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1. INTRODUCTION.

In modeling economies with differentially informed traders it is crucial to recognize that each trader will attempt to infer the private information of other traders from observable market statistics. This idea appears in the concept of rational expectations equilibrium. This equilibrium concept couples the usual market clearing condition with the requirement that each trader's inferences from market prices be correct. Unfortunately it is not obvious that the information transmission in the market required by the rational expectations equilibrium concept is feasible given the market institutions.[1] As Radner [1979] points out: "A thorough theoretical analysis of this situation probably requires a more detailed specification of the trading mechanism than is usual in general equilibrium analysis."

One approach to a more detailed study of trading mechanisms is to search for a message process that will implement the desired equilibrium. Reiter [1976] and Jordan [1982a] have developed message processes which, in virtual time, evolve recursively to a limit point which is a rational expectations equilibrium. A problem with this analysis is that it ignores all aspects of strategic play, especially with respect to information revelation. These are important, for example, in describing the actions of a securities trader with inside information.

An alternative approach to the implementation question is to ask when is there a game whose Bayes-Nash equilibria coincide with (or at least contain) the desired allocation. Postlewaite and Schmeidler [1986] and Palfrey and Srivastava [1986] take this approach. Postlewaite and Schmeidler show that conditions called monotonicity and nonexclusivity in information are sufficient for the implementability of a social welfare correspondence. Palfrey and Srivastava show that a condition on information structures, which is essentially equivalent to nonexclusivity, is sufficient for the implementability of any allocation which would be implementable with full information. They also show that if an asymptotic version of nonexclusivity is satisfied such allocations are asymptotically implementable.

Our approach to the study of trading mechanisms is similarly game theoretic in nature. We ask, when do there exist market institutions–when is there a game–some of whose Bayes-Nash equilibria are in some sense Walrasian. We addressed this question in Blume and Easley [1983a] for Revealing Rational Expectation Equilibria. In that paper we showed that nonexclusivity of information is

[1] This criticism also bears on other expectations equilibrium concepts. See Blume and Jordan [1984].

necessary and sufficient for the implementability of Revealing Rational Expectations Equilibria. Here we address the implementation question for general Walrasian allocation correspondences. We find that nonexclusivity in information is a necessary condition in the sense that for a market economy whose distribution of private information does not have this structure, Walrasian analysis cannot be used to characterize market outcomes. Our necessary condition for the implementability of Walrasian allocations is a portion of the sufficient conditions for implementability of arbitrary allocations. It is, of course, not necessary for the implementability of all social welfare correspondences. In general, as Postlewaite and Schmeidler point out, self selection constraints alone are both necessary and sufficient for implementability. All of the sufficiency results mentioned above suffer from the potential lack of economic interest in the implementing mechanism.[2]

Our research differs both in spirit and in results from the papers cited above. Postlewaite and Schmeidler and Palfrey and Srivastava look for sufficiency results. The conditions they find, especially the nonexclusivity condition, are strong. It is easy to think of markets in which this condition would not be satisfied. Thus knowing whether this condition is necessary is very important. Furthermore, they provide conditions which involve joint restrictions on the economy (preferences and endowments), information structure, and social welfare correspondence which are sufficient for implementability. We fix a social welfare correspondence, the Walrasian correspondence, and ask under what conditions on the information structure is this social welfare correspondence implementable for all well behaved economies.

In this paper we approach Walrasian equilibrium from a point of view which differs from the traditional way of talking about rational expectations, but which is close in spirit to the way we prove theorems about rational expectations equilibrium. We propose an equilibrium information structure; an equilibrium distribution of information among the traders in the economy. We then study the properties of all equilibrium allocations which might arise in an economy with the proposed distribution of information. These allocations are said to be **Walrasian** with respect to the proposed information structure.

In the usual existence proofs for rational expectations equilibria in the case of finite signal spaces, we begin with a proposed equilibrium information structure — full information. The existence proofs answer two questions. First, do markets clear in the generic economy with this equilibrium information structure? This is trivial for full information, but is not, as we shall see,

[2] In our paper we actually construct a mechanism which implements equilibrium allocations, and indeed, this mechanism is completely uninteresting.

for other information structures. Second, is this equilibrium information structure realizable in the generic economy by having the traders observe just equilibrium prices? By "realizable," we mean that, if traders observe just their own private information and the equilibrium price vector, they will be fully informed. This second question, of course, is the only issue which needs to be resolved in the proof of the existence of fully revealing rational expectations equilibria. If, on the other hand, we were to apply the usual proof technique to the case of non-revealing equilibria, we would have to answer the first question as well.

Non-revealing equilibrium information structures arise in rational expectations equilibrium models with high dimensional signal spaces (Jordan [1982b]), models of noisy rational expectations equilibria (Allen [1985]) and in models with statistically manipulated data (Anderson and Sonnenschein [1982]). These papers proceed differently from the fully revealing literature. They identify the statistic that will be used to realize the equilibrium information structure, and ask if a market clearing equilibrium exists when traders condition on this statistic and their private information. Since we will be proving theorems about economies with arbitrary equilibrium information structures, our implementation results address the models mentioned above, and many other conceivable expectations equilibrium models as well.[3]

Walrasian analysis when all traders are identically informed is justified by the belief that the Walrasian model describes the outcome of some market process. We believe that most of the trades which occur in the market are transacted at a price at or near the Walrasian market-clearing price. When we consider markets where differential information is important and apply a rational expectations equilibrium notion, a further degree of belief is required. We must also believe that the information most traders have at the time they trade is summarized by the appropriate market statistic — price, a noisy observation of price, etc. Most of us are more skeptical about this last dogma than we are about the first. The out-of-equilibrium behavior which drives the market towards equilibrium will reveal information to any observer, and it would be providential (and therefore unlikely) that this information would prove to be redundant. Our approach to modeling Walrasian equilibrium avoids this problem by allowing us to consider any information structure which will support an equilibrium, without concern for whether it can be realized by some particular market statistic. If one were to carry out a Walrasian analysis of markets with differentially informed traders, one should probably consider the broader equilibrium concept we propose. However, the

[3] Strictly speaking, our results do not address the equilibria found in the last two papers, since their equilibria are not market clearing.

results of this paper suggest that we should be reluctant to carry out such an analysis. Only when private information is distributed in a particular way will there be a set of trading institutions — a trading process — which will implement the equilibrium for most economies.

The necessary condition for implementability, nonexclusivity in information, requires that each trader's private information be perfectly predictable by an outside observer who could observe the private information of all the other traders. Put slightly differently, if the information observed by all other traders was perfectly transmitted by the market, then the contribution to social knowledge of any one trader's private information is nil. His information is redundant. When this condition is false, some trader has truly private information which he may choose to exploit. His ability to exploit this information destroys the incentive compatibility of any equilibrium allocation.

The necessity of a condition like this in the finite trader case is not surprising, because we know that traders may have residual market power. More important, then, is our asymptotic analysis for sequences of economies with ever larger numbers of traders. We demonstrate the necessity of the straightforward asymptotic version of public predictability in the following sense: If this condition fails, then the gains to exploiting private information do not disappear as the number of traders grows.

Our model is presented in section 2. Implementation of expectations equilibria is considered in section 3. Section 4 contains the asymptotic analysis, and the deeper significance of our results is discussed in section 5.

2. THE MODEL.

Basic Definitions.

We consider the class of pure exchange economies usually studied in the rational expectations literature. Let $\mathcal{I} = \{1, \dots, I\}$ denote the set of traders. Traders must consume non-negative amounts of L goods. Trader i has a strictly positive endowment w_i. The endowment allocation for the economy is $w = (w_1, \dots, w_I) \in \mathbf{R}^{LI}_{++}$. The feasible allocations for the economy are those in the set

$$A = \{(x_1, \dots, x_I) \in \mathbf{R}^{LI}_{+} \; : \; \sum_{i=1}^{I}(x_i - w_i) = 0\}.$$

Trader i observes privately a signal whose value is drawn from the set S_i. The set of possible values for the joint signal is $S = S_1 \times \cdots \times S_I$. We assume that each S_i is finite. The power sets of S_i

and S are denoted by $\mathcal{S}_i$ and $\mathcal{S}$, respectively. The set S_{-i} is the set of possible values for the joint signal of all players other than i. If s is a joint signal, s_{-i} is the vector of signals observed by all traders other than i.

The random selection of joint signals is described by a probability measure μ on S. Let $P(S)$ denote the set of all probability measures on S. We refer to $\mu \in P(S)$ as an **information structure** for the economy.

Each trader i has a utility function $u_i : \mathbf{R}_+^L \times S \mapsto \mathbf{R}$. The number $u_i(x, s)$ is the utility received by trader i when he consumes the consumption bundle x and the realization of the joint signal is s. We assume:

U1. For each $s \in S$, $u_i(x, s)$ is twice continuously differentiable, strictly differentially concave and strictly differentiably monotone.

Let $U(S) = \{(u_1, \ldots, u_I) \; : \; \text{each } u_i \text{ satisfies } U1.\}$. An economy with joint signal space S is specified by an endowment allocation, a utility function for each trader and an information structure. The set of economies with joint signal space S is $E(S) = \mathbf{R}_{++}^{LI} \times U(S) \times P(S)$.

We are interested both in the actual outcomes of a trading mechanism and in the predictions made by an equilibrium concept. These allocations are assumed to depend only upon those variables specified in the description of the economy.[4] The outcome of a trading mechanism and the prediction of an equilibrium concept are both summarized by an **allocation correspondence.** An allocation correspondence is a correspondence $F : E(S) \times S \mapsto A$ such that, for each $e \in E$, $F(e, \cdot, \cdot)$ has measurable graph.

Most generally, we are interested in finding allocation correspondences which are simultaneously a description of the outcomes of a trading mechanism and the predictions of a useful equilibrium concept. In this paper we shall give a condition on information structures which is satisfied whenever, for all economies with that information structure, there is a Walrasian equilibrium concept whose predictions are satisfied by some trading mechanism.

[4] Allowing for random outcomes, such as those that arise in noisy rational expectations models and approximate rational expectations models, does not change our results. See Blume and Easley [1985].

Walrasian Equilibrium Concepts.

In the usual extension of competitive equilibrium concepts to economies with differentially informed consumers, each trader will choose a consumption bundle to maximize expected utility on some budget set. These equilibrium concepts are distinguished only by the random variables upon which each trader conditions his beliefs. We will consider equilibrium concepts wherein each trader conditions on a private signal and also on some "market-generated" statistic.

The range of the market statistic is taken to be a Borel subset Y of a complete separable metric space. Let $\sigma(Y)$ denote the Borel σ-field of Y. A **statistic** is a measurable map $\psi : S \mapsto Y$.

Definition. Let ψ be a statistic and let $D \subset E(S)$ be a set of economies. An allocation correspondence F is **Walrasian with respect to** ψ **on** D if for each $e \in D$ there exists a measurable selection $f(e, \cdot)$ from F such that $f_i(e, \cdot)$ is S_i-measurable; and for each such f there is a function $p : S \mapsto \Delta^{L-1}$, the non-negative unit simplex in $\mathbf{R}^l$, and I functions $f_i : S \mapsto \mathbf{R}^L_+$ such that for each i and μ-almost all s,

$$f_i(s) \in \operatorname*{argmax}_x \{E\{u_i(x,s) \mid s_i, \psi\} \;:\; x \geq 0,\ p(s) \cdot (x - w_i) = 0\}. \tag{1}$$

Any selection satisfying these properties is said to be a **Walrasian selection**. An allocation correspondence F is **Walrasian on** D if there is a statistic ψ such that F is Walrasian with respect to ψ on D.

The function p in the definition is a price function, and is said to **support** the allocation correspondence F. Equation (1) in the definition is the usual maximization condition, requiring, in equilibrium, that every trader is maximizing utility on his budget set. The measurability requirement is that the trader use only information available to him. One might argue that if price is not the market statistic, demand should still depend upon price. We do not dispute this, and the effect of this assumption will be to constrain the information contained in the market price.[5] Each trader's demand can depend only on what he has observed. Revealing rational expectations

[5] It is clear that one cannot hope to find equilibria which are Walrasian with respect to any arbitrarily chosen statistic. The characterization of those statistics which admit Walrasian equilibria for some reasonably large class of economies is an important question. It is another way of asking what ex post information structures are consistent with rational expectations equilibrium. Important though it is, it shall not concern us here.

equilibria, the most familiar equilibria to the reader of the rational expectations literature, give rise to allocations which are Walrasian with respect to the statistic $\psi(s) = s$.[6]

Trading Mechanisms.

A **trading mechanism** is a set of rules for an extensive-form game with incomplete information, whose payoffs and information structure are given by the data specified in e. The data in e is assumed to be common knowledge for all traders in the game. Let Q denote the **Bayes-Nash equilibrium allocation correspondence** for the game.

A trading mechanism **implements** an Walrasian allocation correspondence F on $D \subset E(S)$ if, for each $e \in D$, $Q(e,\cdot) \cap F(e,\cdot)$ contains a Walrasian selection. This is weaker than the usual definition of implementability, but nonetheless acceptable in any search for necessary conditions.

A **direct mechanism** is described by a map $m : E(S) \times S \mapsto A$ which assigns to each vector of announced signals an allocation vector. This map assigns payoffs for the following game: Players observe their private signal s_i, and then announce a signal t_i to the "center". The announced signal t_i may or may not equal the true signal s_i. The center then chooses the final allocation $m(e,t)$, which is then distributed to the players. A direct mechanism is said to be **incentive-compatible** for the economy e if, when traders from economy e play the game, announcing $t_i = s_i$ is a Bayes-Nash equilibrium. A direct mechanism truthfully implements the allocation correspondence F on D if, for each $e \in D$, the truth-telling equilibrium allocations $m(e,s) \in F(e,s)$ μ-almost surely. The importance of direct mechanisms is due to the revelation principle which says in our language that if any trading mechanism implements the allocation correspondence F on D, then there is a direct mechanism m which truthfully implements F on D.[7]

3. IMPLEMENTATION OF EXPECTATIONS EQUILIBRIUM.

Let $D(\mu)$ be the set of all economies in $E(S)$ with information structure μ. In this section we identify a necessary condition which must be satisfied by μ if some Walrasian correspondence can be implemented on $D(\mu)$. The necessary condition requires that there be no "truly private"

[6] It is tempting to say that it is Walrasian with respect to p. But our analytical scheme treats the statistic as exogenously specified, which the variable p is certainly not.

[7] See Myerson [1979] and Harris and Townsend [1981].

information.[8]

Definition. An information structure μ on S has **nonexclusivity in information** (NEI) if for all $i \in \mathcal{I}$ and almost all $s \in S$, $\mu(s_i|s_{-i})$ is either 0 or 1.

Nonexclusivity in information requires that the observation of any one trader be perfectly predictable from the joint observation of all the remaining traders. As we mentioned in the introduction, versions of this condition have appeared previously in the literature on sufficient conditions for implementability; and previously we have shown this condition to be necessary for the implementation of fully revealing rational expectations equilibrium. Here we show that it is necessary for the implementation of a much larger class of equilibrium concepts.

Theorem 1. *If there exists a Walrasian allocation correspondence which can be implemented on $D(\mu)$, then μ satisfies NEI.*

Proof. Our proof of Theorem 1 relies upon the construction of a counter-example. Choose μ which does not satisfy NEI, and let F be an allocation correspondence defined on $D(\mu) \times S$. The revelation principle implies that if F is implementable by any mechanism, then it is truthfully implementable by a direct mechanism. We construct an economy e in $D(\mu)$ for which truthful implementation fails. To keep things simple we build a two-good counter-example, but it is clear that the number of goods is not critical for our construction.

Since NEI fails, there exists a trader, whom we shall identify as trader 1, a signal $t_1 \in S_1$ and a set $A_{-1} \subset S_{-1}$ of positive measure such that, for all $s_{-1} \in A_{-1}$, $\mu(t_1, s_{-1}) > 0$ and there exists $r_1 \neq t_1$ in S_1 such that $\mu(r_1, s_{-1}) > 0$. Let $A = \operatorname{supp} \mu \cap \{s \in S \ : \ s_{-1} \in A_{-1}\}$.

Each trader other than trader 2 has initial endowment $w_i = (1,1)$. Trader 2 has endowment (δ, δ), $\delta > 0$. A consumption bundle for trader i is a vector (x_{i1}, x_{i2}). Prices are normalized to sum to 1, and p is the price of good 1. Trader 1's preferences are described by the utility function:

$$u_1(x, s) = x_{11}^{\alpha_1(s)} x_{12}^{1-\alpha_1(s)},$$

where

[8] The name for this concept comes from Postlewaite and Schmeidler [1986]. Palfrey and Srivastava [1986] and Blume and Easley [1983a] have similar definitions, but use the names "public information" and "publicly predictable information" respectively.

$$\alpha_1(s) = \begin{cases} 1-\epsilon_1, & \text{if } s_1 \neq t_1; \\ 1-\epsilon_2, & \text{if } s_1 = t_1; \end{cases}$$

where $\epsilon_1 \neq \epsilon_2$. Trader 2's preferences are described by the utility function:

$$u_2(x,s) = \alpha_2(s)\log x_{21} + \beta_2(s)\log x_{22},$$

where

$$\alpha_2(s) = \begin{cases} 1-\epsilon_1, & \text{if } s_1 \neq t_1; \\ \epsilon_2, & \text{if } s_1 = t_1. \end{cases}$$

and

$$\beta_2(s) = \begin{cases} \epsilon_1, & \text{if } s_1 \neq t_1; \\ \epsilon_2, & \text{if } s_1 = t_1. \end{cases}$$

For traders $i > 2$,

$$u_i(x,s) = \alpha\log x_{i1} + (1-\alpha)\log x_{i2}, \quad 0 < \alpha < 1$$

for all $s \in S$. Let ψ be any statistic such that F is Walrasian with respect to ψ.

First we will show that ψ and s_2 together must reveal trader 1's signal to trader 2. Suppose not. Then there exists r_{-1}, t_{-1} such that $r_2 = t_2$ and

$$\psi(r_1, r_{-1}) = \psi(t_1, t_{-1}) = \hat{y}.$$

From the measurability hypothesis, $f_2(s)$ depends only on the values of s_2 and ψ. Thus

$$f_2(r_1, r_{-1}) = f_2(t_1, t_{-1}) = (\hat{x}_{21}, \hat{x}_{22}).$$

Since F is Walrasian with respect to ψ on $D(\mu)$,

$$(\hat{x}_{21}, \hat{x}_{22}) \in \operatorname*{argmax}_x \Big\{ E\{u_2(x,s) \,|\, s_2, \psi\} \ : \ x \geq 0,\ p(s)\cdot(x - w_2) = 0 \Big\}$$

for $s = (r_1, r_{-1})$ and $s = (t_1, t_{-1})$. Let $E\{\alpha_2(s) \,|\, s_2, \hat{y}\} = \hat{\alpha}_2$. Calculations show that

$$\begin{aligned} \hat{x}_{21} &= \frac{\hat{\alpha}_2\delta}{p(r_1, r_{-1})}, \\ &= \frac{\hat{\alpha}_2\delta}{p(t_1, t_{-1})}. \end{aligned}$$

Thus $p(r_1, r_{-1}) = p(t_1, t_{-1}) = \hat{p}$. Feasibility requires

$$\frac{1-\epsilon_1 + \hat{\alpha}_2\delta + (I-2)\alpha}{\hat{p}} = I - 1 + \delta,$$

and

$$\frac{1-\epsilon_2+\hat{\alpha}_2\delta+(I-2)\alpha}{\hat{p}}=I-1+\delta.$$

But this is impossible since $\epsilon_1 \neq \epsilon_2$.

Having shown that trader 1's signal must be revealed to trader 2 in equilibrium, we will now compute equilibrium consumption bundles for trader 1. Again, simple calculations show that for all s_{-1},

$$x_{11}(t_1,s_{-1})=\frac{(1-\epsilon_2)(I-1+\delta)}{1-\epsilon_2+\delta\epsilon_2+\alpha(I-2)},$$
$$x_{12}(t_1,s_{-1})=\frac{\epsilon_2(I-1+\delta)}{\epsilon_2+\delta(1-\epsilon_2)+(1-\alpha)(I-2)},$$
$$x_{11}(r_1,s_{-1})=\frac{(1-\epsilon_1)(I-1+\delta)}{1-\epsilon_1+\delta(1-\epsilon_1)+\alpha(I-2)},$$
$$x_{12}(r_1,s_{-1})=\frac{\epsilon_1(I-1+\delta)}{\epsilon_1+\delta\epsilon_1+(1-\alpha)(I-2)}.$$

For small ϵ_1 and ϵ_2, trader 1 prefers the bundle awarded to him when he announces t_1 to the bundle he receives when he announces r_1, regardless of the value of s_{-1}.

If trader 1 reports t_1 when in fact he has observed r_1, two possibilities arise. First, s_{-1} may be such that the joint realization (t_1,s_{-1}) has μ-positive probability. In this case, any direct mechanism which would truthfully implement the Walrasian equilibrium allocation correspondence F is constrained to award consumption bundle $x_1(t_1,s_{-1})$ to trader 1. Second, s_{-1} may be such that (t_1,s_{-1}) has μ-probability 0. In this case we do not know a priori what the direct mechanism truthfully implementing F will assign to trader 1, but we know that 0 is a lower bound for the utility that trader 1 can achieve in this case. We also know that the probability of this happening is no more than $q=\text{Prob}\{s_{-1}\notin A_1 \mid t_1\}$. Since NEI is violated, we know that $q<1$. Thus trader 1's expected utility of announcing t_1 when he observes r_1 is

$$V(t_1\,|\,r_1)\geq(1-q)(\delta+I-1)\left(\frac{1-\epsilon_2}{1-\epsilon_2+\delta\epsilon_2+\alpha(I-2)}\right)^{1-\epsilon_1}\left(\frac{\epsilon_2}{\epsilon_2+\delta(1-\epsilon_2)+(1-\alpha)(I-2)}\right)^{\epsilon_1}.$$

Similarly, trader 1's expected utility from reporting r_1 when he observes r_1 is

$$V(r_1\,|\,r_1)=(\delta+I-1)\left(\frac{1-\epsilon_1}{1-\epsilon_1+\delta(1-\epsilon_1)+\alpha(I-2)}\right)^{1-\epsilon_1}\left(\frac{\epsilon_1}{\epsilon_1+\delta\epsilon_1+(1-\alpha)(I-2)}\right)^{\epsilon_1}.$$

For ϵ_1,ϵ_2 sufficiently small, $V(t_1\,|\,r_1)>V(r_1\,|\,r_1)$ if

$$1-q>\frac{1+\alpha(I-2)}{1+\alpha(I-2)+\delta}.$$

Given the information structure μ, from which we can calculate q, we can satisfy this inequality by choosing δ large enough. ∎

E

This proof depends upon two ideas. First, there are some economies for which any statistic must induce full information in a Walrasian equilibrium. Second, this set of economies is sufficiently rich that it includes economies for which truth-telling does not pay. For these economies a counterexample to implementability is constructed. Similar counterexamples have appeared in Blume and Easley [1983a] and Palfrey and Srivastava [1986].

Remark. If we topologize $E(S)$ in the usual way (product topology, where utility functions $u_i(\cdot, s)$ are topologized with the topology of C^2 uniform convergence on compact subsets of $\mathbf{R}^L_+$) it can be seen that non-implementability of Walrasian allocation correspondences is robust to small perturbations in the specification of the counter-example.

Remark. The proof of Theorem 1 contains the proof of another important result. Let us fix the equilibrium distribution of information and ask, can this distribution arise in a Walrasian equilibrium? We have shown that there is an open set of economies for which the answer is "yes" only if each trader is fully informed. This result follows from the measurability condition in the definition of a Walrasian selection together with the assumption that markets clear. This issue never arises in most of the rational expectations literature because, when equilibrium is fully revealing, the measurability assumption has no force. To achieve the kinds of equilibrium discussed, for example, by Anderson and Sonnenschein [1982] and by Allen [1985], the market-clearing or preference maximization hypothesis must be dropped. The approximation to market clearing in these results is not simply an analytical convenience. It is a crucial assumption which is necessary for any generic (or stronger) existence result.

Remark. Theorem 1 can be trivially extended to economies with a joint signal space that is not finite by making a finite partition of each S_i and setting up the example so that each trader cares only about which element in the finite product partition occurs.

Remark. NEI is sufficient for implementation (in our sense) of any allocation correspondence which is ex-post individually rational (individually rational with respect to each player's ex-post information ψ and s_i). This includes some Pareto and all Walrasian allocation correspondences. The key to understanding NEI is to see that in any direct revelation game, misrepresentation can be detected with probability 1. A mechanism which will implement either such correspondence is the "punishment mechanism", described in Blume and Easley [1983a]. This mechanism implements a selection f from the allocation correspondence F by assigning $f(e,t)$ if the joint signal t is reported and $t \in \operatorname{supp} \mu$, and the endowment allocation otherwise. Since f_i is individually rational for each trader given his information s_i and ψ, it is ex-ante individually rational (individually rational with respect to s_i), and so truth-telling is equilibrium play. Of course this mechanism is completely devoid of any economic interest. Implementation in our sense requires that each measurable selection from the prescribed allocation correspondence also be a selection from the Bayes Nash equilibrium allocation correspondence from some trading mechanism. The additional assumptions found in Palfrey and Srivastava's [1986] and Postlewaite and Schmeidler's [1986] sufficiency analysis are needed to get from implementation in our weak sense to implementation in their stronger sense.

4. INFORMATIONAL SMALLNESS.

Increasing the number of traders does not necessarily cause the implementation problem to disappear. For the class of examples considered in Section 2, increasing the number of traders who have imperfectly correlated signals need not shrink to zero the gains from misrepresentation. Suppose, for example, that traders observe i.i.d. signals with unknown mean. Suppose first that each trader's preferences depend only on his signal and trader 1's signal. It is easy to construct preferences such that trader 1's gains to misrepresentation cannot entirely disappear. The collective information of traders 2 through I can give an increasingly accurate estimate of the mean of the distribution from which trader 1's signal is drawn, but says nothing about the deviation of trader 1's observation from the mean. Thus NEI, or an appropriate asymptotic version, is violated. If instead each trader's preferences depend only on his observation and the average of all the observations, the ability of any one trader to affect the social forecast shrinks as the number of traders grows. Thus the gains to misrepresentation ultimately vanish. In this section we show that an asymptotic version of *NEI* is necessary if the gains from misrepresenting information are to shrink to 0 as the number of traders grows. Our asymptotic version of *NEI* is a necessary condition for any version of approximate implementation in large economies.

We assume that the set of potential traders is countable, and indexed by the positive integers. All traders have identical finite signal sets: $S_i = S_j$ for all i and j. Let $S = \prod_{i=1}^{\infty} S_i$. An economy is specified by identifying the set $\mathcal{I} = \{1, \ldots, I\}$ of traders who will participate. The joint signal space for this economy is $S^I = \prod_{i=1}^{I} S_i$. A typical joint signal is denoted by $s^I \in S^I$. The joint signal of all traders but trader i is denoted by s^I_{-i}. An information structure is a probability distribution on S. Let $P(S)$ denote the set of all information structures on S. The information structure for the economy consisting of players in $\mathcal{I}$ is the marginal distribution μ^I on S^I.

Each potential trader i has a utility function $u_i : \mathbf{R}^{\mathbf{L}}_+ \times S \mapsto \mathbf{R}$. The number $u_i(x, s)$ is the utility received by trader i when he consumes the bundle x and the realization of the joint signal is s. The utility function of trader i is assumed to satisfy *U1.* Let $U(S)$ denote the set of all countable sequences of utility functions satisfying *U1.* Let W denote the set of all strictly positive endowment sequences.

Definition. A sequence of economies is **competitive** if

a) The endowment sequence is bounded, and

b) The set of all functions $\{u_i(s, \cdot) : \mathbf{R}^{\mathbf{L}}_+ \mapsto \mathbf{R} \ : \ s \in S, \ i \geq 1\}$ is compact in the topology of C^2-uniform convergence on compact sets.

The sequence of economies which we will construct for our counterexample is not a replica economy, but nearly so. It does satisfy conditions *a)* and *b)*.

The set of all competitive sequences of economies can be represented by the set $E(S) \subset U(S) \times W \times P(S)$. For any particular element $e \in E(S)$, the sequence of economies $\{e^I\}_{I=1}^{\infty}$ is constructed by taking the first I utility functions and endowments, and the information structure μ^I on S^I. The set of economies of size I is denoted by $E^I(S)$. The set $D(\mu)$ is the set of all economies $e \in E(S)$ with information structure μ. The definitions of the set A^I of feasible allocations, allocation correspondences F^I, statistics ψ^I, and so forth, are as in section 2. For example, a sequence $\{\psi^I\}$ of statistics is a sequence of functions $\psi^I : S^I \mapsto Y$ such that ψ^I is measurable with respect to the σ-field $\mathcal{S}^I$.

The next definition gives the appropriate asymptotic generalization of NEI.

Definition. An information structure μ has **asymptotically nonexclusive information** (ANI) if for all $i = 1, \ldots, \infty$ and almost all $s \in S$, $\lim_{I \to \infty} \mu^I(s_i | s^I_{-i})$ is either 0 or 1.

Asymptotic nonexclusivity requires that the estimate of any one trader's signal from the information of the other traders approaches perfection as the number of other traders becomes large. Another way of posing this definition is to say that *NEI* is satisfied for the entire infinite sequence of joint signals. A martingale convergence theorem then implies the statement of our definition.

A **direct mechanism** for $E(S)$ is a sequence of maps $\{m^I\}_{I=1}^{\infty}$, where $m^I : E^I(S) \times S^I \mapsto A^I$ assigns to each vector s^I of announced signals an allocation vector. The mechanism is **asymptot-**

ically incentive compatible if for each trader i observing signal s_i, the gains from announcing signal $t_i \neq s_i$ shrink to 0 as I gets large when every other trader j announces his true observation s_j. This says that truth-telling is an ϵ-equilibrium of the direct revelation game described by m^I, and that ϵ can be made arbitrarily small by choosing I sufficiently large. This is weaker than requiring that a sequence of equilibrium strategies in the direct revelation games converges to a truth-telling equilibrium.

Definition. A direct mechanism $\{m^I\}_{I=1}^{\infty}$ **truthfully implements** an allocation correspondence $\{F^I\}_{I=1}^{\infty}$ on a set of economies $D \subset E(S)$ if, for each $e^I \in D^I$, $m^I(e^I, s^I) \in F^I(e^I, s^I)$ almost surely with respect to the measure μ^I.

Our goal is to demonstrate that the gains from misrepresentation shrink to 0 as the number of traders increases only if *ANI* is satisfied. This idea is easily stated by referring to Bayes-Nash ϵ-equilibria.

Definition. A **Bayes-Nash ϵ-equilibrium** is a vector of players' strategies for which the payoff vector is within distance ϵ of some Bayes-Nash equilibrium payoff vector.

Let Q_ϵ^I denote the Bayes-Nash ϵ-equilibrium allocation correspondence for the direct mechanism m^I. We say that a mechanism m^I **ϵ-implements** an allocation correspondence F^I if $Q_\epsilon^I(e^I, \cdot) \cap F^I(e^I, \cdot) \neq \emptyset$ μ^I-almost surely. A trivial modification of the revelation principle shows that if any trading mechanism ϵ-implements an allocation correspondence, then there is a direct mechanism which truthfully implements the allocation correspondence and for which truth-telling play is an ϵ-equilibrium.

Put formally, our goal is to prove the following Theorem:

Theorem 1. If there exists a Walrasian allocation correspondence $\{F^I\}_{I=1}^{\infty}$ which can be ϵ^I-implemented on $D(\mu)$ with $\lim_{I\to\infty} \epsilon^I = 0$, then μ satisfies *ANI.*

Theorem 1 follows from the following Lemma:

Lemma 1. Let μ violate *ANI* and let $\{m^I\}_{I=1}^{\infty}$ be a direct mechanism which truthfully implements a Walrasian allocation correspondence $\{F^I\}_{I=1}^{\infty}$ on $D(\mu)$. Then there exists an economy in $D(\mu)$ such that $\{m^I\}_{I=1}^{\infty}$ is not asymptotically incentive-compatible.

The Lemma shows that if μ violates *ANI*, then we can find an economy for which it is impossible to make truth-telling a Bayes-Nash ϵ-equilibrium of the direct revelation game for large I with arbitrarily small ϵ. This is the Theorem.

The rest of this section will be devoted to the construction of a counter-example which will prove the Lemma. Similar counterexamples have appeared in Blume and Easley [1983a] and Palfrey and Srivastava [1986].

We will construct a sequence of economies $e \in E(S)$ with the property that, if the information structure does not satisfy *ANI*, then the gains from misrepresentation do not shrink to 0. In other words, there is no direct mechanism which truthfully implements any Walrasian allocation correspondence for the economy e and which is asymptotically incentive compatible. This example would have great force if it were a replica example — finite numbers of types of utility functions and endowments, so that only information changed as the economy grows large. Our example is not quite that. But it is close. There will be a finite number of endowment types, and all preferences will be small perturbations from one of a finite number of types. Thus we can be sure that the source of incentive incompatibility is not a large endowment share or unusual preferences.

Assume that there are two types of traders. The i'th trader of type 1 receives signal s_{1i} and has utility function

$$u_{1i}(x_1, x_2) = x_1^{\alpha_1(s_{1i})} x_2^{(1-\alpha_1(s_{1i}))},$$

where

$$\alpha_1(s_{1i}) = \begin{cases} 1-\epsilon_i & \text{if } s_{1i} = r_{1i} \\ 1-2\epsilon_i & \text{if } s_{1i} \neq r_{1i} \end{cases},$$

and ϵ_{1i} is a member of the set $[0,\epsilon]$. Traders of type 1 are endowed with 1 unit of each commodity. Let $\mathcal{E}$ denote the set $\prod_{i=1}^{\infty}[0,\epsilon]$ of all sequences $(\epsilon_1, \epsilon_2, \ldots)$.

The i'th trader of type 2 observes private signal s_{2i} and has utility function

$$u_{2i}(x_1, x_2) = \alpha_2(s_{11}) \log x_1 + (1-\alpha_2(s_{11})) \log x_2,$$

where

$$\alpha_2(s_{11}) = \begin{cases} 1-\gamma & \text{if } s_{11} \neq r_{11} \\ \gamma & \text{if } s_{11} = r_{11} \end{cases}.$$

Traders of type 2 are endowed with δ units of each commodity. Prices are normalized so that they sum to 1.

Assume that ANI is violated, and that $0 < \lim_{I\to\infty} \mu^I(s_{11} = r_{11}|s_{12},\ldots,s_{2I}) < 1$ for some set of signals $A \subset S$ with $\mu(A) > 0$.

We will proceed exactly as we did in section 3. First we will show that there exist sequences $\{\epsilon_i\}_{i=1}^{\infty}$ in $\mathcal{E}$ such that each finite economy has only fully revealing equilibria. Then we will show that for some of these sequences, the gains from false representation for the first type 1 trader do not shrink to 0.

Let $p^I(s,y)$ denote the price of good x_1 in the economy of size $2I$. For traders of type 1, demand for good x_1 is:

$$f_{1i}(s) = \frac{\alpha(s_{1i})}{p^I(s,\psi^I(s))}.$$

For traders of type 2, let $\hat{\alpha}_2(s) = E\{\alpha_2(s_{11})\,|\,s_{2i},\psi(s)\}$ denote the conditional expectation of the state dependent parameter in the type 2 utility function given trader $2i$'s private observation and the value of the signal ψ. Demand by trader i of type 2 for good x_1 is

$$f_{2i}(s) = \frac{\hat{\alpha}_2(s)}{p^I(s,\psi^I(s))}.$$

Consider the economy consisting of I players of each type, and suppose there exist two signal vectors s^I and r^I such that for some trader $1i$, $s_{1i} = r_{1i}$, $\psi^I(s^I) = \psi(r^I) = y$ and $p^I(s^I,y) \neq p^I(r^I,y)$. Then

$$\frac{\alpha(s_{1i})}{p^I(r^I,y)} \neq \frac{\alpha(s_{1i})}{p^I(s^I,y)},$$

which contradicts the assumption that trader $1i$'s demand is a measurable function of just his information and the public signal. Thus $p^I(s,y) \neq p^I(r,y)$ implies that, for all i, $s_{1i} \neq r_{1i}$. Hence price can be determined by knowing the value of y and any one s_{1i}. The same argument applies to traders of type 2. Thus price can be written as a function of y and any one private signal.

Now consider the aggregate feasibility constraint:

$$\sum_{i=1}^{I} \alpha_1(s_{1i}) + \sum_{i=1}^{I} \hat{\alpha}_2(s_{2i},y) = I(1+\delta)p^I(s_{2j},y),$$

where trader $2j$ is chosen arbitrarily. It is now easy to see that for almost all ϵ^I, s_{11} must be revealed to trader $2j$ in equilibrium. The aggregate feasibility constraint can be rewritten the following way:

$$\sum_{i=1}^{I} \alpha_1(s_{1i}) + (1-2\gamma)\sum_{i=1}^{I} \operatorname*{Prob}_{\mu}\{s_{11} = r_{11}\,|\,s_{2i},y\} = I(1+\delta)p^I(s_{2j},y) - I\gamma.$$

Let

$$z(s^I) = \sum_{i=2}^{I} \alpha_1(s_{1i}) + (1-2\gamma) \sum_{i=1}^{I} \mathop{\mathrm{Prob}}_{\mu}\{s_{11} = r_{11} \,|\, s_{2i}, y\}.$$

Since the set S^I has only finitely many elements and since ψ^I is a function of s_I, $z(s^I)$ can take on only finitely many values. Consider the condition

$$\{z(s^I) + \alpha_1(r_{11}) \ : \ s^I \in S^I,\ s_{11} = r_{11}\} \cap \{z(s^I) + \alpha_1(t_{11}) \ : \ s^I \in S^I,\ s_{11} = t_{11} \neq r_{11}\} = \emptyset.$$

Falsifying this condition requires that, given $\epsilon_2, \dots, \epsilon_I$, a number of equalities linear in ϵ_1 must be satisfied — namely, those of the form:

$$a + 1 - \epsilon_1 = b + 1 - 2\epsilon_1$$

where a and b are values of $z(s^I)$. Clearly there can be at most one ϵ_1 which solves any one of these equations. Thus it is clear that the set $G^I \subset \mathcal{E}$ of all $(\epsilon_1, \dots)$ which satisfy the condition for economies with I traders of each type has full product lebesgue measure. Then $G = \cap_{I=1}^{\infty} G^I$ also has full measure. Any sequence $(\epsilon_1, \dots)$ in G has the property that any Walrasian equilibrium is revealing. This completes the first step.

Now we will show that if ϵ_1 is sufficiently small, it pays the first type 1 trader to announce r_{11} when he observes $s_{11} \neq r_{11}$. Here we abuse notation to write $p^I(s) = p^I(s, \psi^I(s))$. Since the variable s_{11} is revealed to all players who care, in equilibrium,

$$\lim_{I\to\infty} p^I(s) = \begin{cases} \bar{\alpha}_1 + \gamma\delta & \text{if } r_{11} \text{ is revealed,} \\ \bar{\alpha}_1 + (1-\gamma)\delta & \text{if} t_{11} \neq r_{11} \text{ is revealed,} \end{cases}$$

where $\bar{\alpha}_1$ is the average of $\alpha_1(s_{1i})$ over the entire type 1 population. In the limit, $\bar{\alpha}_1$ is independent of the announcement of s_{11}.

Suppose that the first trader of type 1 observes $s_{11} \neq r_{11}$, and suppose he announces r_{11}. Suppose too that all other traders reveal their true signal. Then asymptotically the first trader of type 1 consumes the bundle

$$\left(\frac{1-\epsilon_1}{\bar{\alpha}_1 + \delta\gamma}, \frac{\epsilon_1}{1 - \bar{\alpha}_1 - \delta\gamma}\right).$$

His utility is at least

$$q\left(\frac{1-\epsilon_1}{\bar{\alpha}_1 + \delta\gamma}\right)^{1-2\epsilon_1} \left(\frac{\epsilon_1}{1 - \bar{\alpha}_1 - \delta\gamma}\right)^{2\epsilon_1},$$

where q is the asymptotic probability of the lie not being detected. Because *ANI* is assumed to be false, $q > 0$. Should he reveal the truth, he gets

$$\left(\frac{1-\epsilon_1}{\bar{\alpha}_1 + \delta(1-\gamma)}, \frac{\epsilon_1}{1 - \bar{\alpha}_1 - \delta(1-\gamma)}\right),$$

and his utility converges to

$$\left(\frac{1-\epsilon_1}{\bar{\alpha}_1+\delta(1-\gamma)}\right)^{1-2\epsilon_1}\left(\frac{\epsilon_1}{1-\bar{\alpha}_1-\delta(1-\gamma)}\right)^{2\epsilon_1}.$$

In these two expressions for asymptotic utility, $\bar{\alpha}_1$ is a number between 0 and 1 whose precise value will depend on the joint signal actually drawn. The gains that accrue to our trader by revealing r_{11} when he does not observe it are greater than 0 so long as

$$q > \left(\frac{\bar{\alpha}_1+\delta\gamma}{\bar{\alpha}_1+\delta(1-\gamma)}\right)^{1-2\epsilon_1}\left(\frac{1-\bar{\alpha}_1-\delta\gamma}{1-\bar{\alpha}_1-\delta(1-\gamma)}\right)^{2\epsilon_1}.$$

For δ sufficiently large, and ϵ_1 sufficiently small, the right hand side is approximately

$$\frac{\gamma}{1-\gamma}.$$

For γ sufficiently small, then, the inequality will be satisfied. Since G has full product lebesgue measure in $\mathcal{E}$, we can choose $\{\epsilon_i\}_{i=1}^{\infty}$ in G with arbitrarily small ϵ_1. This completes the demonstration of the second step.

5. CONCLUSION.

In this paper we have studied the implementation of Walrasian equilibria in economies with differentially informed traders. We have shown that unless the economy's information structure satisfies a distribution condition called *nonexclusivity*, no Walrasian equilibrium is implementable by any trading mechanism. Nonexclusivity in information is sufficiently stringent that we view this Theorem as a negative result. But our analysis takes the distribution of information as exogenous when in fact the acquisition of information can be determined by market forces. The validity of our negative interpretation of the results presented here depends on whether nonexclusivity is satisfied in economies with endogenous determined information structures. We have not addressed this question here because much preliminary work needs to be done addressing the technological and incentive issues concerning the production, dissemination and acquisition of information.

At least two further questions about implementing equilibria arise in economies with differential information. First, if one does not choose to view our results as negative findings, one needs to go further and ask under what conditions are Walrasian equilibria implementable by reasonable, economically interesting mechanisms. We know in the case of fully revealing rational expectations equilibrium that nonexclusivity is sufficient (Blume and Easley [1983a]), but the mechanism that has been shown to work is unreasonable. It looks nothing like any conceivable set of market institutions and so is devoid of any economic interest. We believe that the search for sufficient conditions guaranteeing implementability should be done with constraints on the allowable class of mechanisms. Second, we do not ask what actually happens in market games whose Bayes-Nash equilibria are not Walrasian allocations. The mechanism design approach of this paper is not useful for this kind of positive question. We address this question in Blume and Easley [1983b], but our analysis necessarily depends on the specific market game we choose to analyze. General statements about this question have yet to be discovered.

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