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Abstract

In large social systems agents are characterized as elements in a topological attribute space. Usually there exists a complete relational structure between these agents. If, however, this relational pattern is restricted, there emerge natural organizational structures between agents. We focus our attention to one such a structure, called a network. It turns out that these networks usually exist in a deterministic graph-theoretic setting. Networks can be interpreted as potential or latent organizations, one of which will eventually emerge as a social organization.

This paper is concerned with the question whether in large economies with a restricted relational pattern there exist such potential organizational structures. We state and prove some existence results for a substantial class of these economies, called network economies.

We conclude this paper by defining a core concept for a large network economy. We show that this core is equal to the core of the large economy underlying the network economy. Since the communication requirements of the first core concept are less stringent, the network economy is a more efficient concept whenever communication efforts are taken into account.

1 Introduction

The organization of economic decisions in a society is a fundamental problem in economic theory. A society is modelled as a large social system, in which agents are characterized as elements in a topological attribute space, and in which an allocation mechanism is defined. The best known example in economic theory is the market economy, designed by Walras in 1874, and given its definitive formulation by Arrow and Debreu (1954). These so called general equilibrium models of a market economy have, however, a poor social structure. It is, e.g., assumed that no interaction between agents exists, and that agents are only related to a fictitious agent, called the market. Furthermore, the only social norm involved is to maximize individual utility or profit given the market prices.

The functioning of any economic system, however, depends crucially on the interactions between individual agents and on the social norms and values involved. Those values and norms determine each agent's behaviour in a society, and may depend on the position an agent occupies in the society. In this paper we introduce these positions by means of a graph on the set of agents. The relations between agents in this paper are, however, not specified in terms of values, norms or trade flows, but represent any sort of communication between agents. The only specification in communication that is made is the distinction between direct and indirect communication. In the second part of this paper we will interprete these communication relations as trade relations.

We assume that, whenever some restrictions are exogeneously put on the direct communication between agents, agents will try to circumvent these restrictions by setting up organizational structures to restore full communication in order to attain the desired, yet unspecified goals.

Agents can establish many of such indirect communication links. We call such a structure of agents a network, if it satisfies the requirements of full scope and connectivity. Full scope means that every agent can communicate indirectly with every other agent in the economy by means of the connected network. A network is minimal, if no agent can be deleted without harming these two conditions. The main theorem gives sufficient conditions on the attribute space for existence of a minimal network.

The strength of such a network economy will be illustrated by showing that networks can compensate fully for certain restrictions on communication. We introduce a large exchange economy with the usual assumption of complete and free communication between agents forming coalitions. Communication may be interpreted as establishing trade flows between agents. In the corresponding large network economy, communication is restricted, e.g., because it is costly. Using a theorem by Grodal (1972), we show that the core of this network economy is equal to the core of the corresponding economy with complete communication. Since we may assume that the information cost in a network economy is much lower than in an economy with complete communication, and since the outcome under coalition formation is equal, the network economy is shown to be superior to the economy with complete communication. This result will be even more striking when applied on an economy where optimality conditions require more exchange of information, such as in case of externalities and of public goods.

The idea of introducing an asymmetry between agents in a game by means of a graph goes back to Aumann and Drèze (1974) and notably Myerson (1977). In Gilles and Ruys (1990), this asymmetry is related to the agent's attributes as expressed in a topological space, but not necessarily derived from it. The resulting communication pattern is assumed to be given and deterministic. The idea to be developed further is that only one network from the large set of potential and feasible networks in an economy, may prove fit to perform as an established or social network. Which one from the set of contestible networks will emerge as a social organization, may be analyzed by means of evolutionary game theory. In this case, it is not the individual agent who is determining the final communication pattern, but the determination is based on the interaction of individual decisions. This approach is in line with the micro-to-macro transition, as proposed by Coleman (1990).

Another approach is to consider the choice of an agent with whom to communicate, the communication pattern, to be stochastic. This approach is followed by Kirman (1983), Haller (1990 and 1992), Ioannides (1990), and Vriend (1991).

The remainder of the paper is organized as follows. In section 2 the social environment is introduced. Section 3 develops the notions of a network and a network economy. The core equivalence between a large exchange economy and a corresponding network economy is given in section 4.

2 Abstract social environments

In the literature on general economic equilibrium theory one uses the concept of a *social system* or *abstract economy* to indicate a mathematical system that has the principal features of an exchange economy.[1] Essentially an abstract economy consists of a set of agents and a mapping that assigns to every agent some tuple of individual economic attributes. Usually one takes a topological attribute space. We thus conclude that in most cases an abstract economy is equivalent to a subspace of a topological attribute

[1] For this application of this notion of a mathematical system we refer to, e.g., Debreu (1959), Shafer and Sonnenschein (1975a and 1975b), and Vind (1983). In most of these contributions one uses abstract economies to describe the principles of the existence of a competitive Walrasian equilibrium in a market system.

space. An element in this subspace is a specification of the attributes that characterize agents. Such a specification represents a *type* of agents. Usually many agents may belong to the same type, but in this paper we assume that types are identical to agents.

In the sequel we will use the equivalence between an abstract economy and a topological attribute space to introduce a social system as a topological space endowed with some binary (communication) relation. Such a social system extends the abstract economy in two directions. Firstly, communication restrictions between agents are explicitly described. This is done through the introduction of the binary communication relation on the collection of agents or types. Secondly, we allow for an explicit interdependency of the topological structure and the communication pattern. It is namely assumed that the topology can be generated by a neighbourhood system consisting of sets of relationally linked types only.

We develop the notion of such a social system in several stages. The first stage is the introduction of a type space, representing a collection of economic agents by means of their description with certain individual attributes. We restrict this type space by the requirement that its topologically connected components are at most countable. Usually this number is very small, in order to obtain a comprehensible representation of a type. In most general equilibrium models there is only one such component, viz. a Cartesian product of the commodity space.

Definition 2.1 *A* **type space** *is a pair* (A, τ)*, where* A *is a collection of types and* $\tau \subset 2^A$ *is a topology on* A *such that there exist at most countably many maximally topologically connected components in* (A, τ)*.*

Let $a, b \in A$ be two abstract types in the type space (A, τ). The fact that there exists a neighbourhood $U \in \tau$ of a with $b \in U$, is now regarded as a representation of a generalized notion of distance between the types a and b. (See also Kopperman (1988).) Usually one would require that (A, τ) is a metrizable space. As an example of a compact metrizable type space we mention the classical economic attribute space $\mathbb{R}^\ell_+ \times \mathcal{P}$, where the ℓ-dimensional Euclidean subspace $\mathbb{R}^\ell_+$ represents the commodity space and $\mathcal{P}$ is the space of continuous preference relations on $\mathbb{R}^\ell_+$ endowed with the topology of closed convergence.[2] A type is now a tuple $(w, \succsim)$, where $w \in \mathbb{R}^{\ell}_{+}$ is an initial commodity endowment and $\succsim \in \mathcal{P}$ is a preference relation over the commodity space $\mathbb{R}^{\ell}_{+}$.

As a consequence of this definition we may introduce for every type space (A, τ) a *subdivision* of A as a collection

$$\mathbf{A} := \{A_n \mid n \in \mathbb{N}\},$$

of maximally connected components in (A, τ). This collection is at most countable. In the sequel we denote for every type $a \in A$ by $\mathbf{A}(a) \in \mathbf{A}$ the unique component of A such that $a \in \mathbf{A}(a)$. The components of the subdivision $\mathbf{A}$ of (A, τ) may be interpreted as *social classes* in the following sense. Types within a social class vary gradually, while types between social classes vary discontinuously.

Note that the subdivision is fully determined by the chosen topology. One may consider the world population and choose the distance over land as measure of distance between agents. Then the subdivision of the world population in social classes consists of sets of people living on the same continent. It is also clear that a trivial division consisting of one social class is admitted, in which case the world consists of one continent. Although a specification of these concepts should give a clue to the causes of specific ruptures in a chosen topology, only a dynamic theory can explain why certain ruptures creating social classes evolve.

Definition 2.2 *Let (A, τ) be a type space. A binary relation $R \subset A \times A$ is a* **communication pattern** *on (A, τ) if it satisfies the following properties:*

(i) *R is symmetric and reflexive.*

(ii) *(A, R) is* finitely connected, *i.e., for all $a, b \in A$ there exists a finite sequence $c_1, \ldots, c_k \in A$ such that $c_1 = a$, $c_k = b$, and $(c_i, c_{i+1}) \in R$ for every $1 \leq i \leq k-1$.*

(iii) *For every type $a \in A$ there exists an open neighbourhood $U_a \in \tau$ with*

[2] For a detailed analysis of this space we refer to Hildenbrand (1974) and Grodal (1974).

$$a \in U_a \subset R(a) := \{b \in A \mid (a,b) \in R\}.$$

A communication pattern describes the direct economic relationships between economic agents represented by their type. It is clear that these relations are non-hierarchical (Condition (i)), the economy as a whole forms a communicative unit (Condition (ii)), and finally agents of similar type are able to communicate with each other (Condition (iii)). This last condition explicitly links similar types with each other although in the classical economic attribute space it is least expected that similar types may achieve a profitable trade.

As a consequence of the adoption of a communication pattern R on a type space (A, τ) we may introduce a condensation of that pattern to the class structure of A.

Definition 2.3 *Let (A, τ) be a type space and let $R \subset A \times A$ be a communication pattern on (A, τ). Let $\mathbb{P}$ be given by*

$$\mathbb{P} := \{(A_n, A_m) \in \mathbf{A} \times \mathbf{A} \mid \exists a \in A_n, \exists b \in A_m \text{ such that } (a,b) \in R\}.$$

Then the pair $(\mathbf{A}, \mathbb{P})$ is called the **class structure** *of (A, τ, R).*

The elements in the subdivision $\mathbf{A}$ are interpreted as social classes. In that sense the condensed relations in $\mathbb{P}$ represent the interclass communication pattern. Our framework is completed by the introduction of a finite scope property on the class structure $(\mathbf{A}, \mathbb{P})$ of R on (A, τ).

Definition 2.4 *A triple (A, τ, R) is a* **social environment** *if (A, τ) is a type space and $R \subset A \times A$ is a communication pattern on (A, τ) such that the triple (A, τ, R) satisfies the finite scope property: For every class $A_n \in \mathbf{A}$*

$$|\mathbb{P}(A_n)| < \infty,$$

where

$$\mathbb{P}(A_n) := \{A_m \in \mathbf{A} \mid (A_n, A_m) \in \mathbb{P}\}.$$

A social environment is a type space endowed with a communication pattern such that the class structure represents "sparse" communication possibilities between the different classes in the economy.[3] It may be clear that this assumption of finite scope simplifies our analysis considerably. In Gilles and Ruys (1990) we have shown that the connectivity condition of a communication pattern implies the finite connectedness of the class structure of the social environment. In that case the economy as a whole forms a communicative unit.

Lemma 2.5 (Gilles-Ruys (1990))
Let (A, τ, R) be a social environment. Then its class structure $(\mathbf{A}, \mathbf{P})$ is a finitely connected graph.

3 Networks

There are many ways in which communication between agents in a social environment (A, τ, R) can be established. It is in general not necessary that all communication relations in (A, R) are activated in order to obtain full communication between all agents. The question is how communication will be organized between agents. Not any pattern of agents who communicate with some other agent in (A, R) will be called a *network*. In this section we will define feasibility and efficiency criteria for networks in a social environment (A, τ, R).

Definition 3.1 *A subset $N \subset A$ is a* **network** *in (A, τ, R) if it satisfies the two following requirements:*

Full Scope

It holds that $R(N) := \bigcup_{a \in N} R(a) = A$.

Connectivity

For every $a, b \in N$ there exists a finite sequence $c_1, \ldots, c_n$ in N with $c_1 = a$,

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[3]The concept "social communication" differs from the concept "individual communication" in the sense that the first concept expresses a for everybody observable and commonly known pattern. This is indicated by the condition of *finite scope*. The second concept expresses a pattern based on private information, which is not necessarily observable, nor otherwise restricted.

$c_n = b$, *and* $(c_i, c_{i+1}) \in R$ *for every* $i \in \{1, \dots, n-1\}$.

The definition of a social environment implies that the collection of types A is a network. The next lemma shows that the collection of networks is indeed quite large.

Lemma 3.2 *If* $N \subset A$ *is a network in* (A, τ, R)*, then any set* $M \subset A$ *with* $N \subset M$ *is also a network in* (A, τ, R).

PROOF

Let $N \subset A$ and $M \subset A$ be such that N is a network in (A, τ, R) and $N \subset M$. Now if $M = N$ the assertion is evident, thus we may suppose that $N \subsetneq M$.

This immediately implies that $R(N) = A \subset R(M)$ and thus M satisfies full scope.

By full scope of N it follows that for every type $a \in M \setminus N$ there exists a type $b \in N$ with $(a, b) \in R$. This immediately implies by connectivity of N that M also has to satisfy connectivity.

□

The previous discussion makes clear that the notion of a network is too weak to give a meaningful description of a group of types that is able to handle all communication within a social environment. Additionally we require that such an organization is crudely efficient in the sense that it is constituted of a minimal number of types.

Definition 3.3 *A subset* $N \subset A$ *is a* **minimal network** *in* (A, τ, R) *if it is a network in* (A, τ, R) *and additionally it satisfies*

Minimality

There is no type $a \in N$ *such that* $N \setminus \{a\}$ *is a network in* (A, τ, R).

The next result shows that the efficiency requirement as formulated above is equivalent to minimality in the sense of set inclusion.

Lemma 3.4 *A subset* $N \subset A$ *is a minimal network in* (A, τ, R) *if and only if it is a network in* (A, τ, R) *and there is no proper subset* $M \subsetneq N$*, which is also a network in* (A, τ, R).

Proof

The "if"-part is evident.

To check the "only if"-part we take $N \subset A$ as a minimal network and suppose by contradiction that there is a proper subcollection $M \subsetneq N$ that is a network in (A, τ, R). Take $a \in N \setminus M$. By Lemma 3.2 and $M \subset N \setminus \{a\}$ we know that $N \setminus \{a\}$ is also a network in (A, τ, R). Hence, we have a contradiction with the minimality requirement of N.

$\square$

The first main result concerns the existence of networks in a limited class of social relational systems, satisfying compactness of the topological type space. The literature on general economic equilibrium, e.g., Grodal (1974), Hildenbrand (1974) and Mas-Colell (1985), shows that this requirement is usually acceptable within the traditional setting. In our model compactness of the type space, however, has in general to be evaluated as quite strong an assumption. The reason for this is that the requirement of the interdependency of the topology and the communication pattern as formulated in Definition 2.2 (iii) may be the cause of less nicely configured neighbourhood systems. Theorem 3.5 is therefore considered as a necessary first step in the proof of the more general existence result as stated in Theorem 3.6.

Theorem 3.5 *If (A, τ, R) is a social environment such that (A, τ) is a compact topological space, then there exists a finite minimal network in (A, τ, R).*

Proof

Since (A, τ) is a compact topological space we know that the covering $\mathcal{C} = \{U_a \in \tau \mid a \in A \text{ and } U_a \subset R(a)\}$ of A has a finite subcovering $\mathcal{D}$. Let W be the set given by $W = \{a \in A \mid U_a \in \mathcal{D}\}$.

Furthermore we define

$$\mathcal{Q} := \{N \subset A \mid N \text{ is a finite network in } (A, \tau, R)\}.$$

First we show that $\mathcal{Q} \neq \emptyset$. It is clear that $W \subset A$ is finite and satisfies full scope. Next define the mapping $\Delta \colon W \times W \to 2^A$, where $\Delta(a, b) = \{c_1, \ldots, c_K\} \subset A$ such that

$c_1 = a$, $c_K = b$, and $(c_k, c_{k+1}) \in R$ for every $k \in \{1, \ldots, K-1\}$. This mapping Δ is well defined by the connectivity assumption as given in Definition 2.4 (ii).
Let $\Phi := \bigcup_{\pi \in W \times W} \Delta(\pi)$. Clearly $W \subset \Phi$ and thus $A = R(W) \subset R(\Phi)$. By construction of Φ it is also evident that it satisfies connectivity. Moreover Φ is a finite set and thus $\Phi \in \mathcal{Q}$.

We order the collection $\mathcal{Q}$ by set theoretic inclusion. Take any totally ordered subcollection $\mathcal{B}$ of $\mathcal{Q}$. Now it is evident that $\cap\mathcal{B}$ is a lower bound of $\mathcal{B}$ with respect to inclusion, and that $\cap\mathcal{B} \neq \emptyset$. From finiteness it thus follows that $\cap\mathcal{B} \in \mathcal{Q}$. By application of Zorn's lemma there exists a minimal element in the collection $\mathcal{Q}$, say N^*. Obviously N^* is finite and satisfies full scope and connectivity. Therefore it has to be a finite minimal network in (A, τ, R).

□

As mentioned before the setting of our framework, in particular requirement 2.2 (iii), leaves open the problem whether under less strong conditions there exist minimal networks. In order to formulate a more general existence theorem, we use the finite scope condition as formulated in Definition 2.4.

Reordering Lemma. *Let (A, τ, R) be a social environment. There exists an ordering of the subdivision $\mathbf{A} = \{A_n \mid n \in \mathbb{N}\}$ such that*

(i) *for every $k \in \mathbb{N}$ the graph $(\bigcup_{n=1}^{k} A_n, R \cap [\bigcup_{n=1}^{k} A_n \times \bigcup_{n=1}^{k} A_n])$ is finitely connected and*

(ii) *$\mathbf{A}$ can be partitioned into a countable collection of sets $(\mathbf{B}_i)_{i \in \mathbb{N}}$, where each $\mathbf{B}_i$ is a finite union of sets in $\mathbf{A}$ such that:*

$$\mathbf{B}_1 = \{A_1\},$$

$$\mathbf{B}_2 = \{A_2, \ldots, A_{n_2}\} \quad \textit{with} \quad n_2 > 1,$$

$$\mathbf{B}_r = \{A_{n_{r-1}+1}, \ldots, A_{n_r}\} \quad \textit{with} \quad n_r > n_{r-1}, \quad \textit{for} \quad r \geqq 2,$$

where $n_r \in \mathbb{N}$ for every $r \in \mathbb{N}$.
If $|r_1 - r_2| = 1$, then there exist components $A_{k_1} \in \mathbb{B}_{r_1}$ and $A_{k_2} \in \mathbb{B}_{r_2}$ such that $(A_{k_1}, A_{k_2}) \in \mathbb{P}$.
If $|r_1 - r_2| > 1$, then for all components $A_{k_1} \in \mathbb{B}_{r_1}$ and $A_{k_2} \in \mathbb{B}_{r_2}$ it holds that $(A_{k_1}, A_{k_2}) \notin \mathbb{P}$.

PROOF
The proof of this lemma can easily be derived from the fact that $\mathbf{A}$ satisfies the finite scope property. Take an arbitrary $A_1 \in \mathbf{A}$. Next define $\mathbb{B}_1 := \{A_1\}$ and $\mathbb{B}_2 := \{A_n \in \mathbf{A} \setminus \mathbb{B}_1 \mid (A_n, A_1) \in \mathbb{P}\}$. Moreover, let $\mathbb{B}_{r-1}$, with $r \geqq 2$, be constructed, then we choose

$$\mathbb{B}_r := \left\{ A_n \in \mathbf{A} \setminus \bigcup_{k=1}^{r-1} \mathbb{B}_k \,\middle|\, (A_n, A_m) \in \mathbb{P}, \ \text{ for some } \ A_m \in \mathbb{B}_{r-1} \right\}.$$

$\square$

With the use of the Reordering Lemma[4] we are able to prove an extension of the existence result as formulated in Theorem 3.5.

Theorem 3.6 *Let (A, τ, R) be a social environment. Let the following properties be satisfied:*

(i) *(A, τ) is a Hausdorff space.*

(ii) *For every $n \in \mathbb{N}$ the component A_n is a compact subspace of (A, τ).*

(iii) *Derive an ordering and a partition $(\mathbb{B}_i)_{i \in \mathbb{N}}$ of the condensation $(\mathbf{A}, \mathbb{P})$ as described in the Reordering Lemma. There exists an $\overline{N} \in \mathbb{N}$ such that for every $j \geqq \overline{N}$ there is a unique type $\widehat{a}_j \in A$ with $\mathbf{A}(\widehat{a}_j) \in \mathbb{B}_j$ such that*

$$R(\widehat{a}_j) \cap \mathbf{A}^{-1}(\mathbb{B}_{j+1}) \neq \emptyset,$$

where for every $\mathbf{A}' \subset \mathbf{A}$ we define $\mathbf{A}^{-1}(\mathbf{A}') := \{a \in A \mid \mathbf{A}(a) \in \mathbf{A}'\}$.

[4] We remark that the reordering of the class structure as developed in the Reordering Lemma is not unique.

Then there exists a countable minimal network in (A, τ, R).

PROOF

Let $\mathbf{A}$ be ordered as in the Reordering Lemma and denote by $(\mathbb{B}_j)_{j\in\mathbf{N}}$ the belonging partition of the condensation $(\mathbf{A}, \mathbb{P})$. Note that from the Reordering Lemma it follows that for a fixed $k \in \mathbf{N}$ it holds that for all types $a \in \mathbf{A}^{-1}(\mathbb{B}_k)$ and numbers $m \in \mathbf{N}$ with $|k-m| > 1$: $R(a) \cap \mathbf{A}^{-1}(\mathbb{B}_m) = \emptyset$.

We now take a fixed number $k \in \mathbf{N}$.

We define the collection, denoted by $\mathcal{S}_k \subset 2^A$, as the class of all *finite* networks H in the truncated social environment $(\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j), \tau|\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j), R \cap [\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j) \times \bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j)])$ such that $\widehat{a}_k \in H$. Note that $\mathcal{S}_k \neq \emptyset$. This is deduced from the application of Theorem 3.5 to the compact social environment $(\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j), \tau|\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j), R\cap [\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j) \times \bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j)])$. Moreover, it is evident that the collection $\mathcal{S}_k$ has a minimal element. We denote this minimal element by E_k. We remark that $E_k \in \mathcal{S}_k$, and hence it is a network such that $\widehat{a}_k \in E_k$, but that E_k is not necessarily a minimal network.

From the sequence $(E_k)_{k\in\mathbf{N}}$ we now construct another sequence, denoted by $(E_k^\star)_{k\in\mathbf{N}}$, consisting of minimal networks, i.e., for every $k \in \mathbf{N}$ the collection $E_k^\star$ is a minimal network in the truncated social environment $(\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j), \tau|\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j), R \cap [\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j) \times \bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j)])$.

For the construction of the sequence we take a fixed integer $k \in \mathbf{N}$, and we note that we have two possibilities:

1. E_k is a minimal network in
$$\left(\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j), \tau \left| \bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j), R \cap \left[\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j) \times \bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j)\right]\right.\right).$$
Then we take $E_k^\star = E_k$.

2. If E_k is not a minimal network in
$$\left(\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j), \tau \left| \bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j), R \cap \left[\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j) \times \bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j)\right]\right.\right),$$

then by construction of E_k and property (ii) in the assertion it follows that $E_k \setminus \{\widehat{a}_k\}$ is a minimal network in $(\bigcup_{j=1}^{k} \mathbf{A}^{-1}(\mathbb{B}_j), \tau | \bigcup_{j=1}^{k} \mathbf{A}^{-1}(\mathbb{B}_j), R \cap [\bigcup_{j=1}^{k} \mathbf{A}^{-1}(\mathbb{B}_j) \times \bigcup_{j=1}^{k} \mathbf{A}^{-1}(\mathbb{B}_j)])$. Hence we take $E_k^\star := E_k \setminus \{\widehat{a}_k\}$.

Now for every $k \geqq \overline{N}$ it holds that $E_k^\star \subset E_{k+1}^\star$.
In fact, since E_{k+1} is a network, it holds by property (iii) of the assertion that $\widehat{a}_k \in E_{k+1}$. But it also holds that $E_k \setminus \{\widehat{a}_k\} \subset E_{k+1}$, since there is *no* direct relation between any type in $E_k \setminus \{\widehat{a}_k\}$ and any type in $E_{k+1} \setminus E_k$, i.e., $R \cap (E_k \setminus \{\widehat{a}_k\} \times E_{k+1} \setminus E_k) = \emptyset$. From these properties it easily follows that $E_k^\star \subset E_{k+1}^\star$.

Hence the sequence $(E_k^\star)_{k \in \mathbf{N}}$ is increasing with respect to inclusion, and so we can define the following set:

$$E^\star := \mathrm{Li}(E_k^\star) \equiv \mathrm{Ls}(E_k^\star)$$

By the obvious theorems it is easily established that $E^\star$ is the closed limit of the sequence $(E_k^\star)_{k \in \mathbf{N}}$. (For an elaboration of this remark we refer to Klein-Thompson (1984) and the introduction in Hildenbrand (1974). There are also given the definitions of the operators Li and Ls in connection with the topology of closed convergence on a hyper-space of closed subsets of a certain topological space.)

It is now easily proved that the collection $E^\star$ is in fact a countable minimal network in (A, τ, R):

Countability

$E^\star$ is an at most countable subset of A, since for every $k \in \mathbf{N}$ the collection $E_k^\star$ is finite.

Full Scope

$R(E^\star) = A$.

Suppose that this is not true. Then there exists a type $a \in A$ such that $a \notin R(E^\star)$. But there also exists a number $K \geqq \overline{N}$, such that $a \in \mathbf{A}^{-1}(\bigcup_{j=1}^{K} \mathbb{B}_j) = \bigcup_{j=1}^{K} \mathbf{A}^{-1}(\mathbb{B}_j)$, and hence $a \in R(E_K^\star) \subset R(E^\star)$. This is a contradiction.

Connectivity

The truncated social environment $(E^\star, \tau | E^\star, R \cap [E^\star \times E^\star])$ is finitely connected.

Take any pair of types $a, b \in E^\star$, then there exists a number $K \geqq \overline{N}$ such that $a, b \in E^\star_K$. By construction of the sequence $(E^\star_k)_{k\in\mathbb{N}}$ it holds that a and b are finitely connected within $E^\star_K$, and hence are finitely connected within $E^\star_j$ for every $j \geqq K \geqq \overline{N}$. Therefore a and b are finitely connected within $E^\star$.

Minimality

Suppose there exists a type $a \in E^\star$ such that the collection $E^\star \setminus \{a\}$ also satisfies full scope and finite connectivity, i.e., it is also a network in (A, τ, R).
Now there exists an integer $j \in \mathbb{N}$ such that $a \in \mathbf{A}^{-1}(\mathbb{B}_j)$, with $a \neq \hat{a}_j$ if $j \geqq \overline{N}$. Then it is easy to show that for $K := \max\{j, \overline{N}\}$ it holds that E_K can *not* be a minimal element in the collection $\mathcal{S}_k$, consisting of networks in $(\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j), \tau | \bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j), R \cap [\bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j) \times \bigcup_{j=1}^k \mathbf{A}^{-1}(\mathbb{B}_j)])$ containing the unique element $\hat{a}_K \in \mathbf{A}^{-1}(\mathbb{B}_K)$. This is in contradiction with the assumption on E_K, and hence with the assumptions on $E^\star$.

This concludes the proof of the theorem.

$\square$

4 The core of a large network economy

In this section we consider a specific application of the notion of a network of a social environment as explored in the previous sections. We limit ourselves to social relational systems (A, τ, R) such that (A, τ) is a subspace of the common attribute space $\mathcal{P} \times \mathbb{R}^\ell_+$ in the description of exchange economies.

Let $\ell \in \mathbb{N}$ be the number of commodities to be exchanged. Now the nonnegative orthant of the ℓ-dimensional Euclidean space $\mathbb{R}^\ell_+$ describes the space of all possible commodity bundles. The space $\mathcal{P}$ describes all preference relations on the commodity space $\mathbb{R}^\ell_+$, and is endowed with the topology of closed convergence. Grodal (1974) and Hildenbrand (1974) have shown that $\mathcal{P}$ is a compact, separable and metrizable space. This implies that the product space $\mathcal{P} \times \mathbb{R}^\ell_+$ is separable and metrizable.

Definition 4.1 *A* **large exchange economy** *is a triple* $\mathbb{E} = \langle A, \tau, \mu \rangle$, *where*

(i) (A, τ) *is an uncountable, connected, compact and metrizable subspace of* $\mathcal{P} \times \mathbb{R}^\ell_+$. *Let* $d: A \times A \to \mathbb{R}_+$ *denote the metric belonging to the topology* τ *on* A.

(ii) $\mu: \sigma(\tau) \to [0, 1]$ *is a normalized atomless measure on the* σ*-algebra of all Borel measurable sets of the attribute space* (A, τ).

In a large exchange economy, an economic agent $a \in A$ is represented again by its *type*, i.e., the attributed preference relation $\succ_a \in \mathcal{P}$ on the commodity space $\mathbb{R}^\ell_+$ and the attributed initial endowment $w_a \in \mathbb{R}^\ell_+$ of commodities. We remark that the assignment of preferences and initial endowments are measurable. We will assume that the assignment w of initial endowments is integrable and that $\int w \, d\mu \gg 0$. Since the topological space A is connected, there is only one social class in A.

The assumption that (A, τ) is connected, i.e., that there is only one class in the economy, is usually not required in the literature on core theory. With this additional assumption we do not lose any genericity of the analysis below, but it makes the subsequent analysis more accessible. We remark that we may derive the same results if we assume that (A, τ) is an at most countable union of connected components.

The communication situation in a large exchange economy is assumed to be complete. Evidently this situation corresponds to a social environment $(A, \tau, A \times A)$, i.e., a social environment in which all economic agents are related with each other. This implies that in principle each measurable group of economic agents $E \in \sigma(\tau)$ is supposed to be formable as a coalition in which the members can exercise economic exchange activities.

An *allocation* in a large exchange economy $\mathbb{E} = \langle A, \tau, \mu \rangle$ is defined as an integrable function $f: A \to \mathbb{R}^\ell_+$ such that

$$\int f \, d\mu \leqq \int w \, d\mu.$$

The equilibrium concept to be considered in the setting of a large exchange economy $\mathbb{E}$ is that of the *core*. This is the collection of allocations, which cannot be improved upon by any coalition of economic agents.

Definition 4.2 *Let* $\mathbb{E} = \langle A, \tau, \mu \rangle$ *be a large exchange economy.*

(a) *A coalition $E \in \sigma(\tau)$ is able to* **improve upon** *an allocation $f: A \to \mathbb{R}_+^\ell$ if there exists an integrable function $g: E \to \mathbb{R}_+^\ell$ such that*

$$\int_E g \, d\mu \leqq \int_E w \, d\mu, \qquad \text{and}$$

$$g(a) \succ_a f(a) \quad \text{for all} \quad a \in E.$$

(b) *An allocation $f: A \to \mathbb{R}_+^\ell$ is a* **core allocation** *in* $\mathbb{E}$ *if there is no coalition $E \in \sigma(\tau)$ that is able to improve upon f.*

The core of the large exchange economy $\mathbb{E}$ is now the collection of all core allocations in $\mathbb{E}$. We denote the core of $\mathbb{E}$ by $\mathcal{C}(\mathbb{E})$. In a large exchange economy E $\mathcal{C}(\mathbb{E}) \neq \emptyset$ if for all types $a \in A$ the preference relation $\succ_a \in \mathcal{P}$ is continuous, convex, and monotone.

Next we define an exchange network economy as a large exchange economy endowed with such a communication constraint R on A that $N \subset A$ is a minimal network in the social environment. Let $\mathbb{E} = \langle A, \tau, \mu \rangle$ be a large exchange economy and let $R \subset A \times A$ be a relation on A such that the triple (A, τ, R) is a social environment. Since (A, τ) is a compact metrizable space it immediately follows from Theorem 3.5 that there exists a finite minimal network in (A, τ, R). This justifies the next definition.

Definition 4.3 *An* **exchange network economy** *is defined as a quintuple $\mathbb{E}_{en} = \langle A, \tau, \mu, R, N \rangle$, where $\mathbb{E} = \langle A, \tau, \mu \rangle$ is a large exchange economy, $R \subset A \times A$ is a relation on A such that (A, τ, R) is a social environment, and $N \subset A$ is a minimal network in (A, τ, R).*

An alternative notation for a exchange network economy $\mathbb{E}_{en}$ is given by the triple $\langle \mathbb{E}, R, N \rangle$, where the triple $\mathbb{E} = \langle A, \tau, \mu \rangle$ is a large exchange economy such that $\mathbb{E}_{en} = \langle A, \tau, \mu, R, N \rangle$.

In the sequel we will limit our analysis to a specific type of exchange network economy. Let $\langle A, \tau, \mu \rangle$ be a large exchange economy and let $\varepsilon > 0$ be any positive real number. We define the relation $R_\varepsilon \subset A \times A$ as for every $a, b \in A$ given by $(a, b) \in R_\varepsilon$ if and only if $d(a, b) < \varepsilon$, where d denotes the metric belonging to (A, τ).

Obviously R_ε is a properly defined communication pattern. This, together with the fact that the topological attribute space (A,τ) is assumed to be topologically connected, implies that the conditions of Definition 2.4 are satisfied. Therefore the triple (A,τ,R_ε) is indeed a social environment. We now denote by $\mathbb{E}_\varepsilon$ the network economy $\langle \mathbb{E}, R_\varepsilon, N_\varepsilon\rangle$. Clearly the network economy $\mathbb{E}_\varepsilon$ describes a situation in which "similar" agents are aggregated in social tribes and are able to communicate with each other, while "dissimilar" agents are assumed to be unable to communicate. Here the threshold determining whether agents are similar or dissimilar is given by the test whether the "distance" between the attributes of the agents is smaller than ε.

The application of a limitation on the communication structure implies that there are constraints in coalition formation. In this we follow the rule that the constituting groups of agents forming a coalition are the social tribes as loosely introduced above. Different tribes within a formable coalition have to be able to communicate through the (minimal) network N_ε, and all agents in a neighbourhood in a formable coalition are able to communicate directly. Thus, a formable coalition consists of a finite number of tribes, in which there is complete communication, and such that the finite minimal network N_ε can organize all communication *between* those tribes. Moreover, we will require that the mass or number of agents in a tribe of any formable coalition is limited by ε.

Definition 4.4 *A coalition $E \subset A$ is* **formable** *within the network economy $\mathbb{E}_\varepsilon$ if there exist sets $E_1,\ldots,E_M$ in $\sigma(\tau)$ and $\{a_1,\ldots,a_K\} \subset N_\varepsilon$ such that*

(i) $E = \cup_{m=1}^{M} E_m \cup \{a_1,\ldots,a_K\}$;

(ii) *for every $1 \leqq m \leqq M$: $E_m \in \sigma(\tau)$ with $\mu(E_m) < \varepsilon$ and $\operatorname{diam}(E_m) < \varepsilon$, where the diameter of a set $E \subset A$ is defined as $\operatorname{diam}(E) := \sup\{d(a,b) \mid a,b \in E\}$;*

(iii) *for every $1 \leqq m \leqq M$ and for all $b \in E_m$ there exists $1 \leqq k \leqq K$ with $d(b,a_k) < \varepsilon$, and*

(iv) *$\{a_1,\ldots,a_K\}$ is a connected subnetwork of N_ε in R_ε, i.e., for all $1 \leqq k \leqq K-1$: $d(a_k,a_{k+1}) < \varepsilon$.*

An allocation $f: A \to \mathbb{R}_+^\ell$ is now a *core allocation* in the network economy $\mathbf{E}_\varepsilon$ if f cannot be improved upon by any formable coalition in $\mathbf{E}_\varepsilon$. We denote the collection of all core allocations in $\mathbf{E}_\varepsilon$ by $\mathcal{C}(\mathbf{E}_\varepsilon)$. Since we have introduced constraints in coalition formation it is clear that the collection of all core allocations of the minimal network economy $\mathbf{E}_\varepsilon$ is containing the core of the original large exchange economy $\mathbf{E}$. The reverse inclusion however also holds as is shown in the following proposition.

Proposition 4.5 *Let* $\mathbf{E}_\varepsilon = \langle \mathbf{E}, R_\varepsilon, N_\varepsilon \rangle$. *Then*

$$\mathcal{C}(\mathbf{E}_\varepsilon) = \mathcal{C}(\mathbf{E}).$$

PROOF

As we already noted it is evident that $\mathcal{C}(\mathbf{E}) \subset \mathcal{C}(\mathbf{E}_\varepsilon)$. To show the reverse we apply the main result of Grodal (1972). We remark that $\mathbf{E}$ indeed satisfies the requirements as formulated in Grodal (1972). Her theorem now states that if f can be improved upon by some coalition $E' \in \sigma(\tau)$, then it can also be improved upon by a coalition $E = \bigcup_{m=1}^M E_m$, where $E_1, \ldots, E_M$ in $\sigma(\tau)$ are such that $\mu(E_m) < \varepsilon$ as well as $\operatorname{diam}(E_m) < \varepsilon$. We recall that N_ε is a finite subset of A, and thus $N_\varepsilon \in \sigma(\tau)$ and $\mu(N_\varepsilon) = 0$.
By definition of the minimal network N_ε in (A, τ, R_ε) for every $1 \leqq m \leqq M$ and every $b \in E_m$ there exists $a \in N_\varepsilon$ such that $d(b, a) < \varepsilon$. Thus, for every $1 \leqq m \leqq M$ there exists $\{a_1^m, \ldots, a_{k(m)}^m\} \subset N_\varepsilon$ such that for every $b \in E_m$ there is $1 \leqq k \leqq k(m)$ with $d(b, a_k^m) < \varepsilon$. Define

$$Q := \bigcup_{m=1}^M \left\{a_1^m, \ldots, a_{k(m)}^m\right\}.$$

If the collection Q is a connected subnetwork of N_ε in R we have shown that $E \cup Q$ is a formable coalition in $\mathbf{E}_\varepsilon$, which is able to improve upon f.
If Q is not a connected subnetwork of N_ε in R, we may add network types $\hat{a}_k \in N_\varepsilon$, $1 \leqq k \leqq K$, such that $Q \cup \{\hat{a}_k \mid 1 \leqq k \leqq K\}$ forms a connected subnetwork of N_ε in R. Clearly $E \cup Q \cup \{\hat{a}_k \mid 1 \leqq k \leqq K\}$ now is a formable coalition in $\mathbf{E}_\varepsilon$, which is able to improve upon f.
We therefore conclude that $\mathcal{C}(\mathbf{E}_\varepsilon) \subset \mathcal{C}(\mathbf{E})$ and thus we have shown the assertion.

$\square$

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