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AN ALTERNATIVE DEFINITION OF MARKET EFFICIENCY AND SOME COMMENTS ON ITS EMPIRICAL TESTING

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Working Paper

No. 50 November 2006

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www.bankofgreece.gr

Printed in Athens, Greece
at the Bank of Greece Printing Works.

ISSN 1109-6691

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ABSTRACT

An alternative definition for market efficiency, based on econometric rather than financial arguments is suggested. It is argued that this new definition, though equivalent to the existing one, has some comparative advantages. Moreover, the conditions under which the results from the application of some commonly used methods for the empirical testing of market efficiency are meaningful are examined, and guidelines for practitioners are suggested. Further, market efficiency is examined in a time-varying risk framework.

Keywords: Market efficiency; Return predictability; Serial correlation in stock returns; Market efficiency in the presence of conditional heteroscedasticity.
JEL Classification: G14; C10; C22

Acknowledgements: The author is grateful to Heather Gibson and an anonymous referee for helpful comments. The views expressed in the paper are those of the author and do not necessarily reflect those of the Bank of Greece.

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1. Introduction

There is little doubt that the concept of market efficiency is of much importance in modern financial theory and this is reflected in the volume of relevant published research work, which is really vast. Although market efficiency is defined differently by different authors (e.g. Rubinstein (1975), Beaver (1981), Black (1986), Malkiel, (1992)) it is the definition due to Fama (1970) that has become the established one. According to this definition, a market is efficient if "*prices "fully reflect" all available information*". The classic categorization of the available information introduced by Roberts (1959) and adopted by Fama (1970), classifies efficiency as weak-form, when the information set includes past prices, semi-strong, when the information set includes all publicly available information, and strong-form, when the information set includes all publicly or privately available information. In the so-called tests for return predictability (Fama, 1991) the available information set, in addition to past prices, may also include firm specific characteristics (e.g. the firm size, the price-earnings ratio, the book to market value ratio and the dividend yield), macroeconomic variables (e.g. variables related to term structure of interest rates and unexpected inflation), or even calendar effects (Fama, 1991). In an efficient market the results from tests of return predictability should not reject the null hypothesis of no predictability.

Among the published papers on the subject, the number of which, as mentioned already, is huge, the two review papers by Eugene Fama (1970, 1991) continue to remain the most eminent reference points and compulsory reading for every new scholar of finance. In the first of these papers Fama states the theoretical foundations of market efficiency and reviews the results from the empirical work on market efficiency until that time. The second paper is very rich with new results on tests for market efficiency, but there is no further theoretical analysis. At this point it should be noted that the statistical part of Fama's treatment of market efficiency has received some criticism (e.g. Leroy, 1976), and even the author himself has accepted that readers find it difficult to follow, or even misleading (Fama, 1976). In addition, it has been observed that, occasionally, practitioners and scholars use the statistical methodology on return predictability and link their results in a rather mechanistic way with the hypothesis of market efficiency. This may be attributed, at least in part, to the fact that the existing definition of efficiency is not based on well defined concepts. Further, the way it is linked with returns predictability may leave space for misinterpretation.

In this paper market efficiency is approached following a different way and an alternative definition of market efficiency, based on well defined econometric notions, is reached. More precisely, the treatment of market efficiency is initially based on econometeric, rather than financial arguments. Fama's definition of market efficiency is then derived as a consequence. Moreover, in addition to the suggestion of an alternative definition for market efficiency, another aim of this paper is to clarify the conditions under which the results from some econometric methods for returns predictability, more precisely the autocorrelation tests, as well the GARCH-M models, can be properly linked to market efficiency. Finally some weak points in Fama's statistical treatment of efficient markets are noted and discussed.

The structure of the paper is as follows: In section 1 Fama's definition of efficiency, as well as the basic objections as stated by LeRoy (1976, 1989), are critically reviewed, and an alternative definition for market efficiency is suggested. In section 2 some remarks on the links between serial correlation in stock returns and market efficiency are made, while in section 3 the special case of GARCH-M model in relation to market efficiency is briefly discussed. Section 4 concludes the paper.

2. Market efficiency

The fact that Fama in his definition of market efficiency felt compelled to put the term *fully reflect* in quotation marks, indicates that its meaning is condensed and it is necessary to explain further the meaning of the term itself, and the way the hypothesis of market efficiency could be tested empirically. Following Fama (1970) it is assumed at first that the conditions of market equilibrium can be stated in terms of (conditional) expected returns. This can be generally expressed as:

$$E(\tilde{P}_{j,t+1} / \Phi_t) = [1 + E(\tilde{R}_{j,t+1} / \Phi_t)]P_{j,t}$$

where: $P_{j,t}$ is the price of security j at time t, $R_{j,t+1}$ is the percentage return of security j between t+1 and t, and Φ_t is the information set that is "fully reflected" in $P_{j,t}$.

Tildes indicate random variables in t.

However, Fama (1970, p.384), possibly having in mind the entire distribution of returns, notes that *"the assumption that the conditions of market equilibrium can be stated in terms of expected returns elevates the purely mathematical concept of expected value to a status not necessarily implied by the general notion of market efficiency*"

Further, Fama (1970, p. 385) defines the random variable $Z_{j,t}$ as the deviation of return of security j from its conditional expectation:

$Z_{j,t+1} = R_{j,t+1} - E(\tilde{R}_{j,t+1} / \Phi_t)$ adding that *"Then* $E(\tilde{Z}_{j,t+1} / \Phi_t) = 0,$ *so that by definition the sequence {* $Z_{j,t}$ *} is a "fair game" with respect to the information sequence {* Φ_t *}".*

This last sentence in Fama's paper is in fact the point that has caused most of the misunderstanding and controversy regarding the notion of market efficiency and its testable implications. As LeRoy (1976) notes the assumption that $Z_{j,t+1}$ is a fair game follows tautologically from its definition and is true for any stochastic process defined in the same way as $Z_{j,t+1}$. Even after Fama's reaction to this argument, in which he suggested a revised definition of market efficiency, criticism of the tautological nature of Fama's definitions continued (e.g. LeRoy, 1989).

Most of the ambiguity that arises from Fama's definition of efficiency can be removed if, without changing his framework, the notion of market efficiency is approached differently as follows. Let $R^*_{j,t+1}$ be the estimator used by the market to forecast $R_{j,t+1}$ using the information set Φ^*_t which contains information up to (and including) time t. To make things as simple as possible let us assume that using <u>all</u> available information at time t (Φ_t) the possible outcomes for $\tilde{R}_{j,t+1}$ are $R_{j,1}$ with probability p_1, $R_{j,2}$ with probability p_2,….., $R_{j,N}$ with probability p_N. In general: $\Phi^*_t \subset \Phi_t$. Then the expectation value of $\tilde{R}_{j,t+1}$ conditional upon Φ_t is: $E(\tilde{R}_{j,t+1} / \Phi_t) = \sum_{i=1}^{N} p_i R_{ji}$. In this case the prediction error $U_{j,t+1}$ will be: $U_{j,t+1} = R_{j,t+1} - E(\tilde{R}_{j,t+1} / \Phi_t)$ and will have the following properties:

(i) $E(U_{j,t+1}) = E\{R_{j,t+1} - E(\widetilde{R}_{j,t+1} / \Phi_t)\} = E(R_{j,t+1}) - E\{E(\widetilde{R}_{j,t+1} / \Phi_t)\}$

but: $E\{E(\widetilde{R}_{j,t+1} / \Phi_t)\} = E(\widetilde{R}_{j,t+1})$

due to a well known theorem (see for example Williams, 1991) and therefore,

$$E(U_{j,t+1}) = 0 \tag{1}$$

(ii) $E(U_{j,t} / \Phi_t) = E(R_{j,t+1} / \Phi_t) - E\{E(\widetilde{R}_{j,t+1} / \Phi_t) / \Phi_t\}$

but $E\{E(\widetilde{R}_{j,t+1} / \Phi_t) / \Phi_t\} = E(\widetilde{R}_{j,t+1} / \Phi_t)$ due to the low of iterated expectations. Hence,

$$E(U_{j,t} / \Phi_t) = 0 \tag{2}$$

Due to (1) and (2) the stochastic process $U_{j,t}$ is a martingale difference with respect to Φ_t (in Fama's terminology a "fair game" process).

However, due to the fact that the information set Φ_t^* used in $R^*_{j,t+1}$ is in general a subset of Φ_t, using Φ_t^* the possible outcomes for $\widetilde{R}_{j,t+1}$ are now $R_{j,1}^*$ with probability p^*_1, $R_{j,2}^*$ with probability p^*_2,….., $R_{j,K}^*$ with probability p^*_K. In general:

$$R_{j,i}^* \neq R_{j,i},\ p_i^* \neq p_i, \text{ and } K \neq N \tag{3}$$

Hence, even if $R^*_{j,t+1}$ is formed as an expected value conditional upon Φ_t^* (e.g. using some asset pricing model), i.e. $R_{j,t+1}^* = E(\widetilde{R}_{j,t+1} / \Phi_t^*)$, it is apparent that in general $R_{j,t+1}^* \neq E(\widetilde{R}_{j,t+1} / \Phi_t)$. Hence, if

$U_{j,t+1}^* = R_{j,t+1} - R_{j,t+1}^* = R_{j,t+1} - E(\widetilde{R}_{j,t+1} / \Phi_t^*)$, then in general:

$$E(U_{j,t+1}^* / \Phi_t) \neq 0 \tag{4}$$

even though $U_{j,t+1}^*$ is a martingale difference with respect to Φ_t^*.

From the above analysis it is concluded that as long as any of the inequalities (3) hold, inequality (4) also holds and market efficiency is rejected. Consequently for market efficiency to hold, relations (3) should not hold as inequalities but as equalities. This lead us to the following definition for market efficiency: *A market is called efficient if the estimator that the market uses to forecast the next period return (of an asset) is the expected value conditional upon all available information up to and including present time*.

In regard to the above definition the following complementary comments can be made:

1) For relations (3) to hold as equalities it is understood that the market should use all available information (K=N and $R^*_{j,i} = R_{j,i}\ \forall i$) and should "perceive" it correctly $(p^*_i = p_i)$, i.e. we reach Fama's definition that prices should reflect all available information, at least to an extent which is sufficient for the empirical testing of market efficiency (of course, algebraically, there is an infinite number of different combinations of the variables that ensure the relation $\sum_{i=1}^{N} p_i R_{j,i} = \sum_{i=1}^{K} p^*_i R^*_{j,i}$ holds true. Here the one which is most appealing conceptually to correspond to the meaning of "fully reflect" has been chosen).

2) Both $U_{j,t+1}$ and $U^*_{j,t+1}$ are martingale difference processes, but not with respect to the same information set. Indeed, $U_{j,t+1}$ is a martingale difference process with respect to Φ_t, while $U^*_{j,t+1}$ is a martingale difference process with respect to Φ^*_t. This clearly rejects Leroy's argument, mentioned earlier, about the tautological nature of the definitional equation for $Z_{j,t}$.

3) Fama (1970) shows that observations of a "fair game" variable are linearly independent, which is correct. Further, in a footnote, he adds that a "fair game" also rules out many types of non-linear dependence, providing an example. Strictly speaking this not the whole truth. In a martingale difference process (a "fair game" in the parlance of Fama) the existence of <u>any</u> function (linear as well as non-linear) of past values of the process that could be used as a basis for one step ahead forecasts is ruled out, not just the existence of <u>many types of</u>

non-linear functions. That, of course, does not harm, as it validates even further Fama's approach on the testable implications of market efficiency.

4) In contrast to Fama's view on the use of conditional expectations, as quoted earlier, the alternative definition explicitly involves the conditional expectation, clearly indicating in that way its importance to market efficiency. This is done for the following reasons: (i) it is clear nowadays that the hypothesis that successive returns are independently and identically distributed (random walk-type models) assumes a framework unadjusted for risk while in a risk-adjusted framework it is sufficient to focus on a summary statistic of returns, rather than on the entire distribution, to test for market efficiency. (ii) the most suitable summary statistic is the conditional expectation, as it is the optimal estimator of next period's returns in terms of the minimization of a quadratic loss function (e.g. the mean square error). For a formal proof see for example Hamilton (1994).

3. Serial correlation in stock returns

While it is clear that the deviation of returns from expected returns has a zero autocovariance, this does not entail that one-period returns should also have a zero autocovariance, as Fama (1970) explicitly points out. However, he only provides a sketch of a formal explanation and this has led to misinterpretations, especially owing to the way that he subsequently interpreted the empirical evidence from tests on interdependence in stock returns. As LeRoy (1989) notes, Fama seems to interpret a market as efficient if returns are serially independent. Additionally, LeRoy (1989, p. 1594) points out that Fama "identified efficiency with the characterization of returns as a fair game, contrary to his formal statement". It must also be noted that, in spite of its vital importance for the testable implications for market efficiency, the statistical treatment of this topic in the established graduate textbooks is not satisfying. For example, Elton and Gruber (1995, chap. 17) explain the possible existence of serial dependence in successive returns in an efficient market using qualitative rather that quantitative arguments; in Campbell, Lo and MacKinlay (1997) the topic is not discussed; while Copeland and Weston (1988, chap. 10) provide a quantitative proof which is incorrect (e.g. they begin their proof by equating the autocovariance between

$R_{j,t+1}$ and R_j with: $\int_{R_{j,t}} [R_{j,t} - E(R_{j,t})] \cdot [R_{j,t+1} - E(R_{j,t+1})] \cdot f(R_{j,t}) dR_{j,t}$, which is apparently wrong. The correct expression for the autocovariance is used in the text below. Additionally, tests for the existence of autocorrelation in the returns themselves are very common in the literature (see for example Elton and Gruber (1995, p. 416) for a review). Therefore, it is important to provide a formal statistical proof that interdependence in returns is, in general, compatible with market efficiency and further it is useful, particularly for the practitioners, to clarify the conditions under which the autocorrelation or related tests for market efficiency using returns are meaningful. From the definition of the autocovariance we have:

$$\mathrm{COV}(\widetilde{R}_{j,t}, \widetilde{R}_{j,t+1}) = \iint_{R_t R_{t+1}} (\widetilde{R}_{j,t} - E(\widetilde{R}_{j,t})) \cdot (\widetilde{R}_{j,t+1} - E(\widetilde{R}_{j,t+1}))\, f(R_{j,t}, R_{j,t+1}) dR_t dR_{t+1} =$$
$$\iint_{R_t R_{t+1}} (\widetilde{R}_{j,t} - E(\widetilde{R}_{j,t})) \cdot (\widetilde{R}_{j,t+1} - E(\widetilde{R}_{j,t+1}))\, f(R_{j,t})\, f(R_{j,t+1}/R_t) dR_t dR_{t+1},$$

as $f(R_t, R_{t+1}) = f(R_t)\, f(R_{t+1}/R_t)$

From the definition of the conditional expected value, we have:

$\int_{R_t} (\widetilde{R}_{j,t+1} f(R_{t+1}/R_t) dR_{t+1} = E(\widetilde{R}_{j,t+1}/R_t)$ hence:

$$\mathrm{COV}(\widetilde{R}_t, \widetilde{R}_{t+1}) = \int_{R_t} \{\widetilde{R}_t - E(\widetilde{R}_t)\} \cdot \{E(\widetilde{R}_{t+1}/R_t) - E(\widetilde{R}_{j,t+1})\} \cdot f(R_t) dR_t \quad (5)$$

Equation (5) is the one used by Fama. As $E(\widetilde{R}_{t+1}) = E\{E(\widetilde{R}_{t+1}/R_t)\}$, equation (5) may be also written as:

$$\mathrm{COV}(\widetilde{R}_t, \widetilde{R}_{t+1}) =$$
$$= \int_{R_t} \{\widetilde{R}_t - E(\widetilde{R}_t)\} \cdot \{E(\widetilde{R}_{t+1}/R_t) - E\{E(\widetilde{R}_{t+1}/R_t)\} \cdot f(R_t) dR_t \quad (6)$$

However, from the above analysis it is evident that both equations (5) and (6) are equivalent to the definitional equation of autocovariance and there is nothing specific for $\widetilde{R}_{j,t}, \widetilde{R}_{j,t+1}$ in either of these equations. They are true for any random variables $\widetilde{X}, \widetilde{Y}$. In addition, the fact that $Z_{j,t}$ is a martingale difference process does not help in any way to find out the autocovariance between $\tilde{R}_{j,t}, \tilde{R}_{j,t+1}$. Hence, in general, $COV(\tilde{R}_t, \tilde{R}_{t+1}) \neq 0$, as $E(\tilde{R}_{t+1} / R_t) - E\{E(\tilde{R}_{t+1}/R_t) \neq 0$, and it is clear that for the integral in equation (6) to vanish an additional assumption should be made. This assumption is the one of the so-called constant expected returns (for stocks Fama (1970) in a footnote provides a justification for this assumption), under which apparently $E(\tilde{R}_{t+1} / R_t) = E\{E(\tilde{R}_{t+1}/R_t)\}$, therefore, $COV(\tilde{R}_t, \tilde{R}_{t+1}) = 0$.

It is in this case only that it makes sense to perform autocorrelation tests in which the existence of autocorrelation in stock returns themselves can be taken as evidence for the rejection of market efficiency (more precisely for the rejection of the joint hypothesis of market efficiency and the constant expected returns assumption). Otherwise, it is the deviations of observed returns from expected returns that should be considered in autocorrelation tests for market efficiency. It must be emphasized at this point that the assumption of constant expected returns, which was introduced in order to make the autocovariance of returns equal to zero, imposes stronger restrictions than just uncorrelated returns. Indeed, under this assumption $E(\tilde{R}_{j,t+1} / R_{j,t}) = E(\tilde{R}_{j,t+1})$ and it can be shown (see Williams, 1991) that $COV(\tilde{R}_{j,t+1}, g(\tilde{R}_{j,t})) = 0$, where $g(\tilde{R}_{j,t})$ is any function of $\tilde{R}_{j,t}$. Hence, $\tilde{R}_{j,t}, \tilde{R}_{j,t+1}$ are not just uncorrelated but mean independent. In fact all market efficiency testing procedures for $\tilde{Z}_{j,t}$ can also be applied for $\tilde{R}_{j,t}$ under the constant expected returns assumption.

In the 1991 paper, Fama reviews the empirical evidence which shows that, over relatively long horizons, expected returns are time varying rather than constant. Even so, under its general definition, the market efficiency hypothesis may be perfectly maintained. In this case however, caution is needed on how the results of autocorrelation tests in relation to market efficiency are interpreted if stock returns themselves, rather than their deviations from the expected returns, are used, as statistically significant autocorrelations in returns are compatible with market efficiency.

4. Market efficiency in the presence of GARCH-M models

The fact that a function of any kind cannot be used for one step ahead forecasts of the martingale difference processes $\widetilde{R}_{j,t}$, does not rule out that higher moments may depend on past values of $\widetilde{R}_{j,t}$, or generally on past information, i.e. in general $E(\widetilde{Z}^{k}_{t+1} / \Phi_{t}) \neq 0$ with k≥2. A well known example of such dependencies is the case of conditional heteroscedasticity. Such models, originally introduced by Engle (1982) and generalized by Bollerslev (1986) may be expressed, for the case of $\widetilde{Z}_{j,t}$, as:

$E(\widetilde{Z}^{2}_{j,t+1} / \Phi_{t}) = \widetilde{h}^{2}_{t+1}$ with $\widetilde{Z}_{j,t+1} = \widetilde{\nu}_{t+1}\widetilde{h}_{t+1}$, where $\widetilde{\nu}_{t}$ is a unit variance white noise process independent of $\widetilde{h}_{t}$ and $\widetilde{h}^{2}_{t}$, which represents the conditional variance, follows a GARCH(p,q) process, i.e. $\widetilde{h}^{2}_{t} = \omega + \sum_{i=1}^{q} \alpha_{i} \widetilde{Z}^{2}_{t-1} + \sum_{i=1}^{p} \beta_{i} \widetilde{h}^{2}_{t-1}$ (see Bollerslev, 1986 for restrictions on model parameters and further details).

For market efficiency, a particularly interesting type of models for conditional heteroscedasticity, omitted in the 1991 review article of Fama, are the co-called GARCH-M models (Engle et. al, 1987), in which the conditional variance can be used as a predictor for returns. Such models may be generally expressed as:

$\widetilde{R}_{j,t+1} = f(\Omega_{t}; \widetilde{h}^{2}_{t+1}; \vec{\theta}) + \widetilde{u}_{t+1}$. This equation expresses the return of security j at time t+1 as a function f of the information set Ω_t available at time t, a parameter vector $\vec{\theta}$, and the conditional variance $\widetilde{h}^{2}_{t+1}$, which has been excluded from Ω_t (u_{t+1} is the stochastic disturbance term of the model which is assumed to be i.i.d.).

In this case, caution is needed on how to interpret the results of such a model in relation to market efficiency (e.g. Milionis and Moschos (2000) discuss a case study where the published results of a GARCH-M model are misinterpreted in terms of their implications for market efficiency). For the particular case of a GARCH-M model the condition: $\frac{\partial}{\partial \widetilde{h}^{2}_{t+1}} f(\Omega_{t}; \widetilde{h}^{2}_{t+1}; \vec{\theta}) \neq 0$ is not enough evidence to reject market efficiency. Indeed, in a risk-adjusted framework a change in conditional return may be related to a change in conditional variance. In this case the implications for market efficiency may be stated as follows:

1) if the partial derivative of the function f with respect to $\tilde{h}^2_{t+1}$ is negative, an increase in the conditional variance (hence, in risk) will be associated with a decrease in expected returns. In that case, provided that the model is correctly specified, the hypothesis of market efficiency should be rejected.

2) If the partial derivative of the function f with respect to $\tilde{h}^2_{t+1}$ is positive, then an increase in risk will be associated with an increase in expected return. This is not inconsistent with the general form of market efficiency, as pointed out previously, and market efficiency cannot be rejected.

5. Summary and conclussions

Both Fama's review papers are an invaluable contribution to finance, but they still leave some ambiguity with respect to the substance of market efficiency as well as the statistical methodology of its empirical testing. Using simple statistical arguments, the aim of this paper was to remove part of this ambiguity by suggesting an alternative definition for market efficiency, which is simpler, clearer, and more operational, and by commenting on some aspects of empirical testing which have caused confusion, without changing the flavour of Fama's framework.

The suggested alternative definition for market efficiency, as compared to the existing one, has some considerable advantages which are briefly coded below:

1) It is conceptually more appealing than the existing definition of market efficiency, as an estimator is a well-defined statistical notion, while the meaning of the expression "fully reflect" is rather condensed and, to some extent, equivocal requiring further explanation. With the alternative definition the fact that prices should fully reflect all available information, at least to an extent that is sufficient for market efficiency to be tested empirically, is derived as a consequence.

2) It immediately links the efficient market hypothesis with the mechanism of producing conditional expectations of returns, i.e. an asset pricing model. In that way, it minimizes the distance between definition and empirical testing; the peril of misinterpretation of results from market efficiency tests is also minimized.

3) For testing market efficiency it is sufficient to use a summary statistic instead of the entire distribution of returns, as the latter it is now understood to be unnecessarily restrictive. As explained, the conditional expected value of returns is the optimal statistic for this purpose.

4) Market efficiency is defined in terms of the same quantities as any pricing model is expressed, i.e. in terms of (an estimator of) returns, rather than in terms of prices.

As far as the implications of statistical tests on predictability of returns for market efficiency are concerned, two special cases were discussed. In the first, the way that the results of autocorrelation tests on returns should be interpreted, in terms of market efficiency, were analysed. In the second, it was argued that the GARCH-M model is an exception to the general rule, as far as market efficiency is concerned. The reason is that in the cases where the conditional variance (of returns) can be used as a predictor for the returns themselves, this fact is not by itself enough evidence for the rejection of market efficiency. It is argued that, for the case of the GARCH-M model, the rejection of market efficiency also requires the effect of conditional variance on the returns, found by the empirical model, to be negative.

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