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QUADERNI DEL DIPARTIMENTO
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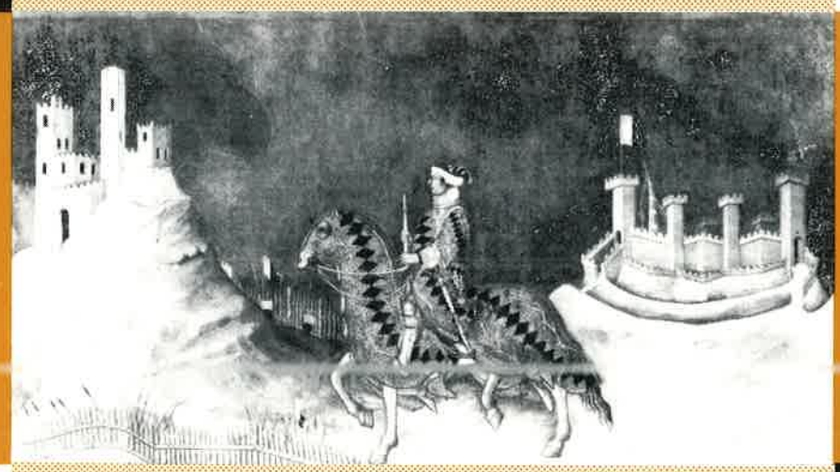
NICOLA DIMITRI

LEARNING PARTITIONS



QUADERNI DEL DIPARTIMENTO DI ECONOMIA POLITICA

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LEARNING PARTITIONS

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LEARNING PARTITIONS[1]

1. Introduction

In economic theory partitional information structures are seen to be the outcome of individuals' information processing, where agents are supposed to have quite a high degree of sophistication. In particular, partitions are assumed to be the way in which information is imparted to Bayesian-rational agents. However, several authors have recently discussed some possible systematic departures from this kind of sophistication and formalized lower degrees of rationality (Geanakoplos (1989), Samet (1989), Brandenburger-Dekel-Geanakoplos (1992), Samet (1992)). The basic idea is that of structuring the imparting of information on the basis of some identifiable information processing ability; a whole taxonomy of such properties can be found in Geanakoplos (1989). When certain remarkable properties are satisfied generalized information structures become partitions.

Worth of notice is that the context in which the discussion is typically framed is static, in the sense that time does not explicitly enter these models. This entails a seemingly important consequence; reasonings about information structures properties can only be

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conducted on a counterfactual basis. Moreover, due to the absence of time, agents can never be in a position that would allow them to effectively implement some of these properties on the basis of their intuitive meaning. For example, a generalized information structure which enjoys the property of being *nested* could be interpreted as a structure reflecting the information processing ability of an individual with *memory*[2]. Within a static framework, this interpretation seems to make sense more from the point of view of an external modeller/observer than from that of an agent inside the model. In this particular case the agent would never be called upon to show his/her memory because experiments are not repeated.

In this note we introduce repeated experiments, and so time, in order to be able to model, and implement according to their interpretations, certain information processing skills on the part of the agents. In particular, we shall investigate and formalize some abilities sufficient to guarantee the almost sure convergence of a sequence of generalized information structures (possibly time-dependent) to a time-independent partition.

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2 An analogous reasoning would hold for the property of Knowing That You Know (KTYK) as regard to its interpretation. See Geanakoplos (1989).

2. The Model

Let W_t be the *true* finite state space and w_t the generic element of the space at time t, with $t=1,2,\ldots$. Assume the system evolves over time as a stochastic process made of independent and identically distributed (i.i.d.) random experiments. The probability law governing the process can be interpreted as an *objective* probability distribution; moreover, every state is assumed to have *strictly* positive probability of occurrence. Throughout the paper we shall assume that $W_t=W$, namely that the state space is time-independent; furthermore, the ensuing analysis will concern a single agent context.

We now introduce a *possibility correspondence* as the mapping $P_t:W\rightarrow 2^W-(\phi)$, with the usual interpretation that when, at time t, the true state w_t occurs the agent thinks as possible a non-empty subset of W indicated by $P_t(w_t)$. Every $P_t(w_t)$ will be called a possibility set. Notice that working with possibility correspondences, rather than with partitions, implies that an agent *can not* be aware of the mapping P_t; namely he/she can not invert the mapping and trace back the true state on the basis of his/her possibility set. Indeed, if the alleged inversion were possible (which would amount to being aware of the possibility correspondence) we would necessarily have partitions (Geanakoplos (1989)).

Unlike the above assumption concerning the state space, the possibility correspondence in general *does depend* upon time. In fact, the object of the work is precisely that of characterizing conditions which would lead *any* possibility correspondence to become, in the long run, a partition of the state space. In order to start formalizing these conditions we need first some definitions.

Definition 1 *We say that, at time t, the agent has perfect recall if all* $P_i(w_i)$ *are recalled, for* $i=1,2,..t$ *and every* $t=1,2,....$

The above simply says that the individual is completely aware of what he/she thought as possible in the past; whether or not this is a reasonable assumption depends upon the context at hand. However, the important point that one should underline here is that the definition explicitly establishes a condition concerning the *memory* of the agent. One could certainly consider the implications of adopting weaker concepts of recall; however, this is not what we shall do in this note.

The second definition we introduce concerns the ability with which the agent "connects" the current state of the world with the possibility sets thought as being possible in the current period and in the past.

Definition 2 *We say that the possibility correspondence* P_t *satisfies the property of being Sequentially Nested with Perfect Recall (SNPR) if* $w_{t+1}\epsilon P_i(w_i)$ *and* $w_{t+1}\epsilon W-P_j(w_j)$, *for some i and j (with* $i,j=1,2,..,t$, $t=1,2,..$ *and* $w_{t+1}\epsilon W$*) implies* $P_{t+1}(w_{t+1})\subseteq \cap_i P_i(w_i)-U_j P_j(w_j)$ *for all such i and j.*

The idea behind such definition should be quite clear. At each t, if the agent thought w_t as being possible in the past then he/she is currently processing information *consistently* with past possibility sets. If SNPR holds it means that the individual has the ability of recognizing that what happened today was thought as being possible in the past, when indeed this is the case. Moreover, the agent excludes from today's possibility set *all* past possibility sets (having perfect recall) which do not include today's state. The SNPR property could be considered some kind of generalization, to a dynamic setting, of the *Nested* property (Geanakoplos (1989)), since, whenever $w_{t+1}\epsilon U_i P_i(w_i)$, $i=1,..,t$, each $P_{t+1}(w_{t+1})$ is either included or disjoint from previous possibility sets. Of course, within the dynamic setting we are analyzing, the generalization needs also an assumption about memory.

Worthy of notice is that for the above definition to be given we do not need to set any hypothesis about the agent being aware of the *true* state space. Indeed, an individual may believe in a state space different from the true one; however, this is an issue which we are not

exploring here. Under this assumption we can define the following two properties.

Definition 3 *We say that the possibility correspondence P_t satisfies the property of* Sequential Knowing That You Don't Know *(SKTYDK) if $w_{t+1} \epsilon W-U_k P_k(w_k)$ implies $P_{t+1}(w_{t+1}) \subseteq W-U_k P_k(w_k)$, where $k=1,2,..,t$, $t=1,2,..$ and $w_{t+1} \epsilon W$. We say that P_t satisfies the property of* Sequential Non-Delusion *(SND) if $w_t \epsilon P_t(w_t)$ for all $t=1,2,..$*

Notice that the above properties hold irrespectively of the agent having perfect recall; for SKTYDK it is enough that he/she would recall the union of events considered as possible in the past. The property of SKTYDK generalizes, to a dynamic context, the *axiom of wisdom* (see Binmore-Brandenburger 1990) that is one of the three axioms, characterizing a knowledge operator, needed to have a partition.

It is important to underline that we are not assuming here an agent being aware of his/her information structure at *each time*, but an agent whose only *awareness* is given by his/her possibility set at time t[3] and, possibly, the previous ones. Moreover, we do not assume that the agent is aware of his/her intertemporal information processing skills.

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3 For a discussion on this point see, among others, Geanakoplos (1989), Dimitri (1992).

The three definitions given lay the ground work to the first result that we formalize below. However, before stating the proposition it is necessary to introduce some more terminology and notation.

If P_t is a partition we write Q_t and if P_t is independent of time we write P (and Q in case of a partition) .

Definition 4 *We say that as t tends to infinity a possibility correspondence tends with probability one to a partition, and we write $P_t \rightarrow Q$ w.p.1., if there exists w.p.1 a $t=T$ such that $P_t(w)=P(w)$ (time-independent) for all $t>T$, and $w' \epsilon P(w)$ implies $P(w')=P(w)$, for all $w \epsilon W$.*

It is worth pointing out that the convergence criterion does not specify which partition we are converging to. Indeed, the statement is of *qualitative* nature since the final result may depend upon the path followed by the system and the agent's specific ability in processing information. Below we formulate the main proposition which characterizes such convergence.

Proposition *If P_t satisfies SNPR and SKTYDK then $P_t \rightarrow Q$ w.p.1..*

Proof Since the experiments are i.i.d. (and the probability of each state is strictly positive) we know that w.p.1. every state $w \epsilon W$ will be visited infinitely often and that there exists, by SKTYDK, a *large enough*

$t=T$ such that $U_t P_t(w_t)=W$, with $t=1,2,..,T$. Moreover, still by SKTYDK , there is a subsequence $P_{i(1)}(w_{i(1)}),..$ $...,P_{i(n)}(w_{i(n)})$ of n possibility sets, with $n\leq T$, partitioning W. So, to prove the proposition it is enough to show that $P_{i(k)}(w_{i(k)})$, for all $k=1,..,n$, is eventually partitioned w.p.1..

Let $t(1)=min(\ t>i(k)|w_{j(1)}\epsilon P_{i(k)}(w_{i(k)})\ )$; then by SNPR we have $P_{t(1)}(w_{t(1)})\subseteq P_{i(k)}(w_{i(k)})$. Analogously, if $t(2) = min\ (\ t>t(1)|w_{t(2)}\epsilon P_{t(1)}(w_{t(1)})\ )$ we obtain $P_{t(2)}(w_{t(2)})\subseteq P_{t(1)}(w_{t(1)})$[4]. It is easy to see that the above reasoning can be iterated to obtain a nested sequence of possibility sets, which general term is given by $P_{t(k)}(w_{t(k)})$, where $k=1,2,..$.

Since the possibility sets are non-empty the sequence must converge to a non-empty possibility set, say $\underline{P}^1$. Consider a *sufficiently* large t and take $w\epsilon\underline{P}^1$; then by SNPR we have $P_t(w)=\underline{P}^1$ which implies that $P_t(w)=P_t(w')$ for all w and w' belonging to $\underline{P}^1$.

Thus, it is clear that every other nested sequence of possibility sets of this kind converges to a possibility set included in $P_{i(k)}(w_{i(k)})$. From the above argument we can then conclude that any two such limiting possibility sets, say $\underline{P}^1$ and $\underline{P}^2$, are either coinciding or disjoint. Of course, i.i.d. experiments and strictly positive probability, guarantee the long run coverage w.p.1. of $P_{i(k)}(w_{i(k)})$, which is then asymptotically partitioned by possibility sets. Q.E.D.

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4 Notice that the random variables $t(i)$, with $i=1,2,..$, will be finite w.p.1..

Some comments are in order. First of all we can immediately notice that if the weak inclusion characterizing SNPR would hold as a strict inclusion for large enough t the asymptotic partition will be the finest one which, moreover, would also be non-deluded. However, the property of being non-deluded always characterizes the sets forming the asymptotic partition even if the partition is coarser then the finest one. Below we formalize such conclusion

Corollary 1 *If P_t satisfies SNPR and SKTYDK then $P_t\rightarrow Q$ w.p.1. and Q is non-deluded.*

Proof Immediate from the main proposition. Q.E.D.

It should be observed that the main role of SKTYDK is that of guaranteeing the "coverage" of all elements of the state space in a manner "consistent" with previous possibility sets. However, the asymptotic partition seems to owe more to the sequential refining of the information which is formalized by the SNPR property. This consideration is corroborated by the following lemma.

Lemma *If P_t satisfies SNPR and SND then $P_t\rightarrow Q$ w.p.1..*

Proof The argument is analogous to that put forward in the proposition and we omit it. Q.E.D.

The two main results proposed seem to suggest that as long as individuals' processing abilities guarantee, over time, the coverage of the *whole* state space by means of possibility sets the crucial role, for an asymptotic partition to emerge, is played by SNPR. In the above lemma the alleged coverage is guaranteed by non-delusion. However, even though both in the proposition and in the lemma an asymptotic non-deluded partition is obtained, there is a fundamental difference which need be underlined. Indeed, while in the former asymptotic non-delusion is an *outcome* of the sequential information processing, in the latter non-delusion is *assumed* at each date rather than being explained as the outcome of individuals' abilities.

3. Conclusions

This note is based on the idea that information structures can be discussed in a more appropriate manner when time is explicitly brought into the model. In a static setting the discussion around properties like *Knowing That You Know* can only be founded on a counterfactual reasoning, since they can never be effectively implemented as a result of agents' information processing abilities. The argument can only be hypothetical because there is only one experiment. By introducing time the information processing can be made explicit and effectively implemented; agents can indeed link possibility sets over time as a result of their

processing skills. In the work we have shown conditions under which some time-dependent possibility correspondences can converge w.p.1. to a time-independent partition. While in a static setting we have partitions when the axioms of transparency, knowledge and wisdom are satisfied by the knowledge operator, in a dynamic setting only two properties are needed. Their interpretation however can not be considered as just a straightforward generalization of the three properties above and, in this sense, they seem to be more powerful than their *static* counterparts. The limiting partition we obtain is of the known kind, namely non-deluded.

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