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On Application of Optimal Multihypothesis Tests for the Bounds Construction for the Increase of Growth Rate of Stock Market

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Abstract

In the present paper new bounds for increase of the growth rate of stock market (when an erroneous probability distribution is used) are obtained applying the matrix of reliabilities of optimal tests.

Keywords: Hypothesis testing, Stock market, Growth rate, Portfolio.

1. Introduction

The model of stock market considered in this paper is presented in [1], where the bound for the increase of the growth rate of stock market in case of continuous distributions is constructed. This model and the corresponding optimal portfolio problems were deeply investigated in [1] – [8].

The application of results on the hypothesis of logarithmically asymptotically optimal (LAO) testing ([9] – [13]) in portfolio theory is introduced in [11], where using error probabilities and raliabilities, new, more exact bounds are found for the increase of the growth rate of stock market. Using the existence theorem of LAO test [10] bounds obtained in [11] are refined in the present paper.

We study a stock market with $K(\geq 1)$ stocks defined by a random vector $\mathbf{X} = (X_1, X_2, ..., X_K)$, $X_k \geq 0$, $k = \overline{1, K}$, where the price relatives (the ratio of the price at the end of the day to the price at the beginning of the day) X_k, $k = \overline{1, K}$, are independent random variables (RVs) with unknown probability distributions (PDs) defined on the finite set $\mathcal{X}$.

We assume that M distinct PDs G_m, $m = \overline{1, M}$, are given on $\mathcal{X}$ which are possible PDs for RVs X_k, $k = \overline{1, K}$. If the right PD of the RV X_k is G_{m_k}, $k = \overline{1, K}$, then the joint PD of the stock market vector $\mathbf{X}$ will be $G_{m_1, m_2, ..., m_K}(\mathbf{x}) = \prod_{k=1}^{K} G_{m_k}(\mathbf{x}_k)$, where $\mathbf{x} = (x_1, x_2, ..., x_K) \in \mathcal{X}^K$.

Portfolio vector $\mathbf{b} = (b_1, b_2, ..., b_K)$, $b_k \geq 0$, $k = \overline{1, K}$, $\sum b_k = 1$, is an allocation of the wealth across the stocks, where b_k is the fraction of one's wealth invested in stock k [1].

When an investor uses a portfolio b for stock market $\mathbf{X}$, then the wealth relative will be $S = \mathbf{b}^t\mathbf{X}$ ($\mathbf{b}^t$ is the transposed vector of $\mathbf{b}$). And if the investor invests in the stock market for N consecutive days and uses the same betting strategy $\mathbf{b}$ each day, then the wealth at the end of N days is given by $S_N = \prod_{n=1}^{N} \mathbf{b}^t\mathbf{X}_n$, where the stock market vectors $X_1, X_2, ...$ are independent and identically distributed with PD $G_{m_1,m_2,...,m_K}(\mathbf{x})$.

The optimal growth rate is $W^*(G) = \max_{\mathbf{b}} W(\mathbf{b}, G)$, where $W(\mathbf{b}, G) = \mathbf{E}(\log \mathbf{b}^t\mathbf{X})$ is the growth rate of a stock market at portfolio $\mathbf{b} = (b_1, b_2, ..., b_K)$ with respect to a stock PD $G_{m_1,m_2,...,m_K}$ (if the logarithm is to base 2, the growth rate is called a doubling rate [1]). Then a portfolio $\mathbf{b}^* = \mathtt{Arg}(\max_{\mathbf{b}} W(\mathbf{b}, G))$, is called a log – optimal portfolio or a growth optimal portfolio.

In this paper we assume that PD $G_{m_1,m_2,...,m_K}$ is unknown and must be determined on the base of sample (results of N independent observations) $\mathbf{x}_n = (x_{1,n}, x_{2,n}, \ldots, x_{K,n})$, $n = \overline{1, N}$, where $x_{k,n}$ is a result of the n – th realization of the price relative X_k, $k = \overline{1, K}$. With the sample $\mathbf{x}^N = (\mathbf{x}_1, \mathbf{x}_2, ..., \mathbf{x}_N)$ we can consider the empirical PD of the stock market after N days:

$$G^{(N)}_{m_1,m_2,...,m_K}(\mathbf{x}^N) \;=\; \prod_{n=1}^{N} G_{m_1,m_2,...,m_K}(\mathbf{x}_n) = \prod_{n=1}^{N}\prod_{k=1}^{K} G_{m_k}(x_{k,n}).$$

We consider the case, when each PD from the given PDs G_m can be adopted for some price relatives simultaneously.

The procedure of decision making is a non-randomized test $\varphi^{(N)}$, which can be defined by a division of the sample space $\mathcal{X}^{KN}$ into M^K disjoint subsets

$$\mathcal{A}^{(N)}_{l_1,l_2,...,l_K} = \{\mathbf{x}^N : \varphi^{(N)}(\mathbf{x}^N) = (l_1, l_2, ..., l_K)\}, l_k = \overline{1, M}, k = \overline{1, K}.$$

The probability of the erroneous acceptance of hypothesis $H_{l_1,l_2,...,l_K}$ provided that $H_{m_1,m_2,...,m_K}$ is true, for $(l_1, l_2, ..., l_K) \neq (m_1, m_2, ..., m_K)$, is [9]

$$\alpha^{(N)}_{l_1,l_2,...,l_K|m_1,m_2,...,m_K} = G^{(N)}_{m_1,m_2,...,m_K}(\mathcal{A}^{(N)}_{l_1,l_2,...,l_K}).$$

For the probability of rejection of hypothesis $H_{m_1,m_2,...,m_K}$, when it is true the following definition is adopted:

$$\alpha^{(N)}_{m_1,m_2,...,m_K|m_1,m_2,...,m_K} = \sum_{(l_1,l_2,...,l_K)\neq(m_1,m_2,...,m_K)} \alpha^{(N)}_{l_1,l_2,...,l_K|m_1,m_2,...,m_K}.$$

For the sequence φ of tests we will consider error probability exponents which are called reliabilities:

$$-\overline{\lim_{N\to\infty}} \frac{1}{N} \log \alpha^{(N)}_{l_1,l_2,...,l_K|m_1,m_2,...,m_K} = E_{l_1,l_2,...,l_K|m_1,m_2,...,m_K} \geq 0,\ m_k, l_k = \overline{1, M}.$$

It is known, that

$$E_{m_1,m_2,...,m_K|m_1,m_2,...,m_K} = \min_{(l_1,l_2,...,l_K)\neq(m_1,m_2,...,m_K)} E_{l_1,l_2,...,l_K|m_1,m_2,...,m_K}.$$

The matrix $\mathbf{E} = \{E_{l_1,l_2,...,l_K|m_1,m_2,...,m_K}\}$ is a matrix of reliabilities of the sequence of tests φ.

We call the test sequence φ^* LAO if for the given positive values of certain part of elements of the matrix of reliabilities $\mathbf{E}(\varphi^*)$ the procedure provides maximal values for all the other elements of it.

2. Problem Statement

Let the true PD of the stock market $\mathbf{X} = (X_1, X_2, ..., X_K)$ be $G_{m_1,m_2,...,m_K}$ with the corresponding log – optimal portfolio $\mathbf{b}_{m_1,m_2,...,m_K}$ and let $\mathbf{b}_{l_1,l_2,...,l_K}, (l_1, l_2, ..., l_K) \neq (m_1, m_2, ..., m_K)$ be a log – optimal portfolio corresponding to some other, wrong PD $G_{l_1,l_2,...,l_K}$.

When the incorrect portfolio $\mathbf{b}_{l_1,l_2,...,l_K}$ is used instead of $\mathbf{b}_{m_1,m_2,...,m_K}$, then the increase of the growth rate is the following:

$$\Delta W = W(\mathbf{b}_{m_1,m_2,...,m_K}, G_{m_1,m_2,...,m_K}) - W(\mathbf{b}_{l_1,l_2,...,l_K}, G_{m_1,m_2,...,m_K}) \geq 0.$$

The investor can use the same incorrect portfolio for the next period and have some financial losses. The bounds for ΔW will show the maximal possible amount of losses.

Consider the following quantities:

$$q^{l_1,l_2,...,l_K}_{m_1,m_2,...,m_K}(\mathbf{x}) = \frac{\mathbf{b}^t_{m_1,m_2,...,m_K}\mathbf{x}}{\mathbf{b}^t_{l_1,l_2,...,l_K}\mathbf{x}} G_{l_1,l_2,...,l_K}(\mathbf{x}),\ \mathbf{x} \in \mathcal{X}^K$$

$$g^{l_1,l_2,...,l_K}_{m_1,m_2,...,m_K} = \sum_{\mathbf{x}\in\mathcal{X}^K} G_{m_1,m_2,...,m_K}(\mathbf{x}) \log \frac{q^{l_1,l_2,...,l_K}_{m_1,m_2,...,m_K}(\mathbf{x})}{G_{m_1,m_2,...,m_K}(\mathbf{x})}.$$

As a direct consequence of the Kuhn – Tucker conditions, it was proved in [1] and [3] that $\mathbf{E}\frac{S}{S^*} \leq 1$, for all S, where $S^* = \mathbf{b}^{*t}\mathbf{X}$ is the random wealth resulting from the log – optimal portfolio $\mathbf{b}^*$, and $S = \mathbf{b}^t\mathbf{X}$ is the wealth resulting from any other portfolio $\mathbf{b}$. From inequality $\mathbf{E}\frac{S}{S^*} \leq 1$ and the fact that $\mathbf{b}_{l_1,l_2,...,l_K}$ is a log – optimal portfolio for $G_{l_1,l_2,...,l_K}$, we have

$$q^{l_1,l_2,...,l_K}_{m_1,m_2,...,m_K}(\mathbf{x}) \leq \sum_{\mathbf{x}\in\mathcal{X}^K} q^{l_1,l_2,...,l_K}_{m_1,m_2,...,m_K}(\mathbf{x}) \leq 1.$$

Let $D(R\|P) = \sum_{z\in\mathcal{Z}} R(z) \log \frac{R(z)}{P(z)} < \infty$ by (Kullback - Leibler) divergence for PDs by R and P, $z \in \mathcal{Z}$.

Theorem 1 [11]: *If* $(l_1, l_2, ..., l_K) \neq (m_1, m_2, ..., m_K)$, *then*

$$\triangle W = D(G_{m_1,m_2,...,m_K} \parallel G_{l_1,l_2,...,l_K}) + g^{l_1,l_2,...,l_K}_{m_1,m_2,...,m_K},$$

where $g^{l_1,l_2,...,l_K}_{m_1,m_2,...,m_K} \leq 0$ *with equality if and only if* $q^{l_1,l_2,...,l_K}_{m_1,m_2,...,m_K}(\mathbf{x}) = G_{m_1,m_2,...,m_K}(\mathbf{x})$, *for all* $\mathbf{x} \in \mathcal{X}^K$.

Corollary 1: *The analog of the bound exposed in [1] in the case of discrete PDs is*

$$\triangle W \leq D(G_{m_1,m_2,...,m_K} \parallel G_{l_1,l_2,...,l_K}).$$

From Theorem 1 it follows that for each pair $(l_1, l_2, ..., l_K) \neq (m_1, m_2, ..., m_K)$ the investor first must check the condition $q^{l_1,l_2,...,l_K}_{m_1,m_2,...,m_K}(\mathbf{x}) = G_{m_1,m_2,...,m_K}(\mathbf{x})$, for all $\mathbf{x} \in \mathcal{X}^K$. In such cases his losses will be maximal.

All other cases $(l_1, l_2, ..., l_K) \neq (m_1, m_2, ..., m_K)$ (and the corresponding portfolios $\mathbf{b}_{l_1,l_2,...,l_K} \neq \mathbf{b}_{m_1,m_2,...,m_K}$) we will call cases (portfolios) of "*nonmaximal losses*" and will assume that the following condition is fulfilled:

$$g^{l_1,l_2,...,l_K}_{m_1,m_2,...,m_K} \geq -D(G_{l_1,l_2,...,l_K} \parallel G_{m_1,m_2,...,m_K}). \tag{1}$$

3. New Bound for Growth Rate

Let $N(x|\mathbf{x})$ be the number of repetitions of the element $x \in \mathcal{X}$ in the vector $\mathbf{x} \in \mathcal{X}^N$, and let

$$Q = \{Q(x) = N(x|\mathbf{x})/N, x \in \mathcal{X}\}$$

be the empirical distribution (type) of the sample $\mathbf{x}$.

For the given positive diagonal elements $E_{1|1}, E_{2|2}, \ldots, E_{M-1|M-1}$ of the reliability matrix we consider sets of PDs

$$\mathcal{R}_l = \{Q : D(Q||G_l) \leq E_{l|l}\}, \quad l = \overline{1, M-1}, \tag{2}$$

$$\mathcal{R}_M = \{Q : D(Q||G_l) > E_{l|l}, \quad l = \overline{1, M-1}\}, \tag{3}$$

and define the values for the elements of the future reliability matrix of the LAO tests sequence as follows:

$$E^*_{l|l} = E^*_{l|l}(E_{l|l}) = E_{l|l}, \quad l = \overline{M-1}, \tag{4}$$

$$E^*_{l|m} = E^*_{l|m}(E_{l|l}) = \inf_{Q \in \mathcal{R}_l} D(Q||G_m), \; m = \overline{1, M}, m \neq l, \; l = \overline{1, M-1}, \tag{5}$$

$$E^*_{M|m} = E^*_{M|m}(E_{1|1}, \ldots, E_{M-1|M-1}) = \inf_{Q \in \mathcal{R}_M} D(Q||G_m), \; m = \overline{1, M-1}, \tag{6}$$

$$E^*_{M|M} = E^*_{M|M}(E_{1|1}, \ldots, E_{M-1|M-1}) = \min_{l=\overline{1,M-1}} E^*_{M|l}. \tag{7}$$

The LAO test existing theorem concerning one object is the following [10]:

Theorem 2 [10]: *If the distributions G_m are different, that is all divergences $D(G_l||G_m)$, $l \neq m$, $l, m = \overline{1, M}$, are strictly positive, then two statements hold:*
a) when the given numbers $E_{1|1}, E_{2|2}, \ldots, E_{M-1|M-1}$ satisfy the conditions

$$0 < E_{1|1} < \min_{l=\overline{2,M}} D(G_l||G_1), \tag{8}$$

$$0 < E_{m|m} < \min[\min_{l=\overline{1,m-1}} E^*_{l|m}(E_{l|l}), \min_{l=\overline{m+1,M}} D(G_l||G_m)], m = \overline{2, M-1}, \tag{9}$$

then there exists a LAO sequence of tests φ^*, the elements of the reliability matrix of which $\mathbf{E}(\boldsymbol{\varphi}^*) = \{E^*_{l|m}\}$ are defined in (4)–(7) and all of them are strictly positive;
b) even if one of the conditions (8) or (9) is violated, then the reliability matrix of any such test includes at least one element equal to zero.

Theorem 3: *When the first M-1 diagonal elements of reliability matrix are fixed so that the numbers $E_{1|1}, E_{2|2}, \ldots, E_{M-1|M-1}$ satisfy the conditions (8)-(9), then in case of condition (1), for portfolios $\mathbf{b}_{l_1,l_2,\ldots,l_K} \neq \mathbf{b}_{m_1,m_2,\ldots,m_K}$, $(l_1, l_2, ..., l_K) \neq (m_1, m_2, ..., m_K)$, of non - maximal losses the following bound is true:*

$$\Delta W \leq D(G_{m_1,m_2,\ldots,m_K} \parallel G_{l_1,l_2,\ldots,l_K}) - E^*_{l_1,l_2,\ldots,l_K|m_1,m_2,\ldots,m_K},$$

where

$$E^*_{l_1,l_2,\ldots,l_K|m_1,m_2,\ldots,m_K} = \sum_{k=\overline{1,K}:\; m_k \neq l_k} E^*_{l_k|m_k}(\varphi_k).$$

Proof: By Corollary 1 from [11] in case of condition (1), for portfolios $\mathbf{b}_{l_1,l_2,\ldots,l_K} \neq \mathbf{b}_{m_1,m_2,\ldots,m_K}$, $(l_1, l_2, ..., l_K) \neq (m_1, m_2, ..., m_K)$, of non-maximal losses we have

$$\Delta W \leq D(G_{m_1,m_2,\ldots,m_K} \parallel G_{l_1,l_2,\ldots,l_K}) - E_{l_1,l_2,\ldots,l_K|m_1,m_2,\ldots,m_K}.$$

Therefore the best bound for the increase of the growth rate will be in case of maximal values of reliabilities.

When the first M-1 diagonal elements of one dimensional reliability matrix are fixed corresponding to the conditions (8)-(9) then from Theorem 2 it follows that there exists a LAO sequence of tests φ^*, the elements $\mathbf{E}(\boldsymbol{\varphi}^*) = \{E^*_{l|m}\}$ of one dimensional reliability matrix of which are defined in (4) – (7) with maximal values.

The compound test $\varphi^{(N)}$ for K stocks can be represented as a collection of K individual tests $\varphi_1^{(N)}$, $\varphi_2^{(N)}$, ..., $\varphi_K^{(N)}$ for each of K stocks [12], then the infinite compound test φ is a collection of infinite tests φ_1, φ_2,..., φ_K. By the Lemma from [12] if elements $E_{l_i|m_i}(\varphi^i)$, $m_i, l_i = \overline{1, M}$, $i = \overline{1, K}$, are strictly positive, then for $\varphi = (\varphi_1, \varphi_2, ..., \varphi_K)$

$$E_{l_1,l_2,...,l_K|m_1,m_2,...,m_K}(\varphi) \quad = \sum_{i=\overline{1,K}:\ m_i \neq l_i} E_{l_i|m_i}(\varphi_i).$$

Since the elements $E^*_{l_i|m_i}(\varphi_i)$ are maximal, therefore the sum $E^*_{l_1,l_2,...,l_K|m_1,m_2,...,m_K}(\varphi)$ will also be maximal.

Theorem is proved.

The following example illustrates the result of the Theorem 3.

Example: Consider the set $\mathcal{X} = \{1; 2\}$ and two PDs $G_1 = \{1/2; 1/2\}$ and $G_2 = \{1/3; 2/3\}$ defined on $\mathcal{X}$. Corollary 1 gives the following bounds:

$$\Delta W = \Delta W(G_1 \parallel G_2) \leq D(G_1 \| G_2) \approx 0.05889$$

and

$$\Delta W = \Delta W(G_2 \parallel G_1) \leq D(G_2 \| G_1) \approx 0.05663.$$

Applying Theorem 3 we shall improve the bounds. For two hypothesis we can take $E_{1|1} = 0.05$. Let $Q = \{q_1; q_2\}$ be the type of the vector $\mathbf{x} \in \mathcal{X}^N$, where $q_1 = N(1|\mathbf{x})/N$ and $q_2 = N(2|\mathbf{x})/N$.

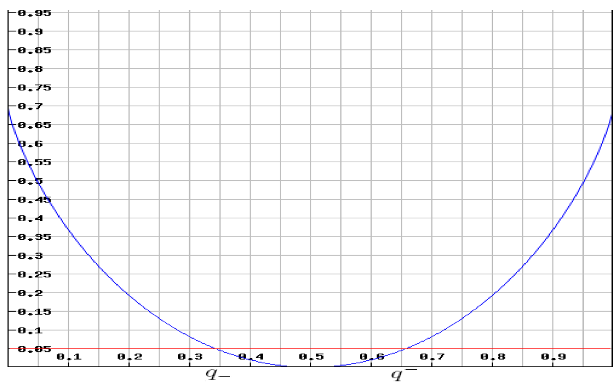

Fig. 1. $q \log 2q + (1-q) \log 2(1-q)$

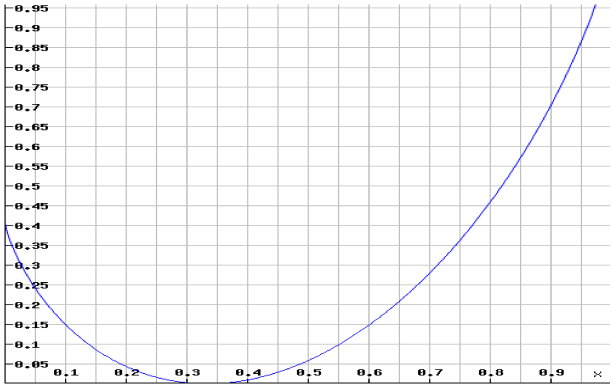

Fig. 2. $q\log 3q + (1-q)\log(\frac{3}{2}(1-q))$

We need to calculate (5) and (6)

$$E^*_{1|2} = \inf_{D(Q||G_1)\leq E_{1|1}} D(Q||G_2) = \inf_{q_1\log 2q_1+q_2\log 2q_2\leq E_{1|1}} (q_1\log 3q_1 + q_2\log(\frac{3}{2}q_2))$$

and

$$E^*_{2|1} = \inf_{D(Q||G_1)>E_{1|1}} D(Q||G_1) = \inf_{q_1\log 2q_1+q_2\log 2q_2>E_{1|1}} (q_1\log 2q_1 + q_2\log(2q_2)).$$

Taking into account that $q_1+q_2 = 1$, from the expression $q_1\log 2q_1+q_2\log 2q_2 = 0.05$ we obtain the equation $q\log 2q + (1-q)\log 2(1-q) = 0.05$. The approximate solutions of this equation are $q_- \approx 0.34322$ and $q^- \approx 0.65678$. In Fig. 1 and Fig. 2 the graphs of the functions $q\log 2q+(1-q)\log 2(1-q)$ and $q\log 3q+(1-q)\log(\frac{3}{2}(1-q))$ are represented. The solution of the inequality $q\log 2q+(1-q)\log 2(1-q) \leq E_{1|1} = 0.05$ is $q \in [q_-; q^-]$. Therefore, now it is easy to see that

$$E^*_{1|2} = \inf_{[q_-;q^-]} (q\log 3q + (1-q)\log(\frac{3}{2}(1-q))) \approx 0.00022.$$

It is also obvious that

$$E^*_{2|1} = \inf_{[0;q_-)\cup(q^-;1]} (q\log 2q + (1-q)log(2(1-q))) = 0.05.$$

Thus, new bounds are

$$\Delta W(G_1 \parallel G_2) \leq 0.00889,$$

$$\Delta W(G_2 \parallel G_1) \leq 0.05641.$$

4. Conclusion

This paper represents the application of coefficients of the reliability matrix of LAO tests in Stock Market portfolio theory. Investors can use the obtained formula for bound to evaluate the future risks, minimal incomes and do necessary corrections in current portfolio. Choosing some PD from the given set of PDs, the investor will have some errors. The existing empirical data allow to estimate statistically the probabilities of those errors. And the reliability coefficients of the corresponding error probabilities are used for obtaining of new bounds. It is shown that the bounds can be minimized using LAO tests. Fixing values for diagonal elements of reliability matrix the LAO test allows to obtain maximal values for all other elements which enables obtaining of lesser bounds for increase of growth rate of the stock market. The derived bound can be effective in modeling of stock market. Evaluating with new bound the investor having historical data can minimize his losses more than the investor without using the historical data.

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Արժեթղթերի շուկայի մեծացման արագության աճի գնահատականի կառուցմանը բազմակի վարկածների նկատմամբ օպտիմալ տեստերի կիրառության մասին

Ե. Հարությունյան, Ա. Մարտիրոսյան և Ա. Եսայան

Ամփոփում

Օպտիմալ տեստերի հուսալիությունների մատրիցի կիրառմամբ ստացված է սխալ հավանականային բաշխման կիրառման դեպքում արժեթղթերի շուկայի տոկոսային աճի նոր գնահատական:

О применении оптимальных тестов относительно многих гипотез для построения оценки увеличения скорости роста рынка ценных бумаг

Е. Арутюнян, А. Мартиросян и А. Есаян

Аннотация

Путем использования матрицы надежностей оптимальных тестов получена новая оценка увеличения скорости роста рынка ценных бумаг при применении ошибочного распределения вероятностей.