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Volume of Trade and Revelation of Information

by

Tito Pietra*
Paolo Siconolfi**

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* Università degli Studi di Modena e Reggio Emilia
Dipartimento di Economia Politica
Via Berengario, 51
41100 Modena (Italia)
e-mail:tpietra@unimo.it

** Columbia University
Graduate School of Business
Uris Hall, New York
N.Y.10027
e-mail:tpietra@unimo.it
e-mail:atella@uniroma2.it

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1. Introduction

The purpose of this paper is to study the existence of partially revealing *rational expectation equilibria* (REE) in a general equilibrium economy with ex-ante asymmetric information and a continuum of states of private information. The dimension of the set of states of private information (at least (C+1)(C+2), where (C+1) is the number of commodities) is larger than the dimension of the "market information" (equal to (2C+1)).

Our purpose is to give a relatively simple setting to study some properties of partially revealing REE. To this aim, we drastically simplify the model by assuming the existence of two types of identical agents, perfectly informed and completely uninformed.

We depart from the classical framework (see, in particular, Allen (1981, 1982) and Jordan (1982)) with respect to an essential feature: Agents observe both market prices and the volume of trade (i.e., the sum over the agents of the positive excess demand of the individual commodities).

The inclusion of the volume of trade among the market signals has a crucial role. Information on the volume of trade is readily available on many markets (in particular, on financial markets). Casual empiricism suggests that it is exploited by the agents to formulate expectations (again, this phenomenon seems to be very common in financial markets). Hence, we believe that it is important to analyze the consequences of this kind of information on the set of equilibria.

If the volume of trade is one of the market signals, the two-types of agents framework is very restrictive. In this setting, to observe the volume of trade at the equilibrium is equivalent to observe the absolute value of each (type of) agent's excess demand. The analysis of more general models with heterogeneous agents (in terms of endowments, preferences and, more relevant, in terms of structures of private information) is still an open issue.

The basic idea of the paper is to exploit the particular nature of the informational structure to obtain, for each observed price-volume pair, the set of states of private information which are compatible with the behavior of the informed agents. Then, the excess demand function of the uninformed agents is well-defined even out of equilibrium. Equilibria of the full communication economy (FCE, i.e., the economy where each agent is fully informed) can be supported as REE (Theorem 1). Generically, there are also REE (in fact, a continuum of REE) which are not equilibria of the FCE and which are *partially revealing* (Theorem 2 and 3).

Our restrictions on agents' preferences and on the informational structures are strong. The first kind of restrictions could probably be relaxed at the cost of some technical complications. Instead, for the argument of our proofs to work, it is essential that one subset of agents is fully informed and that all the non-fully informed agents have the same private information. To simplify, we assume that they are completely uninformed.

In the general equilibrium literature, there are only a few results on the existence of partially revealing REE. Jordan (1982) shows that, generically, there are partially revealing equilibria arbitrarily close to the fully revealing ones. The equilibrium map is discontinuous on a dense set of states of private information. Allen (1983) studies a class of economies where REE prices partially reveal information. However, each agent, observing the equilibrium price and his own private signal, has full information at the equilibrium. Ausubel (1990) is closer to our result. However, we consider a more general state space, without the specific structure which plays an important role in his construction (in Ausubel, the state space is $\{H,L\}\times[0,1]$).

More recently, several paper have studied the existence of partially revealing (or nonrevealing) equilibria in sequential economies where assets are nominal (Polemarchakis and Siconolfi (1993) and Rohi (1995)) or where sunspots matter (Dutta and Morris (1997) and Pietra and Siconolfi (1997)). In all these papers, the set of states of private information has finite cardinality. The existence of nonrevealing REE rests crucially on the indeterminacy of equilibria induced by the existence of an incomplete set of nominal assets or by the endogeneity of the probability law on the extrinsic events. Strictly related is also the literature on *noisy* REE: See, for instance, Grossman (1977), Grossman and Stiglitz (1980) and, more recently, DeMarzo and Skiadas (1996).

2. The Model

We consider an economy with two types of agents: *informed* and *uninformed*. There is a continuum (say, the interval [0,1]) of identical agents of each type. A generic informed agent is denoted by a subscript i, a generic uninformed agent by a subscript n. The behavior of agents of type h, h = i, n, is identical a.e. on the set [0,1]. Hence, to simplify notation, we will use the subscript h to denote both the behavior of a single agent of type h and the average behavior of agents of type h and we will omit the integration over the agents of type h. Clearly, all the statements concerning agents' behavior should be interpreted as true a.e. on the set [0,1], even if not explicitly stated.

Let $(S,\mathcal{F},\mu)$ be the probability space, where S is a compact manifold without boundary, without loss of generality, the sphere of dimension J. $\mathcal{F}$ is the Borel σ-field of subsets of S, μ the Lebesgue measure on the space $(S,\mathcal{F})$. A particular element of S is $s \equiv (s_0,\dots,s_J)$. For each j, $(S_j,\mathcal{F}_j)$ is a Borel space, where $\mathcal{F}_j$ is the Borel set and μ_j the Lebesgue measure on $(S_j,\mathcal{F}_j)$. Given the collection μ_j, μ is the product measure on $(\prod_{j=0}^{J} S_j, \mathscr{F}_0 \otimes \ldots \otimes \mathscr{F}_J) \equiv (S, \mathscr{F})$. We will also use the notation $s \equiv (s(1), s(2)) \equiv ((s_0, \ldots, s_K), (s_{K+1}, \ldots, s_J)) \in S(1) \times S(2) \equiv \prod_{j=0}^{K} S_j \times \prod_{j=K+1}^{J} S_j$ where both $(S(1), \mathscr{F}(1), \mu(1))$ and $(S(2), \mathscr{F}(2), \mu(2))$ are Borel spaces while $\mu(1)$ and $\mu(2)$ are the product measures on $(S(1), \mathscr{F}(1), \mu(1))$ and $(S(2), \mathscr{F}(2), \mu(2))$ induced by the collection μ_j.

For each s, there are (C+1) commodities, indexed by c = 0, ..., C. Agent h's consumption vector is $x_h(s) \equiv (x_h^0(s), \ldots, x_h^C(s))$. Excess demand is $z_h(s)$. Throughout the analysis, endowments (e_i, e_u) are fixed and known with certainty by all the agents.

For each s, prices are denoted by $p(s) \equiv (p^0, \ldots, p^C) \in \mathbb{R}^{C+1}_{++}$. The set of prices is $\mathbf{P} \equiv \{ p \in \mathbb{R}^{C+1}_{++} \mid p^0 \equiv 1 \}$.

For each h, preferences are described by a utility function $U_h(x_h; s)$, $U_h: \mathbb{R}^{C+1}_{++} \times S \to \mathbb{R}$. We assume that $U_h \in C^3$ on $\mathbb{R}^{C+1}_{++} \times S$ (i.e., U_h is thrice continuously differentiable in both the consumption vector and the realization s). Moreover, for each $s \in S$, U_h is strictly monotone and differentiably strictly concave in x_h and satisfies the usual boundary conditions: the set $\{x_h \in \mathbb{R}^{C+1}_{++} \mid U_h(x_h; s) \geq U_h(x_h^*; s)\}$ is closed in $\mathbb{R}^{C+1}_{++}$ for each $x_h^* >> 0$.

Let **U** be the space of the economies given by a utility profile for each type of agent, and endow **U** with the C^3 compact-open topology, turning it into a metric space.

Before trade takes place, informed agents receive a *private signal* $s \in S$, i.e., they know the actual realization of the economy. Uninformed agents don't receive any private signal, but they observe market prices and the volume of trade and they can use these *market signals* to update their ex-ante probability measure on the set S.

Define $V(p,s) \equiv \sum_h \max \{z_h(p,s), 0\}$ the volume of trade, a vector in $\mathbb{R}^{C+1}_{+}$.

A REE is a measurable function $(P,V):(S,\mathcal{F}) \to ((\mathbf{P}\times\mathbb{R}_{+}^{C+1}), (\Im(\mathbf{P})\otimes\Im(\mathbb{R}_{+}^{C+1}))$ where $\Im(\mathbf{P})$ and $\Im(\mathbb{R}_{+}^{C+1})$ are the Borel σ-field on **P** and $\mathbb{R}_{+}^{C+1}$, respectively. The function (P,V)(.) induces a sub-σ-field $\mathcal{F}_{p,V}$ of $\mathcal{F}$: Hence, for agent n, to observe a particular ralization of the map (P,V)(.) is equivalent to know that the true state of the world lies in a particular element of $\mathcal{F}$.

We use a further (strong) assumption:

Assumption S: There is a subcollection s(1) of (C+1)(C+2) = K signals (without loss of generality the first ones) such that, for each h and each $(x_h,s) \in D\times S$, with $D = \{ x_h \in \mathbb{R}_{++}^{C+1} \mid x_i \leq 2(e_i+e_u) \}$, the (K×K)-dimensional matrix $[D^2_{x,s(1)} U_h(x_h,s)^T, D^3_{xxs(1)} U_h(x_h;s)]$ has full rank K.

Assumption **S** is clearly satisfied by an open set of economies.

In the proofs of several results, we exploit locally linear perturbations of the utility function, constructed as follows: For each h, let B_h^1 and B_h^2 be open (possibly empty) sets such that $clB_h^k \subset \mathbb{R}_{++}^{C+1}$, for k = 1, 2. Also, assume that, given B_h^k, for k = 1, 2, there is an open set $B_h^{\varepsilon k}$ which satisfies $clB_h^k \subset B_h^{\varepsilon k} \subset clB_h^{\varepsilon k} \subset \mathbb{R}_{++}^{\ell}$ and $clB_h^{\varepsilon 1} \cap clB_h^{\varepsilon 2} = \varnothing$. Given $U \in \mathbf{U}$, sets B_h^k and $B_h^{\varepsilon k}$, for k = 1, 2, and vectors $\delta_h^1 \in \mathbb{R}^{C+1}$ and $\delta_h^2 \in \mathbb{R}^{C+1}$, define U^δ the economy where, for each h, U_h^δ is obtained by replacing U_h with the function

$$U_h^\delta(x_h;s) \equiv U_h(x_h;s) + \Theta^1(x_h,B_h^{\varepsilon 1})(\delta_h^1 x_h) + \Theta^2(x_h,B_h^{\varepsilon 2})(\delta_h^2 x_h),$$

where, for each k, $\Theta^k(x_h,B_h^{\varepsilon k})$ is a smooth "bump" functions, $\Theta^k: \mathbb{R}_{++}^{C+1} \to [0, 1]$, which takes the value 1 if

$x_h \in B_h^k$ and the value 0 if $x_h \notin clB_h^{\epsilon k}$. Evidently, if $U_h \in \mathbf{U}^*$, $U_h^\delta \in \mathbf{U}^*$ for δ_h^1 and δ_h^2 small enough. This parameterization allows us to use independent perturbations of the utility function on the disjoint sets B_h^k, for k = 1, 2. The precise nature of the set B_h^k considered would depend upon the issue considered. In some istances, $B_h^k \subset \mathbb{R}_{++}^{C+1}$ (i.e., we perturb in the consumption space), in others $B_h^k \subset S$.

2.1 Individual behavior and equilibrium

If $(P,V):(S,\mathcal{F}) \dashrightarrow \mathbf{P}\times\mathbb{R}_+^{C+1}$ is the price-volume map, let (p,v) to denote a particular realization of the map. Also, let $F:\mathbf{E} \subset \mathbf{P}\times\mathbb{R}_+^{C+1} \dashrightarrow (S,\mathcal{F})$ be the measurable map which associates with each realization (p,v) a measurable subset of S.

Given s and (p,v), agent i chooses a vector $z_i(p,s)$ solving the optimization problem

$$[i] \qquad \max U_i(e_i+z_i;s) \text{ subject to } \quad pz_i(s) = 0.$$

Given the map F(.) and the *observable* vector $(p,v) \in \mathbf{P}\times\mathbb{R}_+^{C+1}$, agent n chooses a vector $z_n(p,v)$ solving the optimization problem

$$[n] \qquad \max E(U_n(e_n+z_n;s) \mid s \in F(p,v)) \qquad \text{subject to} \qquad pz_n = 0.$$

Definition 1: A rational expectations equilibrium (REE) is a function $(P,V):(S,\mathcal{F}) \dashrightarrow \mathbf{P}\times\mathbb{R}_+^{C+1}$ and a correspondence $F: (P,V)(S) \dashrightarrow (S, \mathcal{F})$, $F(p,v) \equiv (P, V)^{-1}(p,v)$, such that:

i. a.e., $z_i(p,s)$ is the optimal solution to [i], given (p,v);

ii. a.e., $z_n(p,v)$ is the optimal solution to [u] given (p,v) and F(.);

iii. a.e., $V(p,s) = \max \{0,z_i(p,v,s)\} + \max \{0,z_n(p,v)\}$;

iv. a.e., $z_i(p,s) + z_n(p,v) = 0$,

Bear in mind that all the conditions above must hold a.e. on the set S (of course, i and ii also hold a.e. on the set [0,1] of agents of each type). Also, notice that, generically, each state of private information is associated with a unique (p,v), so that each realization (p,v) unambiguously identifies the set of possible states of private information.

We associate with each economy U with asymmetric information a *full communication economy* (FCE) U, the economy with the same fundamentals and where both types of agents know the actual value of the realization s (as in Radner (1979)).

Definition 2: A REE is *fully revealing* (for short, is a FRE) if, a.e. $P(s) = \Pi(s)$, where $\Pi(s)$ is an equilibrium of the associated FCE at state s. A REE is *partially revealing* (for short, is a PRE) otherwise.

In Definition 2 an equilibrium is a FRE if its allocation is an equilibrium allocation of the associated FCE. Evidently, at a FRE, a given realization (p,v) can be associated with more than a single realization s. However, given (p,v), the optimal behavior of each agent is identical at s and s'.

3. The auxiliary economy

The canonical argument for the existence of REE is not constructive. It considers a fictitious economy where agents are endowed with an arbitrarily given information structure and behave "naively", i.e., they do not extract information from the knowledge of the equilibrium price function. Usually, this fictitious economy is a Walrasian economy whose equilibria exist under standard assumption. The equilibrium price function of the fictitious economy, P(.), induces an information structure. If P(.), together with the information structure of the original economy, induces, for all the agents, the arbitrarily given information structure of the fictitious economy, then the map P(.) is a REE equilibrium of the original economy.

This argument requires to guess the informational content of a REE and then to assign it exogenously in the fictitious economy. Walrasian equilibria are the obvious candidate when dealing with fully revealing REE. However, in the case of "higher dimensional" information and partial revelation, it is typically impossible to guess what the informational content of the "market signals" will be at a partial revealing equilibrium. Hence, we are forced to follow a constructive approach.

Consider our original economy. Suppose that agent n exploits the observation of the price and volume realizations, but not of the price-volume equilibrium function. In other words, having observed a realization (p,v), agent n reconstructs the set of states that could have generated v at prices p, i.e., he considers as possible only the states which, given p and i's utility function, are compatible with $|z_i(.)| = v$. For each (p,v), this is a closed and, therefore, measurable subset of S. This procedure is well-defined even out of equilibrium. Moreover, the set of states it generates adjusts continuously to changes in prices. Exploiting this construction, we can compute an equilibrium for each realization of s using a fixed point argument. Hence, we can generate, modulo the choice of a selection, a *naive equilibrium function* (P,V)(.). We call (P,V)(.) *naive*, since individuals do not extract information from the equilibrium map, but only from its realizations. Is (P,V)(.) a REE? Unfortunately, the answer is, in general, negative: (P,V)(.) is, by construction, typically, a function but there are (open sets of) distinct realizations (p,v) and (p',v') such that $(P,V)^{-1}(p,v) \cap (P,V)^{-1}(p',v') \neq \emptyset$. Equivalently, there are (open sets of) states s and s' such that $(P,V)(s) \neq (P,V)(s')$, but $s \in (P,V)^{-1}(p',v')$. Obviously, when the uninformed agent observes (P,V)(s'), he should rule out the possibility that state s realized (since $(P,V)(s) \neq (P,V)(s')$) and, hence, should not condition his expectations on the set $(P,V)^{-1}(p,v)$, but on a proper subset.

Suppose now that the naive equilibrium function (P,V)(.) enjoys the additional property that, typically in S, $(P,V)(s) = (p,v) \neq (p',v') = (P,V)(s')$ implies $(P,V)^{-1}(p,v) \cap (P,V)^{-1}(p',v') = \emptyset$. Then, (P,V)(.) is a REE. Hence, our problem is to construct a *naive equilibrium* map whose inverse images do not intersect (or they intersect on a negligible subset of S). The original economy can not be used for such a task. To solve the problem, we introduce a fictitious economy which we call *auxiliary*.

In the auxiliary economy, uninformed individuals observe, together with the price, the informed trader's excess demand realization and some additional information. We will show that, typically, at a *naive equilibrium*, excess demand and volume functions induce the same sigma algebra on a full Lebesgue measure subset of S or that, equivalently, volume and excess demand are, typically, informationally equivalent. Still, we have to explain why we switch from volume to excess demand. As already argued, the main obstacle in constructing a REE from a naive equilibrium function (P,V)(.) is that the naive equilibrium function may self-intersect. In general, also the naive equilibrium function, $(P,Z_i)(.)$, constructed by letting the uninformed individual observe the i's excess demand realization, self-intersects. However, the Z-REE (REE of the economies where individuals observe excess demand realizations in addition to prices) enjoy the following property: Let $(P,Z_i,L)(.)$ be the L-REE function of an economy where individuals in addition to the realization (p,z_i) observe the realization of some additional variable ℓ and, as in any REE, exploit the knowledge of the function $(P,Z_i,L)(.)$ to refine their private information. Then, the same equilibrium function $(P,Z_i)(.)$ defines (as shown in Lemma 1) a Z-REE of an economy where only (p,z_i) is observed. Evidently, this implies the well known result of existence of fully revealing Z-REE, $(P,Z_i)(.)$. However, for an appropriate choice of the map $L(.)$, it allows us to construct naive equilibria which do not self-intersect and that do not convey full information, i.e., partially revealing L-REE.

To summarize, the essence of our argument is to exploit three key facts:

i. naive equilibrium functions which do not self-intersect are L-REE functions;

ii. any L-REE function $(P,Z_i,L)(.)$ induces a Z-REE function $(P,Z_i)(.)$;

iii. volume and excess demand are, typically, informationally equivalent. Hence, a Z-REE is a REE of the actual economy.

Before, defining in details the auxiliary economy, we prove formally fact ii.

Let $(P,Z_i,L)(.)$ be an L-REE function, where $P(.)$ and $Z_i(.)$ associate with each realization of s a price and an informed trader's excess demand vector, while $L(.)$ is any additional variable dependent on the realizations of s (for instance, some coordinates of the state realization). Given $s^* \in S$ and $(P,Z_i,L)(s^*) = (p^*,z_i^*,\ell^*)$, let

[n1] $z_n((P,Z_i,L),s^*) = \text{argmax } E(U_n(e_n+z_n;s) | \, s \in (P,Z_i,L)^{-1}(p^*,z_i^*,\ell^*))$ subject to $p^*z_n = 0$.

Also, for $s^* \in S$ and $(P,Z_i)(s^*) = (p^*,z_i^*)$, let

[n2] $z_n((P,Z_i),s^*) = \text{argmax } E(U_n(e_n+z_n;s)|\ s \in (P,Z_i)^{-1}(p^*,z_i^*))$ subject to $p^*z_n = 0$.

Observe that the set $(P,Z_i,L)^{-1}(p^*,z_i^*,\ell^*)$ will, in general, be smaller than the set $(P,Z_i)^{-1}(p^*,z_i^*)$.

Lemma 1: Let $(P,Z_i,L)(.)$ be an L-REE. For each $(p^*,z_i^*) \in (P,Z_i)(S)$, let

$$F(p^*,z_i^*) \equiv \cup_\ell \{\ s \in S \mid s \in (P,Z_i,L)^{-1}(p^*,z_i^*,\ell)\ \}.$$

Then, $z_n((P,Z_i,L),s^*) = z_n((P,Z_i),s^*)$ for each $s^* \in S$ and $((P,Z_i),F(.))$ is a Z-REE.

Proof of Lemma 1: If for each $(p^*,z_i^*) \in (P,Z_i)(S)$ and $(p^*,z_i^*,\ell^*) \in (P,Z_i,L)(S)$, $(P,Z_i,L)^{-1}(p^*,z_i^*,\ell) = (P,Z_i)^{-1}(p^*,z_i^*)$ there is nothing to prove.

Hence, suppose that, for some (p^*,z_i^*,ℓ^*), $(P,Z_i,L)^{-1}(p^*,z_i^*,\ell^*) \subset (P,Z_i)^{-1}(p^*,z_i^*)$. Let s' and s'' $\in$ $(P,Z_i)^{-1}(p^*,z_i^*)$ be any pair of states satisfying $L(s') = \ell^1 \neq L(s'') = \ell^2$. Clearly, $(P,Z_i,L)^{-1}(p^*,z_i^*,\ell^1) \cup (P,Z_i,L)^{-1}(p^*,z_i^*,\ell^2) \subset (P,Z_i)^{-1}(p^*,z_i^*)$. Since $(P,Z_i,L)(.)$ is an L-REE and $(P,Z_i)(s') = (P,Z_i)(s'') = (p^*,z_i^*)$, we have $z_n((P,Z_i,L),s') = z_n((P,Z_i,L),s'') = -z_n$. Therefore, since age0et n is an expected utility maximizer and $(P,Z_i,L)^{-1}(p^*,z_i^*,\ell^1) \cap (P,Z_i,L)^{-1}(p^*,z_i^*,\ell^2) = \emptyset$, the solutions to the programming problems [n1] and [n2] above coincide. ■

Evidently, this step depends heavily on the two types of agents assumption.

We now establish the existence of L-REE for the auxiliary economy. Our starting point are the naive equilibria. As explained above, in a naive equilibrium of the auxiliary economy, uninformed traders ignore the equilibrium functions. We specify the map L(.) defining the auxiliary economy as follows: Uninformed agents update their information after observing the price, p, the excess demand function of the informed trader, his Lagrange multiplier λ_i (in fact, which is equivalent, the gradient of his utility function, $D_x U_i(e_i+z_i;s)$) and his Hessian matrix, $D_x^2 U_i(e_i+z_i;s)$. Hence, with reference to the previous section, the map L(.) coincides with $(D_x U_i(e_i+z_i(p^*,s^*);s^*), D_x^2 U_i(e_i+z_i;s))$.

Consider a fixed signal s^* and let $z_i^* = z_i(p^*,s^*)$ be the optimal solution to problem [i] at prices p^*. Define

$$\Delta_i^*(p^*,s^*) = (D_x U_i(e_i+z_i(p^*,s^*);s^*), D_x^2 U_i(e_i+z_i(p^*,s^*);s^*))$$

and

$$H(p^*,s^*) \equiv \{ s \in S \mid ((D_x U_i(e_i+z_i(p^*,s);s), D_x^2 U_i(e_i+z_i(p^*,s);s)) = \Delta_i^*(p^*,s^*) \}.$$

Given assumption S, $H(p^*,s^*)$ is a smooth, connected manifold of dimension (S-(C+1)(C+2)). By construction, $z_i(p^*,s)$ is s-invariant on the set $H(p^*,s^*)$. $D_p z_i(.)$ is also s-invariant because

$$D_p z_i(.) = -\begin{bmatrix} D_x^2 U_i & -p \\ -p^T & 0 \end{bmatrix}^{-1} \begin{bmatrix} -diag(\lambda_i) \\ -z_i^T \end{bmatrix}$$

In the auxiliary economy, the uninformed trader solve [n"] $z_n(p^*,s^*) = \text{argmax } E(U_n(e_n+z_n;s)|\ s \in H(p^*,s^*))$ subject to $p^*z_n = 0$.

Evidently, given s^*, $z_n(p,s^*)$, $z_i(p,s^*)$ and $\Delta_i(p,s^*)$ are continuous functions of p. Hence, a standard fixed point argument suffices to establish the existence of a *naive equilibrium* price vector p(s), for each s^*. For given s, let $\zeta''(p,s,U) = z_i(p,s,U_i)+z_n(p,\Delta_i,U_n)$. Also, let $\zeta(p,s,U)$ be the aggregate excess demand function for all commodities but commodity 0 and let $\zeta_U(p,s)$ be $\zeta(p,s,U)$ for given U.

To summarize,

Lemma 2: Under the maintained assumption, for each $s \in S$, there is a *naive equilibrium*, i.e. a p(s) such that $\zeta(p(s),s,U) = 0$.

At a naive equilibrium, $D_p\zeta(.)$ is s-invariant on the set H(.). Evidently, equilibria with non-zero determinant of $D_p\zeta(.)$ are locally isolated and continuous. We now show that equilibria associated with signal in a connected component of the set of regular economies do not self-intersect.

A preliminary result concerns the differentiability of the excess demand functions in the auxiliary economy.

Lemma 3: Under the maintained assumptions, for each s and each $p \in \mathbf{P}$,

I. $z_i(p,s,U_i)$ is a smooth function of (p,s) and continuous in U_i.

ii. rank $D_{s(1)}\ [\zeta_i(p,s,U_i), D^2_x\ U_i(e_i+z_i;s)] = (C+1)^2 + C$.

iii. $z_n(p,\Delta_i,U_n)$ is a smooth function of (p,Δ_i) and continuous in U_n.

Proof of Lemma 3: i. Straightforward.

ii. Let $\lambda_i(p,s,U_i)$ be the Lagrange multiplier of optimization problem associated with the optimal solution of problem [i]. $D_{s(1)}[z_i(p,s,U_i),\lambda_i(p,s,U_i),D^2_x U_i(e_i+z_i;s)] =$

$$\begin{bmatrix} \begin{bmatrix} D_x^2 U_i(.) & -p \\ -p^T & 0 \end{bmatrix}^{-1} & 0 \\ 0 & I_{(C+1)(C+1)} \end{bmatrix} \begin{bmatrix} \begin{bmatrix} D^2_{xs(1)} U_i(.) \\ 0 \end{bmatrix} \\ D^3_{xxs(1)} U_i(.) \end{bmatrix}$$

where $I_{(C+1)(C+1)}$ is the (C+1)(C+1)-dimensional identity matrix.

The matrix $D_{s(1)}[\zeta_i(p,s,U_i),D^2_x U_i(x_i;s)]$ is obtained from $D_{s(1)}[z_i(p,s,U_i),\lambda_i(p,s,U_i),D^2_x U_i(x_i;s)]$ deleting rows 1 and (C+2), i.e., deleting these columns from the left-hand matrix and these rows form the right-hand matrix. By assumption S, the right-hand matrix so obtained has full rank $(C+1)^2+C$. Hence, rank $D_{s(1)}[\zeta_i(p,s,U_i),D^2_x U_i(x_i;s)] = (C+1)(C+1)+\text{rank}A$, where A is the top left submatrix in the left-hand matrix. Evidently, rank A = C (A is obtained eliminating two columns from a square matrix of full rank (C+2)). Hence, rank $D_{s(1)}[\zeta_i(p,s,U_i),D^2_x U_i(x_i;s)] = (C+1)^2+C$.

iii. Consider optimization problem [n']. Without loss of generality, restrict the analysis to some compact set $X \subset \mathbb{R}^{C+1}_{++}$. Hence, the first order conditions of problem [n'] are necessary and sufficient for an optimal solution. Then, the result follows by a standard argument. ■

The next result is that naive equilibria are, geenricallregular equilibria.

Lemma 4: For $U \in$ U', an open and dense subset of **U**, there is an open, dense subset $S(U) \subset S$ (of full Lebesgue measure) such that, for each $s \in S(U)$, $|D_p\zeta(p,s)| \neq 0$ at each equilibrium p of the *naive economy*.

Proof of Lemma 4: It follows by a standard transversality argument applied to the auxiliary economy after setting $z_n(p,s,U_n) = \text{argmax } E(U_n(e_n+z_n;s)|\ s \in H(p,s))$.

Consider the map $\zeta(p,s,U')$. It is straightforward to check that

$$\det D_{\kappa,i}\zeta(.) \neq 0.$$

Hence, by the transversality theorem, there is an open dense set **U'** such that, for each $U \in$ **U'**, $\zeta_U(p,s) \pitchfork 0$. It follows that there is an set S(U) (with $\mu(S(U)) = 1$) such that $\zeta_{U,s}(p,s) \pitchfork 0$. Hence det $D_p\zeta(p,s,U) \neq 0$ at each naive equilibrium of $s \in S(U)$. ■

Consider $U \in$ **U'**. By Lemma 4 and a standard argument, we can pick a selection of the equilibrium map which is continuous on each connected component of S(U), $S^k(U)$. The crucial fact is that if two signals s'', s' are in the same connected component of the regular economies (and are associated with distinct price-excess demand pairs), then $H(p',s') \cap H(p'',s'') = \emptyset$.

Lemma 5: For each $U \in$ **U'**, if $s, s' \in S^k(U)$, for some k, and $(P_1(s'),\Delta_i(P_1(s'),s')) \neq (P_1(s),\Delta_i(P(s),s))$, then $H(P_1(s),s) \cap H(P_1(s'),s') = \emptyset$.

Proof of Lemma 5: Given a connected component, say $S^1(U)$, of regular economies, pick a continuous selection $P_1(s)$ of the equilibrium map. By definition of function, $H(P_1(s),s) \cap H(P_1(s'),s') = \emptyset$ on the set

$S^1(U)$.

Assume, by contraddiction, that $H(P_1(s),s) \cap H(P_1(s'),s') = s''$ for some $s'' \notin S^1(U)$. Consider the two paths from s and s' to s'' defined by $H(P_1(s),s)$ and $H(P_1(s'),s')$. Let $C(U)$ be the set of critical economies. Notice that, by construction, at each point $s^c \in H(P_1(s),s) \cap C(U)$ (or $s^c \in H(P_1(s'),s') \cap C(U)$) at the equilibrium $P_1(s)$, $|D_p\zeta(P_1(s),s^c)| \neq 0$. Hence, the map $P_1(s)$ can be extended as a function to all the connected components $S^k(U)$ such that $S^k(U) \cap H(P_1(s),s) \neq \emptyset$ for some $s \in S^1(U)$■

The last two Lemmmat immeduiately imply the following.

Proposition 1: Under the maintained assumptions, there is an open and dense set of economies $\mathbf{U}^0$ such that, for each $U \in \mathbf{U}^0$ there is a Z-REE $((P,Z_i)(.),F(.))$.

Proof of Proposition 1: For each regular s and for each equilibrium selection $P_k(s)$, define the non-empty set $A_k(s) \equiv \{s'' \in S^k(U) \mid s'' \in H(P_k(s),s) \text{ or } s'' \notin H(P_k(s),s) \text{ and } H(P_k(s),s) \cap H(P_k(s''),s'') = \emptyset\}$.

Let $\mu_k(s) = \mu(A_k(s))$ and $\mu(A(s)) = \max_k \mu(A_k(s))$. For critical economies, set $\mu(A(s)) = 0$. Finally, let $s^* \in \arg\sup \mu(s)$. Evidently, $\mu(s^*) > 0$.

Finally, for $s \notin A(s^*)$, set $(P(s),Z(s))$ be the equilibrium realization in the full communication economy.

This is a Z-REE. In fact, if $s \notin A(s^*)$, then necessarily $(P(s),Z(s)) \neq (P(s'),Z(s'))$ for each $s' \in A(s^*)$. Otherwise, one would have $s \in H(P(s'),Z(s'))$ for some $s' \in A(s^*)$. ■

Remark: By repeating the construction (restricting the analysis to $s \notin A(s^*)$), we could enlarge the set of signals such that the associated equilibrium is (potentially) partially revealing. However, it does not seem to be possible to show that (generically) for a measure 1 set of signals the equilibrium is partially revealing.

3.1 Existence of a REE of the Original Economy

We now show that generically, at an equilibrium, the map $(P,Z_i)(s)$ is informationally equivalent to the map $(P,|Z_i|)(s) \equiv (P,V)(s)$.

We establish the result for all the equilibria. A fortiori, it holds fore signals in the set $A(s^*)$. Let s and s' be two distinct state whose equilibria satisfy $(P,Z_i)(s) \neq (P,Z_i)(s')$ while $(P,V)(s) = (P,V)(s')$. By definition of the map V(.), given two arbitrary excess demand vectors z_i and z_i', $z_i \neq z_i'$ and $V = V'$ if and only if $|z_i| = |z_i'|$. Since we are going to use the transversality theorem, this last expression is not suitable for differential analysis. Let C be the set of commodity indexes and C(C) the set of nonempty subsets of C which always contains c = 0. Since C(C) is finite, we denote by C(k), k = 1, ..., #C(C), one of its elements. Then, $z_i \neq z_i'$ and $V = V'$ if and only if the there exists k such that the following system of equations has a solution

$$z_i^c = z_i^{c\prime}\ , \text{ for } c \in C(k),\ \ z_i^c + z_i^{c\prime} = 0 \text{ for } c \in C\backslash C(k).$$

Denote this system by $Q(z_i,z_i',k)$, k = 1,...,#C(C) and observe that $D_z Q = I$ for each K.

Define a realization of the equilibrium map $(P,Z_i)(s)$ *confounding* if there is another s' such that $(P,Z_i)(s) \neq (P,Z_i)(s')$, while $(P,V)(s) = (P,V)(s')$.

Let

$$B(U) \equiv \{ (p,\zeta_i) \in \mathbb{R}^{2C} \mid (p,\zeta_i) = (p,z_i^1(p,s),\ldots,z_i^C(p,s)) \text{ for some } s \in A(U) \}.$$

Under the maintained assumptions, since p is not required to be an equilibrium price, B(U) is an open set, hence a smooth manifold. Moreover the correspondence $F(p,z_i)$ (or, equivalently the correspondence $F(p,\zeta_i)$, is well-defined on this set.

Define now as $\zeta_n(p,\zeta_i,U_n)$ the map given by the last C coordinates of $z_n(p, F(p,\zeta_i),\Sigma,U_n)$.

Let M = (m,m') be a pair of disjoint and closed (relative to B(U)) balls contained in B(U) with rational radius and rational center. Let $\mathbf{M}$ be the countable collections of pairs (m,m').

Proposition 2: Under the maintained assumptions, there is a residual set of economies, $\mathbf{U}^1 \subset \mathbf{U}$, such that, for each $U \in \mathbf{U}^1$, there is an open, dense set of full Lebesgue measure, S'(U), such that, for each pair s, s' ∈ S'(U) such that $(P,Z_i)(s) \neq (P,Z_i)(s')$, $(P,V)(s) \neq (P,V)(s')$.

Proof of Proposition 2: Pick $(m,m') = M \in \mathbf{M}$. For k = 1,...,#C(C), define the maps

$$\Psi^k(p,p',\zeta_i,\zeta_i',U) = (\zeta_n(p,\zeta_i,U_n)+\zeta_i,\ \zeta_n(p',\zeta_i',U_n)+\zeta_i',\ p-p',\ Q(\zeta_i,\zeta_i',k)),$$

$$\Psi^k: M\times\mathbf{U}^0 \dashrightarrow \mathbb{R}^{4C}.$$

Evidently, if (p,ζ_i) is a realization of a Z-REE at some s, then $\zeta_n(p,\zeta_i,U_n)+\zeta_i = 0$. Moreover, if $\Psi^k(p,p',\zeta,\zeta',U_n) = 0$, for some k, then (p,ζ_i) is confounding.

We are going to show that, given M, for each U in a generic subset of $\mathbf{U}^0$, $\mathbf{U(M)}$, B(U) contains at most a countable number of *confounding* equilibria (p,ζ_i). This follows by a standard transversality argument. We will conclude the proof by iterating the argument on the countable collection of pairs M and taking intersections of $\mathbf{U(M)}$.

By definition of the two sets m and m', if $\Psi(p,p',\zeta_i,\zeta_i,U_n) = 0$, we can *independently* perturb n's utility function on two disjoint neighborhoods $B(-\zeta_i+e_n)$ and $B(-\zeta_i+e_n)$ proceeding as follows.

Consider a vector $(p,p',\zeta_i,\zeta'_i,U_n)$ such that $\Psi(p,p',\zeta_i,\zeta_i,U_n) = 0$. Then,

$$D_{(p,\zeta,\delta,\delta')}\Psi^k(.) = \begin{bmatrix} D_p\zeta_n(.) & D_\zeta\zeta_n(.) & D_{\zeta'}\zeta_n(.) & 0 \\ 0 & 0 & 0 & D_\delta\zeta_n(.) \\ I & 0 & 0 & 0 \\ 0 & I & 0 & 0 \end{bmatrix}$$

where I is the C-dimensional identity matrix..

Since rank $D_\delta\zeta_n(.) = C$, at each $(p,p',\zeta_i,\zeta_i,U_n)$ such that $\Psi(p,p',\zeta_i,\zeta'_i,U_n) = 0$, rank $D_{(p,\zeta,\delta,\delta')}\Psi^k(.) = 4C$, for all K. Hence, $\Psi^k \pitchfork 0$. Therefore, there are open and dense subset $\mathbf{U(M,k)} \subset \mathbf{U}^0$ such that $\Psi^k_U \pitchfork 0$. Select $U \in \mathbf{U(M)} \equiv \cap_k \mathbf{U(M,k)}$, an open and dense subset of $\mathbf{U}$.

Since $\Psi^k : M \subset \mathbb{R}^{4C} \to \mathbb{R}^{4C}$ and $U \in \mathbf{U(M)}$, $(\ldots,\Psi^{k}{}_U^{-1}(0),\ldots)$ is (at most) countable, given, say, by a collection (p_j,ζ_j), j = 1, 2, ... Let $S(M,U) = \cup_j H(p_j,\zeta_j)$. Since $\mu(H(p_j,\zeta_j)) = 0$ for each j and since the collection is countable, $\mu(S(M,U)) = 0$.

Repeat the procedure for each $M(t) \in \mathrm{M}$, t = 1, 2, ... and define the sets $\mathbf{U(M(t))}$ and S(M(t),U) in the obvious way. Then, let $\mathbf{U}^1 \equiv \cap_t \mathbf{U(M(t))}$ and $S'(U) \equiv S \setminus (\cup_t S(M(t),U))$. Given that the collection M is countable, $\mathbf{U}^1$ is a residual set while, for $U \in \mathbf{U}^1$, S'(U) is open, dense and of full Lebesgue measure.

Consider an economy $U \in \mathbf{U}^1$ and the associated set S'(U). By construction, for each pair s and s' $\in$ $S^*(U)$, if $(P,Z_i)(s) \neq (P,Z_i)(s')$, then $(P,V)(s) \neq (P,V)(s')$, i.e. the set $(P,Z_i)(S'(U))$ does not contain any *confounding* realization of the equilibrium. ■

To complete the construction, we need to show that Z is informationally equivalent to V for the equilibria of the full communication economy and that, generically, no confusion may arise among equilibria associated with signals in the set $A(s^*)$ and in $S \setminus A(s^*)$ (i.e., to signals with associated partially revealing equilibrium price versus signals with associated fully revealing equilibrium).

Moreover, we need to show that the equilibria associated with s in A(U) are not (tipically) fully revealing.

First, we establish the well-known fact that this class of economies always has a FRE.

Theorem 1: Under the maintained assumptions, there is a residual set of economies $\mathbf{U}^2 \subset \mathbf{U}$ such that, for each $U \in \mathbf{U}^2$, there is a FRE. Moreover, the FRE map $((\Pi,V)(.), F(.))$ is continuous at each $s \in S(U)$, an open and dense subset of S of full Lebesgue measure.

Proof of Theorem 1: Consider an economy U and the associated FCE. Under the maintained assumptions, the FCE has an equilibrium correspondence, say $\psi(.)$, defined on the set S. In the FCE, all the excess demand functions depend just on (p,s). Hence, we will use the natural notation.

First, observe that, by a standard argument, there is an open, dense set of economies, $\mathbf{U}^* \subset \mathbf{U}$, such that, for each $U \in \mathbf{U}^*$, there is an open, dense subset of S, of full Lebesgue measure $S^*(U)$ such that the equilibrium price correspondence of the FCE, $\psi(.)$, is continuous and has a finite number of elements for each $s \in S^*(U)$, i.e., locally, $\psi(.) = \Pi_1(.) \cup \ldots \cup \Pi_K(.)$.

The issue is: Can we support a continuous selection of $\psi(.)$, that we denote with $\Pi(.)$, as a REE of the actual economy?

Let π be a value taken on by $\Pi(.)$ for some s.

Given $\Pi(.)$, define the correspondence $F(\pi,v) \equiv \{ s \in S^1(U) \mid s \in (\Pi,V)^{-1}(\pi,|z_i(\Pi(s),s)|) \}$, defined on the set $(\Pi(.),z_i(\Pi(.),.))(S^*)$. Let $V(.) = |z_i(\Pi(s),s)|$.

We need to show that $((\Pi,V)(.), F(.))$ is a FRE.

The argument is essentially analogous to the one we exploited in the proof of Proposition 2. Hence, we just outline how to modify that proof.

Given s^*, define the correspondences $H_i(\pi,\zeta_i) \equiv \{ s \in S^1(U) \mid \zeta_i(\pi,s) = \zeta_i(\pi,s^*) \}$ and $H_n(\pi,\zeta_n) \equiv \{ s \in S^1(U) \mid \zeta_n(\pi,s) = \zeta_n(\pi,s^*) \}$.

Let $H(\pi,\zeta_i) \equiv H_i(\pi,\zeta_i) \cap H_n(\pi,\zeta_n)$, so that both $\zeta_i(\pi,s)$ and $\zeta_n(\pi,s)$ are s-invariant on $H(\pi,\zeta_i)$.

As in Proposition 2, define the open set

$$B(U) \equiv \{ (\pi,\zeta_i) \in \mathbb{R}^{2C} \mid (\pi,\zeta_i) = (\pi,z_i^1(\pi,s),\ldots,z_i^C(\pi,s)) \text{ for some } s \in S^*(U) \}.$$

Evidently, $H(p,\zeta_i)$ is well-defined on $B(U)$. As above, let $M = (m,m')$ be a pair of disjoint and closed (relative to $B(U)$) balls contained in $B(U)$ with rational radius and rational center. Let $\mathcal{M}$ be the countable collections of pairs (m,m').

As in Proposition 2, pick $(m, m') = M \in \mathcal{M}$ and, for $k = 1,\ldots,\#C(C)$, define the maps

$$\Psi^k(p,p',\zeta_i,\zeta_i',U) = (\zeta_n(\pi,\zeta_i,U_n)+\zeta_i,\ \zeta_n(\pi',\zeta_i',U_n)+\zeta_i',\ \pi-\pi',\ Q(\zeta_i,\zeta_i',k)),$$

where Ψ^k:$M\times\mathbf{U}^* \text{-->} \mathbb{R}^{4C}$.

Evidently, if (π,ζ_i) is a realization of a FRE at some s, then $\zeta_n(\pi,\zeta_i,U_n)+\zeta_i = 0$. Moreover, if $\Psi^k(\pi,\pi',\zeta,\zeta_i',U_n) = 0$, for some k, then (p,ζ_i) is confounding.

The remaining of the proof is identical to the one of Proposition 2. ■

Remark: Given the relationship between FRE and equilibria of the FCE, self-intersections are not an issue here, because the starting point is the *function* $\Pi(.)$, an arbitrary (but - generically - continuous) selection out of the equilibrium price correspondence in the FCE.

We can now show that the Z-equilibria of Proposition 1 are actually REE.

Theorem 2: Under the maintained assumptions, there is a residual set of economies $\mathbf{U}^1 \subset \mathbf{U}$ such that, for each $U \in \mathbf{U}^1$, the Z-equilibrium of Proposition 1 is a REE. Moreover, the REE map ((P,V)(.), F(.)) is continuous at each $s \in S(U)$, an open and dense subset of S of full Lebesgue measure.

Proof of Theorem 2: It follows from the same argument of Proposition 1 and Theorem 1 after one defines the map $\Psi^k(p,p',\zeta_i,\zeta_i',U) = (\zeta_n(p,\zeta_i,U_n)+\zeta_i,\ \zeta_n(\pi,\zeta_i',U_n)+\zeta_i',\ p-\pi',\ Q(\zeta_i,\zeta_i',k))$ where the first map $\zeta_n(p,\zeta_i,U_n)+\zeta_i$ refers to the equilibria considered in Proposition 1 while $\zeta_n(\pi,\zeta_i',U_n)+\zeta_i'$ refers to the equilibria of the full comunication economy. ■

To conclude, we need to establish that the equilibria of Theorem 2 are (generically) PRE. The crucial difference between these equilibria and the ones of Theorem 1 is that in Theorem 1 the starting point is the set of states of information where the *equilibrium of the FCE is s-invariant*. In Theorem 2, instead, the set $H(p,\zeta_i)$ (hence, the set $F(p,v)$) is (a subset of) the set of states of private information such that, given p, the *informed agent's excess demand is s-invariant*. Except for economies in a null set, the two constructions lead to distinct equilibria (Theorem 3): Hence, generically, the equilibrium of Theorem 2 is a PRE, i.e., at least on some subset of S of positive measure, its equilibrium allocation does not coincide with any equilibrium allocation of the FCE.

Theorem 3: Under the maintained assumptions, there is a residual set of economies $\mathbf{U}^3 \subset \mathbf{U}^1 \cap \mathbf{U}^2$ such that, for each $U \in \mathbf{U}^3$, there is a PRE. Moreover, for each $U \subset \mathbf{U}^3$, the PRE map is continuous on an open, dense subset $S^3(U)$ of full Lebesgue measure.

Proof of Theorem 3: Let $\mathbf{U}' \equiv \mathbf{U}^1 \cap \mathbf{U}^2$. Remember that A(U) is the set of signals such that the equilibrium constructed in Proposition 1 and Theorem 2 is (potentially) non fully revealing.

Given $U \in \mathbf{U}^*$, pick an open ball B(U). Consider the FCE. Pick $s \in A(U)$ for each $U \in B(U)$ (this can be done for B(U) small enough) and consider $(\Pi,V)(s)$. Define the open balls $B'(s)$, $B^{\varepsilon\prime}(s)$, $B''(s)$, $B^{\varepsilon\prime\prime}(s)$, $B(x_n)$ and $B^{\varepsilon}(x_n)$ with the following properties:

a. $x_n(\Pi(s),s,U_n) \in B(x_n)$ for each $U \in B(U)$ and $s \in S^*(U)$. Moreover, $clB^{\varepsilon}(x_n) \subset \mathbb{R}^{C+1}_{++}$;

b. For each $U \in B(U)$, $B'(s) \cap F(\Pi(s),V(S)) \neq \emptyset$ and $B''(s) \cap F(\Pi(s),V(S)) \neq \emptyset$, $clB^{\varepsilon\prime}(s) \cap clB^{\varepsilon\prime\prime}(s) = \emptyset$.

Let $\Theta^{s'}(s,B'(s))$, $\Theta^{s''}(s,B''(s))$ and $\Theta^{x}(x_n,B(x_n))$ be smooth bump functions taking the value 1 if s s

$\in B(s)$, the value 0 if $s \notin B^{\varepsilon}(s)$. Bear in mind that one can take $\Theta^{s}(s,B^{\varepsilon}(s))$ to be a non-negative function (e.g., Hirsch [1976, p.17]).

Replace the utility function U_n with the function

$$U_n^{\delta}(e_n+z_n;s) = U_n(e_n+z_n;s) + \delta\Theta^{x}(x_n,B(x_n))[\Theta^{s'}(s,B'(s'))\textstyle\sum_{c>1}a_c^{'}x_n^c + \Theta^{s''}(s,B''(s''))\sum_{c>1}a_c^{''}x_n^c].$$

Clearly, given strictly positive (C+1)-dimensional vectors a' and a'' (and the "bump" functions), $(U_n^{\delta},U_i) \in \mathbf{U}^1 \cap \mathbf{U}^2$ for each δ small enough.

Define the map $\Psi:\mathbf{P}\times\mathbf{P}\times clB^{\varepsilon'}(s)\times clB^{\varepsilon''}(s)\times B(U) \dashrightarrow \mathbb{R}^{3C}$, defined by

$$\Psi(\pi,p,s,U) = (\zeta_n(\pi,s,U_n) + \zeta_i(\pi,s,U_i),\ \zeta_n(p,H(s),s,U_n) + \zeta_i(p,s,U_i),\ \pi - p).$$

Suppose that, at a zero of $\Psi(\pi,p,s,U)$, for some $s \in clB^{\varepsilon'}(s)$, $\zeta_n(\pi,s,U_n) = \zeta_n(p,H(s),s,U_n)$. The Jacobian of $\Psi(\pi,p,s,U)$ contains the submatrix

$$D_{(\pi,a',a'')}\Psi(\pi,p,s,U) = \begin{bmatrix} D_{\pi}\zeta(\pi,s,u) & D_{a'}\zeta(\pi,s,U) & 0 \\ 0 & D_{a'}\zeta(p,s,U) & D_{a''}\zeta(p,s,U) \\ -I & 0 & 0 \end{bmatrix}$$

It is straightforward to check that the matrices $D_{a'}\zeta(\pi,s,U)$ and $D_{a''}\zeta(\pi,s,U)$ have full rank C. Therefore, the submatrix above has full rank and $\Psi \pitchfork 0$. Hence, for some open and dense subset of B(U, B'(U)), $\Psi_U \pitchfork 0$. This in turn implies that, for $U \in B'(U)$ there is an open, dense set of full Lebesgue measure $S^3(U)$ such that $\Psi_{U,s} \pitchfork 0$. This implies $\Psi_{U,s}^{-1}(0) = \emptyset$. ■

4. On the "number" of FRE and PRE

The set of FRE exhibits indeterminacy of the set of equilibrium allocations whenever, at some $s \in S^1(U)$, the FCE has multiple equilibria. To compare the "number" of PRE and FRE abstracting from this trivial indeterminacy, in this last section we assume:

Assumption U: For each economy $U \in \mathbf{U}$ and each $s \in S$, there is a unique equilibrium of the FCE economy.

For this class of economies, typically, there is still a continuum of PRE, parameterized by a variable $\lambda \in (0,\eta)$ for some $\eta > 0$ (it will be evident that richer parameterizations would be possible). To be precise, we now show that, for each pair of equilibria $(P_\lambda,V_\lambda)(.)$ and $(P_{\lambda'},V_{\lambda'})(.)$ with $\lambda \neq \lambda'$, λ and λ' small enough, the two PRE allocations are different on some non-zero measure subset $S' \subset S$. Hence, that there is a nonzero dimensional family of distinct PRE which are continuous a.s..

Theorem 4: Assume that $C > 2$. Then, under the maintained assumptions, there is a residual subset of $\mathbf{U}$, $\mathbf{U}' \subset \mathbf{U}$, such that, for each $U \in \mathbf{U}'$, and for each $\lambda \in (0,1]$ there is a PRE, $(P_\lambda,V_\lambda)(.)$. Moreover, there is an open and dense subset of $(0,\eta] = \mathbf{O}$, such that, for each pair λ and $\lambda' \in \mathbf{O}$, with $\lambda \neq \lambda'$, $(P_\lambda,V_\lambda)(.) \neq (P_{\lambda'},V_{\lambda'})(.)$ on some open, dense subset $S'(U) \subset S(U)$ of full Lebesgue measure.

Proof of Theorem 4: In this proof (in repeating the construction of Theorem 2), we replace, for each (p,s), the set $H(p,s)$ with the set $H(p,s) \cap B_\lambda(s)$, where $B_\lambda(s)$ is the open ball of radius λ centered on s. Evidently, for λ small enough, $H(p,s) \neq H(p,s) \cap B_\lambda(s)$. Evidently, for each λ there is a PRE, say

$(P_\lambda,V_\lambda)(s)$.

Bear in mind that we have established that for all the economies in an open, dense set $\mathbf{U}^0$ there is a Z-REE defined on an open, dense set of full Lebesgue measure $S^0(U)$. For each economy in $\mathbf{U}^0$, the set $S^0(U)$ can be expressed as the union of a countable collection of disjoint, connected components. In the sequel we will outline the proof for a particular connected component of the set $S^0(U)$. Notice that, by construction, each component $S^0(U)$ is obtained as the union of a disjoint collection of manifolds of dimension [S-(C+1)(C+2)] and it can be easily parameterized by a (C+1)(C+2)-dimensional (connected) surface in S(U), say the surface K.

For each economy U, let L(p,s) be the Least Upper Bound of the radius of the sets $B_\varepsilon(s)$ such that $H(p,s) \subset B_\varepsilon(s)$. Evidently, for each (p,s), $L(p,s) > 0$. Set $\eta = \min_{(p,s)} L(p,s)/2$. Then, for each (p,s), $H(p,s) \neq B_\lambda(s) \cap H(p,s) \equiv H_\lambda(s)$ for each $\lambda \in [0,\eta]$. Also, the equilibrium associated with $\lambda = 0$ is clearly a FRE.

Consider the countable collection $\mathcal{L}$ of pairs of compact balls (Λ,Λ') of rational radius contained in $[0,\eta]$. Let λ be a typical element of Λ and λ' a typical element of Λ'. Define the map

$$\Xi(p,p',\lambda,\lambda',s,U) = (\zeta_n(p,H_\lambda(p,s)) + \zeta_i(p,s),\ \zeta_n(p',H_{\lambda'}(p',s)) + \zeta_i(p',s),\ p - p').$$

Evidently, if $\Xi(p,p',\lambda,\lambda',s,U) = 0$, then the equilibria associated with λ and λ' entail the same equilibrium allocation at state s. We now show that, typically in economy space, for a generic set of states $S(\Lambda,\Lambda')$, $\Xi^{-1}(0) = \varnothing$.

Without loss of generality, assume that $\lambda < \lambda'$ so that, at each p, $H_\lambda(p,s) \subset H_{\lambda'}(p,s)$ and $H_\lambda(p,s) \neq H_{\lambda'}(p,s)$.

Pick any pair of open sets with the following properties: B is the union of the collection of open balls of radius λ centered on each $s \in K$. Withou loss of generality, assume that, for some $\varepsilon > 0$, $clB^{\varepsilon} \subset S$. Let B' be any open ball such that, for each $s \in K$, $H_{\lambda}(P(s),s) \cap B' \neq 0$, $clB^{\varepsilon'} \subset S$ and $clB^{\varepsilon} \cap clB^{\varepsilon} = \varnothing$. Clearly, such a pair of sets exists. Hence, we can perturb U_n on the set B' without affecting $z_n(p,H_{\lambda}(p,s))$. Therefore, at each $(p,p',\lambda,\lambda',s,U)$ such that $\Xi(p,p',\lambda,\lambda',s,U) = 0$,

$$D_{(p,p',\delta^1_n,\delta^2_n)}\Xi(p,p',\lambda,\lambda',s,\delta^1_n,\delta^2_n) = \begin{bmatrix} D_p\zeta(.) & 0 & D_{\delta^1_n}\zeta(.) & 0 \\ 0 & D_{p'}\zeta'(.) & D_{\delta^1_n}\zeta'(.) & D_{\delta^2_n}\zeta'(.) \\ I & -I & 0 & 0 \end{bmatrix}$$

Hence, $\Xi(p,p',\lambda,\lambda',s,U) \pitchfork 0$. Therefore, there is an open, dense set **U(Λ,Λ')** such that, for each $U \in$ **U(Λ,Λ')**, $\Xi_U \pitchfork 0$. This means that, for each $U \in$ **U(Λ,Λ')**, there is an open, dense set of full Lebesgue measure $S(\Lambda,\Lambda')$ such that, for each $s \in S(\Lambda,\Lambda')$, $\Xi_{Us} \pitchfork 0$. Given that $\Xi_{Us}:\mathbb{R}^{2C+2}_{++} \dashrightarrow \mathbb{R}^{3C}_{++}$ and that $C > 2$, $\Xi^{-1}_{Us}(0) = \varnothing$.

By iterating the procedure for each $(\Lambda,\Lambda') \in \mathcal{L}$ and taking the intersection of the corresponding **U(Λ,Λ')** sets of economies, we establish the claim for the Z-REE. Then, the argument of Theorem 2 applies here. ■

5. An Example

Consider an economy with two agents, three commodities and three signals, s_1, s_2 and s_3, with $s_j \in (0,1)$, $j = 1, \ldots, 3$. To simplify as much as possible the computations, assume that both agents have quasi-linear preferences: $U_i(.) = (s_1+s_2)\ln x^0_i + (s_2+s_3)\ln x^1_i + x^2_i$ and $U_n(.) = s_1\ln x^0_n + s_3\ln x^1_n + x^2_n$. Also assume that $e_h = (1,1,1)$. While, of course, quasi-linear utility functions have very peculiar properties, we can not see any reason why they should have an essential effect on the results discussed here.

a. **FRE**

A straightforward computations shows that, in the FCE, the unique equilibrium is $P(s) = ((2s_1+s_2)/2, (s_2+2s_3)/2, 1)$. Agent i's equilibrium allocation is $z_i(s) = (s_2/(2s_1+s_2), s_2/(s_2+2s_3), -s_2)$. The FRE is given by the map $(P,|z_i|)(.)$. Indeed, given that $V^2(s) = s_2$, knowledge of the map $(P,V)(.)$ and observation of the realization (p,v) always allow agent n to infer the true realization s.

b. **PRE**

For expositional easiness, we will proceed by "conjecturing" an information structure (for agent n) which exhibits partial information and we will show that it is consistent with the information revealed by equilibrium prices and volume. We now exhibit a one-dimensional family of FRE (whose allocations differ on a generic set of states) obtained, essentially, using the trick exploited in Theorem 3.

Pick λ such that $0 < \lambda < 1$. We first construct REE restricting the analysis to the following two possible cases:

a. $s_1 > s_3$;

b. $s_1 < s_3$.

Evidently, the set S' of s satisfying one of the previous conditions is a generic subset of S.

Case a: Set $E(s_1) = s_1-\lambda(s_1-s_2)$. The restrictions described above then imply that $E(s_2) = s_2+ \lambda(s_1-s_2)$

and $E(s_3) = s_3-\lambda(s_1-s_2)$. Notice that $0 < E(s_j) < 1$ for each j. Given the map $E^a(.)$, the "candidate" equilibrium price-allocation functions are given by

$$P^a(.) = ((s_1+(s_1+s_2)-\lambda(s_1-s_2))/2, ((s_2+s_3)+s_3-\lambda(s_1-s_2)/2, 1)$$

$$z_i^a(.) = (((s_2+\lambda(s_1-s_2))/(s_1+(s_1+s_2)-\lambda(s_1-s_2)), ((s_2+\lambda(s_1-s_2))/((s_2+s_3)+s_3+\lambda(s_1-s_2)),$$
$$(s_1+s_3-2\lambda(s_1-s_2)).$$

It is easy to check that $(P^a,|z_i^a|)(.)$ would be a REE if we would restrict s to the manifold $s_1 > s_3$. It is also easy to check that different values of λ induce different allocations.

Case b: Set $E(s_3) = s_3-\lambda(s_3-s_2)$. Then, $E(s_2) = s_2+\lambda(s_3-s_2)$ and $E(s_1) = s_1-\lambda(s_3-s_2)$. Given the map E(.), the "candidate" equilibrium price-allocation functions are given by

$$P^b(.) = (((s_1+(s_1+s_2)-\lambda(s_3-s_2))/2, ((s_2+s_3)+s_3-\lambda(s_3-s_2)/2, 1)$$

$$z_i^b(.) = ((s_2+\lambda(s_3-s_2))/(s_1+(s_1+s_2)-\lambda(s_3-s_2)), ((s_2+\lambda(s_3-s_2))/((s_2+s_3)+s_3+\lambda(s_3-s_2)),$$
$$(s_1+s_3-2\lambda(s_3-s_2)).$$

It is easy to check that $(P^b,|Z_i^b|)(.)$ would be a REE if we would restrict s to the manifold $s_1 < s_3$. It is also easy to check that different values of λ induce different allocations.

Consider now the entire space of states of private information. We first show that the map $(P,Z_i)(.)$ obtained "gluing" $(P^a,Z_i^a)(.)$ and $(P^b,Z_i^b)(.)$ is a Z-REE. Denote by s a typical element of the subset of S considered in case a and by s' a typical element of the subset of S considered in case b. We just need to show that there are no s, s' such that $(P^a,Z_i^a)(s) = (P^b,Z_i^b)(s')$. Bear in mind that observation of a realization (p,z_i) is equivalent to the observation of (s_1+s_2) and (s_2+s_3). Hence, if $(P^a,Z_i^a)(s) = (P^b,Z_i^b)(s')$, $(s_1+s_2) =$

$(s_1'+s_2')$ and $(s_2+s_3) = (s_2'+s_3')$. Moreover, inspection $(P^a,Z_i^a)(.)$ and $(P^b,Z_i^b)(.)$ and an obvious simplification implies that $(P^a,Z_i^a)(s) = (P^b,Z_i^b)(s')$ if and only if

i. $s_1-\lambda(s_1-s_2) = s_1'-\lambda(s_3'-s_2')$

ii. $s_3-\lambda(s_1-s_2) = s_3'-\lambda(s_3'-s_2)$

However, i and ii can never be simultaneously satisfied because subtracting ii from i, we obtain $(s_1-s_3) = (s_1'-s_3')$, while, by construction, $(s_1-s_3) > 0$ an d $(s_1'-s_3') < 0$. Hence, the map constructed above is a Z-REE. The same observation also establishes that the given map is a REE: If $(s_1+s_2) = (s_1'+s_2')$ and $(s_2+s_3) = (s_2'+s_3')$ and $p^0(s) = p^0(s')$, then $p^1(s') > p^1(s)$.

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