Recent Developments in the Theory of Efficient Capital Markets*

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I. Introduction

The hypothesis that prices reflect all available information in financial markets is predominant in the financial literature. According to this socalled efficient capital market hypothesis a "market in which prices fully reflect available information is called efficient" (*Fama*, 1970, p. 383). Despite the popularity of this hypothesis and numerous empirical tests of its implications rigorous analysis of the underlying problem of information aggregation and dissemination have until recently been few. For this reason sufficient conditions for market efficiency have hitherto been conjectured to be (*Fama*, 1970) i) absence of transactions costs, ii) all available information is freely available to all agents, and iii) homogeneous expectations, i.e. all agents agree on the implications of the available information for current and future asset prices. These sufficient conditions imply essentially that the information problem is assumed away from the outset, since by assuming all information to be freely available to all agents together with homogeneous expectations is to assume market efficiency, and hence to deprive the notion of capital market efficiency of any meaning[1]. Rather we shall analyse the problem of capital market efficiency under the assumptions i) frictionless (absence of transactions costs) competitive financial markets, and ii) model consistent or rational expectations.

To understand the market systems ability to use all available information efficiently, and hence to evaluate the efficient capital market hypothesis, a rigorous analysis of information aggregation and dissemination in decentralized markets is indispensable. Recently a highly technical literature has

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[1] In *Andersen* (1984) it is, however, shown how even under these assumptions the notion of market efficiency may be unclear since the relevant information set may not be well-defined, see section 9.

developed in which problems of information in competitive markets is rigorously analysed, and where the issue of informational efficiency of financial markets is explicitly addressed. The purpose of this paper is to give a non-technical introduction and review of this theoretical literature as it specifically relates to the efficient capital market hypothesis.

Agents trading in financial markets will for numerous reasons have different opinions (information/expectations) about the returns on the assets. The fact that agents trade conditional on different information implies in a competitive market that the equilibrium prices reflect the information of the traders since the competitive market prices depend on the demand of all agents, which in turn depends on the information possessed by the agents. Hence, the market price vector embodies to some degree all information currently available to the traders, and the agents should be able to infer some of this information from the prices. Observed prices constitute in this way important information sources since they aggregate the information possessed by different agents and disseminate this aggregated information to all traders.

In order to analyse the problem of how agents can infer information from prices it is necessary to say something about how agents perceive prices and information to be related. Obviously, the rational expectations equilibrium concept, cf. *Muth* (1961) and *Lucas* (1972), suggests itself by saying that the relation between prices and information perceived by agents is identical to the objective relation between prices and information. The rational expectations equilibrium concept has thus made a rigorous analysis of the problem of information and the price system possible, and motivated by the papers by *Kihlstrom* and *Mirmann* (1975) and *Grossman* (1976) a microeconomic literature[2] has been building up dealing with the problem of information dissemination and aggregation in competitive markets. The topic of this paper is restricted to this theoretical literature in relation to the efficient capital market hypothesis[3].

Market efficiency can be defined with respect to different information sets, and commonly a distinction is made between the following forms (*Fama,* 1970)[4]: i) weak-form efficiency, where only historical prices are

[2] Simultaneously a macroeconomic branch of literature has been building up where the role of prices as disseminaters of information has been stressed. This literature was motivated by the seminal paper by *Lucas* (1972), for a survey and introduction see *Barro* (1981) and *Taylor* (1983).

[3] This survey does not treat the relation between information and speculation (see *Stiglitz* (1983) for a recent discussion) nor any empirical work related to the efficient capital market hypothesis.

[4] On this see also *Neumann* and *Klein* (1982).

included in the information set, ii) semi-strong-form efficiency, where all public information is included in the information set, and iii) strong-form efficiency, where all information (public and private) is included in the information set. For the present purpose we shall primarily discuss the efficient capital market hypothesis in its strong-form.

The paper is organized as follows: Since the discussion depends critically on the rational expectations equilibrium concept we shall start by giving a short discussion of the appropriability of this equilibrium concept in analysing aggregation and dissemination of information by prices (section II). The following discussion will be with reference to a simple illustrative model set-up in section III, and the role of prices as aggregators and disseminators of information is analysed in section IV. In section V to IX we shall introduce information costs, wealth dynamics, quantity signals, existence of markets and sequential trading into the analysis. Finally, section X offers some concluding remarks.

II. The Rational Expectations Equilibrium Concept

In analysing informational questions we shall make extensive use of the rational expectations hypothesis. Although it is a technical attractive and nice hypothesis which avoids the problem of ad-hoc assumptions about expectations, is it also a reasonable hypothesis to use in analysing informational problems?

Let us start by making clear what the hypothesis of rational expectations entails. *Muth* (1961) formulated the idea that "Expectations, since they are informed predictions of future events, are essentially the same as the predictions of the relevant economic theory.", or to put it in another way, that agents use all available information in a correct way, i.e. consistent with theory.

It should be stressed that the assumption of rational expectations is not only a behavioural postulate with respect to the agents, but also an equilibrium concept. Expectation formation of endogenous variables requires that the agents have a perception of how endogenous variables are related to state or exogenous varables. This structural dependence is determined by the behaviour of all agents in the economy. The rational expectations hypothesis imposses the restriction that the agents perception of the reduced form of the model is identical to the true reduced form. In other words the expectations formation underlying the behaviour of any agent is consistent

with the expectation formation and hence behaviour of all other agents[5], i.e. the rational expectations hypothesis is an equilibrium concept.

It is essential that given this definition the appropriateness of assuming rational expectations can not be seen independently of the model in which it is put to use. One should not, therefore, necessarily identify the rational expectations hypothesis with the well known and controversial Lucas-Sargent-Wallace proposition saying that systematic macroeconomic policy is ineffective. This proposition hinges equally on the structural form of the model, and the expectation hypothesis, and is not necessarily implied by the rational expectations hypothesis as such.

It is important to distinguish between the way in which the rational expectations hypothesis has been used in macro models of the ISLM-variety and the "micro-models" discussed here. In the former the term is used to describe equilibria in a sequence of markets under uncertainty in which traders possessing homogeneous information anticipate the stochastic process of the equilibrium prices correctly, and information problems are only treated in a very rudimentary way. In the micro-version the information problem is explicitly analysed and the term describes an equilibrium concept for a market in which traders possessing different information use the equilibrium market prices as informational signals. It is the latter which is the topic of this survey.

The rational expectations hypothesis requires that agents know the true reduced form and this can be interpreted in either of two ways. In the first interpretation agents are assumed to learn the structure of the model over time, and in the limit (the long run) they will know the true structure and hence have rational expectations. Obviously this interpretation does not apply for markets which only are open infrequently or markets with frequent structural shifts[6]. Another interpretation is to regard the assumption of rational expectations as an equilibrium concept for an economy where the agents posses perfect knowledge on the structure of the economy. In either interpretation it is seen that the rational expectations assumption is the limit or the most which can be made of the idea that information is used optimally and consistent with theory.

All ad-hoc models of expectation formation suffer from the problem that any result derived subject to them is liable to the critique that all available information is not used optimally. Hence, if the agents in any way can

[5] This does not necessarily imply that agents have homogeneous expectations of endogenous variables in a rational expectations equilibrium, cf. below.

[6] Furthermore there is the problem of convergence of the learning process, see *Bray* et al. (1982), *Champsaur* (1983).

benefit from it they will attempt to acquire more information and use it, and this in turn changes the results.

The rational expectations hypothesis eliminates this problem, although obviously at the cost of being an informationally demanding equilibrium concept. However, in the context of financial markets where markets are well organized, the items traded are standardized, and a large number of agents participate this "strong" equilibrium concept may represent a reasonable first-approximation. This is reinforced by the fact that transactions costs in financial markets typically will be negligible and specialized traders to some degree will be able to counter-act the effects of 'irrational' traders. Finally, it should be remarked that although the rational expectations equilibrium concept is descriptively too strong it is not devoid of any sensible use in theoretical models, since it is a benchmark which shows the most to be expected as regard consistency in expectations formation.

The applicability of the rational expectations hypothesis is intimately related to the market systems ability to coordinate economic activities. Generally, economists are prejudiced towards the view that the market mechanism succeeds quite well in coordinating economic activities. Since the rational expectations hypothesis implies that all information is used correctly it tends to tilt the result towards well-behaved results, and one should think that the hypothesis only seems reasonable to those who are prejudiced towards the view that economic activities are well coordinated[7].

This is, however, not necessarily the case since the rational expectations hypothesis "permits us to show that even in such a world the invisible hand may cease to guide before it has made citizens as well off as, in the given circumstances, they could be". (*Hahn,* 1982, p. 11).

The advantage of the rational expectations equilibrium concept is that it allows a rigorous analysis of problems related to information and the price system. The idea of employing this equilibrium concept is thus primarily that it is a useful benchmark showing the most to be expected from information aggregation and dissemination in decentralized markets rather than a necessarily fully realistic expectations hypothesis.

III. An Illustrative Model

As a benchmark for the following discussion it is useful to develop a simple portfolio model which allows us to discuss the basic issues involved in information aggregation and dissemination by prices.

[7] Admittedly there is a tendency for this to be the case.

Consider a model with H wealth-maximizing households indexed by i, $i = 1, 2, \ldots, H$. Assume that they can invest in a riskless asset with zero return[8] (money) and price normalized to one, and a risky asset with current price p and which pays $\bar{p}$ at the end of the period, i.e. the return on the risky asset is given by the capital gain $\bar{p} - p$. All agents are assumed to be price-takers in the market for the risky asset.

Investor i's budget constraint is given as

$$\underline{m}_i + p\underline{x}_i \equiv \underline{w}_i = m_i + px_i \tag{1}$$

where $\underline{m}_i$ and $\underline{x}_i$ are the initial stocks possessed by agent i of the riskless and the risky asset. The initial wealth $\underline{w}_i$ of investor i is given as the value of the initial stocks. The budget constraint in (1) requires that investments in the riskless (m_i) and the risky asset (x_i) do not exceed the initial wealth. Given investments we find end-of-period wealth to be

$$w_i = m_i + \bar{p}x_i \tag{2}$$

Combining (1) und (2) we get

$$w_i = \underline{w}_i + (\bar{p} - p)x_i \tag{3}$$

Investors are assumed to maximize the expected utility of end-of-period wealth conditional on information available to the agent I_i (to be specified below). For simplicity we assume the utility function of all investors to be a constant absolute risk-aversion utility function[9]. Hence, investor i maximizes

$$E\left[-\exp\left(-a_i w_i\right) \mid I_i\right] \tag{4}$$

subject to (3). $a_i \geq 0$ is the *Arrow-Pratt* measure of absolute risk-aversion of agent i, assumed to be constant.

The excess demand of agent i for the risky asset can now be found to be

$$z_i(p, I_i) = \frac{E(\bar{p} \mid I_i) - p}{a_i \operatorname{VAR}(\bar{p} \mid I_i)} - \underline{x}_i \tag{5}$$

Let us assume that each agent possess some private information, s_i, relevant for predicting the end-of-period value of the risky asset ($\bar{p}$). Since the

[8] The assumption of zero return is not critical, but simplifies the exposition.

[9] An important implication of this is that the demand for the risky asset becomes independent of wealth cf. section VI.

demand for the risky asset and hence the equilibrium price (p) depends on the private information of the agents, the price reveals some of this information, and hence the price constitutes an independent source of information to the agents. That is, the information available to agent i is given by private information s_i and public information from observing the market price, i.e. $I_i = \{s_i, p\}$.

In the following we shall distinguish between a differential information structure and an asymmetric information structure. By a differential information structure is understood that agents have differential ex-ante (private) information, but no agent believes any other agent to be systematically better informed than himself. By an asymmetric information structure is understood a separation of the agents into "informed" and "uninformed" agents, where the latter group of agents possess lesser information than the former[10].

Let $i = 1, 2, \ldots, K$ denote the group of 'informed' agents and $i = K + 1, \ldots, H$ the group of 'uninformed' agents then the asymmetric information structure is characterized by

$$I_i = \begin{cases} I_I & i = 1, 2, \ldots, K \\ I_U & i = K+1, K+2, \ldots, H \end{cases}$$

where $I_U \subset I_I$. Obviously, the asymmetric information structure is a special case of the differential information structure.

Returning to the illustrative model we shall assume that the end-of-period value of the risky asset is determined exogenously as[11]

$$\bar{p} = f + \varepsilon \tag{6}$$

where $f \sim N(\bar{f}, \sigma_f^2)$, $\varepsilon \sim N(0, \sigma_\varepsilon^2)$ and $Ef\varepsilon = 0$.

It is useful to start by considering this model under an asymmetric information structure. Assume that the information set of informed agents is given as $I_I = \{f, p\}$ and the information set of uninformed agents as $I_U = \{p\}$[12], i.e. informed agents can observe the f-part of the end-of-period value of the risky asset whereas uninformed agents only receive the information which they can infer from the equilibrium price. Notice, that the investment

[10] This is common knowledge to all agents.

[11] Notice that this implies a positive probability of a negative end-of-period value of the risky asset. We shall neglect this problem to take advantage of the analytical simplicity offered by normally distributed random variables.

[12] That is, $s_I = \{f\}$ and $s_U = \{\emptyset\}$.

in the risky asset is uncertain for the informed agents since the ε-part of the future spot price is unobservable to the informed agents, moreover the informed agents do not gain any further information from observing the equilibrium price since they already know all relevant private information in the market.

It follows that the market demand of any informed agent can be written $z_I(p, f)$[13], i.e. as a function of the price and the information available to the informed agents. To determine the demand of an uninformed agent is more difficult since these agents only receive the information which they can infer from the equilibrium price. To infer information from the price it is necessary that the uninformed agents conjecture how the price depends on the information (of the informed agents). Assume that the uninformed agents conjecture the equilibrium price to be related to information possessed by informed agents as follows

$$p = h'(f; \cdot) \tag{7}$$

Conditional on this conjecture the uninformed agents infer information on f from the price signal, and hence the (excess) demand of an uninformed agent can be written $z_u(p)$. Notice, that p appears both for its allocational role and for its informational role in the demand of the uninformed agents.

Let the total (per capita) exogenous supply of the risky asset be denoted z_s, and the fraction of agents being informed λ $(= K/H)$ be constant and exogenously given (see section V). The equilibrium condition can be written

$$\lambda z_I(p, f) + (1 - \lambda) z_u(p) = z_s \tag{8}$$

The equilibrium price can now be written

$$p = h(f; \lambda, z_s) \tag{9}$$

Note that even if λ and z_s are constant they have been stated explicitly in the price function to stress that the equilibrium price depends significantly on these two parameters, cf. below.

The resulting equilibrium price (9) depends on the conjecture made by the agents on the relation between the price and information (7). We shall employ the rational expectations equilibrium concept according to which the agents conjecture of the relation between the equilibrium price and information (7) is identical to the objective relation between the equilibrium price and information (cf. section II), i.e.[14]

[13] See *Grossman* (1976) and *Grossman* and *Stiglitz* (1980).

$$h'(f; \lambda, z_S) = h(f; \lambda, z_S) \tag{10}$$

We have here given a simple outline of the technique involved in solving models where prices are important information sources. Since the explicit solution of such models can be rather cumbersome and does not reveal any economic insight we shall leave this out of the present discussion.

From (9) it is seen that the equilibrium price reveals to the uninformed agents the information possessed by the informed agents. Good information, i.e. a high f, leads to a high demand by the informed agents and hence a high price of the asset, and vice versa. The uninformed agents can from the high price infer that the informed agents possess good information on the return on the risky asset. That is, there is a one-to-one relation between the price and the information of the informed agents, which the uninformed agents can use to infer the information available to the informed agents.

If the supply is random we find that the equilibrium price is given as

$$p = \mathrm{h}(f, z_S; \lambda) \tag{11}$$

With a changing supply we may have that the price goes up (down) either because informed agents receive information indicating a high (low) return on the risky asset or because supply has been reduced (increased). The variability of the supply of the risky asset breaks in this way the one-to-one link between the price and the information available to informed agents. The price signal allows no longer the uninformed agents to infer precisely the information available to the informed agents. Though there is still a correlation between the price and the information on f, hence the price signals remain a valuable information signal, although not a perfect signal; the price has become a noisy signal on the information variable f.

IV. Prices and Information

We have in section III seen a simple example of how the equilibrium price perfectly reveals the information available to informed agents. We shall in this section discuss the ability of prices to reveal information in more detail. Consider the more general case of an economy with an N-dimensional price vector, and an M-dimensional vector of state or exogenous variables. Atten-

[14] It is seen that to prove the existence of a rational expectations equilibrium a fix-point problem in the h-function is basically involved. Problems related to the solution and existence of rational expectation equilibria are not treated here, for a discussion of these problems see f.i. *Radner* (1981) and *Jordan* and *Radner* (1982).

tion is here restricted to exogenously given information structures[15], where each agent in principle can possess private information on any of the state variables, i.e. a differential information structure. We can thus in general describe the private information structure by a $H \times M$ matrix S (H is the number of agents in the economy), where any element s_{ij} ($i = 1, 2, \ldots, H; j = 1, 2, \ldots, M$) denotes the private information by agent i on state variable j. Notice, that all elements in any column or row of S may be void, if either no agent receives any information on a given state variable[16] or if a given agent does not receive private information on any state variables. Obviously, agents are interested in inferring the true state of the economy from its private information and the information revealed by the vector of equilibrium prices. We are thus interested in analysing to what extent the vector of equilibrium prices succeeds in aggregating and disseminating all available private information. Notice, that the pooled private information may or may not allow the agents to infer the true state of the economy perfectly.

Grossman (1976) analysed a model similar to the model of section III under a differential information structure and an exogenous (constant) supply of the risky asset. The private information of any agent i is given as the signal $s_i = f + \varepsilon_i$, and the information set of agent i is thus $I_i = \{s_i, p\}$. It follows that the dimension of the price vector in this case is equal to the dimension of the relevant state variable (end-of-period value of the risky asset), since $N = M = 1$. Under the assumption of constant-absolute-risk-aversion utility functions and normally distributed random variables *Grossman* (1976) proved that the equilibrium price perfectly aggregates all available information, that is, any agent can from the equilibrium price infer the same information as if he observed all private information. Or to put in another way the single price aggregates perfectly the H different sources of information available in the market on the end-of-period value of the risky asset[17], i.e. there is market (informational) efficiency.

This result is extended in *Grossman* (1981) to the case of one risk-free asset and N (> 1) risky assets, and more general utility functions, but still with normally distributed random variables. Again the number of current prices is equal to the number of relevant state variables (future asset prices), i.e. $N = M > 1$, and it is shown that given that the utility functions are con-

[15] The problems of an endogenous information structure are considered in section V.

[16] This does not preclude the equilibrium price from revealing information on the state variable.

[17] Notice that this information does not allow the agents to predict the end-of-period value of the risky asset perfectly.

cave and monotone increasing in end-of-period wealth the N prices reveal all available information, provided that the risky assets are not *Giffen* goods[18]. Again we have informational efficiency, since prices perfectly summarize all that investors need to know and disseminate this information to the traders.

Loosely speaking we can thus say that N prices at most can aggregate and disseminate information about N state variables[19].

The proposition of information efficiency stated above has a very strong welfare implication since it implies that a central planner possessing all available information is unable to improve upon the competitive allocation arising from agents using their private information and the information contained in prices, *Grossman* (1976, 1978, 1981).

The fact that prices summarize all information available in the market creates the following paradox of informationally efficient economies: If each agent finds that the current prices reflect all available information, they will recognize that their private information does not provide any useful information not reflected by prices. Hence, they will disregard their private information, but how can prices aggregate dispersed private information if no agent has an incentive to use their private information.

To overcome this problem it is natural to set-up "noisy-models", that is, models where the dimension of the state vector is greater than the dimension of the price vector ($M > N$). We have already seen one example of this in section III where a random exogenous supply implies that uninformed agents no longer can know for certain whether a change in price is due to change in information available to informed agents or a change in the exogenous supply. Although an imperfect signal the price does, however, still reveal some information on the information available to the informed agents. The same applies in the model with a differential information structure since a random supply implies that the dimension of the state vector ($M = 2$) exceeds the dimension of the price vector ($N = 1$), i.e. the price no longer aggregates

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[18] See *Grossman* (1981) for an extension to a two-period state-of-nature model.

[19] It can not generally be concluded that N prices can aggregate and disseminate information on N state variables. To illustrate this take the model of section III with $N = M = 1$. A necessary condition that p reveals f is that the h-function is invertible, i.e. that there does not exist an f and f' such that $h(f; \cdot) = h(f'; \cdot)$. In this case uninformed agents can not distinguish between whether information f or f' is available to informed agents. Since a discussion of these existence problems will be rather technical it has been left out of the present survey, see f.i. *Radner* (1981) and *Jordan* and *Radner* (1982). *Looseley* speaking *Allen* (1982) has, however, shown that if the dimension of the price vector exceeds the dimension of the vector of state variables, then a revealing equilibrium exists generically.

the private information perfectly, cf. *Hellwig* (1980), *Bray* (1981) and *Diamond* and *Verrechia* (1981). It is an obvious implication of this that the private information of any agent is no longer superfluous, and the agents will have an incentive to use and acquire information even if it is costly, but the market is no longer informationally efficient.

So far we have implicitly assumed that all agents possessing relevant information are active in the market, and hence the price vector aggregates to some degree the information possessed by all agents. In general one would often encounter situations where agents possessing market relevant information find it optimal not to be active in the market and thus precludes the price from including their information. As the model in section III is set-up we have tacitly been assuming that there are no restrictions on either borrowing of the risk free asset nor on short-selling of the risk-free asset, that is, an investor having optimistic[20] expectations about the return on the risky asset can borrow whatever amounts he wishes to invest in the risky asset, and an investor having pessimistic expectations about the return of the risky asset can sell whatever amount of the risky asset. Consider for instance the plausible case where agents have no possibility of short selling of the risky asset[21]. In this case the market for the risky asset comes to be dominated by the more optimistic agents, and consequently the price tends to reflect the more optimistic information, cf. *Andersen* (1982). It is clear that it is important to pay attention to both how much information prices disseminate and the nature or quality of this information, that is, an inherent inefficiency exists in financial markets since the information reflected by prices tends to be biased towards the more optimistic information.

V. Information Costs

Let us return to the model of section III with a random supply, that is, the price does not perfectly reveal the information available to informed agents. Consider a situation where agents can obtain the information (f) on the return on the risky asset at a cost (c). Who will become informed and who will stay uninformed?

A single agent will choose to become informed if the expected utility conditional on the better information acquired by paying c is greater than the

[20] By optimistic agents we understand agents who conditional on their information have "high" expectations of the end-of-period value of the risky asset, and vice versa for pessimistic agents.

[21] See also *Mayshar* (1983) for a discussion of this point together with the implications of transactions costs.

expected utility conditional on the information which can be inferred from the price.

For the market as a whole the more traders who become informed i.e. λ large, the more information is revealed by the price. Thus the higher λ the lower is the expected utility of the informed agents compared to the uninformed agents. The equilibrium value λ^* of agents being informed is determined by the condition that the expected utility of being informed is equal to the expected utility of being uninformed. In this way the number of informed agents and the informativeness of the price system is jointly determined in an endogenous way.

Some comparative static results can be found. Consider an increase in the information costs, this will decrease the expected utility of informed agents and the informativeness of the price system (λ falls). Although, the decrease in the informativeness of the price system tends to increase λ, the net effect of an increase in the information costs is an unambigious fall in the number of informed agents, cf. *Grossman* and *Stiglitz* (1980).

An increase in the quality of information increases the informativeness of the price system. If the information obtained becomes more informative the demand of the informed agents becomes more responsive to the information received and this implies that the informativeness of the price system increases. The effect on the number of informed agents is ambigious since the increase in the quality of information tends to increase λ, whereas the increase in the information conveyed by the price tends to decrease λ. If the initial position before the change in the quality of information is one where a large (small) amount of information is disseminated by the price the fraction of informed agents will decrease (increase).

If the noise in the information received by informed agents (variance of ε) increases or the noise in the price system (variance of z_S) increases, the price system tends to become less informative and hence the expected utility of uninformed agents tends to be lower. This induces an increase in the number of informed agents, and this has the effect of increasing the informativeness of the price system. In fact the two effects exactly offset each other so that the equilibrium informativeness of the price system is unchanged (*Grossman* and *Stiglitz*, 1980).

Verrechia (1982) provides an interesting extension of the analysis by *Grossman* and *Stiglitz* (1980). The model has the same basic structure but it employs a differential information structure and a continuous cost function of information. The cost function is a strictly increasing and convex function of the precision of the information (the inverse of the variance). *Verrechia*

(1982) shows that the information each agent acquires is a decreasing function of the informativeness of the price system and that the informativeness of the price is non-decreasing as information costs decreases. These results are similar to the results derived in the more simple model by *Grossman* and *Stiglitz* (1980).

More interestingly, *Verrechia* (1982) shows that an increase in the noise implies that the informativeness of the price system decreases. That is, the increase in information acquisition of the agents arising from an increase in the noise is not sufficient in equilibrium to outweight the decrease in the information revealed by the price due to the increased noise. In the *Grossmann / Stiglitz* model the two effects exactly balance each other such that an increase in noise has no effect on the informativeness of the price system, cf. above.

Grossman and *Stiglitz* (1980) and *Verrechia* (1982) have shown that as the market tends to be dominated by less risk-averse agents the informativeness of the price system increases.

Information costs imply that no perfectly revealing equilibrium exists even if the dimension of the price vector (N) is equal to the dimension of the state vector (M). To see this consider a situation where nobody acquires any information, in this case no information is revealed by the price and agents have an incentive to buy information (for sufficiently small information costs), hence an equilibrium without information acquisition is not possible. However, once any agent acquires information it is revealed by the price and therefore nobody has an incentive to acquire the information, hence an equilibrium with information acquisition is impossible. It follows that with information costs an information efficient equilibrium does not exist.

This result depends on the fact that agents learn from the current price even before any trade has taken place at this price, i.e. the price clears the market simultaneously with agents using the information revealed by the price, cf. *Hellwig* (1982). If agents are allowed to learn information only from prices at which trade already has taken place i.e. past prices, there will be a delay in the dissemination of information. The information acquired by informed agents is transmitted by the price with a one-period lag to the uninformed agents. This lag in the dissemination of information by prices gives an advantage to the agents who acquire the information, that is, they have time to use the information before the uninformed agents learn it[22].

If the time intervals between trading are sufficiently small the market equilibrium where uninformed agents only learn from past prices approxi-

[22] See also *Neumann* and *Klein* (1982).

mates a full information efficient market arbitrary closely, and still the return of being informed is bounded away from zero, cf. *Hellwig* (1982).

VI. Wealth Dynamics

We have thus far been looking upon information efficiency as been brought about if prices perfectly aggregate and disseminate information. Another route by which information efficiency may be obtained is through a process of wealth reallocation, initiated by the fact that better informed agents make a positive profit. We should expect this to imply an increase in their wealth and hence an increase in the weight to their information in the market price, whereas worse informed agents loose money and eventually are driven out of the market. This process is caused by the fact that markets weight a traders information not by its quality, but by the amount of money behind it ("dollar votes"). Hence, information efficiency is achieved in the long run by a process where wealth is redistributed from worse informed agents to better informed agents, "If this process worked well enough, the present price would reflect the best information about the future ..." *Cootner* (1964, p. 80). That is, the worse informed agents are squeezed out of the market, and only well informed agents remain in the market with the price perfectly reflecting their information.

Implicitly we have so far been assuming this important wealth dynamic process to be absent by having restricted attention to constant absolute risk-aversion utility functions implying that asset demand is independent of wealth. We shall in this section discuss this wealth dynamics in some detail.

Feiger (1978) discusses this problem in a simple two period model with spot markets at date t and $t + 1$, and a forward market at date t for delivery at date $t + 1$. Informed agents have some information on the period $t + 1$ spot price, which forms the basis for their trade in the forward market. It can now be shown that if the informed agents dominate the market the forward price will reflect their information, and consequently uninformed agents have access to the information of the informed agents. Given that the price is revealing all have the same information, hence there will be no wealth redistribution.

On the other hand if the uninformed agents with homogeneous, but erroneous information dominate the market they will make the price, and this prevents the price from revealing the information available to informed agents. Hence, imperfect information persists in equilibrium implying a transfer of wealth from uninformed to informed agents. This wealth reallo-

cation increases, however, the importance of the informed agents and an upper limit to this process is set by the point where they come to dominate the market, since in this case the price reflects the information of the informed agents. Hence, starting from a position where uninformed agents dominate the market sets into motion a wealth reallocation process which runs until the informed agents come to dominate the market, i.e. their wealth has increased so as to make them dominate the market.

Similarly *Figlewski* (1979) analyses the wealth dynamics resulting from differences in information. Using a model with an asymmetric information structure with agents partioned into two groups the informational efficiency of a financial market is analysed. The central point is that the price aggregates agents information, but the weights in aggregation are given by wealth and not by the quality of information. It is shown that agents with information overvalued in the price tends to loose money and vice versa.

Interestingly it is shown that agents with inferior information are not driven out of the market by the better informed agents, but tend to lose money as long as their information is overvalued. Hence the worse informed agents will lose money as long as their information is overvalued by the price, and generally the adjustment of wealth stops before the agent is driven out of the market.

The distribution of wealth will in this way in the short run tend towards the distribution of wealth consistent with market efficiency. This convergence is, however, in expected value since we have a stochastic equilibrium, i.e. the market will be informationally efficient in the mean. Or to put it in another way the long run equilibrium can with a positive probability be far away from the informationally efficient equilibrium. Thus markets should not always be expected to be informationally efficient, it can, however, be shown that it is close to information efficiency if either all agents have a high risk aversion or if the traders have homogeneous information, cf. *Figlewski* (1979).

VII. Quantity Signals

We have seen how prices play a role as informational signals in financial markets, but if this is a correct description of the real world, how can it be that records from financial markets often alongside prices provide information on the amounts traded of the assets[23]?

[23] Alternative if such quantity information is not made available to the traders one could, to the extent that quantity signals reveal relevant information not contained in

Consider the model of section III under an asymmetric information structure. If the supply of the risky asset is random ($M = 2$) we have seen that the price becomes a noisy signal on the information available to the informed agents. The total quantity traded in the markets depends, however, on the information of the informed agents and the random supply as does the equilibrium price. In *Andersen* (1983) it has been shown that the quantity signal actually reveals information on the information of the informed agents and the random supply in a qualitatively different way than the price signal, although the quantity signal as the price signal is a noisy signal on the information available to the informed agents.

It turns out that the quantity signal may be a more reliable signal on the information available to the informed agents than the price. Whether the price or the quantity signal is the most reliable signal depends on the relative slope of the aggregate demand and supply curves, cf. *Andersen* (1983). This contradicts the traditional presumption that price signals alone play an informational role, cf. *Hayek* (1945).

Since the price signal and the quantity signal reveal different information it follows that the uninformed agents can gain information by combining the two signals. In the case referred to above the combined use of the price and the quantity signal implies that the uninformed agents can infer the information available to the informed agents. That is, even though the dimension of the price vector ($N = 1$) is less than the dimension of the state vector ($M = 2$), the inclusion of the quantity signal increases the dimension of the vector of observed signals to be equal to the dimension of the state vector, and hence information efficiency is obtained. Both price and quantity signals are in this way relevant for the allocation of economic resources and capital market efficiency is not attained solely through the informational role of the price signal, but requires the inclusion of the quantity signal as an information signal. Of course the combined price and quantity signal can be made a noisy signal on the information possessed by informed agents (cf. section III) by increasing the dimension of the state vector, but the conclusion remains that the quantity signal continues to be an important independent information signal.

VIII. Existence of Markets

We have previously taken the number of markets to be exogenously given, and it was shown that the price system is not informationally efficient if the

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the price signals, justify the incurrence of costs to collect and release such quantity information.

dimension of the price vector is less than the dimension of the vector of state variables ($N < M$). We shall argue that the number of markets (N)[24] depends crucially on the information disseminated by prices and transaction- and information costs.

If the number of markets is reduced two things will generally happen: i) the dimension of the price vector is reduced, and therefore prices reveal less information, ii) the dimension of the state vector is increased as a result of stocks of non-traded goods, and this tends to reduce the amount of information disseminated by prices, *Grossman* (1977, 1978).

Hence, the amount of information disseminated by prices is an increasing function in the number of markets. We should therefore expect that, if given a market structure where the prices disseminate a small amount of information ($N < M$), there will be a tendency for the number of markets to increase, and in the limit approach the number of state variables.

Consider the following two-period model (due to *Grossman* (1977)) for a single commodity, with a spot market at date 0 and 1. Supply is exogenously given at time 0 and no supply is available at time 1, hence resources can only be transferred to period 1 by means of inventories. If future demand is uncertain, but informed agents possess some information on future demand the period 0 spot price will reflect this information ($N = M = 1$). Therefore the uninformed agents can infer this information from the period 0 spot price.

If, however, both period 0 and 1 demands are uncertain ($M = 2$) the period 0 spot price is no longer a sufficient statistic for the available information, that is, there is an informational difference between informed and uninformed agents. This implies that they do not hold the same expectations as of the period 1 spot price. Since the transfer of resources to period 1 is a speculative activity this difference in expectations imply differences in the speculative commitments of informed and uninformed agents.

This difference in information and consequently expectations gives an incentive to set up a futures market. That is, a new market for trading at date 0 is set up, and the dimension of the price vector is increased. In this case the period 0 spot price and the forward price perfectly reveal the available information ($N = M = 2$).

The existence of this new market depends on the informational efficiency of the period 0 spot market. When this market is informationally effi-

[24] Strictly speaking the dimension of the price vector is equal to the number of markets less one, since the price vector can be normalized to lie on the unit circle without loss of generality.

cient ($M = N = 1$) there are no differences in information and no incentive to set up new markets, but if the market is informationally inefficient ($M = 2$, $N = 1$) there is an incentive to expand the number of markets.

Generalizing this result we can conclude that whenever the price system is informationally inefficient ($N < M$) there will be a tendency for the number of markets to increase. Does this imply that one should expect the number of markets to increase such as to ensure informationally efficiency? Quite obviously the answer is no, since we have left out information and transaction costs.

Trade is caused by differences in endowments, preferences and information. If endowments and preferences are identical for all agents, trade will only take place if information differs between agents. If the number of markets increases to make the price system informational efficient we will find that no trade is taking place. If there for instance are fixed costs in setting up and operating markets, there will not be enough trade to pay the fixed costs. Hence we should not expect the number of markets to increase to make the price system informationally efficient unless transaction costs are absent.

In the same way information costs preclude the expansion of the number of markets to establish informationally efficiency. If there are information costs and the number of markets is expanded so as to imply informational efficiency we run into the non-existence problem discussed in section V. It is seen that this is in contrast to the traditional view that if only the set of markets is complete the traditional *Arrow-Debreu* results hold. Given information costs an increase in the number of markets decrease the incentive to acquire information. Or to put it in another way there is a trade-off between the allocative gain that traditionally is seen to arise from an expanded set of markets and the disincentive effects on information acquisition of expanding the number of markets. Hence, there is an optimum number of markets (short of a complete set) determined by information and transaction costs.

IX. Sequential Trading

Up to now we have only been considering one-shot markets, that is, agents trade today in a market for a risky asset which has an exogenously given end-of-period value. This turns out to be a critical assumption since the return on risky assets depends on the market's valuation of the asset tomorrow, it is therefore necessary to consider the problem of sequential trading.

Sequential trading introduces some problems which did not arise in the models considered so far. To see this consider a simple speculative market for a single risky asset where the current price in period t depends on the expectations of the spot price which will prevail in period $t + 1$, since the return on the risky asset is given by the capital gain on the asset. Given rational expectations agents will realize that the period $t + 1$ price depends on the expectation of the period $t + 2$ price as of date $t + 1$, and that the period $t + 2$ price in turn depends on the expectation of the period $t + 3$ price and so on. Hence, in a sequence of markets[25] the fact that agents form expectations rationally introduces a dynamic element into the model, which did not appear in the models considered so far.

It is well-known from macromodels with rational expectations that a sequence structure implies, even under homogeneous expectations, that spurious variables or sunspots may influence the solution. It is thus possible that totally irrelevant variables may influence the equilibrium, and consequently an infinity of equilibria exists, cf. f.i. *Gourieoux* et al. (1982). This shows that purely speculative manias or bubbles are consistent with the assumption of rational expectations, cf. *Blanchard* (1979) and *Flood* and *Garber* (1980)[26]. Moreover it is consistent with rational expectations that the bubble "bursts" and the market goes back to "normal" (market fundamentals)[27].

In a frictionless market investors will be concerned with the short-run gain to be made by investing in a given risky asset, i.e. they behave myopically. In *Andersen* (1984) it is shown, within a model similar to the model of section III, that if the market is informationally efficient, the expectations of future asset prices become indeterminate. Since prices depend on price expectations it follows that asset prices are indeterminate, and hence they become determined in an arbitrary way similar to *Keynes'* analogy between a beauty contest and the operation of financial markets. Keynes' view on stock markets is therefore not necessarily inconsistent with the assumptions of the efficient capital market hypothesis, cf. section I. The indeterminancy of asset prices implies in turn that it becomes impossible to define the infor-

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[25] Most macroeconomic models with rational expectations have a sequence structure, but the problem discussed here is partly avoided by assuming homogeneous information.

[26] *Flood* and *Garber* (1980) study the German hyperinflation in the 1920's, and they are unable to disprove the hypothesis that speculative bubbles were absent in the period.

[27] See *Aziaridis* (1982) for an interesting analysis of how extraneous information variables may come to influence the equilibrium in an overlapping-generations model with rational expectations.

mation relevant for the pricing of financial assets in any precise way, that is, any information which agents conjecture to be relevant for asset prices comes in a self-fulfilling way to be reflected in the equilibrium prices of the assets, cf. *Andersen* (1984).

Finally, important work by *Futia* (1981) on a sequence of markets under differential information should be mentioned. In a simple model with a differential information structure *Futia* (1981) shows that the rational expectations equilibrium not generically will be revealing, and in fact it turns out that i) there exists non-revealing rational expectations equilibria, i.e. agents information and therefore expectations will differ in equilibrium, and ii) a rational expectations equilibrium needs not even exist.

A further interesting implication is that some rational expectations equilibria may possess the property that traders are fully informed, i.e. know all the information available to the economy, when they combine the information revealed by the price with their private information. In this case the price only reveals part of the total information set, that is, even if the rational expectations equilibrium is revealing the private information is not superflous, i.e. the price alone does not reveal all information. In this case the paradox of private information mentioned in section IV is avoided.

X. Conclusion

According to the efficient capital market hypothesis financial markets are highly efficient in the sense of being arbitraged and having all available information fully reflected in current asset prices. The normative appeal of this hypothesis is quite obvious; efficient market prices give the right incentives for the firms' production-investment decisions and investors portfolio decisions.

In the present paper the recent theoretical development on the problem of information aggregation and information in financial markets has been reviewed and discussed. It is clear from this work how restrictive the efficient capital market hypothesis is in its strong-form; capital market efficiency should not in general be expected to prevail. This conclusion is supported by the fact that the dimension of the vector of state-variables is greater than the dimension of the observed market signals (prices), section IV, and that costs of acquiring information precludes informational efficiency, section V.

In evaluating this recent theoretical literature on market efficiency it is important to keep in mind that although parts of the efficient capital market

hypothesis have been challenged some of its basic insights remain intact. This applies in particular to capital market efficiency in its weak and semi-strong form which has been amply supported by empirical research; none of the recent contributions leave any possibility that traders can make a profit in financial markets by exploiting public information.

It should be kept in mind that although good theoretical reasons have been found why capital markets are not efficient in the strong-form, this sort of inefficiency does not leave open an obvious role for any active policy, i.e. it is not clear whether there exists a suitable and implementable policy to cope with these inefficiencies[28]. More research is needed to clarify this point. Furthermore, these inefficiencies do not necessarily indicate any social suboptimality of the market allocation. To take an example, costs of acquiring information which prevent capital market efficiency are as much a fact of life as are the costs of producing commodities.

Finally, let us comment shortly on the methodology, viz. the rational expectations equilibrium concept. Although, as noted, the rational expectations equilibrium concept is very restrictive it has proved to be part of a fruitful research strategy. One should not, however, be satisfied with the rational expectations equilibrium concept in its present form, and the important work on the problems of learning, learning adjustment costs must eventually lead to more descriptively realistic expectations models. The major advantage of the rational expectations equilibrium concept relative to other expectations models is that it allows an explicit modelling of information dissemination in decentralized markets, and in this way it has been valuable in analysing the efficient capital market hypothesis. The rational expectations equilibrium concept is a benchmark showing the most to be expected regarding information dissemination in decentralized markets, and when it turns out that even the most is far from being perfect it is a reliable indicator of the fact that real-world markets are inefficient.

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[28] See, however, *Weiss* (1982) for an example of a workable policy.

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Zusammenfassung

Neue Entwicklungen der Theorie effizienter Kapitalmärkte

In der Finanzliteratur herrscht die Hypothese vor, daß die Preise in Märkten für Finanzaktiva sämtlich verfügbare Information reflektieren. Ungeachtet ihrer Beliebtheit unterliegt der Hypothese eines effizienten Kapitalmarktes keine rigorose theoretische Fundierung. Neuerdings ist eine sehr technische Literatur entwickelt worden, die die Informationsprobleme auf Wettbewerbsmärkten rigoros analysiert und die Frage der Informationseffizienz von Finanzmärkten ausdrücklich behandelt. Dieser Aufsatz soll einen untechnischen, einführenden Überblick über diese theoretische Literatur geben und zwar speziell im Hinblick auf die Hypothese effizienter Kapitalmärkte.

Da diese Literatur ausführlich auf das Konzept eines Marktgleichgewichts bei rationalen Erwartungen zurückgreift, beginnen wir mit einer eingehenderen Diskussion dieser Methodologie. Anschließend wird zur Illustration ein Modell entwickelt, das es uns erlaubt, die folgenden Informationsprobleme in Finanzmärkten zu behandeln: die Verbreitung von Information durch Preise, Informationskosten, Informations- und Vermögensdynamik, Verbreitung von Information durch Mengensignale, die Existenz von Märkten und sequentieller Handel.

Summary

Recent Developments in the Theory of Efficient Capital Markets

The hypothesis that prices reflect all available information in financial markets is predominant in the financial literature. Despite the popularity of the efficient capital market hypothesis it has not been based on a rigourous theoretical foundation. Recently a highly technical literature has developed in which problems of information in competitive markets are rigourously analysed, and where the issue of informational efficiency of financial markets is explicitly addressed. The purpose of this paper is to give a non-technical introduction and review of this theoretical literature as it specifically relates to the efficient capital market hypothesis.

Since the literature relies heavily on the rational expectations equilibrium concept market hypothesis we shall start out by discussing this methodology in some detail. Subsequent to this an illustrative model is developed which allows us to address the

following issues of information in financial markets: information dissemination by prices, information costs, information and wealth dynamics, information dissemination by quantity signals, existence of markets and sequential trading.

Résumé

Développements récents dans la théorie des marchés des capitaux efficaces

Dans la littérature financière prédomine l'hypothèse que les prix reflètent toutes les informations disponibles sur les marchés financiers. Malgré la popularité de l'hypothèse du marché des capitaux efficace, elle ne repose pas sur un fondement théorique rigoureux. Il s'est développé récemment une littérature hautement technique dans laquelle les problèmes d'information sur des marchés compétitifs sont analysés rigoureusement et où le thème de l'efficacité de l'information sur les marchés financiers est traité explicitement. La présente étude vise à donner une introduction non-technique et un compte rendu de cette littérature théorique qui se rapporte spécifiquement à l'hypothèse du marché des capitaux efficace.

La littérature se basant fortement sur l'hypothèse du marché d'équilibre avec des attentes rationnelles, nous commencerons à discuter en détail cette méthodologie. Ensuite, nous développerons un modèle pour illustrer les critères de l'information sur les marchés financiers: dissémination de l'information par les prix, coûts de l'information, information et dynamisme de richesse, dissémination de l'information par des signaux de quantité, existence de marchés et commerce séquentiel.