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Xiaokai Yang

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Monash University
Victoria 3800
Australia

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Xiaokai Yang

Department of Economics, Monash University
Email: xiaokai.yang@buseco.monash.edu.au

and

Shuntian Yao

School of Economics and Finance, Victoria University of Wellington, New Zealand
Email: shuntianyao@netscape.net

Abstract

In the paper, the concept of Walrasian sequential equilibrium is developed to formalize the notions of fundamental social and endogenous uncertainties and entrepreneurial discovery. It predicts that social sequential experiments with efficient as well as inefficient network patterns of division of labor can gradually acquire organization information for society as a whole. The experiment process is decentralized and based on individuals' bounded rationality. In this process, each individual never knows others' characteristics, although all players collectively learn abstract organization information carried by price signals gradually. This paper proves an existence theorem of equilibrium for a general class of well-closed Walrasian sequential equilibrium models and avoids the recursive paradox in the presence of individual bounded rationality.

JEL Classification: D11, D50, D51.

1. Introduction

The purpose of the paper is twofold. First, we shall develop a Walrasian sequential equilibrium model based on bounded rationality and adaptive dynamic decisions to describe a mechanism that can gradually acquire information of the efficient network pattern of division of labor via decentralized sequential social experiments. In this process, each individual knows only a very small part of information even if society as a whole gradually acquires all information. Second, we prove an existence theorem for a general class of Walrasian sequential equilibrium models which involve interactions between evolution in division of labor and evolution in organization information about the efficient network pattern of division of labor that is acquired by society through the price system. Let us motivate the two tasks one by one.

So far there is no consensus among economists about the definition of bounded rationality. Simon (1982b, 409) called the theories of bounded rationality "theories that incorporate constraints on the information-processing capacities of the actor." He proposed to introduce incomplete information, information processing cost, and some non-neoclassical objective functions of the actor into economic models. Most of the suggestions have been absorbed by the mainstream. For instance, the Savage research program of decision-making under incomplete information, the Wald research program of costly observation, the Radner research program of computation cost and spinning, and many other programs have absorbed most of Simon's suggestions (Radner, 1996) within the paradigm of constrained optimization and equilibrium. Here, constrained optimization allows a great variety of objective functions and complicated constraints. Also an equilibrium, as a consequence of direct or indirect interactions via the price system among self-interested decisions, does not necessarily mean market clearing or steady state. Some game equilibria may involve shortage (see Qian, 1994) and many dynamic equilibrium models can generate spontaneous evolution of endogenous variables. In game models of finite automata (Neyman, 1985, and Rubinstein, 1986) players are assumed to choose only fixed limited pure strategies because of calculation costs.

For many game economists, bounded rationality is much more than complicated constraints, incomplete information, and more variety of objective functions in the decision problem. Aumann (1997) reviews several types of game models of bounded rationality. Many models of evolutionarily stable strategy (Smith, 1982, Weibull, 1995, Fudernberg and Levine, 1998) can predict evolution of the numbers of players choosing various strategies toward their Nash equilibrium values in the absence of individuals' rationality. This research line echoes some economists who draw the distinction between social rationality and individual rationality. On the one hand, the game of prisoners' dilemma may generate a collectively irrational outcome based on individually rational strategies. On the other, seemingly socially rational outcome can be generated by evolutionary models via interactions between individuals in the absence of individual rationality. The evolutionally stable equilibrium generates some expectation of fair game rules, which relates to rule rationality, where individuals do not individual act rationality. Güth et al. (1982), Binmore et al. (1985), and Aumann (1997) consider rule rationality as a kind of bounded rationality. They provide experiment evidence which supports rule rationality, but not individual act rationality. Some game models of the trembling hand can predict dominance of crazy (irrational) strategies that occur with a small probability (Kreps, Milgrom, Roberts, and Wilson, 1982).[1]

However, many economists have forgotten that the Walrasian equilibrium model can be used to formalize the idea that prohibitively high calculation cost can generate socially rational outcomes based on individual bounded rationality. If we assume that in a Walrasian model with uncertainties, costs for a person to process complete or incomplete information about all other players' characteristics are prohibitively high, then individuals may just pay attention to prices and assume that it carries all the information of the rest of the world. Then, the Walrasian equilibrium prices will indeed carry all information of realized states of all players' characteristics and interactions among them, even if each individual does not know the set of states of other players' characteristics and their distribution functions.

In particular, the notion of general equilibrium can be used to formalize the feedback loops between prices, individuals' decisions, and their private information. Hence, society may exploit all private information when each individual knows only abstract price information and a very small part of all individuals' private information of their characteristics. The notion of Walrasian equilibrium is therefore a powerful vehicle to predict socially rational outcomes

[1] Recent reviews of research on bounded rationality in game theory can be found from Kalai (1990), Norman (1994),

based on individuals' bounded rationality. In the decentralized Walrasian mechanism, prices can transmit information that is essential for a player's decision-making to her, meanwhile keeping her away from others' private information of their characteristics, which she should not know from a viewpoint of avoiding unnecessary information processing costs.

Hurwicz, (1973) was one of the first economists to point out that the Walrasian mechanism needs the least information processing cost to achieve socially optimal outcome. Hence, social rationality can coexist with individuals' bounded rationality and a great deal of information asymmetry between individuals in a Walrasian equilibrium. Here, information asymmetry can be more than in any game models since each individual in a Walrasian model with uncertainties does not know states and their distribution functions of all other players' characteristics, while, for instance, in an entry deterrence game model, a player knows other players' production function and distribution function of a production parameter. As Aumann (1997, p. 8) points out, the entry deterrence game model and other models with incomplete information and refinement of the notion of Nash equilibrium involve super rationality rather than bounded rationality. Information asymmetry in them might be much less than in a Walrasian model with uncertainties where the equilibrium prices carry only aggregate information about realized states of all players' characteristics.

In this paper, we develop a Walrasian sequential equilibrium model with fundamental uncertainty, which is different from incomplete information or risk

Lipman (1995), Weibull (1995), Mailath (1998), Fudernberg and Levine (1998), and Rubinstein (1998). Reviews by

(Knight, 1921 and Georgescu-Roegen, 1971, p. 82, Shackle, 1961, p. 55, and Slater and Spencer, 2000, p. 77). Fundamental uncertainty has three characteristics. First, an individual may not know the set of states of others' characteristics or may not know distribution functions of the states even if she knows all contingent states. This is of course different from incomplete information which means that an individual knows all contingent states and distribution functions on the states. This type of uncertainty is called by post Keynesian economists "epistemic uncertainty" (Lawson, 1960, pp. 42-43). Second, fundamental uncertainty implies that uncertainty is endogenously generated by interactions among decisions rather than exogenously given (Slater and Spencer, 2000, p. 74). Hence, it is possible that fundamental uncertainties exist even if no uncertainty of individuals' characteristics exists. Third, such endogenous uncertainty is social uncertainty, which is different from uncertainty of individual players' characteristics, as noted by Minsky (1996, p. 360) and Slater and Spencer (2000, pp. 76, 78). Endogenous and social uncertainty is called by Keynes "aleatory uncertainty" (Keynes, 1973, p.113).

In our model of Walraisian sequential equilibrium, there is a continuum of ex ante identical consumer-producers who can choose one from many occupations. There are no uncertainties of each player's characteristics. However, there is a prohibitively high cost for each individual to collect all information of other players' characteristics and to figure out implications of all direct interactions among individuals' decisions. Hence, each individual relies on prices to get

non-game-theorists can be found from Conlisk (1996), Nelson (1995), and Kirzner (1997).

information about the implications of indirect interactions among individuals' decisions. There is a trade-off between economies of specialization and transaction cost for each consumer-producer's decision problem. The efficient trade-off is associated with a corner solution, which is dependent on prices, which are in turn dependent on all individuals' participation decisions in the network of division of labor. A static general equilibrium is one of many corner equilibria, of which each is a combination of compatible corner solutions of individuals. The static general equilibrium efficiently trades off positive network effects of the division of labor on aggregate productivity against total transaction costs in society as a whole.

Since values of decision variables are discontinuous between corner solutions and between corner equilibria, marginal analysis does not work for an individual choosing one from many corner solutions. An inframarginal analysis is needed, which is the total cost-benefit analysis across corner solutions in addition to marginal analysis of each corner solution. It is assumed that the Walrasian auctioneer calls only the prices of goods that are offered for sale or asked for purchase. Therefore, which set of prices can be seen depends on individuals' decisions in choosing their number of traded goods and occupations, while all individuals' choices of occupations generate a network pattern of division of labor that is dependent on the set of prices that can be seen. This interdependence between decisions and prices that can be seen from the market generates fundamental social and endogenous uncertainties. The uncertainties imply that individuals can only gradually acquire information on implications of indirect interactions among their decisions via evolutionary observable prices.

Bounded rationality in our model implies the following elements. First, it is assumed that information processing cost is prohibitively high for observing all other players' characteristics and for figuring out implications of direct interactions among all individuals' decisions. Hence, each individual makes her decision according to price signals via a sequential Walrasian pricing process.

Second, in period 0, each individual has no information about prices and other players' characteristics. She knows her characteristics and her local optimum utility in autarky. But she has a subjective distribution function for utility values that she may receive from a network pattern of division of labor. The expected value of utility of each network pattern of division of labor is the same as her utility in autarky in period 0. This implies that she has no more information in period 0 than she knows in autarky. We call this "lack of information" which is different from incomplete information. However, each person knows that if she offers some good for sale, the Walrasian auctioneer will call a price of this good and the price mechanism will operate to sort out local equilibrium prices in a structure trading this good. The local equilibrium prices will carry part of information about consequences of indirect interactions among individuals' decisions via the price mechanism.

We will prove that the static local (corner) equilibrium in each structure exists and it is locally Pareto optimal. Also, individuals have incentives to shift from a local equilibrium to a Pareto superior local equilibrium if price information in the two structures is available. We assume that there is a fixed cost for each person to start trading a good that has not been traded so far. This implies that there is no coordination difficulty for individuals choosing a locally Pareto superior local equilibrium from several local equilibria that have been tried over time as soon as the set of traded goods in these structures is determined by all individuals' choices of occupations and all prices of the traded goods in these structures are called by the auctioneer. Hence, if individuals try some network pattern of division of labor with trade in each period, they will not be worse off and will be better off with a positive probability. This means information gains from a social experiment with a network pattern of division of labor via the price mechanism. The fixed cost for trading a good that has so far not been traded generates a trade-off between information gains and experiment cost. Each person's dynamic programming problem that efficiently balances this trade-off can then generate a sequential social experiment path that gradually acquires organization information via the price system. The coordination difficulty may or may not occur for the sequential social experiments to search the static general equilibrium from many local equilibria, dependent on the experiment cost and discount rate.

Third, the bounded rationality in our model implies that the decision horizon is limited due to the calculation cost of a very complicated dynamic programming problem and due to fundamental endogenous and social uncertainties. Because of such social and endogenous uncertainties, each person may choose a very limited decision horizon and adaptively choose experiment path according to updated information generated by previous social experiments in each period.

A sequential decentralized Walrasian pricing mechanism will trade off gains from information acquisition against experimentation costs to determine the equilibrium pattern of experiments with patterns of division of labor over time. In the process, individuals use Bayes' rule and dynamic programming to adjust their beliefs and behavior according to updated information. Hence, we refer to the solution to the model as Walrasian sequential equilibrium. It is found that if the experiment cost and discount rate are sufficiently small, the social search process based on bounded rationality will find all organization information.

The paper is organized as follows. In section 2, the model is specified. Section 3 proves an existence theorem of static equilibrium, ignoring the cost of discovering prices that generates the interdependence between decisions and price information. In section 4, Walrasian sequential equilibrium is defined and the existence theorem for a general class of models is proved.

2. A Large Economy and Basic Assumptions

2.1. The Economy E

In this paper we consider a large economy $E = [I, M, f, g, u]$. Here I is a continuum set of mass 1 of ex ante identical consumer-producers who live for infinitely many periods. $L = \{L^i : i \in I\}$ is the set of labor endowments. We assume that each individual i is endowed with one unit of labor per period. $M = \{1, ..., m\}$ is the set of consumer goods. Each individual $i \in I$ can produce each good j in each period if she allocates some amount l^i_j of labor to the production of this good. $f = (f_1, ..., f_m)$ is a set of production functions for every individual, where $q^i_j = f_j(l^i_j)$ is the quantity of good j produced when amount l^i_j of labor is allocated for the production of good j by any individual i. $g = (g_1, ..., g_m)$ is a set of transaction functions with $g_j(y_j)$ being the quantity of good j any individual actually receives when she buys an amount y_j of good j from some other individuals. Here $g_j(y_j) \leq y_j$ is always assumed due to the transaction costs. Finally $u : \mathbf{R}^m{}_+ \rightarrow \mathbf{R}$ is the utility function for any individual. Furthermore, when we consider the dynamic decision-making process, the life-time total discounted utility of any individual, on the other hand, is calculated by

$$\sum_{t=1}^{\infty} \delta^{t-1} u(z^i(t)) \tag{1}$$

where $z^i(t)$ is the vector of goods she consumes at the end of period t, and $\delta \in (0,1)$ is a discount factor. Note that there is no exogenous uncertainty of physical environment. Later, we will show that all social uncertainties endogenously come from indirect interactions among decisions via the price mechanism.

2.2. Basic Assumptions

In the following discussions, we need some assumptions on the production functions, the transaction functions and the utility function.

Assumption 1. For every $j = 1,\ldots,m$, $f_j : \mathbf{R}_+ \to \mathbf{R}_+$ is continuous, non-decreasing and

weakly convex.

Assumption 2. For every $j = 1,\ldots,m$, $g_j : \mathbf{R}_+ \to \mathbf{R}_+$ is continuous, strictly increasing,

satisfying $g_j(0) = 0$, $g_j(y_j) \le y_j$, $\lim g_j(y_j) = \infty$ as $y_j \to \infty$.

Assumption 3. $u : \mathbf{R}^m{}_+ \to \mathbf{R}$ is continuous, non-decreasing in each variable, and for any

given j, and for any $(z_1,\ldots, z_{j-1}, z_{j+1},\ldots, z_m) >> 0$, it holds that

$$\lim_{z_j \to \infty} u(z_1,\ldots,z_{j-1}, z_j, z_{j+1},\ldots,z_m) = \infty \qquad (2)$$

2.3. The Fixed Production Cost

Let f_j be the production function for good j. Let $l_{0j} = \max\{l_j : f_j(l_j) = 0\}$. We always have $l_{0j} \ge 0$. This l_{0j} is said to be the *fixed production cost* for good j. Thus $l_{0j} > 0$ means that, before any positive quantity of good j can be produced, the producer has to pay a cost in terms of an amount of labor to learn the production skill or to get ready for production.

We will show later that a Walrasian equilibrium is a combination of a sequence of static corner equilibria and the solution of an individual's dynamic programming problem. In the next section, we first ignore interdependence between observable market prices and individuals' decisions caused by the cost of pricing process. Hence, there is no real time dimension in the model. We can then consider equilibria in a static model. We shall define sequential equilibrium in section 4.

3. Static Equilibrium

3.1. Configurations and Structures, Corner Equilibria

Because of the assumption of a continuum of ex ante identical consumer-producers and because increasing returns are localized (which do not extend beyond the size of each person's labor endowment), a Walrasian regime prevails in this model and there are many corner solutions and one interior solution that have to be considered in an individual's static decision problem. We first show that each person's number of possible profiles of zero and positive values of decision variables is finite.

Definition 1. A configuration chosen by an individual specifies the goods she is going to produce, the goods she is going to sell, and the goods she is going to buy.

Concerning the number of feasible configurations, we have

Lemma 1. Assume that any agent produces at least one good. Then, ignoring the constraint by the labor endowment, there are $\kappa \equiv [\sum_{l=1}^{m} C_m^l \cdot (2^l)](2^m)$ different feasible configurations for her.

Proof. To choose l goods to produce, there are C_m^l different options. With some specified l goods being produced, each of them can be chosen for selling, and as a result, there are 2^l choices. Thus the number of different feasible production-selling options is $[\sum_{l=1}^{m} C_m^l \cdot (2^l)]$. On the other hand, the number of different options for determining buying which goods is 2^m. Our conclusion thus follows.

Remark. The most important information we get from Lemma 1, although it is trivial, is that the number of configurations is finite.

In the later discussion, when we refer to that any individual has chosen a configuration in which several goods are to be produced, we always assume that she has paid for the fixed learning costs for all these goods. In particular, if good j is to be produced, then in her budget constraints, it must hold that $l_j \geq l_{0j}$.

Definition 2. A (market) structure consists of a set of *compatible* configurations chosen by different individuals such that, if there are some individuals who choose a configuration to sell (buy) any good, then there are also some individuals who choose a configuration to buy (sell) this same good.

Concerning the number of structures we have

Lemma 2. The number of different market structures is finite.

Proof. The argument is almost trivial. Since the number of configurations is finite. The number of all subsets of configurations, 2^κ, is finite. While a subset of configurations may or may not form a structure, any structure, on the other hand, corresponds to a subset of configurations. As a result, the number of structures is not greater than 2^{κ}. We are done. **QED**

In a structure of our model, it is possible that market clearing and utility equalization conditions hold. Hence, a local equilibrium (a corner equilibrium) which looks like a neoclassical Walrasian equilibrium may exist for a given structure. But in our model of consumer-producer, a corner equilibrium may not be a general equilibrium since individuals may have incentive to deviate to configurations that are not constituent configurations in the given structure. But a corner equilibrium might be part of a dynamic general equilibrium, as shown in section 4. Hence, we first consider the notion of corner equilibrium for a given structure with a fixed set of traded goods.

Given a structure in which $n \leq m$ goods in $N \subseteq M$ are traded, assume that a price vector p^N for these n goods is announced by the Walrasian auctioneer. Assume that an individual chooses a configuration of, say, producing a subset of goods $M' \subseteq M$, selling a subset of goods $X \subseteq M' \cap N$, and buying a subset of goods $Y \subseteq N$. For every $j \in M'$, let l_j be the amount of labor she allocates for good j's production. For every $j \in X$, let x_j be the amount of good j she sells. For every $j \in Y$, let y_j be the amount of good j she buys. An individual's nonlinear programming problem is then

$$\max u = u(z_1, \ldots, z_m)$$

subject to the constraints:

(i). for every $j \in M'$, $l_j \geq l_{j0}$, $\sum_{j \in M'} l_j \leq 1$; and

(ii). for every $j \in X$, $0 \leq x_j \leq fj(lj)$; and

(iii). for every $j \in Y$, $y_j \geq 0$, $\sum_{j \in Y} y_j p^N_j \leq \sum_{j \in X} x_j p^N_j$; and

(iv). for every $j \in M$, $z_j = fj(lj) - x_j + y_j$.

In (iv), we assume that $fj(lj) = 0$ for every $j \in M \backslash M'$, $x_j = 0$ for every $j \in M \backslash X$, and $y_j = 0$ for every $j \in M \backslash Y$. We are now ready to define the concept of a *corner equilibrium*.

Definition 3. Given an economy E together with a given set of traded goods $N \subseteq M$, assume that, when a price vector p^N is announced, every individual $i \in I$ chooses a feasible configuration $(M', X, Y)^i$ and a decision plan $v^i = (l_j^i, x_j^i, y_j^i, z_j^i)$ satisfying the above mentioned constraints (i)(ii)(iii) and (iv). By a *corner equilibrium* of E we mean a price vector p^N and the decision plan $\{v^i: i \in I\}$ such that (a) for every i, the choice of $(M', X, Y)^i$ and v^i maximizes the utility of i, and (b) the market of every good $j \in N$ is cleared under the price vector p^N and the individuals' decisions $\{v^i: i \in I\}$. The structure generated by the individuals' optimal decisions is said to be a corner equilibrium structure of E.

The difference between a corner equilibrium and a general equilibrium is that N is exogenously given for the former and it is endogenously determined in the latter.

Lemma 3. At any corner equilibrium of E, every individual achieves the same maximal utility.

Proof. The argument is trivial: if one individual i has a lower maximal utility than that of another, say i'. She could change her choice of configuration and decision plan to those chosen by i', making an improvement. But this implies that her original choice is not optimal. **QED**

3.2. Existence of the Corner Equilibria

We are now ready to establish

Theorem 1. Given any economy E satisfying Assumptions 1, 2 and 3 together with a given set of traded goods $N \subseteq M$, there always exists at least one corner equilibrium in which every individual sells at most one good, and all the individuals selling the same good choose the same decision plan.

Before we present our proof, we would like to point out that our arguments here are quite different from those in the conventional equilibrium existence proof for a large economy with nonconvex production sets and nonconvex consumption sets. In the conventional proof, measure theory plays a critical role and the idea of convexification is applied in order to show the existence of a market-clearing price vector under which individuals choose the utility maximization production and consumption plan. When the existence is established in this way, the equilibrium market structure is not mentioned. In fact, in our model, given any price vector, any individual usually has quite a few different optimal decision plans, but the set of all these optimal decision plans is not convex due to the nonconvexity of the production sets and the presence of the transaction costs. At any general equilibrium of such an economy, the ex ante identical individuals usually must be divided among different optimal decision plans in order that the market is cleared, which is the essence of "convexification". But how the population of these ex ante identical individuals are divided into different groups with sizes of appropriate measures and how different groups should choose different optimal decision plans are not addressed by the conventional proof. As a result, the conventional proof does not provide any systematic approach for the equilibrium computation.

On the other hand, the proof we will present below is "constructive" in the sense that, it concentrates on the realization of a corner equilibrium through a specific market structure. We divide the whole population of ex ante identical individuals into n (n is the counting number of N) groups with the measures of their sizes to be determined. The individuals in group j will be allowed to sell at most one good - good $j \in N$, which is an "additional constraint" they subject to when they choose their decision plan for utility maximization. We will see that the "constrained equilibrium" with the above mentioned additional constraint is actually a corner equilibrium when this additional constraint is removed. We will also see that our proof actually provides a systematic method for the equilibrium computation.

In the following discussion, for convenience, we will assume that $N = \{1,\ldots,n\}$, and we will refer to any individual who is allowed to sell good j as an *individual of type j*. We need several lemmas.

Lemma 4. Given any price vector $p \in \mathbf{R}^n_{++}$, the maximal utility $U^j(p)$ for any individual of any type j always exists and depends on p continuously.

Proof. The existence of the maximum $U^j(p)$ and the continuity of the mapping $p \mapsto U^j(p)$ all follows from the compactness of the decision set $\{v^j\}$. See Hildenbrand (1974, p.30). **QED**

Lemma 5. There exists a price vector such that $U^j(p) = U^{j'}(p)$ for any $j, j' \in N$. We will call such a price vector as a *maximal utility equalizing price vector*, or a MUEPV.

Proof. Consider a family of *perturbed* economies $\{E_\varepsilon: \varepsilon \in (0,1)\}$ generated by E. In E_ε, for given any price vector $p \in P = \{(p_1, \ldots, p_n) : p_j \geq 0, \Sigma_j p_j = 1\}$, the price vector $p^\varepsilon =$

$(p_1+e, \ldots, p_m+\varepsilon)$ is used for allocation computation. Correspondingly, the indirect utility function for any individual selling good j is denoted $U^j(p^\varepsilon)$. According to Lemma 4, for any $\varepsilon > 0$, the mapping $p \mapsto U^j(p^\varepsilon)$ is continuous in P.

Now consider the mapping $\psi_\varepsilon : P \to P$ defined by

$$[\psi_\varepsilon(P)]_j = \frac{p_j + \max\{0, U(p^\varepsilon) - U^j(p^\varepsilon)\}}{1 + \sum_l \max\{0, U(p^\varepsilon) - U^l(p^\varepsilon)\}}, \; j = 1, \ldots, n$$

where $U(p^\varepsilon) = [\Sigma_l U^l(p^\varepsilon)]/m'$. Obviously ψ_ε is a continuous mapping from P into P itself. Since P is convex and compact, by Brouwer's fixed point theorem there exists a $p^*(\varepsilon) \in P$ such that $[\psi_\varepsilon(P^*(\varepsilon))] = p^*(\varepsilon)$, i.e.

$$[p^*(\varepsilon)]_j = \frac{[p^*(\varepsilon)]_j + \max\{0, U([p^*(\varepsilon)]^\varepsilon) - U^j([p^*(\varepsilon)]^\varepsilon)\}}{1 + \sum_l \max\{0, U([p^*(\varepsilon)]^\varepsilon) - U^l([p^*(\varepsilon)]^\varepsilon)\}}, \; j = 1, \ldots, n \qquad (3)$$

In view of (2), by a standard argument it is easy to establish the uniform boundedness of $\{p^*(\varepsilon) : \varepsilon\in(0,1)\}$: there exists a sufficiently small real number $r>0$, such that for any $\varepsilon\in(0,1)$ and any j, it holds that $[p^*(\varepsilon)]_j > r$. (Otherwise, assume, say, that $[p^*(\varepsilon)]_1/[p^*(\varepsilon)]_n = \max\{[p^*(\varepsilon)]_j/[p^*(\varepsilon)]_{j'} : j, j' = 1,\ldots,n\}$. Then with the help of (2) it is easy to verify that $U^1([p^*(\varepsilon)]^\varepsilon) > U^n([p^*(\varepsilon)]^\varepsilon)$. As a result (3) will be not true for the subscript h such that $U^h([p^*(\varepsilon)]^\varepsilon) = \max\{ U^j([p^*(\varepsilon)]^\varepsilon) : j = 1,..,n\}$.)

In (3) let $\varepsilon\to 0$, and let $\lim p^*(\varepsilon) = p^*$. Then we have

$$p^*_j = \frac{p^*_j + \max\{0, U(p^*) - U^j(p^*)\}}{1+\sum_l \max\{0, U(p^*) - U^l(p^*)\}},\ j = 1,\ldots,n \tag{4}$$

Obviously we still have $p^*_j > r$ for every j. This p^* must be a MUEPV. Otherwise, without loss of generality we may assume that $U^1(p)$ is the largest equilibrium utility among the $U^j(p)$. Then (4) will not hold for $j = 1$.**QED**

To compete the proof of Theorem 1, we need to find the measures of each type of individuals $(d^*_1,\ldots d^*_n)$ which clears the market under the price vector p^*. This is proved in

Lemma 6. For the MUEPV p^* determined in Lemma 4, there always exists a column vector of measures $d^* = (d^*_1,\ldots d^*_n)^t$ which clears the market.

Proof. Assuming that under p^*, the individuals of type j chooses the same optimal decision for trading $(x^*_j ; y^*_{j1},\ldots,y^*_{jj-1}, y^*_{jj+1},\ldots,y^*_{jn})$, $j = 1,\ldots, n$. Let $T = (t_{ij})$

be the trading matrix with $t_{ij} = -x^*_j$, if $i=j$, and $t_{ij} = y^*_{ij}$ if $i \neq j$. We are looking for a m'-dim column vector $d \geq 0$ such that $Td = 0$, where 0 is the m'-dim zero vector.

Let $x = \max \{ x^*_j : j=1,\ldots,n\}$. Let J be then $n \times n$ identity matrix. Then $F = T+xJ$ is a nonnegative matrix. Denote by λ_F the Frobenius eigenvalue of F, let d be the associate eigenvector. We have $\lambda_F\, p^*d = p^*Fd = p^*(T+xJ)d = p^*Td + p^*xJd = xp^*d$. Here we have used the budget constraints $p^*T = 0$ to get $\lambda_F\, p^*d = xp^*d$. Since $p^*d > 0$, we must have $x = \lambda_F$. As a result we have $Td = (F-\lambda_F.J)d = Fd-\lambda_F.d = 0$. Finally we obtain d^* by setting $d^*_j. = d_j./(\sum_l d_l)$.[2]**QED**

Proof of Theorem 1 Since lemmas 5 and 6 have established that there exist maximal utility equalizing price vector and measure vector of different specialists that clear market, to show that p^* is a corner equilibrium price vector, we need only to show that the maximal utilities $U(p^*)$ that the individuals have achieved under the additional constraint that at most one good is allowed to be sold is actually the maximal utility when this additional constraint is removed. In fact, let $V(p^*)$ be the maximal utility any individual can achieve when she is allowed to sell as many goods in M' as she wants under p^*. In view of the weak convexity of the production functions, according to the generalized Wen theorem, $V(p^*)$ can be

[2] Note that the vector d^* may have some zero components, which means that at the corner equilibrium some goods in M' may be not traded or even not produced.

always achieved through selling just one of the goods, say good j.[3] As a result we have $U(p^*) = U^j(p^*) = V(p^*)$. **QED**

This existence theorem, together with the first welfare theorem (theorem 3), imply that there is no difficulty in coordinating individuals' impersonal networking decisions to reach a locally Pareto optimal network pattern of division of labor for a given set of traded goods. This is very important for the coordination of social experiments in the dynamic model.

3.3. General Equilibrium and Its Existence

In essence a general equilibrium of the economy E is a corner equilibrium in which there is a complete market for trading of all goods in M (or N is endogenously determined). Since every individual is allowed to choose *any* configuration under any given price vector p for all the m goods, the decision problem for any individual can be also described as

$$\max u = u(z_1,\ldots,z_m)$$

subject to the constraints:

(i). for every $j \in M$, $l_j \geq 0$, $\sum_{j\in M'} l_j \leq 1$; and

(ii). for every $j \in M$, $0 \leq x_j \leq fj(lj)$; and

(iii). for every $j \in M$, $y_j \geq 0$, $\sum_{j\in M} y_j p^N_j \leq \sum_{j\in M} x_j p^N_j$; and

(iv). for every $j \in M$, $z_j = fj(lj) - x_j + y_j$.

[3] Yao's proof of the generalized Wen theorem can be found from Yang (2000, ch. 6).

The difference between this decision problem and the one in section 3.1 is that a person can choose traded goods from set N in the latter and she can choose from set M in the former. The existence proof for a general equilibrium is very much the same as the existence proof for a corner equilibrium. We thus omit the proof and state the result below:

Theorem 2. Given any economy E together with Assumptions 1, 2 and 3, E has at least one general equilibrium in which every individual sells at most one good, and all the individuals selling the same good choose the same decision plan.

Note that, by definition, any general equilibrium is a corner equilibrium. It is easy to show that the equilibrium utility at any corner equilibrium is not greater than in any general equilibrium.

Theorem 3. (First Welfare Theorem) The allocation of resource in any general equilibrium is Pareto optimal and each corner equilibrium is locally Pareto optimal for a given structure.

Proof. Assume that p is a general equilibrium price vector and that the equilibrium utility for every individual is $U(p)$. Let p' be any other price vector, and $z' = \{z'^i : i \in I\}$ be any feasible final allocation under p'. We want to show that, if there exists a positive-measured subset $I' \subset I$ such that

$$u(z'^i) > U(p), \forall i \in I'$$

Then there must exist a positive-measured subset I'' of $I \backslash I'$, such that

$$u(z'^i) < U(p), \forall i \in I''$$

Assume, by contradiction, that we have both $u(z'^i) > U(p)$, $\forall i \in I'$ and $u(z'^i) \geq U(p)$, $\forall i \in I \backslash I'$. For $\forall i \in I'$, let her decision plan be $d'^i = (l'^i, x'^i, y'^i)$ under the price vector p'.. (Here l'^i is a m-dim vector representing i's allocation of labor, of which the jth component is the amount of labor she allocates for good j's production; x'^i is a m-dim vector of which the jth component is the amount of good j she sells; and is a m-dim vector of which the jth component is the amount of good j she buys.) Such a decision will *no longer* be feasible under the price vector p, otherwise any individual may make an improvement by switching from her decision at the general equilibrium to this d'^i. As a result we must have

$$p \cdot y'^i > p \cdot x'^i, \forall i \in I' \tag{5}$$

Similarly from $u(z'^i) \geq U(p)$, $\forall i \in I \backslash I'$ one can deduce that

$$p \cdot y'^i \geq p \cdot x'^i, \forall i \in I \backslash I' \tag{6}$$

Integrating $p \cdot y'^i$ over the whole population I, we then have

$$p \cdot \int_I y'^i di = p \cdot \int_{I'} y'^i di + p \cdot \int_{I \backslash I'} y'^i di > p \cdot \int_{I'} x'^i di + p \cdot \int_{I \backslash I'} x'^i di = p \cdot \int_I x'^i di$$

from which it follows that for *at least one j*:

$$\int_I y'^i{}_j di > \int_I x'^i{}_j di \tag{7}$$

But (7) implies that the final allocation z' under the price vector p' violates material balance, and hence not feasible! The proof of the second statement in theorem 3 is similar. We have thus established theorem 3. **QED**

Directly following from Theorem 3 we have

Corollary 1. Let $U(p^N)$ be the corner equilibrium utility at any corner equilibrium of E and $U(p)$ be the equilibrium utility at any general equilibrium of E. Then

$U(p^N) \leq U(p)$. All corner equilibria can be Pareto ranked. All individuals have incentives to deviate from a Pareto inefficient corner equilibrium and have no incentive to move away from a corner equilibrium to another Pareto inferior corner equilibrium.

It is important to note that theorem 3 and corollary 1 have very important implications for a socially rational dynamic searching process for organization information when bounded rationality is present. In our model, there are network effects of division of labor on aggregate productivity (an individual's decision to choose her pattern of specialization determines not only her own productivity, but also the extent of the market for others' produce, thereby imposing a constraint on others' decisions in choosing their occupations that determine their productivities, see Young, 1928 and Yang 2000). The impersonal networking decision in this model differs from the strategic networking decision. It does not generate network externality in a static Walrasian model. However, it may generate coordination problems in a dynamic model with cost of pricing process. We will show later that theorem 3 and corollary 1 imply that coordination difficulties in a social search process can be avoided even if network effects of division of labor present.

3.4. A Simple Example

Let us consider a simple example with three goods. Assume that every individual has the utility function $u = 216xyz$, where x, y and z are, respectively, the amount of good 1, good 2 and good 3 she consumes. Assume that each individual has the same set of production functions defined by $f_j(L_j) = \max\{0, L_j\text{-}1/6\}$, where L_j is the amount of labor she allocates for good j's production. Assume that the transaction functions are given by $gj(yj) = kyj$, $(0<k\leq 1)$.

To compute the corner equilibria, we consider the possible market structures. We will denote the autarky structure by S_0. For structures with two traded goods, we consider S_{12}, S_{23}, and S_{31}, where S_{12} consists of configurations (1|2), which represents producing goods 1 and 3, selling part of good 1 in exchange for good 2, and (2|1), which represents producing goods 2 and 3, selling part of good 2 in exchange for good 1. S_{23} consisting of configurations (2|3) and (3|2), and S_{31} consisting of (3|1) and (1|3) can be explained similarly. For structures with three traded goods, we have S_{123}, S'_{123} and S''_{123}, where S_{123} represents the structure with complete division of labor: every individual produces one good only, selling part of her produce in exchange for the other two goods. On the other hand, S'_{123} consists of (1|2), (2|3), (3|1) and represents the structure in which type 1 individuals produce good 1 and good 3, selling good 1 and buying good 2, type 2 individuals produce good 2 and good 1, selling good 2 and buying good 3, and type 3 individuals produce good 3 and good 2, selling good 3 and buying good 1; and S''_{123} consisting of (1|3), (3|2), (2|1) can be explained similarly.

Let us consider S_0 first. The corner solution for the configuration in this structure is $Lj = 1/3$ for every j and the corner equilibrium utility of the autarky structure is $U(S_0)= 1$.

Now let us consider the structure S_{12}. By symmetry we can show that (0.5, 0.5) is the corner equilibrium price vector. The corner solutions for two configurations, the market clearing and utility equalization conditions between configurations yield the corner equilibrium utility in this structure $U(S_{12}) = 64k/27$ and corner equilibrium measure vector of individuals choosing configurations (1|2) and (2|1), d = (0.5, 0.5). By symmetry again, we can find the corner equilibrium utility values in structures S_{23} and S_{31}, $U(S_{23}) = U(S_{31}) = 64k/27$. Similarity, we have $U(S'_{123}) = U(S''_{123}) = 64k/27$, $U(S_{123}) = 125k^2/27$, and the measure vector of specialists in S_{123}, $d = (1/3, 1/3, 1/3)$.

The general equilibrium structure is autarky if $k<27/64$, is structure S_{12}, S_{23}, S_{31}, S'_{123}, or S''_{123}, if $k\in(27/64, 64/125)$, and is S_{123} if $k>64/125$.

4. Dynamic Decisions and Walrasian Sequential Equilibrium

4.1. Lack of Information and Initial Belief

We now assume that in a period there is a cost in terms of utility loss for each individual starting to trade goods which are not previously traded. The cost is proportional to the number of traded goods chosen by an individual. In addition, the Walrasian auctioneer calls only the prices of those goods that are offered for sale or asked for purchase in a period. This assumption generates the following interdependence between observable prices and decisions, and thereby individuals might be kept in a corner equilibrium even if it is not a general equilibrium.

The prices that are observable are determined by all individuals' decisions in choosing their configurations. In period 0 all individuals are in autarky. They have no idea about other individuals' characteristics and about what prices might emerge from interactions among individuals' decisions in choosing configurations in the next period. In other words, we assume that there are prohibitively high information collecting cost for each person to figure out other individuals' characteristics and direct interactions among all individuals' decisions. Each person must then use the price system to gradually figure out the consequence of indirect interactions between her decision and others' decisions. She may have a guess about information gains, that is, if she tries a configuration in each period, she may gradually figure out price information in various structures period by period. As soon as an individual has an incentive to start trading a good that was not traded before, the set of traded goods for society will change. Society will try a new structure that has not been tried. Because of the existence theorem of a corner equilibrium for any given structure, no difficulty in coordinating individuals' choices of a corner equilibrium will occur. In the next period as long as individuals have incentives to start trading more goods that have not been traded, society will gradually experiment with various corner equilibria and gradually acquire organization information.

Formally, in economy $E = [I, M, f, g, u]$, I and M is common knowledge, the knowledge of g_j^i, f_j and u^i is the private information of individual i. All individuals are in autarky in period 0. As a result, while every individual can compute her maximal utility in the autarky structure, she cannot deduce her corner equilibrium utility in any other structure in period 0.

The initial belief for any individual is given as a probability distribution of her expected corner equilibrium utilities over the set of her possible configurations. Note that there is no uncertainties of individuals' characteristics and physical environment. The uncertainties here are generated by possible social interactions. Formally, let $\{S_1,\ldots,S_H\}$ be the set of all non-autarky configurations, and $r^i_h = U^i_r(S_h)$ be the random variable representing the highest corner equilibrium utility which this individual can achieve after she has tries configuration S_h. Then an initial belief of individual i is a joint probability distribution of $(r^i_1,\ldots,r^i_H)$ over a region in $\mathbf{R}^H$. Because all individuals are ex ante identical, it seems reasonable to assume that every individual actually holds the same initial belief, although no one knows this fact. As a result we may write $(r^i_1,\ldots,r^i_H)$ as $(r_1,\ldots,r_H)$, or just as r^H. It is assumed that $\mathrm{E}U^i_r(S_h) = U^i(S_0)$ for any h in period 0. This implies that in period 0 each person knows little other than her local optimum utility in autarky.

In the later discussion we always assume the following:

Assumption 4. The joint distribution representing the initial belief of each and every individual has an integrable density function $J_0 : \mathbf{R}^H_+ \to \mathbf{R}_+$ which has the following properties:

Either (A) $J_0(r^H) > 0$ for all $r^H \in \mathbf{R}^H_+$;

Or (B) J_0 has a compact support $R^H = R_1 \times \ldots \times R_H \subset \mathbf{R}^H_+$, such that $R_h > U$ for every h and $J_0(r^H) = 0$ for any r^H with any $r_h \geq R_h$, and $J_0(r^H) > 0$ for any r^H with $0 < r_h < R_h$ for all h, where U is general equilibrium utility for every individual.

Note that the implication of that $R_h > U$ for every h is that, while every individual does not know the certain value of the general equilibrium utility U or which structure is the general equilibrium structure, her initial belief safely includes U in the range of $[0, R_h]$.

4.2. Costs and Benefits of Conducting an Experiment

To start trading a good, in the next period, that has not been traded so far requires the individual learning new trade skill and preparing essential facilities for trading this good. This incurs a cost in terms of utility loss, which can be considered as an experiment cost for a configuration since the set of traded goods differs from configuration to configuration.

Assumption 5. Assume that, for every configuration S_h, the experiment cost is given by

$$C(S_h) = c_h U(S_h),\ 0 < c_h < 1 \tag{8}$$

and the Walrasian auctioneer calls only the prices of those goods that are offered for sale in a period.

This assumption relates to three types of coordination difficulties in sequential social experiments. First, if individuals have different beliefs, they may want trying different configurations and thereby coordination difficulty may occur. This coordination difficulty would not occur for the following reason. If some individuals want trying configuration B and other individuals want trying configuration C, while B and C might not be compatible with each other (say B sells good 1 and buys good 2, C sells good 3 and buys good 4), then prices of all goods traded in B and C will be called by Walrasian auctioneer. Assumption 5 implies that no extra costs will be incurred for individuals shifting between any two configurations in B and C. This, together with corollary 1, imply that only the Pareto superior one between corner equilibria in B, C, and other structures with the same set of traded goods as in B or C or in B and C will be finally chosen.

Second, if some individuals want to return to status quo but other individuals do not want to in the end of a period after an experiment in the beginning of this period, coordination difficulty may occur. But corollary 1 again rules out such possibilities. Finally, individuals may have incentive to free ride others' experiments. This type of coordination difficulty would not occur because of the assumption that all ex ante identical individuals have the same belief. They will have the same updated information about prices in various structures that have been so far tried. Hence, waiting will lose expected net benefit of experiments.

However, if individuals have different characteristics as well as different initial beliefs, corner equilibria may not be Pareto ranked, thereby causing coordination difficulty of social experiments. We leave this extended model which might generate coordination difficulty to future research.

Assumption 5 implies that a person will not be locked in a constituent configuration of a structure that has been tried by society. Thus, no difficulty will occur for coordinating the choices of different occupation configurations within a structure that has been tried in the beginning of a period or finally chosen in the end of this period. However, she might be locked in a corner equilibrium which is not Pareto optimal if individuals do not want to pay the experiment cost to trade the goods that are not traded in the structures tried. Coordination difficulty for choosing the Pareto optimum corner equilibrium which is a static genera equilibrium may occur if the experiment cost or the discount rate is too large. In daily life language, such coordination difficulty is associated with underestimation of the market demand for some potentially tradeable goods.

Imagine that, at some period t of the non-autarky configurations $\Sigma = \{S_l : l = h_1,\ldots,h_t\}$ have been tested. Denote by S^t the structure which gives i (and all others in the population) the highest corner equilibrium utility among all the configurations in $\{S_l : l = 0, h_1,\ldots,h_t\}$. Let Σ' be the set of untested configurations. To determine whether it is worthwhile for her to conduct an experiment with an untried configuration $S_{h'} \in \Sigma'$, i wants to compute the expected net benefit for conducting such an experiment.

In computation of the expected net benefit, please note that, if it is discovered by the experiment that $U(S_{h'}) \leq U(S^t)$, this individual could at least return to status quo in S^t. On the other hand, if it is discovered that $U(S_{h'}) > U(S^t)$, then beginning from this period t+1, she will switch to her configuration in $S_{h'}$, getting a per period utility gain of $U(S_{h'})$-$U(S^t)$. Let $\Lambda = \{l : S_l \in \Sigma\}$, and $\Lambda' = \{l : S_l \in \Sigma'\}$. According to Bayes updating rule, the random variables representing her equilibrium utility in those untested configurations must have the following joint distribution density function at the end of period t:

$$J_{\Lambda'}(r^{\Lambda'}) = \frac{J_0(r^H \mid r_l = U(S_l) : l \in \Lambda)}{\int_{R^{\Lambda'}} J_0(r^H \mid r_l = U(S_l) : l \in \Lambda) dr^{\Lambda'}} \tag{9}$$

where $r^{\Lambda'}$ is the $(H\text{-}t)$-dim vector of which the components represent i's equilibrium utilities in the untested configurations, $r^H \mid r_l = U(S_l) : l \in \Lambda$ is the H-dim vector obtained from r^H with its lth component replaced by $U(S_l)$, $l \in \Lambda$, and $R^{\Lambda'}$ is the region generated by the *intersection* of R^H (or $\mathbf{R}^H$) with *all* the hyperplanes $r_1 = U(S_l)$. As a result, the *per period expected utility gain* for conducting an experiment with $S_{h'}$ is

$$b_{\Sigma h'} = \int_{[R^{\Lambda'} : r_{h'} > U(S')]} J_{\Lambda'}(r^{\Lambda'})[r_{h'} - U(S')] dr^{\Lambda'} \tag{10}$$

Note that, it follows from Assumption 4 that $b_{\Sigma h'} > 0$ for all possible Σ and $S_{h'} \in \Sigma'$.

Since this expected gain will be maintained in the subsequent periods but the expected cost of conducting such an experiment is to be paid for just one period, the *expected net benefit* is

$$B_{\Sigma h'} = (1-\delta)^{-1} b_{\Sigma h'} - c_h[U(S') + b_{\Sigma h'}] \tag{11}$$

Obviously, when (10) is sufficiently small, or when the period utility discount factor δ is sufficiently close to 1, we will have $B_{\Sigma h'} > 0$. In this case this individual i may want to try a configuration $S_{h'}$ potentially.

However, in determining *which* of the untested configuration should be tested in the current period, it is not as simple as to find an h' to maximize $B_{\Sigma h'}$.

After the test of one of the untested configurations and updating of her belief, this individual may find it necessary to test another untested configuration, …, and so forth, until she believes that no further test is required. Thus there is a set of different *onward experiment paths*, each starting from the current period, from which i has to choose the optimal one which maximizes *her onward expected total discounted utility* given her current belief. It seems what i has to solve is a dynamic programming problem with Bayes updating according to observed prices. However, due to fundamental social and endogenous uncertainties, it is impossible to coordinate all individuals' dynamic decisions when each decision-makers is short of information. Since each individual does not know if others' beliefs are the same as hers, it is possible that when person A wants trying a configuration with goods 1 and 2 traded while person B wants trying a configuration with goods 1, 2, 3 traded in a period. As a consequence, prices of goods 1, 2, 3 will be observed in this period, and therefore locally maximum utilities for all configurations with goods 1, 2, 3 traded (configurations (1|2), (1|3), (2|1), (2|3), (3|1), (3|2), (1|23), (2|13), and (3|12)) will be sorted out by the Walrasian pricing mechanism in this period. Hence, it is fundamentally uncertain how many distinct configurations that a person has to try because social uncertainties caused by interactions of individuals' decisions when they are short of information.

If the fact is considered that the calculation cost of the dynamic programming problem increases exponentially as the number of goods (thereby the number of configurations) increases, the efficient horizon, which efficiently trades off benefit of a longer horizon (amortizing experiment cost over a longer period of time) against cost, is very limited even if the dynamic programming can be well defined and all individuals' dynamic decisions can be coordinated.

Hence, each person just maximizes $B_{\Sigma h'}$ in (11) with respect to h' according to updated information in each period. In the process information is updated according to the Bayes rule and to observed prices in each period. We assume each person has perfect recall of the history of the economy. The adaptive maximization problem generates a configuration that a person wants trying in a period. We call such a configuration that will be tried by person i in period t $C_t(i)$ and define $C(i) = \{C_t(i), t = 1, 2, ...\}$ as an individual's evolutionary path. The aggregate consequence of all individuals' choices of configurations to be tried in this period will generate a set of traded goods which is a union set of each and every individuals' sets of traded goods in their configurations to be tried in this period. Let this union set be D. Hence, the prices of all goods in set D will be observed in this period and the corner equilibrium that generates the highest utility for all individuals than any other structures with set of traded goods D'$\subset$D will be finally chosen in this period. Note that all individuals' utilities will be equalized in any corner equilibrium. We call the corner equilibrium that has been finally chosen in period τ, T_τ. Finally we call sequential corner equilibria chosen in period 1, 2, ..., $T = \{T_\tau, \tau = 1, 2, ...\}$ an evolutionary path for society as a whole.

Definition 7. A *Walrasian sequential equilibrium* of the economy E specifies an evolutionary path for each and every individual $i \in I$ and an evolutionary path for society as a whole such that all individuals' evolutionary paths generate an evolutionary path for society as a whole.

4.5. Existence of a Sequential Equilibrium

The existence of a Walrasian sequential equilibrium requires the existence of the corner equilibrium for each given structure and the existence of the solution of each person decision to maximize $B_{\Sigma h'}$ in (11) with respect h' in each period. In addition, it needs to be shown that all individuals' evolutionary paths will generate an evolutionary path for society as a whole.

Theorem 4. Given any economy E satisfying the Assumptions 1,2,3,4,5. Beginning from any period t+1 with any t tested structures Σ', every individual has a well-defined onward evolutionary path.

Proof. We will apply mathematical induction on the number $n = |\Sigma'|$ of untested structures. First assume that n =1, and that the only untested structure is $S_{h'}$. Assume that S^{H-1} *is* the structure in $\Sigma \cup \{ S_0\}$ which gives the highest equilibrium utility to i. To determine whether it is worthwhile to conduct an experiment with $S_{h'}$, she compute the expected net benefit $B_{H,h'}$ according to the formulae in (10) and (11). If this expected net benefit zero or negative, she will choose T_H = O, and will maintain S^{H-1}. As a result her onward evolutionary path will be (O, S^{H-1}). On the other hand, if $B_{\Sigma h'} > 0$, she will conduct an experiment on $S_{h'}$. Then she will switch to $S_{h'}$ if $U(S_{h'}) > U(S^{H-1})$, having an onward evolutionary path ($S_{h'}$, $S_{h'}$), or she will maintain $S_{h'}$ if $U(S_{h'}) \leq U(S^{H-1})$, having an onward evolutionary path ($S_{h'}$, S^{H-1}). Thus the conclusion of Theorem 4 is true for n=1. Moreover, at the beginning of this experiment period, in any case she can compute her onward life-time total discounted utility $E_{\Sigma.h'}$:

$$E_{\Sigma h'} = (1-\delta)^{-1}U(S^{H-1}), \text{ if } B_{\Sigma h'} \leq 0; \quad E_{\Sigma.h'} = [(1-\delta)^{-1}-c_{h'}][U(S^{H-1})+b_{Hh'}], \text{ if } B_{\Sigma h'} > 0 \quad (15)$$

Now assume that the conclusion of Theorem 4 is true for $n \leq l < H$, ($|\Sigma| \geq H-l$) and that the onward life-time expected total discounted utility for this individual along the evolutionary path following from Σ is $E_{\Sigma.\Sigma'}$ for *any* Σ with $|\Sigma| \geq H-l$. We want to show that the conclusion must be also true for $n=l+1$, ($|\Sigma|=H-l-1$). Since the set Σ' of untested structures has a counting number of l+1, there are l+1 random variables representing i's corner equilibrium utilities in the untested structures. To determine whether it is worthwhile to conduct an experiment with the corresponding structure $S_{h'} \in \Sigma'$, this individual compute the expected net benefit $B_{\Sigma h'}$ for each $h' \in \Lambda'$ (or each $S_{h'} \in \Sigma'$).

If, in the extreme, the expected net benefit from conducting experiment with *any* untested structure is less than or equal to zero, then she will stay in a configuration in the structure S^{H-l-1} which has given to her the highest equilibrium utility so far. All individuals will have no coordination difficulty in choosing this structure because of corollary 1. An individual will conduct an experiment with one of untested structures with $B_{\Sigma h'} > 0$. For simplicity we assume that $B_{\Sigma h'} > 0$ holds for any untested structure $S_{h'}$.

To determine which one should be tested, we have to compute the onward life-time expected total discounted utility beginning with every one of them. Imagine that she conducts an experiment with any particular $S_{h'}$. After the experiment, she will either switch to her configuration in this *new* structure, or stays in the structure of S^{H-l-1}, whichever gives her a higher equilibrium utility. Passing on to the next period, there are at most l structures remained untested. By the mathematical induction hypothesis, the onward evolutionary path: $(T_{t+1}(\Sigma\cup\{S_{h'}\}), S^{t+1}(\Sigma\cup\{S_{h'}\})),\ldots,(T'_H(\Sigma\cup\{S_{h'}\}), S^H(\Sigma\cup\{S_{h'}\}))$, and the onward life-time expected total discounted utility beginning from the *next* period could be computed, and is denoted $E_{\Sigma\cup\{h'\}.\Sigma'\backslash\{h'\}}$, which of course all depend on her equilibrium utility value $U(S_{h'})$. Note that at the beginning of *this* period $t=H-l$, before the experiment with $S_{h'}$ is conducted, this $U(S_{h'})$ is not known, and is represented by the random variable $r_{h'}$. Thus the above mentioned onward evolutionary path can be written, respectively as

$$[(T_{t+1}(\Sigma\cup\{S_{h'}\}), S^{t+1}(\Sigma\cup\{S_{h'}\})),\ldots,(T'_H(\Sigma\cup\{S_{h'}\}), S^H(\Sigma\cup\{S_{h'}\}))](r_{h'}),$$

$$E_{\Sigma\cup\{Sh'\}.\Sigma'\backslash\{Sh'\}}(r_{h'}) \quad (16)$$

Now the updated belief of this individual is represented by the density function as given in (9). As a result, her onward life-time expected total discounted utility beginning from *this* period is estimated to be

$$E_{\Sigma.\Sigma'}(h')= [(1-c_{h'}][U(S^{H-l-1})+b_{Hh'}] + \delta\int\eta(r_{h'})\, E_{\Sigma\cup\{Sh'\}.\Sigma'\backslash\{Sh'\}}(r_{h'})\mathrm{d}r_{h'} \quad (17)$$

where the density function $\eta(r_{h'})$ is defined by

$$\eta(r_H) = \int_{R^{\Lambda' \setminus \{H\}}} J_{\Lambda'}(r^{\Lambda'}) dr^{\Lambda' \setminus \{H\}} \tag{18}$$

Let h' run over Λ', and choose the one, say h'^* which leads to the maximal value for (17). Then the corresponding untested structure will be experimented with in this period t. Let this be $T_t(\Sigma)$, and let the structure she want to participate in after the test be $S^t(\Sigma)$. Then the onward evolutionary path beginning from t following Σ is obtained by putting

$$[(T_{t+1}(\Sigma \cup \{S_{h'}\}), S^{t+1}(\Sigma \cup \{S_{h'}\})), \ldots, (T'_H(\Sigma \cup \{S_{h'}\}), S^H(\Sigma \cup \{S_{h'}\}))](r_{h'^*})$$

after $(T_t(\Sigma), S^t(\Sigma))$. Thus the conclusion of Theorem 4 is true for $n=l+1$. Theorem 4 is thus proved. **QED**

As a special case of the result in Theorem 4, we have

Corollary 2. Given any economy E satisfying the Assumptions 1,2,3,4,5, every individual has a well-defined evolutionary path.

Because all individuals in the population are ex ante identical, every one must have the same evolutionary path, although, in each period, different individuals may choose different configurations in the same structure. Since individuals have no difficulty for coordinating choices of different configurations in a given structure (theorem 3 and corollary 1), assumption 5 and the corollary 2 together imply that the coordination of choice of one from many corner equilibria by society is sorted out by the solution of each person's dynamic programming problem and evolutionary path. We thus have

Theorem 5. Given any economy E satisfying the Assumptions 1,2,3,4,5, a Walrasian sequential equilibrium always exists, and a steady corner equilibrium can be achieved after at most H rounds of experiments.

In general, as is mentioned above, along an evolutionary path, it is possible some structures may never be tested because of the expected net benefit from conducting an experiment with it is less than or equal to zero. Thus it is possible that in a sequential equilibrium of our dynamic model, the structure being maintained to the infinite horizon is not a general equilibrium of the static model. This will not occur, however, if the discount factor δ is sufficiently close to 1. In fact, for any given experiment cost coefficients c_h, one can compute an interval of δ-values, sufficiently close to 1, such that, if δ falls into this interval, then an experiment will be conducted with every structure along any evolutionary path. This is proved in the following theorem.

Theorem 6. Let $b = \min\{b_{\Sigma h'}: \Sigma, S_{h'} \in \Sigma'\}$. $b > 0$ since every $b_{\Sigma h} > 0$. Let $c = \max\{c_h : h=1,\ldots, H\}$. If $\delta > \delta_0 \equiv \max\{0, 1-b/[c(b+U)]\}$, then along any evolutionary path, an experiment is conducted with each and every structure. As a result a general equilibrium structure will be maintained to the infinite horizon in any sequential equilibrium. (Please recall that U is the general equilibrium utility for the static model.)

Remark: Since the expression b/[c(b+U)] is positive, hence 1- b/[c(b+U)] < 1 always holds. As a result, the interval $(\delta_0, 1)$ is always nonempty.

Proof. We only need to show that, under the above assumptions, $B_{\Sigma, h}> 0$ holds for every subset of tested structures Σ and every $h' \in \Sigma'$. (As a result, as far as there are still some structures not been tested, the individual will always have an incentive to conduct an experiment with one of them.)

In fact, we have

$B\Sigma h' = (1-\delta)^{-1} b\Sigma h' - ch'[U(S^t)+b\Sigma h'] = [(1-\delta)^{-1}-ch'] \; b\Sigma h' - ch' U(S^t) \geq [(1-\delta)^{-1}-c]b - cU$

and the last expression is positive if If $\delta > 1-b/[c(b+U)]$. We are done. **QED**

4.6. Limited Horizon due to Social and Endogenous Uncertainties

If the number of goods is very large, each person's dynamic programming problem in choosing experiment sequence will be extremely complex since the number of possible evolutionary paths increases much more rapidly as the number of goods increases. If we assume the calculation cost for such a dynamic programming problem to be proportional to the number of possible evolutionary paths, the optimum decision horizon that efficiently trades off the benefit of a longer horizon (which can amortize fixed experiment cost over a longer period of time) against calculation cost will be very limited.

More importantly, if individuals have different initial beliefs, individuals' solutions of their dynamic programming problems might be inconsistent with each other. In this case which structure will be tried in a period cannot be accurately predicted by each person because of the fundamental endogenous uncertainties caused by interactions between dynamic decisions in such social experiments. Hence, the efficient horizon is very limited because of the trade-off between benefit and cost caused by mistakes in calculating the optimal dynamic decision of a longer horizon. Since we assume that it is prohibitively expensive for individuals processing all information about direct interactions among individuals' dynamic decisions, each person will choose a horizon of one period. Hence, in each period each person uses an adaptive approach to deciding if she will try an untested configuration in the next period according to updated information generated by previous experiments. A person's decision in each period is to maximize $B_{\Sigma h'}$ in (11) with respect h' and to check if the maximum $B_{\Sigma h'}$ is positive to determine to determine whether trying a configuration that has not been tried and which configuration should be tried. The solution of such a decision always exists. Hence, the existence of Walrasian sequential equilibrium boils down to the existence of corner equilibrium in each structure and the question if there is coordination difficulty for individuals choosing a corner equilibrium that generates the highest utilities to each and to every individual. As we have already proved that there is no such coordination difficulty among ex ante identical individuals who might have different initial beliefs. Therefore, a Walrasian sequential equilibrium exists in a model with limited decision horizon.

A shown in Ng and Yang (1995) and Zhao (1999), all structures will be tried and all organization information will be acquired if the experiment cost coefficient and discount rate are sufficient small. This implies that a long decision horizon and perfect rationality are not essential for efficient social searching for organization information. When the experiment cost coefficient is large and the horizon is limited, however, the Walrasian sequential equilibrium may not reach static general equilibrium even if the discount rate is zero. A large discount rate has a similar effect on the social search process.

In our model with limited or infinite decision horizon and with bounded rationality, the Walrasian sequential equilibrium is usually not Pareto optimal. Individuals try the structure with a small number of traded goods before trying the one with a large number of traded goods because the experiment cost is an increasing function of the number of traded goods and we assume the lack of information in period 0. But it is possible that the structure with a large number of traded goods is Pareto superior to the one with a small number of traded goods if trading efficiency represented by the transaction functions is high (total transaction cost is more likely to be outweighed by positive network effects of the division of labor on the aggregate productivity). A striking feature of experiments with various structures of division of labor is that mistakes are not only unavoidable, but also necessary for distinguishing the efficient structure from inefficient ones. The first welfare theorem about the Pareto optimality of market equilibrium in a static model is incompatible with the notion of experimenting. An experiment with a Pareto inefficient structure of division of labor is certainly not Pareto optimal and seems irrational. But without experimenting with inefficient as well efficient structures, society can never know which structure is efficient and which is not because of interdependence between decisions and price information. It follows that seemingly irrational experiment with Pareto inefficient network pattern of division of labor might be socially rational. A sophisticated pursuit of the Pareto optimum structure of division of labor should encourage experiments with Pareto inefficient as well as Pareto efficient structures. The simple and direct pursuit of the Pareto optimum may impede the efficient social search, since such a pursuit is like asking a researcher to find the optimum design without experimenting with inefficient patterns.

Casual observation suggests that countries with many organizational inventions and innovations usually have relatively higher rates of bankruptcy of firms. This view of bounded rationality helps us not to overestimate successful businesses that are successful by and large because of luck in their experiments with various structures of division of labor. It also helps us not to underestimate the value of failed businesses which might be necessary for society to acquire information about the efficient pattern of division of labor. In this sense, our model has formalized the notion of entrepreneurial discovery proposed by the Austrian School (Kirzner, 1997).

Ng and Yang (1995) and Zhao (1999) provide two special examples of the model in this paper. Their comparative dynamics of the Walrasian sequential equilibrium suggest that if the experiment cost coefficient is large, then the market will not experiment with any sophisticated pattern of division of labor. If the coefficient is sufficiently small, all possible patterns of division of labor will be experimented with. In this process, simple patterns of division of labor are experimented with before the more complicated ones are, so that a gradual evolution of division of labor may occur. If the coefficient is at an intermediate level, then only simple patterns of division of labor will be experimented with, so that society cannot acquire all information about the efficient network pattern of division of labor.

5. Concluding Remarks

Our model of Walrasian sequential equilibrium has formalized the notions of bounded rationality, entrepreneurial discovery, and fundamental social and endogenous uncertainties, which are different from incomplete information. This well closed dynamic general equilibrium model is used to avoid the recursive paradox in the adaptive decision based on bounded rationality (see Conlisk, 1996). This paradox implies that a decision or equilibrium model cannot be well closed in the presence of bounded rationality. We have proved the existence theorem of equilibrium for a general class of Walrasian sequential equilibrium models. This kind of models can be used to investigate decentralized sequential social experiments based on bounded rationality and adaptive decisions. It involves very complicated feedback loops among individuals' impersonal networking decisions, dynamic decisions in using the impersonal price system to experiment with different network patterns of trade, the number of participants in the network of division of labor, and social information on the efficient network pattern of division of labor. This dynamic general equilibrium mechanism can search for the efficient network pattern of division of labor via a trial-error process, though it may not reach the most efficient network pattern of division of labor if the discount rate and experiment cost coefficient are too large. It generates uncertainties of the direction of spontaneous coevolution of the division of labor and organization information acquired by society and an evolutionary pattern from simple to complex network structure of division of labor (Nelson, 1995).

The following features of our model distinguish it from Kreps and Wilson's (1982) sequential equilibrium model. In our model, each individual never knows other players' characteristics, even if they gradually learn social organization information carried by prices. It has more information asymmetry than in the Kreps and Wilson model as far as private information of all individuals' characteristics is concerned. But it has less information asymmetry as all players have the same organization information carried by prices in each period. In a Walrasian sequential equilibrium each player's rationality in carrying out complex calculation in a dynamic programming problem is not essential for sequential social experiments acquiring organization information. But in the Kreps and Wilson model, such "super rationality" is essential for coevolution of information and strategies.

Coordination of social experiment and choice of a network pattern of division of labor in our model with multiple corner equilibria is much easier than in the models with multiple general equilibria since the static general equilibrium is only one of many corner equilibria in our model. Our model shows that there are two functions of the market price system in addition to the allocation of resources. The first is to coordinate individuals' impersonal networking decisions to utilize positive network effects of the division of labor on aggregate productivity, net of transaction costs. The second is to exploit the interdependence between impersonal networking decisions and impersonal prices that are observable to coordinate a social search process for organization information about the efficient network pattern of division of labor.[4]

The Walrasian sequential equilibrium model generates a prediction that socially efficient search process may work in the absence of perfect individual rationality. It differs from the evolutionary game models (Weibull 1995, Fudenberg and Levine, 1998, and Rubinstein, 1998) where interactions are strictly bilateral and prices are inessential for an evolutionary stable equilibrium converging toward a static Nash equilibrium. In a Walrasian sequential equilibrium model, multilateral interactions between impersonal prices and decisions based on bounded rationality are essential for socially rational search for organization information. Although most evolutionary stable equilibria converge to Nash equilibria which may be socially inefficient, some evolutionary stable equilibria, such as in the coordination game, may allow socially inefficient outcome, even if the social optimum is a strict Nash equilibrium (Weibull, 1995, p. 39). That is, there is no tendency that evolutionary stable equilibria converge

[4] The social search process in our model differs from individual search process in Aghion, et al (1991) and Morgan and Manning (1985) since the former involves fundamental social and endogenous uncertainties based on bounded rationality.

toward the socially efficient outcome. In a Walrasian sequential equilibrium model the impersonal price system can gradually exploit dispersed information meanwhile keeping individuals away from what they should not know from a viewpoint for avoiding prohibitively high information processing cost.[5]

[5] In this sense the informational role of prices in a Walrasian sequential equilibrium model differs from the one in Grossman's model (1989) which is to convey all information to each player.

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