CentER for Economic Research

Discussion paper

[redacted]

TILBURG UNIVERSITY

No. 9313

COMMUNICATION, COMPLEXITY, AND EVOLUTIONARY STABILITY

by Karl Wärneryd

February 1993

SSN 0924-7815

Communication, Complexity, and Evolutionary Stability

Karl Wärneryd*

February 19, 1993

Abstract

In games with costless preplay communication, some strategies are more complex than others in the sense that they induce a finer partition of the set of states of the world. This paper shows that if the concept of evolutionary stability, which is argued to be a natural solution concept for communication games, is modified to take lexicographic complexity preferences into account, then for a class of games of common interest only communication strategies that induce payoff-dominant Nash outcomes of the underlying game are stable.

1 Introduction

Much of economic theory deals with coordination problems. The perhaps most basic is the exploitation of potential gains from trade. In game-theoretic terms, this is the problem of coordinating on a payoff-dominant equilibrium out of a larger set of equilibria. (Such behavior is sometimes called *cooperation.*)

*CentER for Economic Research, Tilburg University, P O Box 90153, 5000 LE Tilburg, The Netherlands, and Department of Economics, Stockholm School of Economics, Box 6501, S—113 83 Stockholm, Sweden. I presented an earlier version of this paper at the 1992 Summer Workshop on Cooperation and Dynamics in Games, MEDS Department, J L Kellogg Graduate School of Management, Northwestern University. I thank Werner Güth, Sjaak Hurkens, Ehud Kalai, and Larry Samuelson for helpful comments. The Swedish Council for Research in the Humanities and Social Sciences provided financial support.

If the players of a game are allowed to communicate before taking actions, we have a strong intuition that they will achieve coordination. The subfield of cooperative game theory is partly based on this intuition.

For a long time it seems to have been taken more or less for granted that explicit modeling of communication opportunities would support the intuition as a formal result in a straightforward manner. As it turns out, there are complications. The only immediate effect of adding a preplay communication stage where costless, e g, verbal, messages can be sent to a one-shot game is an expansion of the set of equilibrium outcomes to include correlated equilibrium payoffs (see, e g, Wärneryd [17]).

Some authors (notably Farrell [6, 7]) have recently dealt with this by assuming the messages have established meanings in some language held in common by the players. If the players adhere to such meanings when there are no positive incentives not to, a refinement of the set of equilibria may be the result. It is hard to see, however, how this amounts to much more than assuming what is to be proved, namely that communication allows the players to coordinate. The "semantic" approach begs the question of where those meanings come from in the first place.

A less philosophically problematic approach sees meaning as an equilibrium property of messages at stationary states of some evolutionary or trial-and-error process. This line of thinking was intuitively suggested in the early work of Crawford and Sobel [5], and is formally developed in, e g, Kim and Sobel [9], Matsui [10], and Wärneryd [16, 18].

The present paper falls in the latter category, but differs in applying the idea of lexicographic complexity preferences in the spirit of Binmore and Samuelson [4]. There is a natural complexity measure for "languages" in the sense of these models. A language is more complex the more finely it distinguishes between different possible messages, i e, the more nuances it has. The intuition behind the results in this paper is that if such complexity is costly, it can only be used to coordinate on efficient solutions. Anderlini [1] also discusses complexity issues in the context of communication in coordination games, but from the standpoint of perturbations of *a priori* restricted sets of strategies.

The paper is organized as follows. Section 2 presents the general model. The concept of evolutionary stability is defined in Section 3, which also discusses evolutionary approaches to communication games without complexity considerations. Section 4 introduces a complexity measure for the model, and discusses its motivation. A payoff function that takes complexity into account in a lexicographic manner is constructed, and evolutionary stability redefined in terms of it. Section 5 contains a result on efficiency and stability (under the complexity-adjusted stability notion) in common interest games where only pure communication strategies can be used. Finally, Section 6 warns the reader that if mixed strategies are allowed, the result does not carry over. Furthermore, in the population game setting implied by the use of notions of evolutionary stability, there will always be asymmetric population distributions of inefficient strategies that can persist.

2 Preliminaries

Let G be a two-player, symmetric normal form game with a finite set A of pure strategies (actions) available to both players, and a payoff function $u : A \times A \rightarrow \Re$. If $x = (a, a') \in A \times A$ is an action profile of G, define $\hat{x} := (a', a)$. Thus if $u(y)$ is the payoff of one player when the profile y is played, $u(\hat{y})$ is the payoff of his opponent. Let $N(G)$ denote the set of pure strategy Nash equilibria of G.

We shall consider games extended by a preplay communication stage where the players simultaneously each send a costless message from the common finite message set M. The messages are observed by both players before they play G. The messages are not assumed to have any conventional meanings that enter into the deliberations of agents. The only thing that distinguishes a message set is its number of elements. It is assumed throughout that $|M| \geq 2$ (where $|X|$ denotes the number of elements, or cardinality, of a set X). Call the communication-extended game $G^\star$.

A pure strategy of the reduced normal form of $G^\star$ consists of a message $m \in M$ and a function $\alpha : M \rightarrow A$ that prescribes an action of G for every possible message sent by the opponent. Let S be the set of pure strategies. Note that our construction implies that we rule out self-inconsistent behavior. A player need not plan an action at information sets other than those in which he has sent the signal specified by the strategy. One might think that the possibility of mistakes at the message stage should be allowed for. But we shall think of strategies as minimal finite-state machines for playing $G^\star$. Such machines

	a_1	a_2
a_1	3,3	0,0
a_2	0,0	1,1

Figure 1: A game of common interest.

have no states for messages not sent by the strategy, and could therefore not send them even by mistake.

We consider only pure strategies. The payoff function of the communication-extended game is defined as $U(m\alpha, m'\alpha') := u(\alpha(m'), \alpha'(m))$. However, we also need to define payoffs to mixed strategies for use in defining evolutionary stability later. Let $\sigma : S \to [0,1]$ such that $\sum_S \sigma(s) = 1$ be a mixed strategy. With no risk of confusion, we shall say that $U(\sigma, \sigma') := \sum_S \sum_S \sigma(s)\sigma'(s')U(s, s')$.

The possibility of communication by itself does not guarantee cooperation if added to a one-shot game. As an example, consider the game in Figure 1. This game exhibits *common interest*, a property that will be formally defined later but has an obvious meaning here. Although it seems reasonable to think that players who could communicate would be able to coordinate on the payoff-dominant (a_1, a_1) equilibrium and rule out anything else, communication of the fairly general form we have introduced here does not yield this result. Consider a situation where both players play strategies $m\alpha$ where $\alpha(m') = a_2$ for all m'. This is a Nash equilibrium since a best reply to $m\alpha$ can do no better than play a_2 when the opponent sends m, yielding the same inefficient expected payoff.

This general problem is sometimes expressed by saying that every game of costless communication has inefficient "babbling" equilibria, where messages are ignored. It is this problem in particular that motivates the approach taken in this paper.

3 Evolutionary Stability

Of course one should not expect players to be able to come to a one-shot game and utilize abstract symbols, that have no prior established meanings, to coordinate. We must study games that are played repeatedly. Repeated games, as such, are not what we want, however. A repeated game is just one big game, and with communication it will suffer from the same problems as any other isolated game. To understand the origin of conventions of language that allow players to coordinate, we must look at games that are played many times by different combinations of players and evolve over time, i e, we must study evolutionary games.

A convenient way of doing this, that avoids complications associated with dealing with explicit dynamical systems, is to apply the concept of an evolutionarily stable strategy, defined for a general game by Maynard Smith [11] as follows.

Definition 1 *Let Γ be a symmetric normal form two-player game with (mixed) strategy set Σ and payoff function $\pi : \Sigma \times \Sigma \to \Re$. A strategy $\sigma^\star \in \Sigma$ is said to be an* evolutionarily stable strategy (ESS) *of Γ if for all $\sigma \neq \sigma^\star$*

$$\pi(\sigma^\star, \sigma^\star) > \pi(\sigma, \sigma^\star),$$

or

$$\pi(\sigma^\star, \sigma^\star) = \pi(\sigma, \sigma^\star) \text{ and } \pi(\sigma^\star, \sigma) > \pi(\sigma, \sigma).$$

Think of the game as being played by a large population of players who are repeatedly randomly matched in pairs. The criterion is then equivalent to requiring that, if all agents play the ESS, a small invasion of agents playing some other strategy should do strictly worse than the ESS players. That is, the above conditions are equivalent to saying there exists $\delta > 0$ such that for all $\sigma \neq \sigma^\star$ and all $\epsilon \in (0, \delta)$,

$$\pi(\sigma^\star, (1-\epsilon)\sigma^\star + \epsilon\sigma) > \pi(\sigma, (1-\epsilon)\sigma^\star + \epsilon\sigma).$$

In biological game theory, the ESS notion is usually justified by reference to the fact that an ESS is an asymptotically stable fixpoint of the so-called replicator dynamics, a model of asexual genetic reproduction. (See, e g, Taylor and Jonker [14].) For economic applications, we would rather think of the strategy population as evolving through a process of learning or imitation. Clearly, however, the ESS concept is a reasonable notion of stability also in such a setting. If anything, it is too strong a requirement. In many games, an ESS fails to exist. We shall therefore also use a weakening of the ESS conditions called *neutral* stability, which only requires that a mutant does not do strictly better against the perturbed population than does the incumbent. That is, a strategy $\sigma^\star$ will be said to be neutrally stable if there is $\delta > 0$ such that for all $\sigma \neq \sigma^\star$ and all $\epsilon \in (0,\delta)$, we have that

$$\pi(\sigma^\star, (1-\epsilon)\sigma^\star + \epsilon\sigma) \geq \pi(\sigma, (1-\epsilon)\sigma^\star + \epsilon\sigma).$$

The effect of this is to weaken the second inequality of the equivalent two-part definition.[1]

We note that both a_1 and a_2 are ESSs of the game in Figure 1. So evolutionary stability in itself is not enough to rule out inefficient play. However, Robson [12] suggests that communication possibilities in combination with evolution will help. This is because if communication possibilities are not utilized, a mutant that communicates with players of its own type in order to coordinate on the efficient outcome could arise and eventually reproduce to supplant the original population. Robson shows that in every game that has an inefficient ESS it is possible to construct a mutant that recognizes its own type and destabilizes the inefficient ESS.

A problem with Robson's approach is that it fails to consider the entire set of possible mutants. Once you admit the idea of a signaling mutant, what is there to stop evolution from introducing mutants that use the signal in other ways? For the analysis to be complete, we must study the stability of efficiency-inducing mutants in a situation where any kind of mutant could arise, i e, in the general setting described in the previous section.

Such an inquiry gives a limited positive result.

Proposition 1 *Let G be a 2×2 game of the form*

	a_1	a_2
a_1	u_H, u_H	$0,0$
a_2	$0,0$	u_L, u_L

where $u_H > u_L > 0$. Then s is a neutrally stable pure strategy of the communication-extended game $G^\star$ if and only if $U(s,s) = u_H$.

A proof is given in Wärneryd [18].

This result does not extend beyond the class of 2×2 games, however. To see why, consider the counterexample of the game in Figure 2.

[1]There is a dynamic justification also for neutrally stable strategies. Weibull [19] shows that they are Lyapunov-stable fixpoints of the replicator dynamic. Similar results are discussed in Thomas [15].

	a_1	a_2	a_3
a_1	3, 3	0, 0	0, 0
a_2	0, 0	2, 2	0, 0
a_3	0, 0	0, 0	1, 1

Figure 2: A counterexample.

Consider the strategy $m_1\alpha$ of the communication-extended game such that

$$\alpha(m) = \begin{cases} a_2 & \text{if } m = m_1 \\ a_3 & \text{otherwise.} \end{cases}$$

This is a neutrally stable strategy since any alternative best reply to $m_1\alpha$ must also send m_1 (otherwise it could get at most a payoff of 1) and respond with a_2 to m_1. But then it also gets a payoff of 2 when it meets itself. So $m_1\alpha$ sustains an inefficient payoff by threatening to do something even worse.

However, it could be argued that $m_1\alpha$ is an unnecessarily complicated way of getting a payoff of 2. You could get that by not bothering to distinguish between messages at all and just responding with a_2 to everything.

Consider a population where everybody plays $m_1\alpha$. A mutant could arise that also sends m_1 but then always plays a_2 regardless of the message sent by the opponent. Since the mutant gives rise to the same payoff, it seems reasonable to think that the population distribution could drift over to favor the mutant. But then a population dominated by the mutant could be invaded by a strategy that sends a different message and plays a_1 against itself.

A form of this argument is the basis for the set-valued stability notion approaches of Kim and Sobel [9] and Matsui [10]. In the following, we shall explore a slightly different approach that takes complexity considerations into account explicitly. The drifting away of inefficiency-inducing strategies will be assumed to happen because evolution directly favors less complex strategies.

4 Complexity

In general, any strategy or decision rule can be viewed as a function from some set Ω of states of the world to a set of actions. Such a function induces a partition of Ω into equivalence classes of states of the world that induce the play of the same action. The degree of complexity of a strategy will here be identified with the fineness of its implicit partition of the set of states of the world. This reflects the idea that a strategy is more complicated and costly the more different ways it has of conditioning on past events, or, put differently, the more detailed is the information it requires.

The application of complexity measures is perhaps best known from the theory of repeated games, and the most common measure is that of the number of states required by the unique minimal deterministic finite-state machine (henceforth, DFM)[2] that implements the strategy (see, e g, Rubinstein [13]). This measure is shown by Kalai and Stanford [8] to be equivalent to the definition given above given a suitable definition of the state space. In particular, the definition utilizes the recursive nature of repeated game histories.

For the present application, the minimal DFM that implements a given strategy of the communication game has a trivial structure. In fact, given the way strategies have been specified above, a strategy may be directly identified with its minimal machine implementation. Consider the strategy $s = m\alpha$. The minimal machine has an initial output state outputting the message m, and then transits to final output states as a function of an opponent's message input according to α, which may thus be regarded as a transition function. The final output states correspond to the actions in the range of α. A minimal machine implementation of s therefore has $1 + |\alpha(M)|$ states. Disregarding the initial output state that every machine has to have, we shall call $c(m\alpha) := |\alpha(M)|$ the *complexity* of $m\alpha$. Clearly, the least complexity a strategy could have is 1, which corresponds to playing the same action regardless of the opponent's message, and the greatest is $\min\{|A|, |M|\}$, which corresponds to discriminating perfectly between different messages sent by the opponent.

[2] In the following I assume some very limited familiarity with the theory of finite-state machines. Such knowledge is not necessary to understand any of the results of this paper, however.

We now modify the payoffs to take into account the complexity of a strategy in a lexicographic manner. Let U^c be the complexity-adjusted payoff function. We shall say that

1. $U^c(s,s') > U^c(s'',s')$ if $U(s,s') > U(s'',s')$ or if $U(s,s') = U(s'',s')$ and $c(s) < c(s'')$.
   It follows that

2. $U^c(s,s') \geq U^c(s'',s')$ if $U(s,s') > U(s'',s')$ or if $U(s,s') = U(s'',s')$ and $c(s) \leq c(s'')$.

We now wish to incorporate these complexity-adjusted preferences into a notion of evolutionary stability. A major problem with the strength of the ESS criterion is that, in general, an ESS does not always exist. In particular, the games considered here typically fail to have an ESS in pure strategies. This is because as a consequence of the lexicographic complexity preferences a necessary requirement for stability will turn out to be that a strategy has complexity 1, i e, that it always plays the same action. But then any other strategy that also always plays the same action, but sends a different initial message, will be an alternative best reply that does as well against itself as the first strategy does against it.

Since it seems reasonable not to care about the distinction between strategies that in effect behave alike when faced with one another and can thus stably coexist, we shall consider strategies that are neutrally stable in terms of the lexicographic complexity-adjusted payoff function instead. We therefore require of a strategy s for it to be considered stable that for every $s' \neq s$ there exist $\delta > 0$ such that for all $\epsilon \in (0,\delta)$,

$$U^c(s,(1-\epsilon)s+\epsilon s') \geq U^c(s',(1-\epsilon)s+\epsilon s').$$

This is the case if either

$$(1-\epsilon)U(s,s)+\epsilon U(s,s') > (1-\epsilon)U(s',s)+\epsilon U(s',s') \text{ for all } \epsilon \in (0,\delta)$$

or

$$(1-\epsilon)U(s,s)+\epsilon U(s,s') = (1-\epsilon)U(s',s)+\epsilon U(s',s') \text{ and } c(s) \leq c(s') \text{ for all } \epsilon \in (0,\delta).$$

The following equivalent definition is easier to apply in practice.[3]

[3]This is the same thing, except of course for the difference in the intended application, as what Binmore and Samuelson [4] call a *modified evolutionary stable strategy*. Also, the exact motivation for the concept is slightly unclear from their paper.

Definition 2 *A strategy s of G^* is said to be* neutrally stable with respect to U^c (c-stable) *if for all $s' \neq s$*

$$U(s,s) > U(s',s)$$

or

$$U(s,s) = U(s',s) \text{ and } U(s,s') > U(s',s')$$

or

$$U(s,s) = U(s',s) \text{ and } U(s,s') = U(s',s') \text{ and } c(s) \leq c(s').$$

Observe that with a lexicographic utility function there is no longer an equivalence between the two-part definition of a neutrally stable strategy and the definition in terms of stability in the face of a small invasion of mutants. Furthermore, a c-stable strategy is not necessarily in Nash equilibrium with itself in terms of the lexicographic utility function.

We note that if a strategy is an ESS in ordinary payoff terms alone, it satisfies the first two conditions and is c-stable.

The following result is immediate.

Proposition 2 *If s is a c-stable strategy of G^*, then $c(s) = 1$.*

PROOF. Let $s = m\alpha$ be some strategy with $c(s) > 1$. Consider the alternative best reply $s' = m\alpha'$ such that $\alpha'(m') = \alpha(m)$ for all m'. We have that $U(s',s') = U(s,s') = U(s',s) = U(s,s)$, but $c(s') = 1 < c(s)$, so s is not c-stable. □

Note that this means that c-stable strategies are necessarily of the "babbling" kind, where in effect no communication takes place. Yet, as we shall see below, the *potential* for effective communication in the model forces efficient behavior in some types of games. There is a similarity to the results of Ben-Porath and Dekel [3], who do not study costless communication, but allow players to "burn money," i e, unilaterally decrease their expected utility, before a game is played. In pure coordination games, the strategies that survive iterated elimination of weakly dominated strategies induce efficient outcomes without any money actually being burnt.

5 Common Interest

Aumann and Sorin [2] discuss a class of games that have a unique payoff profile that strictly dominates all other feasible payoff profiles. The following definition utilizes the fact that in a symmetric game, such a payoff profile if it exists must give both players the same payoff.

Definition 3 *G is said to be a game of* common interest *if there is $\bar{u}$ such that $u(x) = u(\hat{x}) = \bar{u}$ for some $x \in A \times A$, and for all $y \in A \times A$, if $(u(y), u(\hat{y})) \neq (\bar{u}, \bar{u})$, then $u(y) < \bar{u}$ and $u(\hat{y}) < \bar{u}$.*

It should be stressed that an obvious necessary condition for the existence of a c-stable strategy is that G has a symmetric pure strategy equilibrium. Accordingly, the following result does not guarantee existence of a c-stable strategy.

Proposition 3 *If G is a game of common interest and there is $x \in A \times A$ such that $u(x) = \bar{u}$ and $x = \hat{x}$, then a strategy s of $G^\star$ is c-stable if and only if $U(s, s) = \bar{u}$ and $c(s) = 1$.*

PROOF. To prove the "if" part, let $s = m\alpha$ be such that $U(s, s) = \bar{u}$ and $c(s) = 1$. Clearly, no strategy can do strictly better against s. Let s' be an alternative best reply to s. We have that $U(s', s) = \bar{u}$. Since G is a game of common interest, where if one player gets $\bar{u}$ so does his opponent, we have that $U(s, s') = U(s', s) = \bar{u}$. Then since $\bar{u} \geq U(s', s')$ and $c(s') \geq 1$, s is c-stable.

To prove the "only if" part, we start by noting that by Proposition 2 s cannot be c-stable if $c(s) > 1$. So we need only consider strategies of complexity 1. Let s be such that $c(s) = 1$, but $U(s, s) < \bar{u}$. We can find an alternative best reply $s' = m'\alpha'$ such that $m' \neq m$, $\alpha'(m) = \alpha(m') = \alpha(m)$, and $u(\alpha'(m'), \alpha'(m')) = \bar{u}$. Since $U(s', s') = \bar{u} > U(s, s') = U(s, s)$, s is not c-stable. □

6 *Caveat*

If mixed strategies are allowed, the efficiency result from the previous section does not hold anymore. As an example of this, consider again the game in Figure 1. Let the communication-extended game have a message set consisting of two messages, m_1 and m_2. Consider the two pure strategies $s_1 = m_1\alpha_1$ and $s_2 = m_2\alpha_2$ such that

$$\alpha_1(m) = \begin{cases} a_2 & \text{if } m = m_1 \\ a_1 & \text{if } m = m_2, \end{cases}$$

and

$$\alpha_2(m) = \begin{cases} a_1 & \text{if } m = m_1 \\ a_2 & \text{if } m = m_2. \end{cases}$$

Now construct a mixed strategy σ that plays s_1 and s_2 with equal probability. We have that $U(\sigma, \sigma) = 2$.

Regardless of how we choose to define a complexity measure for mixed strategies, σ cannot be destabilized, because it is an ESS already strictly in payoff terms. This means complexity considerations will not even enter the picture.

To see that σ is an ESS, consider alternative best replies to σ. Clearly, any alternative best reply must after having sent m_1 behave like s_1, and after having sent m_2 like s_2. So let σ' be a probability mix of s_1 and s_2 different from that of σ. We have that $U(\sigma', \sigma') < U(\sigma, \sigma') = 2$, so σ is an ESS.

This problem extends also to the pure-strategy case if the random-matching story underlying the use of the stability concept is taken seriously. Then even if only pure strategies can be played, there are stable asymmetric population distributions of strategies that induce inefficient outcomes. As an example, consider a population faced with the game discussed above where half of the agents play s_1 and half play s_2. In complete analogy with the mixed strategy case, no strategy can invade such a population.

References

[1] Luca Anderlini. Communication, computability and common interest games. 1990. Working Paper, St John's College, Cambridge.

[2] Robert Aumann and Sylvain Sorin. Cooperation and bounded recall. *Games and Economic Behavior*, 1:5–39, 1989.

[3] Elchanan Ben-Porath and Eddie Dekel. Signaling future actions and the potential for sacrifice. *Journal of Economic Theory*, 57:36–51, 1992.

[4] Kenneth G Binmore and Larry Samuelson. Evolutionary stability in repeated games played by finite automata. *Journal of Economic Theory*, 57:278–305, 1992.

[5] Vincent P Crawford and Joel Sobel. Strategic information transmission. *Econometrica*, 50(6):1431–1451, 1982.

[6] Joseph Farrell. Cheap talk, coordination, and entry. *Rand Journal of Economics*, 18(1):34–39, 1987.

[7] Joseph Farrell. Communication, coordination and Nash equilibrium. *Economics Letters*, 27:209–214, 1988.

[8] Ehud Kalai and William Stanford. Finite rationality and interpersonal complexity in repeated games. *Econometrica*, 56:397–410, 1988.

[9] Yong-Gwan Kim and Joel Sobel. An evolutionary approach to pre-play communication. 1990. Manuscript, University of California-San Diego.

[10] Akihiko Matsui. Cheap-talk and cooperation in a society. *Journal of Economic Theory*, 54:245–258, 1991.

[11] John Maynard Smith. *Evolution and the Theory of Games.* Cambridge University Press, Cambridge, 1982.

[12] Arthur J Robson. Efficiency in evolutionary games: Darwin, Nash and the secret handshake. *Journal of Theoretical Biology*, 144:379–396, 1990.

[13] Ariel Rubinstein. Finite automata play the repeated prisoner's dilemma. *Journal of Economic Theory*, 39:83–96, 1986.

[14] Peter D Taylor and Leo B Jonker. Evolutionarily stable strategies and game dynamics. *Mathematical Biosciences*, 40:145–156, 1978.

[15] Bernhard Thomas. On evolutionarily stable sets. *Journal of Mathematical Biology*, 22:105–115, 1985.

[16] Karl Wärneryd. Cheap talk, coordination, and evolutionary stability. 1992. Forthcoming in *Games and Economic Behavior*.

[17] Karl Wärneryd. Communication, correlation, and symmetry in bargaining. *Economics Letters*, 39:295–300, 1992.

[18] Karl Wärneryd. Evolutionary stability in unanimity games with cheap talk. *Economics Letters*, 36:375–378, 1991.

[19] Jörgen Weibull. Introduction to evolutionary game theory. 1992. Working Paper, Department of Economics, Stockholm University.

Discussion Paper Series, CentER, Tilburg University, The Netherlands:

(For previous papers please consult previous discussion papers.)

No.	Author(s)	Title
9146	Th. van de Klundert and S. Smulders	Reconstructing Growth Theory: A Survey
9147	J. Greenberg	On the Sensitivity of Von Neuman and Morgenstern Abstract Stable Sets: The Stable and the Individual Stable Bargaining Set
9148	S. van Wijnbergen	Trade Reform, Policy Uncertainty and the Current Account: A Non-Expected Utility Approach
9149	S. van Wijnbergen	Intertemporal Speculation, Shortages and the Political Economy of Price Reform
9150	G. Koop and M.F.J. Steel	A Decision Theoretic Analysis of the Unit Root Hypothesis Using Mixtures of Elliptical Models
9151	A.P. Barten	Consumer Allocation Models: Choice of Functional Form
9152	R.T. Baillie, T. Bollerslev and M.R. Redfearn	Bear Squeezes, Volatility Spillovers and Speculative Attacks in the Hyperinflation 1920s Foreign Exchange
9153	M.F.J. Steel	Bayesian Inference in Time Series
9154	A.K. Bera and S. Lee	Information Matrix Test, Parameter Heterogeneity and ARCH: A Synthesis
9155	F. de Jong	A Univariate Analysis of EMS Exchange Rates Using a Target
9156	B. le Blanc	Economies in Transition
9157	A.J.J. Talman	Intersection Theorems on the Unit Simplex and the Simplotope
9158	H. Bester	A Model of Price Advertising and Sales
9159	A. Özcam, G. Judge, A. Bera and T. Yancey	The Risk Properties of a Pre-Test Estimator for Zellner's Seemingly Unrelated Regression Model
9160	R.M.W.J. Beetsma	Bands and Statistical Properties of EMS Exchange Rates: A Monte Carlo Investigation of Three Target Zone Models Zone Model
9161	A.M. Lejour and H.A.A. Verbon	Centralized and Decentralized Decision Making on Social Insurance in an Integrated Market Multilateral Institutions
9162	S. Bhattacharya	Sovereign Debt, Creditor-Country Governments, and

No.	Author(s)	Title
9163	H. Bester, A. de Palma, W. Leininger, E.-L. von Thadden and J. Thomas	The Missing Equilibria in Hotelling's Location Game
9164	J. Greenberg	The Stable Value
9165	Q.H. Vuong and W. Wang	Selecting Estimated Models Using Chi-Square Statistics
9166	D.O. Stahl II	Evolution of Smart$_n$ Players
9167	D.O. Stahl II	Strategic Advertising and Pricing with Sequential Buyer Search
9168	T.E. Nijman and F.C. Palm	Recent Developments in Modeling Volatility in Financial Data
9169	G. Asheim	Individual and Collective Time Consistency
9170	H. Carlsson and E. van Damme	Equilibrium Selection in Stag Hunt Games
9201	M. Verbeek and Th. Nijman	Minimum MSE Estimation of a Regression Model with Fixed Effects from a Series of Cross Sections
9202	E. Bomhoff	Monetary Policy and Inflation
9203	J. Quiggin and P. Wakker	The Axiomatic Basis of Anticipated Utility; A Clarification
9204	Th. van de Klundert and S. Smulders	Strategies for Growth in a Macroeconomic Setting
9205	E. Siandra	Money and Specialization in Production
9206	W. Härdle	Applied Nonparametric Models
9207	M. Verbeek and Th. Nijman	Incomplete Panels and Selection Bias: A Survey
9208	W. Härdle and A.B. Tsybakov	How Sensitive Are Average Derivatives?
9209	S. Albæk and P.B. Overgaard	Upstream Pricing and Advertising Signal Downstream Demand
9210	M. Cripps and J. Thomas	Reputation and Commitment in Two-Person Repeated Games
9211	S. Albæk	Endogenous Timing in a Game with Incomplete Information
9212	T.J.A. Storcken and P.H.M. Ruys	Extensions of Choice Behaviour
9213	R.M.W.J. Beetsma and F. van der Ploeg	Exchange Rate Bands and Optimal Monetary Accommodation under a Dirty Float

No.	Author(s)	Title
9214	A. van Soest	Discrete Choice Models of Family Labour Supply
9215	W. Güth and K. Ritzberger	On Durable Goods Monopolies and the (Anti-) Coase-Conjecture
9216	A. Simonovits	Indexation of Pensions in Hungary: A Simple Cohort Model
9217	J.-L. Ferreira, I. Gilboa and M. Maschler	Credible Equilibria in Games with Utilities Changing during the Play
9218	P. Borm, H. Keiding, R. Mclean, S. Oortwijn and S. Tijs	The Compromise Value for NTU-Games
9219	J.L. Horowitz and W. Härdle	Testing a Parametric Model against a Semiparametric Alternative
9220	A.L. Bovenberg	Investment-Promoting Policies in Open Economies: The Importance of Intergenerational and International Distributional Effects
9221	S. Smulders and Th. van de Klundert	Monopolistic Competition, Product Variety and Growth: Chamberlin vs. Schumpeter
9222	H. Bester and E. Petrakis	Price Competition and Advertising in Oligopoly
9223	A. van den Nouweland, M. Maschler and S. Tijs	Monotonic Games are Spanning Network Games
9224	H. Suehiro	A "Mistaken Theories" Refinement
9225	H. Suehiro	Robust Selection of Equilibria
9226	D. Friedman	Economically Applicable Evolutionary Games
9227	E. Bomhoff	Four Econometric Fashions and the Kalman Filter Alternative - A Simulation Study
9228	P. Borm, G.-J. Otten and H. Peters	Core Implementation in Modified Strong and Coalition Proof Nash Equilibria
9229	H.G. Bloemen and A. Kapteyn	The Joint Estimation of a Non-Linear Labour Supply Function and a Wage Equation Using Simulated Response Probabilities
9230	R. Beetsma and F. van der Ploeg	Does Inequality Cause Inflation? - The Political Economy of Inflation, Taxation and Government Debt
9231	G. Almekinders and S. Eijffinger	Daily Bundesbank and Federal Reserve Interventions - Do they Affect the Level and Unexpected Volatility of the DM/$-Rate?
9232	F. Vella and M. Verbeek	Estimating the Impact of Endogenous Union Choice on Wages Using Panel Data

No.	Author(s)	Title
9233	P. de Bijl and S. Goyal	Technological Change in Markets with Network Externalities
9234	J. Angrist and G. Imbens	Average Causal Response with Variable Treatment Intensity
9235	L. Meijdam, M. van de Ven and H. Verbon	Strategic Decision Making and the Dynamics of Government Debt
9236	H. Houba and A. de Zeeuw	Strategic Bargaining for the Control of a Dynamic System in State-Space Form
9237	A. Cameron and P. Trivedi	Tests of Independence in Parametric Models: With Applications and Illustrations
9238	J.-S. Pischke	Individual Income, Incomplete Information, and Aggregate Consumption
9239	H. Bloemen	A Model of Labour Supply with Job Offer Restrictions
9240	F. Drost and Th. Nijman	Temporal Aggregation of GARCH Processes
9241	R. Gilles, P. Ruys and J. Shou	Coalition Formation in Large Network Economies
9242	P. Kort	The Effects of Marketable Pollution Permits on the Firm's Optimal Investment Policies
9243	A.L. Bovenberg and F. van der Ploeg	Environmental Policy, Public Finance and the Labour Market in a Second-Best World
9244	W.G. Gale and J.K. Scholz	IRAs and Household Saving
9245	A. Bera and P. Ng	Robust Tests for Heteroskedasticity and Autocorrelation Using Score Function
9246	R.T. Baillie, C.F. Chung and M.A. Tieslau	The Long Memory and Variability of Inflation: A Reappraisal of the Friedman Hypothesis
9247	M.A. Tieslau, P. Schmidt and R.T. Baillie	A Generalized Method of Moments Estimator for Long-Memory Processes
9248	K. Wärneryd	Partisanship as Information
9249	H. Huizinga	The Welfare Effects of Individual Retirement Accounts
9250	H.G. Bloemen	Job Search Theory, Labour Supply and Unemployment Duration
9251	S. Eijffinger and E. Schaling	Central Bank Independence: Searching for the Philosophers' Stone
9252	A.L. Bovenberg and R.A. de Mooij	Environmental Taxation and Labor-Market Distortions

No.	Author(s)	Title
9253	A. Lusardi	Permanent Income, Current Income and Consumption: Evidence from Panel Data
9254	R. Beetsma	Imperfect Credibility of the Band and Risk Premia in the European Monetary System
9301	N. Kahana and S. Nitzan	Credibility and Duration of Political Contests and the Extent of Rent Dissipation
9302	W. Güth and S. Nitzan	Are Moral Objections to Free Riding Evolutionarily Stable?
9303	D. Karotkin and S. Nitzan	Some Peculiarities of Group Decision Making in Teams
9304	A. Lusardi	Euler Equations in Micro Data: Merging Data from Two Samples
9305	W. Güth	A Simple Justification of Quantity Competition and the Cournot-Oligopoly Solution
9306	B. Peleg and S. Tijs	The Consistency Principle For Games in Strategic Form
9307	G. Imbens and T. Lancaster	Case Control Studies with Contaminated Controls
9308	T. Ellingsen and K. Wärneryd	Foreign Direct Investment and the Political Economy of Protection
9309	H. Bester	Price Commitment in Search Markets
9310	T. Callan and A. van Soest	Female Labour Supply in Farm Households: Farm and Off-Farm Participation
9311	M. Pradhan and A. van Soest	Formal and Informal Sector Employment in Urban Areas of Bolivia
9312	Th. Nijman and E. Sentana	Marginalization and Contemporaneous Aggregation in Multivariate GARCH Processes
9313	K. Wärneryd	Communication, Complexity, and Evolutionary Stability

P.O. BOX 90153, 5000 LE TILBURG, THE NETHERLAND