})^{\prime}\Sigma_{2|\theta}^{-1}B_2](B_2^{\prime}\Sigma_{2|\theta}^{-1}B_2+\Sigma_\theta^{-1})^{-1}$$
$$\delta W_0r_2B_1^{\prime}-2\delta W_0(\underline{a}_1-r_1\underline{l})^{\prime}r_2 \tag{A16b}$$

$$P=[\underline{\mu}_\theta^{\prime}\Sigma_\theta^{-1}-(\underline{a}_2-r_2\underline{l})^{\prime}\Sigma_{2|\theta}B_2](B_2^{\prime}\Sigma_{2|\theta}^{-1}B_2+\Sigma_\theta^{-1})^{-1}$$
$$[\Sigma_\theta^{-1}\underline{\mu}_\theta-B_2^{\prime}\Sigma_{2|\theta}^{-1}(\underline{a}_2-r_2\underline{l})]-2\delta W_0r_1r_2-$$
$$(\underline{a}_2-r_2\underline{l})^{\prime}\Sigma_{2|\theta}^{-1}(\underline{a}_2-r_2\underline{l})-\underline{\mu}_\theta^{\prime}\Sigma_\theta^{-1}\underline{\mu}_\theta \tag{A16c}$$

Differentiating (A15) with respect to $\underline{x}_1$ and setting the first derivative to be zero, we obtain the first-order condition for the maximization problem of (A15). That is

$$2R\underline{x}_1+\underline{q}=0 \tag{A17}$$

Substituting (A16a), (A16b), and (A16c) into (A17), we finally obtain, with tedious derivation, the following investor's optimal asset holding in the first period

$$W_0\underline{x}_1=\frac{1}{\delta r_2}[\Sigma_1-\Sigma_{12}\Sigma_2^{-1}\Sigma_{21}]^{-1}\{(\underline{a}_1+B_1\underline{\mu}_\theta-r_1\underline{l})-\Sigma_{12}\Sigma_2^{-1}(\underline{a}_2+B_2\underline{\mu}_\theta-r_2\underline{l})\}$$

which is (6).

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