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ON PRICE RECOGNITION AND COMPUTATIONAL COMPLEXITY IN A MONOPOLISTIC MODEL

by

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Abstract

The paper introduces a simple economic model in which the decision makers differ in their ability to recognize price offers. The cornerstone of the model is a market for an indivisible good produced by a monopolist who receives exclusive information on the state of nature affecting the production costs and the consumers' evaluation of the good. The market operates so that the monopolist has to commit himself to a price and each consumer has to decide whether he accepts or rejects the offer. The monopolist has an interest in only a fraction of the consumers accepting the offer. The heterogeneity of the consumers is modelled first, in terms of the limits on the fineness of the price recognition and second, in terms of the limits on the complexity of the computations they can make. In the second submodel, tools are borrowed from the parallel computation literature. In equilibrium, the monopolist announces a price scheme which is sufficiently complicated that only some of the consumers (the more "sophisticated" ones) can decode all the information contained in the prices. Such pricing strategies enable the monopolist to increase his profits relative to those he could derive from a set of homogeneous consumers.

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1. Introduction

In almost all models of economic theory, behavioral differences among consumers are attributed to differences in preferences or in the information they possess. In real life, differences in consumer behavior are often attributed to varying intelligence and ability to process information. Agents reading the same morning newspapers with the same stock price lists, will interpret the information differently. Even if they do receive the same impressions, the agents may differ in either their mental ability to utilize information or to calculate the "optimal" course of action.

The family of "Rational Expectations" models constitutes an important class of models within perfect perception of information and the ability to make accurate calculations are assumed. In these models, the asymmetric information regarding market parameters are relevant to the decision makers' considerations and economic agents deduce this information from realized equilibrium prices. A traditional criticism of these models is aimed towards the assumed ability to deduce the information from the actual market prices. This is a complex operation which requiring both skill and a comprehensive knowledge of the model. Since the reasoning process is not found in the rational expectations models, the differing abilities of economic agents in deducing information from the prevailing prices does not exist in the conventional analysis. Intuitively, however, they could affect such economic factors as income distribution, and are helping explaining the rationale of such economic institutions as financial advisers whose existence is dependent on these differences.

The "rational economic man" is a creature devoid of the above mentioned human limitations. Embedding such factors in economic models is impossible unless we enrich the model to include details on the reasoning procedures used by the economic agents in their decision making process. The idea of expanding the established body of economic analysis to encompass the procedural aspects of decision-making (Simon (1982)) is at the heart of the so—called "Bounded Rationality" and as such, the current paper can be viewed as a move in this direction.

This paper is devoted to the construction of a simple economic model in which decision makers differ in their ability to differentiate between the price offers made in the market. The reader may wonder why there would be any difficulty in fully recognizing a posted price; overall a price is only a number. However, recall that it is rare that an offer is indeed given as just one number. Often, an offer is a long list of elements corresponding to features such as the exact characteristics of the product, the payment arrangements and the warranties. The multiplicity of such details make the calculation of "the price number" a non-trivial task.

How to model differences in abilities to process information? Are such differences describable by differences in information? The approach taken in this paper is that while differences in information may be modelled by differences in partitions of the relevant state space, differences in ability to process information may be modeled by the constraints on the family of possible partitions available to the individuals.

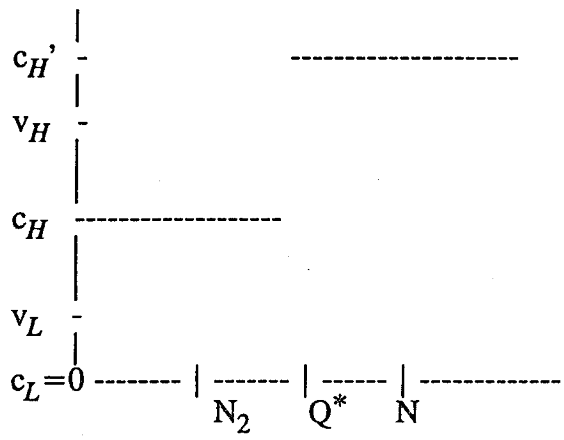
The cornerstone of the model is a market for an indivisible good produced by a monopolist. A random state of nature determines the producer's costs and the consumers' evaluation of the good. In some states of nature the monopolist has an interest in selling the good only to a fraction of the consumers and he therefore, looks for a way of differentiating between consumers. The realization of the state of nature is kept hidden from the consumers. The monopolist, prior to the realization of the state of nature, has to commit himself publicly to a price policy. The consumers are limited in their ability to recognize prices and these limitations are hetrogenous. Notice that the ability to recognize prices is <u>not</u> assumed to be correlated with any other characteristics of the consumers. Being aware of their limitations and the seller's policy, the consumers have to devote their limited attention and perceptive capability to deriving the most useful information from prices. A consumer has to choose a partition of the set of possible prices so that he will recognize the cell of the partition in which the actual price falls into. Once the state of nature is realized, the price corresponding to the state is affective. Each buyer gets the information about the cell of the partition which contains the real price and decides whether to purchase the good or not. If there exists heterogeneity in the consumers' potential fineness of the price space classification, the monopolist will be able to utilize this heterogeneity to discriminate profitably between the more and less sophisticated consumers. He may use price strategies complicated enough so that only some consumers are able to decode all the information contained in the prices. Thus the possibility to discriminate between consumers on the basis of their ability to process the announced offer allows new equilibria which are qualitatively different from those which emerge from the model with a homogeneous set of consumers.

The model of monopoly utilized here, as well as the "bounded rationality" elements introduced in the paper, are admittedly arbitrary. In line of what I consider the objective of economic theory, the paper is aimed mainly at the exposition of the structure of equilibrium with heterogeneity of reasoning processes. No claim is made beyond the clarification of the logic of the equilibrium under such circumstances.

Let us now turn to a detailed description of the basic model.

2. The Basic Model

Consider a market for a single good which is produced by a single seller. The economic parameters of the market depend on a state of nature which may be either H or L. All agents share the initial belief that the probabilities of the states H and L are π_H and π_L respectively. The information on the realized state of nature is delivered exclusively to the seller. In state L the seller's production cost is constantly zero regardless of quantity, and in state H the seller's marginal cost is a constant c_H up to Q^* units and is a constant c_H' for any quantity above Q^*. These costs are best thought of as the opportunity costs of the seller who may sell his products in another market. The market consists of N consumers, each of whom is interested in consuming only one unit of the commodity. A consumer purchases the good if and only if the expected surplus is strictly positive where the surplus derived from consuming one unit of the commodity for the price p is v_L-p if the state of nature is L and v_H-p if the state of nature is H. It is assumed that $c_H' > v_H > c_H > v_L > 0$ and $N > Q^*$ (see diagram).



The following is the order of events as they occur in the market:

(1) The seller announces a price policy which is a specification of a "lottery" of prices (a probability measure on the price space) for each of the states of nature. The seller's announcement is a <u>commitment</u> to supply whatever quantity of the good is demanded by the consumers at the price resulting from the lottery which follows the realization of the state of nature. Thus, the announcement of the seller forces all fully rational consumers to hold the same beliefs on the state of nature after the

realization of the price.

(2) Nature selects the state of nature and the seller's offer is determined by the probabilistic device to which the seller has committed himself.

(3) The consumers are informed about the realization of the lottery. On the basis of the posted price and the announced pricing policy, each consumer has to make a decision whether to accept or to reject the offer.

To summarize, the model is a conventional Stackeleberg, leader-follower situation in which the seller is the leader who chooses the pricing policy and the consumers are the followers who choose acceptance rules.

Remarks:

(1) The seller's strategy is the choice of a random device for every state of nature. Although he employs random devices, the seller's strategy is a pure strategy, not a mixed strategy. The strategy (including the random devices which are part of it) determines the consumers behavior and in the optimum, the seller may strictly prefer a strategy with stochastic elements over a strategy which specifies a deterministic price for each state of nature. Recall that in contrast, in mixed strategy equilibrium, a player has to be indifferent between all deterministic strategies which lie in the support of his mixed strategy.

(2) Notice that given the consumers' purchasing strategies, the seller may be better off by not following the announced pricing policy. In our model the seller is committed to the policy which he has announced and the posted price must be determined according to the outcome of the random device

which the announced strategy assigns to the realized state of nature.

(3) It is assumed here that the seller's announcement of a price is a commitment to sell whatever quantity of the good will be demanded. In practice the seller could announce also a limit on the quantity to be sold in the market. To motivate this assumption let us stick to the interpretation of the model in which the seller produces a "huge" number of units and sells some of them in the market and some of them in another market. The economic relevance of the model relies on the existence of institutional reasons which forbid the seller from rejecting "local" buyers from purchasing the good for the "local" price.

The realization of the posted price reveals information about the state of nature if the lotteries which correspond to the different states of nature are not identical. The basic seller's dilemma is that at state H he cannot gain from selling more than Q^* units. In the market there are $N>Q^*$ consumers and if all of them conclude that the state of nature is H, then there will be too many consumers ready to pay v_H for the commodity. The over-selling is not desirable since $c_H' > v_H$. It is assumed further that conditional on the state H, the seller prefers not to sell any unit over selling N units even for the maximal price of v_H, i.e., $Nv_H < Q^*c_H + (N-Q^*)c_H'$. The ideal for the seller would be to inform only Q^* buyers that the state of nature is H so that they are ready to pay the high reservation value. Can the seller, the exclusive information holder, distribute the information only among <u>some</u> of the participants in the market?

Distributing information about the real price can be done in this model only via the price mechanism but if all consumers are identical, the price mechanism does not enable the seller to discriminate between agents and the seller's bound on his expected profits is $\Pi * = \pi_L N v_L$. To see that he can achieve (almost) this level of profits, notice that by charging v_L-ε in state L and charging a very high price in state H, the seller receives (in expectation) profits amounting close to $\pi_L N v_L$. Let us verify that the seller cannot achieve higher profits by any other price strategy (including those which employ random devices). For any price p which accords with the seller's strategy and which is accepted by the buyers,
$p < \text{Prob}(H \mid p)v_H + \text{Prob}(L \mid p)v_L$, the revenues cannot exceed
$\text{Prob}(H \mid p)Nv_H + \text{Prob}(L \mid p)Nv_L$ and the expected production costs are
$\text{Prob}(L \mid p)Nc_L + \text{Prob}(H \mid p)Q^*c_H + \text{Prob}(H \mid p)(N\text{-}Q^*)c_H'$.
Thus the seller's profits are bounded by
$\text{Prob}(L \mid p)Nv_L + \text{Prob}(H \mid p)[Q^*(v_H\text{-}c_H) + (N\text{-}Q^*)(v_H\text{-}c_H')]$.
By our assumption $Q^*(v_H\text{-}c_H) + (N\text{-}Q^*)(v_H\text{-}c_H') < 0$ and thus, every price which in equilibrium is accepted by the buyers at state H, contributes to the seller's profits less than $\text{Prob}(L \mid p)Nv_L$. Integrating over all p which are offered by the seller's strategy and are accepted by the consumers, we get that the total seller's profits are bounded by $\pi_L N v_L$.

Needless to say, the outcome of the seller's strategy is inefficient. In state H, the seller underproduces (does not produce at all) and it is mutually beneficial for the seller and a consumer that the seller produces and sells the commodity to the consumer for any price below v_H and above c_H.

3. Imperfect Price Recognition

We are ready to add a new feature to the model — the imperfection in the consumers' calculations. Assume that N_1 of the consumers are of type I and are able to determine only <u>one</u> cutting point, i.e., they can split the price space into only two connected sets and are able to attach, either the order "Buy" or "Don't Buy", to each of the two sets. In other words, the type I consumers are able to make decisions of the following types: "Buy iff $p \leq p^*$", "Buy iff $p < p^*$", "Buy iff $p \geq p^*$", "Buy iff $p > p^*$", "Always Buy" and "Never Buy". The type II consumers are N_2 consumers who are able to determine <u>two</u> cutting points which split the price space into up to three connected sets. This means that a type II consumer can adopt also an acceptance rule of the type "Buy (or don't buy) the commodity if the price lies in a certain interval and don't buy (or buy) the commodity if the price lies outside the interval". It is assumed that $N_2 < Q^*$.

The selection of the partition and the action conditional on the received information is carried out by each of the consumers between stages 1 and 2, i.e., after the buyers learn the announced pricing <u>policy</u> and before the realization of the price. The decision concerning the partition is subject to the restrictions imposed by the consumer's type. To summarize, the order of events in the model is as follows:

Stage (1): The seller announces a pricing policy.

Stage (2): Each consumer selects a partition (given the constraints determined by the consumer's type).

Stage (3): Nature selects the state and the price is determined.

Stage (4): Each consumer gets the information about the cell in his partition which includes the announced price and decides whether or not to purchase the good.

Remark: As in many other "Bounded Rationality" models we limit the ability of the consumers on one aspect but on the same time we require from them more computational ability on another aspect: although the agents are assumed to be bounded in their ability to perceive prices, they are not constrained to make the perfect optimization required to choose the partition used in perceiving prices.

It will be shown that the seller can utilize the differences between type I and type II consumers to derive profits arbitrarily close to $\Pi^* = \pi_L N V_L + \pi_H N_2 (V_H - c_H)$. The idea is quite simple. Choose ε_L and ε_H so that $\pi_L \varepsilon_L > \pi_H \varepsilon_H$ and consider the following pricing strategy:

- in state H charge the price $v_H - \varepsilon_H$;
- in state L charge the price $(v_H + v_L)/2$ with low probability and $v_L - \varepsilon_L$ with high probability.

Given this strategy, a type II consumer is able to partition the price space $\{v_L - \varepsilon_L, (v_H + v_L)/2, v_H - \varepsilon_H\}$ in order to avoid the seller's trap. He purchases the good if the price is above $v_H - \varepsilon$ or below $v_L - \varepsilon$ and does not purchase the good if it is strictly between these two bounds. The type I consumer is deterred by the loss incurred if he buys the commodity for the price $(v_H+v_L)/2$ in state L. He can either purchase the good for a price not higher than $v_L-\varepsilon_L$ or not lower than $v_H-\varepsilon$. The assumption that $\pi_L\varepsilon_L > \pi_H\varepsilon_H$ guarantees that the former is better for the consumer and thus by choosing ε_L and ε_H small enough the seller can approach Π^* arbitrarily close. It is easy to verify that Π^* is the maximal profit which the seller can achieve. In state L the seller achieves the best profit he can hope for. In state H, the highest price which the seller can get is v_H and the number of buyers is either N, Q^* or 0. By assumption having N_2 buyers purchasing the good for v_H is better than having the whole population or none of the population purchasing the commodity even for that price.

4. Parallel Computation

In the previous section the source of consumers' heterogeneity was the fineness of the price space partition which the consumers were allowed to maintain. In this section the constraints on the partition of the offers space are derived from a constraint on the complexity of the calculations which the consumer can make. We follow the parallel computation literature, and especially the literature on "perceptrons", a concept designed to model the operation of the human brain. For an outstanding introduction to this topic see Minsky and Papert (1988).

Assume that the seller splits the price of the commodity into K components and thus, a realized offer is a K-tuple $(p_1,\ldots,p_K)$ where the number p_k is the price of the k-th component of the commodity. The meaning of an acceptance of an offer of the vector p is that the consumer gets one unit of the commodity in exchange for Σp_k units of money. Splitting a price into several parts is quite common in actual markets: for example, when we buy a stereo set we usually get a list of the items' prices as well as the amount of tax and various service fees. We can think about the components of the vector not only as prices but also as the "disvalues" of characteristics attached to the purchase of the commodity.

A consumer who accepts the offer p pays Σp_k; however, the manner in which the sum Σp_k is divided into K components may contain relevant information concerning market conditions. Agents may experience difficulty in decoding the information and may differ in their ability to interpret the information contained in the seller's offers.

We model the consumer's computation by a certain computing machine which goes through two stages: In the first stage, the perceptrons operate in parallel on the realized price vector. Formally, a <u>perceptron</u> is a real function ϕ which receives as its input some of the components of the price vector and which gives as an output a real number. Denote the perceptrons by $\phi_1,\ldots,\phi_M$. In the second stage, the sum of the perceptrons' outputs, $\Sigma\phi_m$, is calculated and the value is compared with a threshold number α^*. The consumer purchases the commodity if and only if $\Sigma\phi_m < \alpha^*$. A consumer's <u>purchasing strategy</u> is the determination of the perceptrons $\phi_1,\ldots,\phi_M$ and the number α^*.

The following is a schematic illustration of the computational device ascribed to the consumers:

$$[p_1,\ldots,p_K] \begin{array}{l} \text{--}\phi_1\text{-->} \\ \text{--}\phi_2\text{-->} \\ \text{--}\phi_M\text{-->} \end{array} \boxed{\Sigma\phi_m(p_1,..,p_K) \text{ is compared with } \alpha^*} \text{--->decision}$$

We are now ready to add to the model the imperfection in the consumers' calculation. The consumers are bounded in the complexity of the perceptrons which they are allowed to use. The complexity of a perceptron is measured by its order, i.e., the number of price vector components in its domain. For example, if ϕ depends on only one of the p_k's, then ϕ is a perceptron of <u>order 1</u> and if it is a function of two prices the perceptron is of <u>order 2</u>. The consumers have no restriction on the size of M and have a perfect ability to compare the outcome of the sum of M numbers with the threshold level, α^*. When the calculated sum of the perceptrons' values is below the threshold level the consumer accepts the offer and when it is above, the consumer rejects the offer.

I wish to emphasize once again that obviously there is no claim that this computing machine and this complexity measure are in any sense a part of the "true" description of the human processing of a vector of price components. The main defense for using the notion of perceptrons and this complexity measure is that the literature on perceptrons provides examples which demonstrate that the approach does capture intuitions regarding computational complexity.

As to the heterogeneity of consumers, it is assumed that consumers differ with respect to the order of perceptrons which they are able to employ. The N_2 type II consumers are able to employ perceptrons of order 2 while the N_1 type I consumers are constrained to use perceptrons of order 1 only.

As in the previous section, the functional difference between the two types depends on the variety of prices existing in the market. Obviously, if there are at most two prices in the market the two types will be able to function equally well. In contrast, if all prices are possible, the type I consumers are not able to execute a policy of purchasing the commodity if and only if the total price is precisely p^*. The proof is quite simple and may be found in Minsky and Papert (1988). A type II consumer is able to pursue such a strategy since $\Sigma p_k = p^*$ is equivalent to $(\Sigma p_k - p^*)^2 = \Sigma_{k,l} p_k p_l - \Sigma_k 2p^* p_k \leq 0$ and all $p_k p_l$ and $-2p^* p_k$ are perceptrons of order 1 or 2.

Let us summarize the structure of the model. The seller first announces a pricing policy which assigns a lottery of price vectors to every state. As before, the seller is committed to that policy. Then, every consumer has to choose his purchasing strategy (constrained by his type). Finally the price vector is realized and the consumers implement their purchasing policy.

We will now see that by utilizing the differences between the two types, the seller can achieve the same level of expected profits Π^* (as in the previous section). Consider the following pricing strategy:

The seller splits the price of the commodity into K=2 parts. In state H the seller chooses the vector $(p,p)=(v_H/2-\varepsilon_H, v_H/2-\varepsilon_H)$. In state L he chooses with probability $1-\delta$ the vector $(q,q)=(v_L/2-\varepsilon_L, v_L/2-\varepsilon_L)$ and with probability $\delta/2$ each of the vectors $(p,q)=(v_H/2-\varepsilon_H, v_L/2-\varepsilon_L)$ and $(q,p)=(v_L/2-\varepsilon_L, v_H/2-\varepsilon_H)$. The type II buyers are able to escape the trap of purchasing the good for the price p+q at state L by having a perceptron of order 2 which gives the value 1 for the vectors (p,p) and (q,q), gives the value -1 for the states (p,q) and (q,p) and setting $\alpha^*=0$. (Alternatively he can choose the strategy "accept (p_1,p_2) iff $p_1{}^2+p_2{}^2-2p_1p_2=(p_1-p_2)^2\leq 0$" which requires perceptrons of order 1 or 2 only). The type I buyers cannot pursue a strategy in which they buy the commodity only at the price vectors (p,p) and (q,q). If such a purchasing strategy exists then there would be two perceptrons ϕ_1 and ϕ_2 and a number α^* so that

$\phi_1(q)+\phi_2(q)<\alpha^*$,

$\phi_1(p)+\phi_2(p)<\alpha^*$,

$\phi_1(p)+\phi_2(q)\geq\alpha^*$ and

$\phi_1(q)+\phi_2(p)\geq\alpha^*$.

These four inequalities clearly result in a contradiction.

Now for any number δ we can choose a small ε_H and ε_L so that $\pi_L\varepsilon_L>\pi_H\varepsilon_H$ which guarantee that the consumer would prefer to avoid the possibility of purchasing the commodity with a probability of $\pi_L\delta/2$ for the price p+q even if he buys the commodity at the state H for the price p+p and prefers to purchase the good for the price q+q in state L than purchasing the good for the price p+p in state H.

Notice that the seller's strategy uses 4 price vectors:
(p,p), (q,q), (p,q), and (q,p). A type II consumer can utilize the partition of the set of four price vectors {{(p,p),(q,q)}, {(p,q),(q,p)}} but a type I consumer cannot. A type I consumer can use a partition like {{(p,p), (p,q), (q,p)}, {(q,q)}} by selecting the rule of buying the commodity if the sum of the components is not more than p+q (this is done by utilizing the two perceptrons $\phi_i(p)=p_i$, and setting $\alpha^*=p+q+\varepsilon$). Similarly a type I consumer can utilize the partition {{(q,q),(q,p),(p,q)}, {(p,p)}}. He can also utilize the partition {{(p,q)}, {(p,p),(q,p),(q,q)}} by choosing two perceptrons ϕ_i so that
$\phi_1(p)=2$, $\phi_2(q)=2$
$\phi_1(q)=-3$, $\phi_2(p)=-3$ and $\alpha^*=0$.
But, as was shown above, the type I consumer is not able to utilize the partition {{(p,p),(q,q)}, {(p,q),(q,p)}}, which is the only a partition which would enable him to increase his payoff above what he is achieving by perceptrons of type I.

5. Related Literature

The endogenous choice of the partition of the set of possible prices has been previously modelled in Dow (1991). His model is a single decision making problem which is not embedded in an equilibrium analysis. Dow analyses a two—stage "search" model where a decision maker receives information in a predetermined sequential order, about the prevailing price of a certain good in two stores. The decision maker cannot remember the exact price which he has observed in the first store when he comes to the second store. He aims to partition the potential price space so that the partition will provide him, "on average", with the most useful information when he arrives at the decision of choosing the store from which to buy the good, a decision which, by assumption, he must take after observing the second price. Dow finds some necessary conditions on the optimal partition.

Also relevant is the literature on equilibrium in markets with search. In these models a consumer makes his purchasing decision through a process of search. The structure of equilibrium in such models reflects the heterogeneity in consumers' search costs. The search process is not necessarily a physical search but can be thought of as a model of a mental process in the consumer's mind. Consequently, the search costs can be interpreted as the costs associated with the searchers' difficulties in recognizing prices, as opposed to physical sampling costs. Within the literature which aims to explain "price dispersion" the closest models are of Salop (1976) and Salop and Stiglitz (1976). In those models, all consumers know what are the prices available in the market but they do not know what store charges what price. A consumer has to choose either to purchase the good in random from one of the stores or spending an exogenously given cost in achieving the information about the location of lowest price available in the market. There is heterogeneity among the consumers regarding the cost associated with getting the information about the identity of the store which charges the best price. Assuming correlation between the consumer's cost and other consumer's characteristics Salop (1976) shows that the model allows an optimal strategy for a monopolist where more than one price is charged. In Rothschild and Salop (1976) there are many sellers and the consumers bear a "search cost" for acquiring the information about which stores are charging what prices. The possibility for an equilibrium with price dispersion is demonstrated.

6. Conclusion

This short paper has presented a very simple model in which the heterogeneity of consumers with respect to their ability to process information is utilized by a monopolist to derive additional profits. In the two versions of the model, the monopolist forces the type I consumers to focus attention on escaping the trap which he has prepared for them by offering a (sometimes) high price in the state of nature L. Being occupied with this task, a type I consumer cannot devote his computational resources or attention to the task of identifying the conditions in which it is desirable for him to purchase the commodity for a high price. In contrast, a type II consumer is able to infer the true state of nature from the monopolist's pricing strategy and is able to both escape the trap and identify the conditions under which paying a high price is profitable.

Within the context of "Industrial Organization", this paper shows that the complexity of the price scheme can be used strategically by price setters. A casual observation of real life, confirms that the price schedules (or the characteristics associated with products) are very complex and that the complexity of the price structure affects the group of economic agents who are active in a given market (e.g., consumers trading in financial markets).

Whatever the case, the main aim of the paper is more abstract. In contrast to other models in which agents possess different information about the state of nature, here the agents differ in their ability to absorb information on the endogenous <u>equilibrium prices</u>. It is a challenge to study richer equilibrium models in which the agents' behavior depends on their ability to process the information embedded in equilibrium prices. Such models may constitute a response to the criticism concerning the assignment of complicated computational tasks to economic agents.

Finally, the model is a simple example of an economic model with "Bounded Rationality" elements. In spite of the arbitrary and simplicity, I hope that the paper suggests some useful modelling ideas of market theories with "Bounded Rationality".

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