Information and Competitive Price Systems

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Although the price system is conventionally praised as an efficient way of transmitting the information required to arrive at a Pareto optimal allocation of resources, the context in which the price system is usually discussed is not one in which the informational efficiency of the price system can be properly evaluated. Questions of how the price system leads the economy to respond to a new situation, how it conveys information from informed individuals to uninformed individuals, and how it aggregates the different information of different individuals, are never directly attacked.

In a series of papers (Grossman 1975a, 1975b, Grossman and Stiglitz 1975, and Stiglitz 1971, 1974), we have attempted to remedy this deficiency. It is the object of this paper to draw attention to some of the more fundamental implications of our approach and to use it to assess the meaning and validity of the efficient market hypothesis. Although our discussion will accordingly focus on the capital market, the kind of analysis developed here is applicable to any competitive market subject to random shocks.

I. Prices and the Transfer of Information

The basic idea behind our analysis[1] may be illustrated by the following example:

Assume there are two assets, one safe and one risky, and that the return to the risky security r, depends on a random variable η, which can be observed at a cost, and another, unobservable random variable ϵ:

$$r = \eta + \epsilon, \tag{1}$$

where η and ϵ are independent, normally distributed random variables. Knowing η reduces but does not eliminate the risk associated with the asset. The per capita demand, X_I, for the asset by those who are informed of η will depend both on the price of the asset and the value of η.

$$X_I = X_I(p, \eta). \tag{2}$$

We assume that $\partial X_I/\partial\eta > 0$ and $\partial X_I/\partial p < 0$. Equilibrium each period requires that demand equal supply:

$$\lambda X_I(p, \eta) + (1 - \lambda)X_U(p) = X^s, \tag{3}$$

where X_U is the per capita demand of the uninformed, X^s is the per capita supply and λ is the fraction of the individuals who are informed. Uninformed individuals observe only price, but from the price they may be able to infer η. For instance, if the stock of the resources were fixed, the uninformed individual can infer that a higher p is associated with a higher η, since an increase in η increases informed demand, and thus the price. Since there are no other stochastic elements in this model, there will be precisely one η corresponding to any p. Hence, the conditional distribution of r given p is the same as the conditional distribution of r given η. Thus, the price system conveys all the information from the informed individuals to the uninformed.

Now, let us introduce some further randomness; e.g., in the stock of the risky asset or in the demand functions of informed or uninformed individuals. Then the price

* This work was supported by National Science Foundation Grant SOC74-22182 at the Institute for Mathematical Studies in the Social Sciences (*IMSSS*), Stanford University. The authors are also indebted to the Dean Witter Foundation for financial support.

[1] See Grossman and Stiglitz (1975) for proofs and a detailed analysis of the model described by equations (1)-(4).

may be high because η is high, but it may be high because the supply of the risky asset is low, or because informed individuals' demand functions have shifted upwards. Hence, corresponding to any p, there is a *distribution* of possible values of η. The price system conveys some information, but does not transmit all the information from the informed to the uninformed: on average, when the price is high, the return is high (i.e., η and price are correlated) but the price is a *noisy signal;* that is p and η do not contain the same information about r.

Assume that the source of randomness is the supply of the risky asset. (We shall use this example through the rest of the paper.) Then, from (3), the equilibrium price will depend on η and the stock of the risky asset, X^s; write $p=p(\eta, X^s)$. Solve for η as a function of (p, X^s) as, say, $\eta=\mathrm{t}(p, X^s)$. Using (1):

$$r = \mathrm{t}(p, X^s) + \epsilon. \tag{4}$$

The distribution of (X^s, ϵ) induces a distribution on r for a given p. Since the uninformed observe r and p, they come to learn the conditional distribution of r given p. When they observe a p, they use this distribution to determine the expected utility from purchasing a given amount of the risky asset; X_U is chosen to maximize expected utility. This is how the uninformed individual's demand function in (3) is derived. Finally for this to be an equilibrium, for all η and X^s, $p=p(\eta, X^s)$ must be a solution to (3). Such an equilibrium entails rational, self-fulfilling expectations.

This is a reasonable condition for long-run equilibrium. If this condition is not satisfied (and the stochastic process describing the returns is stationary),[2] then an individual will eventually observe that the frequency distribution of returns, conditional on the observable variables, is different from the subjective distribution, and accordingly, ought to revise his expectations.

As there are costs of obtaining information, the marginal individual who chooses to become informed must be indifferent to being informed or uninformed, i.e., the increment in expected utility from becoming informed is exactly offset by the cost of the information. In making this calculation, individuals assume that a change in their information (and hence in their demands) would have no effect on prices. This is an adaptation to this context of the conventional Nash equilibrium hypothesis of competitive equilibrium theory.

Since when no one is informed, the price system conveys no information, the value of information about η is likely to be high; when almost everyone is informed, the price system is very informative, so the value of knowing η precisely is low. Thus, provided the costs of information are positive but not too high, equilibrium entails a fraction, λ^*, of the population being informed—that λ which generates a price solution to (3) such that the marginal individual finds the expected utility to being informed equal to the expected utility of being uninformed.

Some striking features of the equilibrium which we have modeled should be noted. First, it provides a resolution of the following classical conundrum. If markets are perfectly arbitraged all the time, there are never any profits to be made from the activity of arbitrage. But then, how do arbitragers make money, particularly if there are costs associated with obtaining information about whether markets are

[2] One can argue that the limitation of our analysis to stationary stochastic processes is not a serious limitation; economic theory is concerned with identifying, describing, and explaining regularities in economic processes. Economic theory attempts to identify within a particular event those characteristics which it has in common with other events which have occurred. It is these regularities that are described by the stationary stochastic process.

already perfectly arbitraged? The conventional answer is that, when markets are not arbitraged, there are profits to be made, and so equilibrium *must* entail perfect arbitrage; the profits accrue in the process of responding to some unspecified disequilibrium. A particular example of this classical conundrum is presented by the efficient market hypothesis, which argues the prices on capital markets reflect all the relevant information instantaneously.

We resolve this paradox by arguing that there are constantly new shocks to the economy; although each of these shocks may have certain individual characteristics—the company president may be sick, a machine may break down—from the point of view of an analysis of market behavior, we are interested not in these individual characteristics, but in how these shocks affect market returns; and we postulate that we can describe the occurrence of these different shocks, in terms of their effects on returns, by a stationary stochastic process. The capital market must continually adjust to these shocks. We have formulated an equilibrium notion which explicitly takes account of the economy's response to these various shocks. Others have described this as a disequilibrium situation, but have been unable to say much about it.

In the structure we have developed, the market never fully adjusts. Prices never fully reflect all the information possessed by the informed individuals. Capital markets are not efficient, but the difference is just enough to provide the revenue required to compensate the informed for purchasing the information. The equilibrium fraction of informed traders λ^* is determined jointly with the informativeness of the price system in such a way as to generate a competitive return to arbitrage.

Perfect arbitrage has one important implication—not all traders need to be informed. The informed traders make prices reflect true values, and the uninformed can simply take advantage of these services provided by the informed. In our analysis this is not true. Indeed, it is only because prices do not accurately represent the true worth of the securities (i.e., the information of the informed is not fully conveyed through the price system, to the uninformed) that the informed are able to earn a return to compensate them for the costs associated with the acquisition of the information.

Those empirical tests of the weak version "efficient market hypothesis" which show there are no gains to be made from looking at current prices and the past performance of the security provide support for our model, which assumes uninformed traders have rational expectations. But contrary to strong versions of the efficient market hypothesis, prices do not fully reflect all available information, in particular, that of the informed; the informed do a better job in allocating their portfolio than the uninformed. "Efficient markets" theorists state that costless information is a *sufficient* condition for prices to fully reflect all available information (Eugene Fama, p. 387). They are not aware that it is a necessary condition as well. But this is a *reductio ad absurdum*, since prices are important only when information is costly. (See Friedrich A. Hayek and Grossman 1975b.) Thus, an individual who throws darts at a dartboard to allocate his portfolio will not do as well as the informed individual;[3] what can be decided by a toss of the coin is not the allocation of the port-

[3] It is still true that if individuals were all identical and purchased the "market basket" of securities, the uninformed would do as well as the informed. Here we assume that the kind of information to make that feasible is not available. If individuals differ in their attitudes towards risk, or in their information structures, even when such a strategy is feasible, it may not be optimal.

folio but whether to be informed or uninformed.[4]

A second important characteristic of our analysis is that there is no proper separation between demand and supply. An increase in supply leads to a lowering of the price; since lower prices *on average* correspond to states in which returns are lower, the lowering of the price leads to a *lowering* of the evaluation of the risky security by the uninformed individuals, and hence of their demand. One cannot describe the equilibrium meaningfully in any period in terms of independently drawn demand and supply schedules, because the demand curves depend on the probability distribution of supply. This has the further consequence that an increase in price may actually increase demand; the presumption for a downward sloping demand curve is much weaker when individuals judge quality by price.

Still a third important and related observation is that prices, in our model, are serving two functions: not only are they being used to clear markets in the conventional way, but they convey information. In this sense, the models we have formulated are closely related to George Akerlof's lemons' model and to Akerlof (1973) and Stiglitz' (1975) analysis of labor markets.

The discussion so far has focused on the decision of whether to be informed or uninformed. There is an alternative way of looking at this question, which may shed some light on an old question discussed by John M. Keynes (p. 156). He suggested that the stock market might be viewed as a beauty contest, where the participants are not concerned with judging who is the most beautiful woman, but with judging who the other judges will believe is the most beautiful woman. Keynes made these remarks with more than a hint of disapproval; our analysis suggests that this may be unwarranted. It may be more efficient for some individuals to obtain information from others—through the price system or by other mechanisms—rather than obtain it directly.

II. Prices as Aggregators

So far, we have discussed equilibrium in markets where prices convey information from the informed to the uninformed. In some market situations, different individuals have different information, and then the price system may serve to aggregate their information. That is, the demands for a risky security of an individual are affected by his information; total demand and accordingly equilibrium market prices thus depend on the information of all the individuals. In this sense the market price aggregates the various pieces of information.

A simple example may make this clearer. Assume there are a large number of isolated farmers. Each knows the size of his own crop, y_i. The size of the crop on any farm at any date is described by

$$y_i = \alpha + \epsilon_i \tag{5}$$

where (ϵ_i, ϵ_j) are uncorrelated, α and ϵ_i are independent, normally distributed random variables with means $(\bar{\alpha}, 0)$ and variances $(\sigma_\alpha^2, \sigma_\epsilon^2)$, respectively. Thus, if $Y \equiv \sum_1^n y_j$, then $E(Y|y_i)$ is just a linear function of y_i, i.e., $E(Y|y_i) = h_1 + nh_2 y_i$.[5] Assume that there is a linear demand curve for the crop, so

$$Y = a - bP_s \tag{6}$$

where P_s is the spot price next period. Then the subjective distribution of P_s is normal, with mean $(a - E[Y|y_i])/b$ and a

[4] This is true only if no one has a comparative advantage in acquiring information.

[5] $E[Y|y_i] = n[\gamma\bar{\alpha} + (1-\gamma)y_i] \equiv h_1 + h_2 y_i$ where $\gamma \equiv \dfrac{\sigma_\epsilon^2(n-1)}{n(\sigma_\alpha^2 + \sigma_\epsilon^2)}$.

variance which is independent of y_i, σ_p^2. Since individuals differ in their expectations, there is an incentive to set up a futures market. Assume all individuals have constant absolute risk aversion, k. Then their demand for "futures" Y_i^f is given by (where P_f is the futures price):[6]

$$(7) \quad Y_i^f = \left[\frac{\dfrac{a - E(Y \mid y_i)}{b} - P_f}{k\sigma_p^2} \right] + y_i$$

and the market equilibrium requires

$$(8) \quad 0 = \sum Y_i^f = \frac{n}{k\sigma_p^2} \left\{ \frac{a - h_1 - h_2 Y}{b} - P_f \right\} + Y.$$

Using (6), we obtain the result that the futures price is a linear function of the spot price:

$$P_f = h_3 + h_4 P_s.$$

It is a perfect aggregator of the information collected by the different individuals, i.e., by observing P_f, one can make a perfect prediction of the quantity available in the market and P_s.[7]

But there is a fundamental problem; if, as one would expect, individuals eventually come to realize that the futures price is a perfect predictor of the future spot price, then they will no longer base their demands on their own information, but rather base it solely on the market information. Since the futures price predicts the spot price perfectly (with zero variance) there is no need for hedging and there will be no trade. But without trade, there is no market; but without a market; their beliefs will differ. This paradox can be put another way. If the market aggregated their information perfectly, individuals' demands would not be based on their own information, but then, how would it be possible for markets to aggregate information perfectly?

So far, we have discussed some of the basic properties of our approach to equilibrium when information is costly. These models can also be used to address conventional questions related to existence, comparative statics, and welfare.

III. Existence of Equilibrium Market Breakdown and Thinness

Both Akerlof (1970) and Grossman (1975a) argue that in markets where prices convey information between informed and uninformed traders, there is a possibility of market breakdown associated with a dwindling in the amount of trading. The example of the stock market presented above showed that this could indeed happen: if the price system were fully informative, there would be no differences in beliefs; and if there were no differences in beliefs, there would be no trade; but then it appears that it is prices in markets in which there are no trades which leads to uniformity of beliefs. Although this problem would be alleviated if prices did not perfectly convey information from the informed to the uninformed or if there were motivations for trade other than differences in information (e.g., differences in attitudes towards risk or in endowments), markets still might be thin, i.e., there would be a small volume of trade, and hence markets may be far from perfectly arbitraged.

Situations where markets might be thin or nonexistent need to be distinguished from those in which equilibrium does not exist. In the absence of noise, with costly information, an (Nash) equilibrium does

[6] Profits are $\pi = (P_f - P_s) + P_s y_i$. Then under normality and constant absolute risk aversion k, the individual maximizes

$$Y_i^f(P_f - E[p_s \mid y_i]) + E(P_s \mid y_i) y_i - \frac{k}{2}(y_i - Y_i^f)^2 \sigma_p^2.$$

Solving for the optimal Y_i^f:

$$Y_i^f = y_i + \frac{E[P_s \mid y_i] - P_f}{k\sigma_p^2}.$$

[7] If $1 \neq nh_2/bk\sigma_p^2$, then $h_4 \neq 0$.

not exist,[8] since when one is informed, every individual believes he can become informed, increase his expected utility and not affect the market price. However, when a positive fraction of the population becomes informed the price system is fully informative, so it does not pay anyone to purchase the information.[9]

IV. Welfare

The evaluation of the efficiency of the market in situations such as those analyzed in this paper is a subtle and difficult question. It is not obvious what the appropriate comparisons ought to be. Two alternative approaches might be delineated. In the *reformist* approach, we take as given the market structure, including the mechanisms for information transmittal. We ask simply, are there too many or too few informed individuals, or, is it desirable to have an information tax or subsidy? Although it is easy to show that the market solution is not, in general, efficient, it is difficult to ascertain whether there is too little or too much information acquisition. There are several effects, operating in different directions: some of the gains arising from *differential* information are private but not social returns, gains that some individuals make at the expense of others; on the other hand, since some information is conveyed by the price system, if that information is socially useful, those who purchase information generate a positive externality to those who do not. See Jerry R. Green (1973) and Stiglitz (1971). Even if there were no differential information, the price distribution does depend on the state of information. To return to our example of Section I, since when everyone is fully informed, price varies with η and X^s, while when no one is informed, price varies only with X^s, it would not be surprising if information increases the variance of prices. Increased price variability is likely to lead to increased uncertainty about the value of one's endowments, and this is likely to lower expected utility. In one example we have analyzed in detail, where individuals have constant absolute risk aversion utility functions and randomly assigned endowments (all individuals having, however, the same endowment distribution), every one is better off if no one is informed than if all are informed.[10]

Finally, if the return to holding an asset for a period is the dividend plus the capital gain, the increased variability in price of the risky asset makes the risky asset riskier; thus, while in general, information reduces the riskiness of a risky asset, this is at least partially offset by this general equilibrium effect.

More fundamental questions are raised by the choice of alternative approaches to

[8] In the case where information is costless, an equilibrium exists; among the set of prices which might clear the market, there is a particular price function which clears it at zero trade and conveys all the relevant information, and this may be considered to be an equilibrium. There is no obvious mechanism for sustaining this particular set of prices, and this is a serious limitation.

[9] There could not exist an equilibrium in which trade occurred even if an individual had a monopoly power over information. For then the uninformed individuals would observe that they would do better not trading with the monopolist than trading with him, and the information-monopolist would simply determine equilibrium market prices. (See Stiglitz 1974.) Thus Jack Hirshleifer's classic analysis is not that of a competitive stock market with rational consumers. If his analysis refers to a market in which there is a monopolist in information, his results require irrationality on the part of other consumers in the market. If his analysis refers to a market in which the market for information-acquisition is competitive, then the results discussed in the text apply.

[10] This is a consequence of the unavailability of endowment insurance. This result has some important implications for a question which until now has not been satisfactorily resolved: Can there be destabilizing speculation? In this context, we interpret that to mean: Can the attempt to engage in intertemporal arbitrage lead to higher price variability which is associated with lower utility? The answer is yes, and indeed such attempts at intertemporal arbitrage can lower welfare. This occurs, in our constant absolute risk aversion example, because by the portfolio separation theorem, information has no allocative role.

information acquisition, e.g., a comparison between the decentralized process of the capital market and a centralized process. This, in some sense, was the central question of the Lange-Lerner-Taylor-Hayek debate.

Although this earlier debate was presumably about the informational efficiency of alternative organizational structures, models in which the systems had to adjust to new information were not formulated; rather it was argued that if the information were to be the same, the allocation would be the same, and thus, a comparison of alternative organizations came down to issues like a comparison of cost differentials arising from different patterns of information flows, or different speeds of convergence. Our analysis has suggested that a decentralized economy is likely to be characterized by individuals having *differential* information, that the separation in the earlier discussion of information and allocative questions is inappropriate, and that alternative informational structures will be characterized by different real allocations. In particular, Grossman (1975b) formalized Hayek's contention that prices are aggregators of information. There it was proved that if prices are sufficient statistics, the competitive economy where traders have diverse information generates allocations that cannot be improved upon by a central planner with all the information. However such markets do not provide incentives for information acquisition for the reasons given earlier. Thus only markets with noise will exist in equilibrium and these markets will not produce prices which are perfect aggregators. In this case a central planner with all the information can improve on the competitive equilibrium. Thus in our view the Lange-Lerner-Taylor-Hayek debate comes down to the fundamental distinction between economies where: (1) prices and hence allocations are the outcome of a competitive arbitrage process which will, of necessity, be imperfect because of the costs of arbitrage as discussed in this paper, and (2) economies where prices and hence allocations are the outcome of a centralized allocative mechanism which will, of necessity, be imperfect because of the costs of monitoring bureaucrats.

Thus, although we cannot provide an answer to whether a centralized or decentralized organization is more efficient, without more knowledge of the costs of operating a centralized informational mechanism, what we have established is that the conventional formulations of this question are misleading if not incorrect.

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