Fondazione Eni Enrico Mattei

Stochastic Stability in Network with Decay

Francesco Feri

NOTA DI LAVORO 40.2005

MARCH 2005

CTN – Coalition Theory Network

Francesco Feri, *Dipartimento di Scienze Economiche, Ca' Foscari University*

Stochastic Stability in Network with Decay

Summary

This paper considers a simple communication network characterized by an endogenous architecture and an imperfect transmission of information. We analyze the process of network formation in a dynamic framework where self – interested individuals can form or delete links and, occasionally, are doing mistakes. Then, using stochastic stability, we identify which network structures the formation process will converge to.

Keywords: Network, Decay, Strategical interaction

JEL Classification: A14, D20, J00

I am very grateful for their advice to Sergio Currarini, Matt Jackson, Giovanni Ponti, Fernando Vega Redondo, Claudio Mezzetti.

Address for correspondence:

Francesco Feri
Dipartimento di Scienze Economiche
Ca' Foscari University
San Giobbe 873
Venezia
Italy
E-mail: francesco.feri@tin.it

1. Introduction

In recent years there has been a growing interest in social and economic networks. Given the large evidence that network structure affects economic outcomes, a very important issue is to know which network structure will form. Indeed many authors have examined the evolution of the interaction structure in different economic contests. A very common characteristic of the networks is the presence of decay, that is the value an individual receives from another is a decreasing function of the number of links of the shorter path among them. Decay could be considered as the effect of generic frictions in the relations among agents, for example noise or delay, that are inevitable in the real world. But with the introduction of decay the network models become very complicated and it is very difficult to provide a complete description of all possible equilibria. In this paper, under the assumption that agents do mistakes, we show a way to provide a full description of all stochastically stable equilibria without the need to know all possible equilibria when agents do not make errors.

We consider the two-way flow model with decay described in Bala and Goyal [1]. It considers a setting in which each individual is a source of benefits, agents unilaterally[1] form (costly) links to access those benefits and in a link the benefits flow in both directions (two-way flow) without distinction of who supports the link cost. Thus individual links generate externalities whose value depends on the associated level of decay. This model does not provide a complete description of all possible equilibria for a large range of the model's parameters and does not provide any result regarding the dynamic process. The contribution of our paper is that, even

[1] One player doesn't need another player's permission to form a link with him and the costs of link formation are supported only by the agent who initiates the link.

though we are not able to describe completely all equilibria system converges, we can provide a full description of a special subset of them: all stochastically stable equilibria in networks with a sufficiently large number of agents. To do this we need a little change in the model's assumptions: in the strategy revision process we allow only nonsimultaneous revisions. With this modification the model becomes more manageable remaining almost identical to that described in Bala and Goyal [1]. Of course, all strict Nash equilibria are the same in both models. To single out stochastically stable equilibria, we have to assume that agents are making mistakes in their decision process; then we study the limit of the invariant distribution as the probability of mistakes goes to zero. The result is a full characterization of equilibria for all possible values of parameters; the equilibrium network architectures are very simple for a sufficiently large number of agents: complete, star or empty network according to link cost.

Another paper that studies the network formation in presence of decay is that of Watts [21]. It considers the dynamics of network formation in the case of the connection model of Jackson and Wolinski [14] and shows that the resulting network structures are path-dependent. However, their approach differs significantly from ours because they restrict attention to models where, to form links, the consensus of both implied players is necessary [2]. Other papers related to network formation are those of Jackson and Watts [12] and Goyal and Vega Redondo [9]. Jackson and Watts study the network formation in a setting where players can form and sever links to play a coordination game and, occasionally, make mistakes; then stochastic stability is used to identify the limiting networks. Goyal and Vega Redondo study a similar model with the difference that links are one-sided. They

[2] The link cost is supported by both implied players

consider both cases where the benefit derives only from directly linked players, and those where the benefit derives from directly and indirectly linked players.[3]

The paper is organized in the following way: In section 2 we describe the model. Section 3 contains the main result. Section 4 discuss the possibility of generalizing the result in different contests. Section 5 concludes the discussion and provides possible directions for further research.

2. The Model

Let $N=\{1,2,...,n\}$ be a set of agents where $n \geq 3$. We assume that every agent is endowed with one unit of private information of value 1 as well as of a quantity of information derived from other agents in the network.

Each agent can choose a subset of other players with whom to establish links. Let $g_i = (g_{i,1},..g_{i,i-1},g_{i,i+1},...g_{i,n})$ be the set of links formed by player i where $g_{ij} \in \{0,1\}$ for each $j \in N \setminus \{i\}$. We say agent i forms a link with agent j if $g_{ij}=1$. The set of all players' link decisions, denoted by $g=(g_1,g_2,....g_n)$, defines a direct graph $\{N,\Gamma\}$ called network. The network will be denoted by g and the set of all possible network will be denoted by G. Specifically, the network g has the set of players N, as its set of vertices, and its set of arrows, $\Gamma \subset N \times N$, is defined as follows:

[3] On the same issue the paper of Bramoulle, Goyal, Lopez Pintado and Vega Redondo [3] considers the link formation in a setting where agents form links to play an anti-coordination game. Droste, Gilles, Johnson [4] consider the dynamic of link formation in a population where players have a fixed location.

(2.1) $$\Gamma = \left\{ (i, j) \in N \times N \, : g_{ij} = 1 \right\}$$

Given a network g, we say that 2 players are directly linked if at least one of them has established a link with the other one, i.e. $\max\left\{ g_{ji},\ g_{ij} \right\} = 1$. To describe the direct links with no regard to who supports them, we define the *closure* $\overline{g}_{ij} = \max\left\{ g_{ij}, g_{ji} \right\}$. Let $\overline{g}_i = \left(\overline{g}_{i,1}, .. \overline{g}_{i,i-1}, \overline{g}_{i,i+1}, ... \overline{g}_{i,n} \right)$ be the set of direct links of agent i. Then $\overline{g} = \left(\overline{g}_1, \overline{g}_2, ... \overline{g}_n \right)$ describes the graph with no regard to who supports the links.

Let $N^d\left(i; g\right) \equiv \left\{ j \in N : g_{i,j} = 1 \right\}$ be the set of players in network g with whom player i has established links, while $v^d\left(i; g\right) \equiv \left| N^d\left(i; g\right) \right|$ is its cardinality. In a similar way, let $N^d\left(i; \overline{g}\right) \equiv \left\{ j \in N : \overline{g}_{i,j} = 1 \right\}$ be the set of players in network g with whom player i is connected, while $v^d\left(i; \overline{g}\right) \equiv \left| N^d\left(i; \overline{g}\right) \right|$ is its cardinality.

We say there is a *path* in g between i and j if $\overline{g}_{ij} = 1$ or there exists a set of agents $\left\{ j_1, j_2 .... j_m \right\} \in N / \left\{ i, j \right\}$ such that $\overline{g}_{ij_1} = \overline{g}_{j_1 j_2} = ... = \overline{g}_{j_m j} = 1$. By T_{ij} we denote the set of all paths between agents i and j.

In g the distance between agents i and j, denoted by $d\left(i, j; g\right)$, is defined as the number of links of the shorter path in T_{ij}[4]. A sub-network $g' \subset g$ is called a *component* of g if for all $i, j \in g'$, $i \neq j$, there exists a path in g' connecting i and j, and there does not exist a path between an agent in g' and one in $g \setminus g'$. A network with only one component is called *connected*.

Given any g, the notation $g+ij$ denotes the network obtained with the formation of a new link between agents i and j; similarly, $g-ij$ refers to the network obtained deleting the link between agents i and j.

By *minimally connected* we mean a connected network g such that $g-ij$ is not connected for all $i,j \in g$ characterized by $g_{ij}=1$.

A network is called *essential* if $g_{ij} \cdot g_{ji}=0$ for $\forall i,j \in N$; *empty* and denoted by g^e if $\overline{g}_{i,j}=0$ for $\forall i,j \in N$; *complete* and denoted by g^c if $\overline{g}_{i,j}=1$ for $\forall i,j \in N$; *star* and denoted by g^s if there exists some $i \in N$ such that $\overline{g}_{i,j}=1$ and $\overline{g}_{k,j}=0$ for all $k,j \in N \setminus \{i\}$ and $j \neq k$; among the star networks we denote by g^{cs} the star with all links supported by the central agent, by g^{ps} the star with all links supported by peripheral agents and by g^{ms} all the intermediate cases. Finally we define the following sets of networks: G^c is the set of all essential g^c; G^s is the set of all essential g^s; G^{ps} is the set of all essential g^{ps}; G^{cs} is the set of all essential g^{cs}.

The links are costly: every agent pays a cost $k>0$ for each link she supports. In our model, as in Bala and Goyal [1] or Goyal and Vega Redondo [9], link formation is one-sided and non-cooperative: the formation of a link requires only the consensus of the supporting player.

In our model decay is exogenous. Let d be the share of information that a player receives from another directly linked player.

---

[4] The shorter path is that with the lower number of direct links and if a path between i and j does not exists we assume $d(i,j;g)=\infty$.

For a generic agent *i* the strategy space is identified by G_i, that is, the set of possible link decisions. In the following we consider that $G_i = G_j$ $\forall i, j \in N$. Then, given the strategies of other players, $g_{-i} = (g_1, ...g_{i-1}, g_{i+1}, ...g_n)$, the payoff to a player *i*, from her participation to the game playing some strategy g_i, is given by:

(2.2) $$\Pi(g_i, g_{-i}) = \sum_{j \in N \setminus i} d^{d(i,j;g)} - k \cdot v^d(i;g)$$

Time is modeled discretely; $t = 1,2,3,....$ At time *t* the state of the system will be given by strategy profile $g(t)$ specifying the links established by each player. At every period *t* one agent is randomly chosen to revise her strategy. When an agent receives this opportunity, she selects a best-response to the strategy profile in the previous periods:

(2.3) $$g_i(t) \in \operatorname{argmax}_{g_i \in G_i} \Pi\left[g_i, g_{-i}(t-1)\right];$$

If there are several best-responses, any one of them is chosen with equal probability. This strategy revision process defines a Markov chain on $G \equiv G_1 \times G_2 \times ... \times G_n$. In the following we denote this process by *unperturbed dynamic or selection mechanism*. As we will see, in our framework, this Markov chain could be characterized by several absorbing sets[5]. Then, the equilibria depend upon the initial conditions.

To select among all possible equilibria, we employ the standard techniques used by Kandory, Mailath and Rob [15] and Young [21][6]. We

---

[5] A nonempty set of networks is *absorbing* if it is a minimal set with the property that, under the selection mechanism, the probability to exit from it is zero; moreover we note that an absorbing set may contain many networks or may contain only a single network, in this case we call it *abosrbing network*.

[6] To see other applications Ellison [5 and 6], Robson and Vega Redondo [18].

suppose, conditional on the chance to revise their strategy, players make mistakes. In this case, the player chooses her strategy at random with some small probability $e > 0$. For any $e > 0$, the process defines an aperiodic and irreducible Markov chain that has a unique invariant probability distribution m_e. We analyze the structure of m_e as the probability of mistakes e converges to zero. A network g is called *stochastically stable* if $\hat{m}(g) > 0$ where $\hat{m} = \lim_{e \to 0} m_e$ and the set of stochastically stable networks is defined as $\hat{G} \equiv \{g \in G : \hat{m}(g) > 0\}$.

3. Results

In this section we describe the equilibria of the model and show the proofs. These results are strictly related to those in section 5 in Bala and Goyal [1]. In proposition 5.3, these authors give a complete description of strict Nash equilibria only for link cost of $k < d - d^2$. But for different link costs, a multiplicity of network architectures can exist that can be strict Nash equilibria and that could be, given the initial conditions, equlibrium states the system will converge to. Bala and Goyal give a complete description of strict Nash and prove the convergence to strict Nash equilibria in all parameter regions only for $n = 4$. But for a general value of *n* they only show how, from every initial configuration, the dynamic process converges to g^c when $k < d - d^2$ and to g^e when $k > d + (n-2) \cdot d^2$. So they leave open the question on which network configurations will form in the interval $d - d^2 < k < d + (n-2) \cdot d^2$ [7]. We do not solve this problem but

---

[7] Table IV in Bala and Goyal [1] shows the results of numerical simulation for different values of n; they show that, with a positive probability, the unperturbed dynamics can generate networks that are different fron a star, like double stars, limit cycles and other architectures.

we are able to provide a complete description of a special subset of equilibria using the concept of stochastic stability. But the model remains sufficiently complex to require a further simplification to carry on the analysis: in each period we only permit one agent to revise the strategy. The interpretation is that strategy revisions are governed by a Poisson process; in other words there exist sufficiently small intervals of time in which only one revision can take place. This modification in the revision process permits us to rule out the possibility of simultaneous revisions producing a simpler dynamic analysis and it does not change the static results described in Bala and Goyal [1]. Indeed the strict Nash equilibria are identical in the two models. The following theorem describes all stochastically stable states.

Theorem 1: *Let* $0 < \mathbf{d} < 1$.

I) If $k < \mathbf{d} - \mathbf{d}^2$, *then* $\hat{G} = G^c$

II) If $\mathbf{d} - \mathbf{d}^2 < k < \mathbf{d}$, *there exists* $n'(k,\mathbf{d})$ *such that if* $n > n'(k,\mathbf{d})$ *then* $\hat{G} = G^s$.

III) If $k > \mathbf{d}$, *there exists* $\hat{k}(\mathbf{d},n)$ *such that if* $k < \hat{k}(\mathbf{d},n)$, $\hat{G} = G^{ps} \cup \{g^e\}$ *while if* $k > \hat{k}(\mathbf{d},n)$ $\hat{G} = \{g^e\}$.

To prove this theorem we use the notion of a recurrent set in the sense of Definition 7.4 in Samuelson [19]: a recurrent set *X* is a collection of absorbing set with the following two properties: *a*) it is impossible, for a single mutation, followed by unperturbed dynamic, to lead the system in an absorbing set not belonging to *X*; *b*) given two absorbing sets s' and s'' in *X*, we can find a sequence of absorbing sets in *X*, $s_1 .... s_k .... s_K$ with $s_1 = s'$ and $s_K = s''$, such that for any $k \in [2, K]$ is possible to move from s_{k-1} to s_k by a transition that includes a single mutation followed by unperturbed dynamics (minimality condition). In the following we denote this kind of sequence as *path of one step mutations*. Finally we use the result of proposition 7.7 in Samuelson [19]: if a state is stochastically stable, then it is contained in a recurrent set and all states in the same recurrent set are stochastically stable.

In the proof we show that only one recurrent set exists for each interval of link cost. In part I, given that the unperturbed dynamic always leads the system in a $g \in G^c$, it is sufficient to demonstrate that property b is satisfied by G^c. In part II we show that, starting from any initial state, a single mutation followed by an unperturbed dynamic is enough to lead the system in a $g \in G^s$; this evidence provides a sufficient condition for the existence of only recurrent sets containing star networks. Then we show that property b is satisfied by G^s; this evidence provides a sufficient condition that all star networks are in the same recurrent set. Finally we show that, starting from any g^s, a single mutation followed by an unperturbed dynamic is never sufficient to lead the system in a different network structure; this evidence is enough to prove that only star networks are in the unique recurrent set. The proof of part III follows similar arguments with the difference that when the link cost is (relatively) small $g^e \cup G^{ps}$ is the unique recurrent set; otherwise only g^e is in the unique recurrent set.

Proof. Consider part I ($k < d - d^2$). In this case the dynamic process converges always to $g \in G^c$ from any network's configuration. Indeed in this interval of link cost, the best-response (for all agents) is to replace all indirect links with direct links. Then, we have to demonstrate that all types of $g \in G^c$ are in the same recurrent set, i.e. for any couple $g', g'' \in G^c$ a path of one-step mutations, that leads from g' to g'', exists in G^c.

Consider an agent $i_1 \in g'$ that changes strategy by choosing her corresponding strategy in g''. Then, if i_1 obtains the chance to revise her strategy after the other agents have revised, we obtain another type of $g \in G^c$ where player i_1 has the same profile of link decisions as in g''. Indeed all agents j such that $\bar{g}_{i_1 j} = 0$ will form a link with agent i_1 and all agents j such that $g_{i_1 j} = 1$ and $g_{j,i_1} = 1$ will sever link ji_1. We note that this new network is a strict Nash equilibrium and denote it by g_1. Consider an agent $i_2 \in g_1 / \{i_1\}$ that changes strategy by choosing her corresponding strategy in g''. We note that the link between i_1 and i_2 does not change with this mutation because after the previous stage this link is supported as in g''. If i_2 obtains the chance to revise its strategy after the other agents have done so, we obtain another type of $g \in G^c$, denoted by g_2, where players i_1 and i_2 have the same profile of link decisions as in g''. Consider an agent $i_3 \in g_2 / \{i_1, i_2\}$ that changes strategy by choosing her corresponding strategy in g''. The links between i_1, i_2 and i_3 do not change with this mutation because in the previous stages these links are supported as in g''. If i_3 obtains a chance to revise her strategy after the other agents have revised, we obtain another type of $g \in G^c$ where players i_1, i_2 and i_3 have the same profile of link decisions as in g''. In this way, we can find a path ofone step mutations, which produce the transition between two generic types of g^c. The rest of the proof derives from the result of proposition 7.7 in Samuelson [19].

Consider part *II* ($d - d^2 < k < d$). In this proof we need the following three lemma.

Lemma 1: *Suppose* $d - d^2 < k < d$. *To induce a transition from any network architecture to a* $g \in G^{cs}$ *it is sufficient to have one mutation followed by an unperturbed dynamic.*

The proof is in the appendix.

Lemma 2: *Suppose* $d - d^2 < k < d$. *For any couple* $g', g'' \in G^s$, *a path of one-step mutations, that leads from* g' *to* g'', *exists in* G^s.

The proof is in the appendix.

Lemma 3: *Let be* $d - d^2 < k < d$ *and suppose any* $g \in G^s$. *Then exists* $n'(k,d)$ *such that after a single mutation followed by an unperturbed dynamic, the system converges to any* $g \in G^s$ *if* $n > n'(k,d)$.

The proof is in the appendix.

The proof moves in three steps. In the first we show that recurrent sets without a $g \in G^{cs}$ cannot exist. To prove this statement the result in lemma 1 is sufficient: assume a recurrent set that does not contain a $g \in G^{cs}$; a single mutation, followed by an unperturbed dynamic, is sufficient to move the system in a $g \in G^{cs}$. This fact violates the property *a* for a recurrent set. In the second step we show that all $g \in G^s$ are contained in the same recurrent set. To show this statement the result in lemma 2, satisfying property *b* for a recurrent set, is sufficient: assume that G^s is split into two or more subsets and that each subset is contained in a separate recurrent set. The result stated in lemma 2 is in contradiction with property *a* of the recurrent set. Hence these two results together tell us that only one recurrent set containing G^s exists. In the third step we show that, for values of *n* sufficiently large, the unique recurrent set contains only G^s. To prove this the result stated in lemma 3 is sufficient. The rest of the proof derives from the result of proposition 7.7 in Samuelson [19].

Proof of part *III* of Theorem 1 ($k > d$) uses similar arguments. We need the following three lemma.

Lemma 4: *Suppose $k > d$. To induce a transition from any network architecture to g^e it is sufficient to have one mutation followed by an unperturbed dynamic.*

The proof is in the appendix.

Lemma 5: *Let be $k > d$ and suppose $g = g^e$. Then after any single mutation followed by unperturbed dynamic the system converges to:*

a. g^e *if* $k > e + (n-1) \cdot e^2/2$

b. $g \in G^{ps} \cup \{g^e\}$ *if* $k < e + (n-1) \cdot e^2/2$.

The proof is in the appendix.

Lemma 6: *Let be $d < k < e + (n-1) \cdot e^2/2$ and suppose any $g \in G^{ps}$. Then after any single mutation followed by an unperturbed dynamic the system converges to any $g \in G^{ps} \cup \{g^e\}$.*

The proof is in the appendix.

In the first step we show that recurrent sets without g^e cannot exist. To prove this statement the result in lemma 4 is sufficient: assume a recurrent set that does not contain g^e; a single mutation, followed by an unperturbed dynamic, is sufficient to move the system into g^e. This fact violates property a for a recurrent set. In the second step we show that, for sufficiently large values of k, the unique recurrent set contains only g^e. To prove this, the result stated in lemma 5, part *a,* is sufficient. In the third step we show that for values relatively small of k the unique recurrent set consists of $G^{ps} \cup \{g^e\}$. To prove this statement we have to check the conditions a and b for a recurrent set. The results stated in lemma 6 and lemma 5, part *b,* tell us that the minimality condition (property b) is verified: the system can move from g^e to any $g \in G^{ps}$ and vice versa by a single mutation followed by an unperturbed dynamic; then for any couple $g', g'' \in G^{ps} \cup \{g^e\}$, a path of one-step mutations, that leads from g' to g'', exists in $G^{ps} \cup \{g^e\}$. Moreover these results are enough to verify property a for a recurrent set: a single mutation followed by an unperturbed dynamic is not enough to move the system in a network $g \notin G^{ps} \cup \{g^e\}$. We note that starting from g^e this is verified in lemma 5 and, starting from any $g \in G^{ps}$, it is verified in lemma 6. The rest of the proof derives from the result of proposition 7.7 in Samuelson [19]. QED

4. Discussion of the results

The key points that permit the results stated in theorem 1 are the setting of the revision process and the link-cost structure.

A change in the revision process affects the number of the perturbations that are necessary to pass from one state to another and consequently the stochastic potential of each equilibrium state. Therefore the set of stochastically stable states could be different. For example, suppose a setting where in every period the chance to revise the strategy pertains to only one link (potential or effective) in the network[8]. Lemma 1 no longer holds, indeed, starting from any network $g \in G$ to cause a transition toward a network $g \in G^{cs}$, one mutation is no more enough, more mutations are necessary. Then, the sufficient condition for the existence of only recurrent sets containing star networks is not satisfied and the result as stated in part II of theorem 1 no longer holds. With similar reasoning, we find that the result of part III of theorem 1 changes too. Indeed lemma 4 no longer holds because, starting from any state, to cause a transition toward an empty network more than one mutation is necessary. Therefore, the sufficient condition for the existence of only one recurrent set containing empty networks is no more satisfied. It is likely that the results in lemma 1 and lemma 4 are true for all revision processes that permit revisions of a sufficiently high number of links at the same time. In this case, a single perturbation affecting a large number of links could be sufficient to promote the transitions as stated in lemma 1 and 4.[9]

Consider now the implications of the link-cost structure. The polar case is one where both players implied in a link have to pay a cost. This change requires a different framework of link revision because the players receiving the proposal have to be able either to accept or reject the formation of new links. Suppose that when a player proposes the formation of new links, all

---

[8] This kind of revision process is a polar case compared with that we use in the model.

[9] Lemma 1 would be true if a single perturbation permits to one player to form a sufficient number of links such that all indirectly linked players have an incentive to link directly with him and to delete every other link; a similar reasoning can be applied to lemma 4 to demonstrate that if a single perturbation permits one player to form a sufficient number of links, the network goes into a state characterized by a positive probability of going into a empty network.

implied players have to accept or not using a miopic behavior[10]. The results as stated in part II and III of theorem 1 change[11]. Lemma 1 is no longer true; for example, consider a double star network in which a central agent tries to form new links with any peripheral agent of the opposite star. It could be that the best-response of these pheriperal agents is not to accept the new links if the proponent is directly linked with (relatively) few agents. Moreover, lemma 3 is not true; indeed, starting from a star, after a single mutation brings the system into a state with one or more disconnected players, there is a positive probability that the system converges to a double star (for example, when after the mutation, the first revising player is a peripherical one). In this state the best-response of both central players is not to accept the formation of new direct links given that indirect links are preferred to the direct ones. Therefore, the sufficient conditions for the existence of only recurrent sets with only star networks are not satisfied. But if we assume the possibility that link costs are asymmetrical, it is likely that theorem 1 part II is still valid for a large set of link-cost structures: all those where the cost to receive a link is lower than $d - d^2$. The intuition is that in this range of (receiving) cost, the best-response of all players is to accept the links proposed by an indirectly linked player. As for the part III of theorem 1, we note that the star is not a stable network because the center has an incentive to cut the links. In this case the candidates for stochastically stable networks are the empty network and the networks where each node is connected with more links. Moreover, we are not able to demonstrate that lemma 4 (or an equivalent statement) is true. Therefore, a sufficient condition for the existence of only one recurrent set containing g^e is not

[10] i.e. they accept the new link if this increases their net payoff considering the state in the previous period.

satisfied. Like for part II of the theorem 1, assuming the cost to receive a link is lower than $d - d^2$, it is likely that these results are still valid.

Finally, we consider the role of n. Indeed the result stated in part II of theorem 1 is true only for sufficiently large values of n. What happens for small values of n is that lemma 3 is no more true in the sense that, starting from a star, a single mutation can induce the system to move to a different architecture[12]. Then the unique recurrent set (therefore the set of stochasticallly stable networks) can contain not only star networks but different network architectures too.

5. Conclusion

In this paper we have analyzed the formation of social networks characterized by an exogenous decay such as that described in Bala and Goyal [1]. Using the concept of stochastic stability, we can produce a reduction in the number of possible equilibrium network architectures in a large range of link costs. Indeed, these authors for intermediate link costs, using dynamic selection, do not provide a full characterization of equilibria. Instead, using our refinement, we find very simple equilibrium networks for intermediate link costs: the star networks. Then we note that this kind of network architecture is very common in many fields: commerce, communication, industrial organization, transport, relationships and so on.

Further development can be made in many directions. First, we might use a framework where small deviations from the best-response are more probable that the large ones. Second, we might study more general conditions that permit the existence of only one recurrent set. Third, we can

---

[11] Linked star is a network with two stars joined by the central agents.

[12] for example in a double star.

model the decay as endogenous using social games that can be more respondent to empirical situations. Finally, we could study applications regarding the diffusion of technologies and the hierarchical and social structure in the enterprises and firms.

References

1. Bala and Goyal (2000): "A Non Cooperative Model of Network Formation", Econometrica 68.
2. Bhaskar and Vega Redondo (1998): "Migration and the Evolution of Convetions", mimeo.
3. Bramoulle, Goyal, Lopez Pintado and Vega Redondo (2001): "Social Interaction in Anti-Coordination Games", mimeo.
4. Droste, Gilles, Johnson (2000): "Evolution of Convetions in Endogenous Social Networks ", mimeo.
5. Ellison (1993): "Learning, Local Interaction and Coordination", Econometria 61
6. Ellison (2000): "Basins of Attraction, Long Run Stochastic Stability and the Speed of Step-by-step Evolution" Review of Economic Studies, 67.
7. Foster and Young (1991). "Cooperation in the Short and in the Long Run", Games and Economic Behavior 3.
8. Freidlin and Wentzell (1984): "Random Perturbations of Dynamical System", New York, Sprinter Verlag
9. Goyal and Vega Redondo (2000): "Learning, Network Formation and Coordination", mimeo.

10. Harsanyi and Selten (1988): “A General Theory of Equilibrium in Games”, Cambridge MIT Press.

11. Jackson (2001): “ The Stability and Efficiency of Economic and Social Networks”, *in* ‘‘Models of the Formation of Networks and Groups’’ (B. Dutta and M. O. Jackson, Eds.), Springer-Verlag, Heidelberg.

12. Jackson and Watts (2002): “On the Formation of Interaction Networks in Social Coordination Games”, Games and Economic Behavior 41.

13. Jackson and Watts (2002): "The Evolution of Social and Economic Networks" Journal of Economic Theory 106.

14. Jackson and Wolinsky (1996): “A Strategic Model of Social and Economic Networks”, J.E.T. 71.

15. Kandori and Rob (1995): “Evolution of Equilibria in the Long Run: A General Theory and Applications”, J.E.T. 65.

16. Kandori, Mailath and Rob (1993): “Learning, Mutation and Long Run Equilibria in Games”, Econometria 61.

17. Karandikar, Mookherjee, Ray and Vega Redondo (1998): “Evolving Aspirations and Cooperation”, J.E.T. 80.

18. Robson and Vega Redondo (1996): “Efficient Equilibrium Selection in Evolutionary Games with Random Matching”, J.E.T. 70.

19. Samuelson L. (1997), Evolutionary Games and Equilibrium Selection, MIT Press, 1997

20. Selten (1991): “Evolution, Learning and Economic Behavior”, Games and Economic Behavior 3.

21. Vega Redondo (2000): "Economics and the Theory of Games", forthcoming, Cambridge University Press.

22. Watts (2001): "A Dynamic Model of Network Formation", Games and Economic Behavior 34.

23. Young (1993): "The Evolution of Conventions", Econometria 61.

24. Young (1996): "The Economics of Convention", J. of Economic Perspective 10.

Appendix

Proof of lemma 1

Consider any network $g \in G$ and suppose an agent *i* switches to a strategy where she forms links with all others. When other agents have the chance to revise their strategy, they delete all their links. If agent *i* has the chance to revise the strategy after all other agents have revised, then the state will be a $g \in G^{cs}$ (with agent *i* at the center). QED.

Proof of lemma 2

Consider a $g \in G^{cs}$ and denote by *c* the central agent and by *p-agents* the peripherals. If *c* deletes all links, the first agent with the chance to revise her strategy forms links with all others. The result will be a $g \in G^{cs}$ with a different identity of *c*. A mutation of *c*, who deletes one link, could induce a transition toward a $g \in G^{ms}$ with n-2 links supported by *c* and one supported by a *p-agent*[13]. From this state a similar mutation of *c* could bring the system to a $g \in G^{ms}$ with *n-3* links supported by *c*. By similar single mutations the system could transit to a $g \in G^{ps}$. Now consider a $g \in G^{ps}$ as initial state. A mutation of a *p-agent*, who deletes her link, could induce a transition towards a $g \in G^{ms}$ with one link supported by *c*. From this state a similar single mutation could induce a transition toward a $g \in G^{ms}$ with two links supported by *c*. Then, by similar single mutations the system could

[13] If the no-connected agent has the chance to revise immediately after the mutation.

transit to a $g \in G^{cs}$. Then for any couple $g', g'' \in G^s$ we can find in G^s a path of one-step mutations, that leads from g' to g''. QED.

Proof of lemma 3

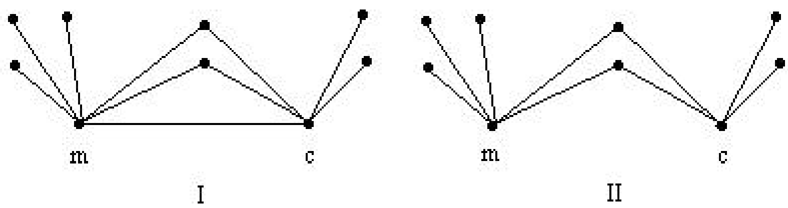
We define two network structures: the *quasi linked stars*, denoted by g^{qls}, and the *quasi linked stars 2*, denoted by g^{qls2}.

The g^{qls} is described as follows: fix 2 agents (*c* and *m*) characterized by $\bar{g}_{cm} = 1$ and partition the remaining agents into the following sets:

$N_c \equiv \{i \in N : \bar{g}_{ic} = 1 \wedge \bar{g}_{ij} = 0 \ \forall j \in N / c\}$
$N_m \equiv \{i \in N : \bar{g}_{im} = 1 \wedge \bar{g}_{ij} = 0 \ \forall j \in N / m\}$,
$N_{cm} \equiv \{i \in N : \bar{g}_{ic} = 1 \wedge \bar{g}_{im} = 1 \wedge \bar{g}_{ij} = 0 \ \forall j \in N / \{c, m\}\}$;

$\# x = |N_x|$ is the cardinality of the set N_x; the set of all possible g^{qls} is denoted by G^{qls}. The g^{qls2} is described as the g^{qls} with the difference $\bar{g}_{cm} = 0$ and $\# cm \geq 1$. The set of all possible g^{qls2} is denoted by G^{qls2}. Figure 1 shows two examples.

Figure 1: g^{qls} (I) and g^{qls2} (II) with n=9

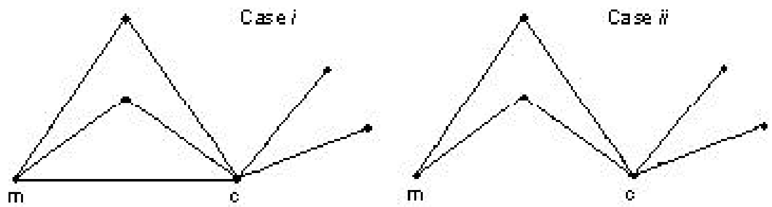


Note that when $d > k$ all strategies that are best response have to produce a connected network.

Consider any $g \in G^s$ with *n* agents. We can distinguish 2 kinds of agents: the central agent, denoted by *c*, and the peripheral agents, named *p-agents*. Suppose a mutation of *c*. She may sever some supported link and/or form new links; the resulting network may be: i) a connected but no essential g^s; ii) a g^s with some no connected agent; iii) a g^e. The first agent with the chance to revise will form links with all no connected agents (if any) and severs all no essential links. Then the system goes in a $g \in G^s$ if at least one of the following conditions is true: *i*) after the mutation the network is either a connected g^s or a g^e; *ii*) agent *c* has the chance to revise before all other agents; otherwise, if both conditions *i* and *ii* are false, the system goes in a g^{qls} with $\#cm = 0$.

Suppose a mutation of a *p-agent* and denote it by *m*; agent *m* may choose to support new links and/or delete the link with *c* (if $g_{mc} = 1$). (Figure 2 shows two examples). We consider the networks that are obtainable with a mutation of *p-agent* as cases of g^{qls} and g^{qls2} characterized by $\#m = 0$. Therefore we prove that, when the system is characterized by any $g \in \{G^{qls} \cup G^{qls2}\}$, it converges in a $g \in G^s$ with probability 1.

Figure 2: possible network structures after a mutation of a p-agent in a g^{qls} with n=6



Consider a $g \in G^{qls}$ with *n* agents. For all $i \in N_m$ to support a link with any $i \in N_{cm}$ is not a best-response because it reduces her payoff of $d^2 - (d - k)$; to support one link with a $i \in N_c$ is dominated by the formation of one link with *c*: in the first case the payoff changes for an amount of $d - k - d^3$, while in the second case for an amount of $d - d^2 + \#c(d^2 - d^3) - k$; we note that $d - d^2 + \#c(d^2 - d^3) - k \geq d - k - d^3$ if $\#c \geq 1$, with strictly inequality if $\#c > 1$; then for any $i \in N_m$, to support a new link with *c* is a best-response if the payoff increases, that is when:

(1.1) $$\#c \geq [k - (d - d^2)]\big/(d^2 - d^3)$$

In this case the best response of any $i \in \{i \in N_{cm} \cup m : g_{ic} = 1\}$ is to continue to support link *ic*[14]. Using the same arguments we can demonstrate that if:

(1.2) $$\#m \geq [k - (d - d^2)]\big/(d^2 - d^3),$$

[14] Note that: *a*) if any $i \in N_{cm}$ severs the link with *c*, she is going into the set N_m and $d(i,c) = 2$; *b*) if *m* severs the link *mc*, then $d(m,c) = 2$.

the best-response of any $i \in N_c$ is to form a new link im, while that one of any $i \in \{i \in N_{cm} \cup c : g_{im} = 1\}$ is to continue to support link im. Note that if:

(1.3) $n \geq 2 + 2[k - (d - d^2)]/(d^2 - d^3)$

the set $g \in G^{qls} : \#cm \leq n - 2 - 2[k - (d - d^2)]/(d^2 - d^3)$, where all networks satisfy at least one condition among (1.1) and (1.2), is not empty.

Consider a network $g \in G^{qls}$ with n agents, where (1.1) and (1.2) are not satisfied and (1.3) is true. Without loss of generality, suppose that $\#c > \#m$. In this state there are the following best responses:

i) for any $i \in N_c \cup \{i \in N_m : g_{im} = 0\} \cup \{i \in N_{cm} : g_{ic} = 0 \wedge g_{im} = 0\}$, it is not to change strategy;

ii) for any $i \in \{i \in N_m : g_{im} = 1\}$, it is to sever link im and support a new link ic;

iii) for any $i \in \{i \in N_{cm} : g_{ic} = g_{im} = 1\}$, it is to sever the link im;

iv) for any $i \in \{i \in N_{cm} : (g_{ic} = 1 \wedge g_{im} = 0) \vee (g_{ic} = 0 \wedge g_{im} = 1)\}$, it is to sever the supported link;

v) for c and m, it is to sever all supported links with agents $i \in N_{cm}$ and, sometimes, link cm[15].

Therefore the unperturbed dynamics brings the system eeither in a network g^{qls2} (if link cm is severed) or in networks $g \in G^{qls}$ characterized by less and less $\#cm$. In this second case the system converges in a network $g \in G^{qls}$ where at least a one condition among (1.1) and (1.2) is verified.

Now suppose a network $g \in G^{qls}$ where only one condition among (1.1) and (1.2) is verified, for example let be true condition (1.1); note that in this state $\#c > \#m$. The best response for any $i \in N$ is to have a direct link with c. For any sequence of strategy's revisions, if (1.2) does not become true[16] and the network does not become[17] a g^{qls2}, the system goes in a $g \in G^{qls}$

---

[15] For agent c to sever link cm is a best response if $\exists i \in N_{cm} : g_{ic} = 1$ and $\#m + |\{i \in N_{cm} : g_{ci} = 1\}| < [k - (d - d^2)]/(d^2 - d^3)$; note the right side is the number of agents in the set N_m after the revision of c and it is the same as right side of (1.1) and (1.2). For agent m we can use similar arguments.

[16] it may happen if c deletes many links with $i \in N_{cm}$

[17] it may happen if c severs the link with m.

with $\#m = 0$ and, from this state, in a g^s. Indeed in a state where all agents are directly linked with *c*, all links *ij* where $i, j \in N/c$ are severed as soon as possible; if *c* has the chance to revise, she severs all direct links with agents that are indirectly linked, but given condition (1.1), these agents will form a direct link with *c* as soon as possible and the network goes back in $g \in G^{qls}$ with $\#m = 0$. When both conditions (1.1) and (1.2) are verified, the best-response of all agent $i \in N$ is to have direct links with c and m. Then, in the revision process, #*c* and #*m* are decreasing. Therefore the system goes in a state where only one condition among (1.1) and (1.2) is verified.

Now suppose that a $g \in G^{qls2}$ with n agents. Using the same arguments for a g^{qls} we find that for any $i \in N_m$ to support a new link with c is a best-response if:

(1.4) $$\#c > [k - (d - d^3)] / (d^2 - d^4)$$

In this case the best response of any $i \in \{i \in N_{cm} : g_{ic} = 1\}$ is to continue to support the link with c. (See arguments for condition (1.1)). Similarly, if the condition:

(1.5) $$\#m > [k - (d - d^3)] / (d^2 - d^4)$$

is verified the best response of any $i \in N_c$ is to form a new link with m, while that one of any $i \in \{i \in N_{cm} : g_{im} = 1\}$ is to continue to support the link with m. We note that right side of (1.4) and (1.5) is smaller than right side of (1.1) and (1.2). Therefore may happen that (1.1) and (1.2) are not satisfied while (1.4) and (1.5) are satisfied. When $d - d^2 < k < d - d^3$, conditions (1.4) and (1.5) are always true given that the right side is negative. The following condition assures the existence of a no empty subset[18] of G^{qls2}, in which all networks satisfy at least one condition among (1.4) and (1.5):

(1.6) $$n \geq 3 + 2[k - (d - d^3)] / (d^2 - d^4)$$

Note that cases of $g \in G^{qls2}$ with at least one true condition among (1.1) and (1.2) can be treated like a $g \in G^{qls}$ (see above); indeed the best response of m and/or c is to support a link cm. Then we consider only the cases of $g \in G^{qls2}$ where (1.1) and (1.2) are no true.

---

[18] $g \in G^{qls2} : \#cm \leq n - 3 - 2[k - (d - d^3)] / (d^2 - d^4)$

Consider a network $g \in G^{qls2}$ where (1.4) and (1.5) are not satisfied and (1.7) is true. Without loss of generality, suppose that $\#c \geq \#m$. Remember that this case is possible only if $d - d^3 < k < d$. In this state we have the following best responses:

i) for any agent $i \in N/c,m$, it is the same that in a g^{qls} when (1.1) and (1.2) are not true but with the following difference: for any $i \in N_{cm}$ to sever one link is a best response only if $\#cm > 1$;

ii) for m, it is to sever all supported links with agents $i \in N_{cm}$ and, if one of the following conditions is true:

a) $g_{mi} = 1 \wedge g_{im} = 0 \; \forall i \in N_{cm}$;

b) $\#c + |\{i \in N_{cm} : g_{mi} = 1\}| \geq [k - (d - d^2)]/(d^2 - d^3)$,

to support a new link with *c*.

iii) for *c*, it is to sever all supported links with agents $i \in N_{cm}$ and, if one of the following conditions is true:

a) $g_{ci} = 1 \wedge g_{ic} = 0 \; \forall i \in N_{cm}$;

b) $\#m + |\{i \in N_{cm} : g_{ci} = 1\}| \geq [k - (d - d^2)]/(d^2 - d^3)$,

to support a new link with m. Therefore the unperturbed dynamics brings the system in a network g^{qls} (if a link *cm* is created) or in networks $g \in G^{qls2}$ characterized by less and less $\#cm$. In this second case the system converges in a network $g \in G^{qls2}$ where at least a one condition among (1.4) and (1.5) is verified.

Now consider a network $g_1 \in G^{qls2}$ where only one condition among (1.4) and (1.5) is true and no one among (1.1) and (1.2) is satisfied; without loss of generality suppose that (1.4) is true. In this case note that $\#c > \#m$ and it is possible only if $d - d^3 < k < d$. In this state there are the following best responses:

i) for *c* and *m* it is the same than previous case;

ii) for any $i \in N_c \cup \{i \in N_{cm} : g_{im} = 0\}$ it is not to change strategy;

iii) for any $i \in N_m$ it is to support a new link with *c* and, if $g_{im} = 1$, to sever link *im*;

iv) for any $i \in \{i \in N_{cm} : g_{im} = 1\}$ it is to sever the link *im* if $\#cm > 1$;

Therefore, if only condition (1.4) remains true and the network does not become a g^{qls}, the system goes in a $g \in G^{qls2}$ where $\#m = 0$ and $|\{i \in N_{cm} : g_{im} = 1\}| = 0$; if m revises her strategy, the resulting network will be a $g \in G^{s}$ (she substitutes all supported links with one link with c), otherwise, if c is revising, the resulting network will be g^{qls2} with $\#m > 0$; but given condition (1.4), all agents $i \in N_m$ will form a direct link with c as soon as possible and the network goes back in $g \in G^{qls2}$ with $\#m = 0$.

When conditions (1.4) and (1.5) are true, the best-response of all agents $i \in N / c,m$ is to have direct links with c and m. Then, in the revision process, #c and #m are decreasing. We have to distinguish two sub-cases: when $d - d^3 < k < d$ and when $d - d^2 < k < d - d^3$. If $d - d^3 < k < d$ the system goes in the state where only one condition among (1.4) and (1.5) is verified and, from this state in a $g \in G^{s}$. When $d - d^3 < k < d$ both conditions (1.4) and (1.5) are true for all possible values of #m and #c. Then, if the network does not become a g^{qls}, the system could go in a $g \in G^{qls2}$ where $\#c = \#m = 0$, $\#cm = n - 2$ and $g_{ci} = g_{mi} = 0 \; \forall i \in N_{cm}$. It is possible to demonstrate that, from this network structure, the system goes in a star network with probability 1 in a finite time

Using similar arguments we can treat cases where are true conditions (1.1) and (1.5) as well as cases where (1.2) and (1.4) are satisfied to show the convergence in a state where only one condition remains true. QED.

Proof of lemma 4

Consider any $g \in G$ and suppose a mutation in which an agent m forms links with all others. When other agents have the chance to revise, they delete their links; then the network becomes a g^{cs}. In this state when agent m has the chance to revise, she severs all links because $k > d$. Consequently, the state will be a g^{e}. QED.

Proof of lemma 5

Note that the best-response of an agent supporting links with agents that are not linked with any other, is to sever such links. Consider a g^{e} with n agents and suppose a mutation in which an agent i switchs to a strategy where she forms x ($0 < x < n-1$) links. All no-connected agents have as best-response to form a link with i if:

(1.8) $$x > (k - e) / e^2$$

otherwise their best-response is no to form links and, when agent i has a new chance to revise, the network transit to g^e. If (1.8) is true and agent i has the chance to revise her strategy after that y no-connected agents have done ($0 < y < n - x$), the state will be a g^{ps} with y agents (agent i deletes all direct links to single agents). Follows that best-response of no-connected agents is to support a link with i if:

(1.9) $$y > (k - e)/e^2$$

Then if (1.9) is true the resulting network will be a g^{ps} with n agents, otherwise the network will be g^e[19]; indeed in this second case the best-response of all agents is no to support links. Arranging conditions (1.8) and (1.9), we find that when the network is a g^e and:

(1.10) $$k > e + (n-1) \cdot e^2 / 2$$

after one mutation followed by unperturbed dynamic the system always converges in g^e, otherwise, if (1.10) is false, the system converges in g^e or in a g^{ps}. QED.

<u>Proof of lemma 6</u>

We use the same notation than in proof of lemma 3. Consider any $g \in G^{ps}$ and suppose a mutation of *c*. If *c* forms new links with any other the network will be a no essential star. In this state *p-agent*s with the chance to revise will sever all no essential links and network will be a g^{ms}. When *c* has the chance to revise, she will severs all supported link with peripheral agents. Therefore the system goes in a state with g^{ps} and *x* no connected agents. If the number of agents connected in g^{ps} (n-x) is sufficiently large the best-response of all agents is to be tied with *c* and the system converges in g^{ps}; otherwise the system converges in g^e. Now we focus our attention on the mutation of a peripheral agent and denote it by *m*. After this mutation the resulting networks can be summarized in two cases: *a) m* supports new links with any (from 1 to *n*-2) p-agents; *b) m* supports new links with any (from 0 to *n*-2) p-agents and severs the link with *c* (See fig. 2).

Consider case *a*. The network is a g^{qls} (See fig. 1) where *c* does not support any link, *m* supports all direct links with *i-agents* and $\#m = 0$. The best-response of any $i \in N_{cm}$ is to be tied with *c* if condition (1.1) is true,

---

[19] After that all peripheral agents have revised their strategy.

otherwise their best-response is to sever the link with *c*. In the first case only *m* has incentive to change strategy. Therefore when *m* has the chance to revise the system goes in the initial state. If condition (1.1) is false and any $i \in N_{cm}$ has the chance to revise before of *m*, the system goes in a $g \in G^{qls}$ with $\#m > 0$. Then we discuss the following sub-cases:

1. $\#c - 1 > \#m$ and following condition is true:

$$(1.11) \qquad d + (\#cm + \#c - 1) \cdot d^2 + \#m \cdot d^3 > k$$

In this case only $i \in N_{cm}$ and *m* have incentive to change strategy. If any $i \in N_{cm}$ revises the system goes in a $g \in G^{qls}$ with a smaller $\#cm$ and larger $\#m$. When *m* has the chance to revise, she severs all links supported with $i \in N_m \cup N_{cm}$ and, if the following it is true:

$$(1.12) \qquad d + (\#cm + \#c) \cdot d^2 < k$$

m severs the link with *c*. In this case the system goes in g^e because no agents have an incentive to be tied with *c*. If (1.12) is false, *c* maintains the link with *m,* as well as the best-response of all no-connected agents is to support a link with *c*; therefore the system goes in $g \in G^{ps}$.

2. Condition (1.11) is true and $\#c - 1 < \#m$. Differently from previous case the best-response of any $i \in N_c$ is to sever the link with *c* and to be tied with *m*. When *m* has the chance to revise, she severs all supported links with $i \in N_{cm} \cup N_m$; if condition (1.12) is true *m* severs the link with *c* otherwise not. If *m* severs the link with *c* the system goes in a state with two components, each one is a g^{ps} with *c* and *m* central agents. In this state if $\#m$ is sufficiently large the best-response of all agents is to be tied with *m* and the system goes in a $g \in G^{ps}$, otherwise the system goes in g^e. If (1.12) is false (*m* remains tied to *c*) the system goes in a $g \in G^{qls}$ with $\#cm = 0$ where all $i \in N_c$ support the link with *c* and all $i \in N_m$ support the link with *m*. In this network the best-response of any $i \in N_m \cup N_c$ is to be tied with *c* or *m* depending on which one provides the larger payoff. Therefore the network will go in a g^{ps}.

3. If condition (1.11) is false any $i \in N_c$ will sever the links with *c* and, eventually, will support one with *m* if $\#m$ is sufficiently large[20]. When *m*

---

[20] that is if $d + (\#cm + \#m - 1)\, d^2 + \#c \cdot d^3 > k$.

has the chance to revise, she severs all supported links. Therefore given that (1.11) is false the system goes in g^e in any case.

Consider case *b*. The network is a g^{qls2} (see fig. 1) where *c* does not support any link, *m* supports all direct links with $i \in N_{cm}$ and $\#m = 0$. The best-response of any $i \in N_{cm}$ is to be tied with *c* if condition (1.4) is true, otherwise their best-response is to sever the supported link with *c* if exists at least another $i \in N_{cm}$. In the first case only *m* has incentive to change strategy. Therefore when *m* has the chance to revise the system goes in the initial state. If condition (1.4) is false and any $i \in N_{cm}$ has the chance to revise before of *m*, the system goes in a $g \in G^{qls2}$ with $\#m > 0$. Then we discuss the following sub-cases:

1. $\#c - 1 > \#m$ and following condition is true:

(1.13) $$d + (\#\mathrm{cm} + \#\mathrm{c} - 1) \cdot d^2 + d^3 + \#\mathrm{m} \cdot d^4 > k$$

In this case only $i \in N_{cm}$ and *m* have incentive to change strategy. If any $i \in N_{cm}$ revises the system goes in a $g \in G^{qls2}$ with a smaller $\#cm$ and larger $\#m$. When *m* has the chance to revise, she severs all links supported with $i \in N_{cm} \cup N_m$ and, if (1.12) is true, no agent has best-response to be tied with *c*. Therefore the system goes in a g^e. If (1.12) is false, *m* will support a link with *c* as well as all no-connected agents when have the chance to revise. Then the network will go in a $g \in G^{ps}$.

2. Condition (1.13) is true and $\#c - 1 < \#m$. The best-response of any $i \in N_c$ is to sever the link with *c* and to be tied with *m*. When *m* has the chance to revise, if condition (1.12) is true she severs all supported links with $i \in N_{cm} \cup N_m$ and the system goes in a state with two components, each one is a g^{ps} with *c* and *m* central agents. In this state if $\#m$ is sufficiently large the best-response of all agents is to be tied with *m* and the system goes in $g \in G^{ps}$, otherwise the system goes in g^e. If (1.12) is false, when has the chance to revise, *m* severs all supported links with $i \in N_{cm} \cup N_m$ and supports a new link with *c*. Given that the resulting network will be a g^{qls} the proof follows case *a*.

3. If condition (1.13) is false, any $i \in N_c$ will sever the links with *c* and, eventually, will support one with *m* if $\#m$ is sufficiently large[21]. When *m*

[21] that is if $d + (\#\mathrm{cm} + \#\mathrm{m} - 1)\ d^2 + d^3 + \#\mathrm{c} \cdot d^4 > k$.

has the chance to revise, she severs all supported links. Therefore given that (1.13) is false the system goes in g^e in any case. QED.

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:

http://www.feem.it/Feem/Pub/Publications/WPapers/default.html
http://www.ssrn.com/link/feem.html
http//www.repec.org

NOTE DI LAVORO PUBLISHED IN 2004

IEM	1.2004	*Anil MARKANDYA, Suzette PEDROSO and Alexander GOLUB*: Empirical Analysis of National Income and So2 Emissions in Selected European Countries
ETA	2.2004	*Masahisa FUJITA and Shlomo WEBER:* Strategic Immigration Policies and Welfare in Heterogeneous Countries
PRA	3.2004	*Adolfo DI CARLUCCIO, Giovanni FERRI, Cecilia FRALE and Ottavio RICCHI:* Do Privatizations Boost Household Shareholding? Evidence from Italy
ETA	4.2004	*Victor GINSBURGH and Shlomo WEBER:* Languages Disenfranchisement in the European Union
ETA	5.2004	*Romano PIRAS:* Growth, Congestion of Public Goods, and Second-Best Optimal Policy
CCMP	6.2004	*Herman R.J. VOLLEBERGH:* Lessons from the Polder: Is Dutch CO2-Taxation Optimal
PRA	7.2004	*Sandro BRUSCO, Giuseppe LOPOMO and S. VISWANATHAN* (lxv): Merger Mechanisms
PRA	8.2004	*Wolfgang AUSSENEGG, Pegaret PICHLER and Alex STOMPER* (lxv): IPO Pricing with Bookbuilding, and a When-Issued Market
PRA	9.2004	*Pegaret PICHLER and Alex STOMPER* (lxv): Primary Market Design: Direct Mechanisms and Markets
PRA	10.2004	*Florian ENGLMAIER, Pablo GUILLEN, Loreto LLORENTE, Sander ONDERSTAL and Rupert SAUSGRUBER* (lxv): The Chopstick Auction: A Study of the Exposure Problem in Multi-Unit Auctions
PRA	11.2004	*Bjarne BRENDSTRUP and Harry J. PAARSCH* (lxv): Nonparametric Identification and Estimation of Multi-Unit, Sequential, Oral, Ascending-Price Auctions With Asymmetric Bidders
PRA	12.2004	*Ohad KADAN* (lxv): Equilibrium in the Two Player, k-Double Auction with Affiliated Private Values
PRA	13.2004	*Maarten C.W. JANSSEN* (lxv): Auctions as Coordination Devices
PRA	14.2004	*Gadi FIBICH, Arieh GAVIOUS and Aner SELA* (lxv): All-Pay Auctions with Weakly Risk-Averse Buyers
PRA	15.2004	*Orly SADE, Charles SCHNITZLEIN and Jaime F. ZENDER* (lxv): Competition and Cooperation in Divisible Good Auctions: An Experimental Examination
PRA	16.2004	*Marta STRYSZOWSKA* (lxv): Late and Multiple Bidding in Competing Second Price Internet Auctions
CCMP	17.2004	*Slim Ben YOUSSEF:* R&D in Cleaner Technology and International Trade
NRM	18.2004	*Angelo ANTOCI, Simone BORGHESI and Paolo RUSSU* (lxvi): Biodiversity and Economic Growth: Stabilization Versus Preservation of the Ecological Dynamics
SIEV	19.2004	*Anna ALBERINI, Paolo ROSATO, Alberto LONGO and Valentina ZANATTA:* Information and Willingness to Pay in a Contingent Valuation Study: The Value of S. Erasmo in the Lagoon of Venice
NRM	20.2004	*Guido CANDELA and Roberto CELLINI* (lxvii): Investment in Tourism Market: A Dynamic Model of Differentiated Oligopoly
NRM	21.2004	*Jacqueline M. HAMILTON* (lxvii): Climate and the Destination Choice of German Tourists
NRM	22.2004	*Javier Rey-MAQUIEIRA PALMER, Javier LOZANO IBÁÑEZ and Carlos Mario GÓMEZ GÓMEZ* (lxvii): Land, Environmental Externalities and Tourism Development
NRM	23.2004	*Pius ODUNGA and Henk FOLMER* (lxvii): Profiling Tourists for Balanced Utilization of Tourism-Based Resources in Kenya
NRM	24.2004	*Jean-Jacques NOWAK, Mondher SAHLI and Pasquale M. SGRO* (lxvii):Tourism, Trade and Domestic Welfare
NRM	25.2004	*Riaz SHAREEF* (lxvii): Country Risk Ratings of Small Island Tourism Economies
NRM	26.2004	*Juan Luis EUGENIO-MARTÍN, Noelia MARTÍN MORALES and Riccardo SCARPA* (lxvii): Tourism and Economic Growth in Latin American Countries: A Panel Data Approach
NRM	27.2004	*Raúl Hernández MARTÍN* (lxvii): Impact of Tourism Consumption on GDP. The Role of Imports
CSRM	28.2004	*Nicoletta FERRO:* Cross-Country Ethical Dilemmas in Business: A Descriptive Framework
NRM	29.2004	*Marian WEBER* (lxvi): Assessing the Effectiveness of Tradable Landuse Rights for Biodiversity Conservation: an Application to Canada's Boreal Mixedwood Forest
NRM	30.2004	*Trond BJORNDAL, Phoebe KOUNDOURI and Sean PASCOE* (lxvi): Output Substitution in Multi-Species Trawl Fisheries: Implications for Quota Setting
CCMP	31.2004	*Marzio GALEOTTI, Alessandra GORIA, Paolo MOMBRINI and Evi SPANTIDAKI:* Weather Impacts on Natural, Social and Economic Systems (WISE) Part I: Sectoral Analysis of Climate Impacts in Italy
CCMP	32.2004	*Marzio GALEOTTI, Alessandra GORIA ,Paolo MOMBRINI and Evi SPANTIDAKI:* Weather Impacts on Natural, Social and Economic Systems (WISE) Part II: Individual Perception of Climate Extremes in Italy
CTN	33.2004	*Wilson PEREZ:* Divide and Conquer: Noisy Communication in Networks, Power, and Wealth Distribution
KTHC	34.2004	*Gianmarco I.P. OTTAVIANO and Giovanni PERI* (lxviii): The Economic Value of Cultural Diversity: Evidence from US Cities
KTHC	35.2004	*Linda CHAIB* (lxviii): Immigration and Local Urban Participatory Democracy: A Boston-Paris Comparison

KTHC	36.2004	*Franca ECKERT COEN and Claudio ROSSI* (lxviii): Foreigners, Immigrants, Host Cities: The Policies of Multi-Ethnicity in Rome. Reading Governance in a Local Context
KTHC	37.2004	*Kristine CRANE* (lxviii): Governing Migration: Immigrant Groups' Strategies in Three Italian Cities – Rome, Naples and Bari
KTHC	38.2004	*Kiflemariam HAMDE* (lxviii): Mind in Africa, Body in Europe: The Struggle for Maintaining and Transforming Cultural Identity - A Note from the Experience of Eritrean Immigrants in Stockholm
ETA	39.2004	*Alberto CAVALIERE:* Price Competition with Information Disparities in a Vertically Differentiated Duopoly
PRA	40.2004	*Andrea BIGANO and Stef PROOST:* The Opening of the European Electricity Market and Environmental Policy: Does the Degree of Competition Matter?
CCMP	41.2004	*Micheal FINUS* (lxix): International Cooperation to Resolve International Pollution Problems
KTHC	42.2004	*Francesco CRESPI:* Notes on the Determinants of Innovation: A Multi-Perspective Analysis
CTN	43.2004	*Sergio CURRARINI and Marco MARINI:* Coalition Formation in Games without Synergies
CTN	44.2004	*Marc ESCRIHUELA-VILLAR:* Cartel Sustainability and Cartel Stability
NRM	45.2004	*Sebastian BERVOETS and Nicolas GRAVEL* (lxvi): Appraising Diversity with an Ordinal Notion of Similarity: An Axiomatic Approach
NRM	46.2004	*Signe ANTHON and Bo JELLESMARK THORSEN* (lxvi): Optimal Afforestation Contracts with Asymmetric Information on Private Environmental Benefits
NRM	47.2004	*John MBURU* (lxvi)*:* Wildlife Conservation and Management in Kenya: Towards a Co-management Approach
NRM	48.2004	*Ekin BIROL, Ágnes GYOVAI and Melinda SMALE* (lxvi)*:* Using a Choice Experiment to Value Agricultural Biodiversity on Hungarian Small Farms: Agri-Environmental Policies in a Transition al Economy
CCMP	49.2004	*Gernot KLEPPER and Sonja PETERSON:* The EU Emissions Trading Scheme. Allowance Prices, Trade Flows, Competitiveness Effects
GG	50.2004	*Scott BARRETT and Michael HOEL:* Optimal Disease Eradication
CTN	51.2004	*Dinko DIMITROV, Peter BORM, Ruud HENDRICKX and Shao CHIN SUNG:* Simple Priorities and Core Stability in Hedonic Games
SIEV	52.2004	*Francesco RICCI*: Channels of Transmission of Environmental Policy to Economic Growth: A Survey of the Theory
SIEV	53.2004	*Anna ALBERINI, Maureen CROPPER, Alan KRUPNICK and Nathalie B. SIMON:* Willingness to Pay for Mortality Risk Reductions: Does Latency Matter?
NRM	54.2004	*Ingo BRÄUER and Rainer MARGGRAF* (lxvi): Valuation of Ecosystem Services Provided by Biodiversity Conservation: An Integrated Hydrological and Economic Model to Value the Enhanced Nitrogen Retention in Renaturated Streams
NRM	55.2004	*Timo GOESCHL and Tun LIN* (lxvi): Biodiversity Conservation on Private Lands: Information Problems and Regulatory Choices
NRM	56.2004	*Tom DEDEURWAERDERE* (lxvi): Bioprospection: From the Economics of Contracts to Reflexive Governance
CCMP	57.2004	*Katrin REHDANZ and David MADDISON:* The Amenity Value of Climate to German Households
CCMP	58.2004	*Koen SMEKENS and Bob VAN DER ZWAAN:* Environmental Externalities of Geological Carbon Sequestration Effects on Energy Scenarios
NRM	59.2004	*Valentina BOSETTI, Mariaester CASSINELLI and Alessandro LANZA* (lxvii): Using Data Envelopment Analysis to Evaluate Environmentally Conscious Tourism Management
NRM	60.2004	*Timo GOESCHL and Danilo CAMARGO IGLIORI* (lxvi):Property Rights Conservation and Development: An Analysis of Extractive Reserves in the Brazilian Amazon
CCMP	61.2004	*Barbara BUCHNER and Carlo CARRARO*: Economic and Environmental Effectiveness of a Technology-based Climate Protocol
NRM	62.2004	*Elissaios PAPYRAKIS and Reyer GERLAGH*: Resource-Abundance and Economic Growth in the U.S.
NRM	63.2004	*Györgyi BELA, György PATAKI, Melinda SMALE and Mariann HAJDÚ* (lxvi): Conserving Crop Genetic Resources on Smallholder Farms in Hungary: Institutional Analysis
NRM	64.2004	*E.C.M. RUIJGROK and E.E.M. NILLESEN* (lxvi): The Socio-Economic Value of Natural Riverbanks in the Netherlands
NRM	65.2004	*E.C.M. RUIJGROK* (lxvi): Reducing Acidification: The Benefits of Increased Nature Quality. Investigating the Possibilities of the Contingent Valuation Method
ETA	66.2004	*Giannis VARDAS and Anastasios XEPAPADEAS*: Uncertainty Aversion, Robust Control and Asset Holdings
GG	67.2004	*Anastasios XEPAPADEAS and Constadina PASSA*: Participation in and Compliance with Public Voluntary Environmental Programs: An Evolutionary Approach
GG	68.2004	*Michael FINUS*: Modesty Pays: Sometimes!
NRM	69.2004	*Trond BJØRNDAL and Ana BRASÃO*: The Northern Atlantic Bluefin Tuna Fisheries: Management and Policy Implications
CTN	70.2004	*Alejandro CAPARRÓS, Abdelhakim HAMMOUDI and Tarik TAZDAÏT*: On Coalition Formation with Heterogeneous Agents
IEM	71.2004	*Massimo GIOVANNINI, Margherita GRASSO, Alessandro LANZA and Matteo MANERA*: Conditional Correlations in the Returns on Oil Companies Stock Prices and Their Determinants
IEM	72.2004	*Alessandro LANZA, Matteo MANERA and Michael MCALEER*: Modelling Dynamic Conditional Correlations in WTI Oil Forward and Futures Returns
SIEV	73.2004	*Margarita GENIUS and Elisabetta STRAZZERA*: The Copula Approach to Sample Selection Modelling: An Application to the Recreational Value of Forests

CCMP	74.2004	*Rob DELLINK and Ekko van IERLAND*: Pollution Abatement in the Netherlands: A Dynamic Applied General Equilibrium Assessment
ETA	75.2004	*Rosella LEVAGGI and Michele MORETTO*: Investment in Hospital Care Technology under Different Purchasing Rules: A Real Option Approach
CTN	76.2004	*Salvador BARBERÀ and Matthew O. JACKSON* (lxx): On the Weights of Nations: Assigning Voting Weights in a Heterogeneous Union
CTN	77.2004	*Àlex ARENAS, Antonio CABRALES, Albert DÍAZ-GUILERA, Roger GUIMERÀ and Fernando VEGA-REDONDO* (lxx): Optimal Information Transmission in Organizations: Search and Congestion
CTN	78.2004	*Francis BLOCH and Armando GOMES* (lxx): Contracting with Externalities and Outside Options
CTN	79.2004	*Rabah AMIR, Effrosyni DIAMANTOUDI and Licun XUE* (lxx): Merger Performance under Uncertain Efficiency Gains
CTN	80.2004	*Francis BLOCH and Matthew O. JACKSON* (lxx): The Formation of Networks with Transfers among Players
CTN	81.2004	*Daniel DIERMEIER, Hülya ERASLAN and Antonio MERLO* (lxx): Bicameralism and Government Formation
CTN	82.2004	*Rod GARRATT, James E. PARCO, Cheng-ZHONG QIN and Amnon RAPOPORT* (lxx): Potential Maximization and Coalition Government Formation
CTN	83.2004	*Kfir ELIAZ, Debraj RAY and Ronny RAZIN* (lxx): Group Decision-Making in the Shadow of Disagreement
CTN	84.2004	*Sanjeev GOYAL, Marco van der LEIJ and José Luis MORAGA-GONZÁLEZ* (lxx): Economics: An Emerging Small World?
CTN	85.2004	*Edward CARTWRIGHT* (lxx): Learning to Play Approximate Nash Equilibria in Games with Many Players
IEM	86.2004	*Finn R. FØRSUND and Michael HOEL*: Properties of a Non-Competitive Electricity Market Dominated by Hydroelectric Power
KTHC	87.2004	*Elissaios PAPYRAKIS and Reyer GERLAGH*: Natural Resources, Investment and Long-Term Income
CCMP	88.2004	*Marzio GALEOTTI and Claudia KEMFERT*: Interactions between Climate and Trade Policies: A Survey
IEM	89.2004	*A. MARKANDYA, S. PEDROSO and D. STREIMIKIENE*: Energy Efficiency in Transition Economies: Is There Convergence Towards the EU Average?
GG	90.2004	*Rolf GOLOMBEK and Michael HOEL* : Climate Agreements and Technology Policy
PRA	91.2004	*Sergei IZMALKOV* (lxv): Multi-Unit Open Ascending Price Efficient Auction
KTHC	92.2004	*Gianmarco I.P. OTTAVIANO and Giovanni PERI*: Cities and Cultures
KTHC	93.2004	*Massimo DEL GATTO*: Agglomeration, Integration, and Territorial Authority Scale in a System of Trading Cities. Centralisation versus devolution
CCMP	94.2004	*Pierre-André JOUVET, Philippe MICHEL and Gilles ROTILLON*: Equilibrium with a Market of Permits
CCMP	95.2004	*Bob van der ZWAAN and Reyer GERLAGH*: Climate Uncertainty and the Necessity to Transform Global Energy Supply
CCMP	96.2004	*Francesco BOSELLO, Marco LAZZARIN, Roberto ROSON and Richard S.J. TOL*: Economy-Wide Estimates of the Implications of Climate Change: Sea Level Rise
CTN	97.2004	*Gustavo BERGANTIÑOS and Juan J. VIDAL-PUGA*: Defining Rules in Cost Spanning Tree Problems Through the Canonical Form
CTN	98.2004	*Siddhartha BANDYOPADHYAY and Mandar OAK*: Party Formation and Coalitional Bargaining in a Model of Proportional Representation
GG	99.2004	*Hans-Peter WEIKARD, Michael FINUS and Juan-Carlos ALTAMIRANO-CABRERA*: The Impact of Surplus Sharing on the Stability of International Climate Agreements
SIEV	100.2004	*Chiara M. TRAVISI and Peter NIJKAMP*: Willingness to Pay for Agricultural Environmental Safety: Evidence from a Survey of Milan, Italy, Residents
SIEV	101.2004	*Chiara M. TRAVISI, Raymond J. G. M. FLORAX and Peter NIJKAMP*: A Meta-Analysis of the Willingness to Pay for Reductions in Pesticide Risk Exposure
NRM	102.2004	*Valentina BOSETTI and David TOMBERLIN:* Real Options Analysis of Fishing Fleet Dynamics: A Test
CCMP	103.2004	*Alessandra GORIA e Gretel GAMBARELLI:* Economic Evaluation of Climate Change Impacts and Adaptability in Italy
PRA	104.2004	*Massimo FLORIO and Mara GRASSENI*: The Missing Shock: The Macroeconomic Impact of British Privatisation
PRA	105.2004	*John BENNETT, Saul ESTRIN, James MAW and Giovanni URGA*: Privatisation Methods and Economic Growth in Transition Economies
PRA	106.2004	*Kira BÖRNER*: The Political Economy of Privatization: Why Do Governments Want Reforms?
PRA	107.2004	*Pehr-Johan NORBÄCK and Lars PERSSON*: Privatization and Restructuring in Concentrated Markets
SIEV	108.2004	*Angela GRANZOTTO, Fabio PRANOVI, Simone LIBRALATO, Patrizia TORRICELLI and Danilo MAINARDI*: Comparison between Artisanal Fishery and Manila Clam Harvesting in the Venice Lagoon by Using Ecosystem Indicators: An Ecological Economics Perspective
CTN	109.2004	*Somdeb LAHIRI*: The Cooperative Theory of Two Sided Matching Problems: A Re-examination of Some Results
NRM	110.2004	*Giuseppe DI VITA*: Natural Resources Dynamics: Another Look
SIEV	111.2004	*Anna ALBERINI, Alistair HUNT and Anil MARKANDYA*: Willingness to Pay to Reduce Mortality Risks: Evidence from a Three-Country Contingent Valuation Study
KTHC	112.2004	*Valeria PAPPONETTI and Dino PINELLI*: Scientific Advice to Public Policy-Making
SIEV	113.2004	*Paulo A.L.D. NUNES and Laura ONOFRI*: The Economics of Warm Glow: A Note on Consumer's Behavior and Public Policy Implications
IEM	114.2004	*Patrick CAYRADE*: Investments in Gas Pipelines and Liquefied Natural Gas Infrastructure What is the Impact on the Security of Supply?
IEM	115.2004	*Valeria COSTANTINI and Francesco GRACCEVA:* Oil Security. Short- and Long-Term Policies

IEM	116.2004	*Valeria COSTANTINI and Francesco GRACCEVA:* Social Costs of Energy Disruptions
IEM	117.2004	*Christian EGENHOFER, Kyriakos GIALOGLOU, Giacomo LUCIANI, Maroeska BOOTS, Martin SCHEEPERS, Valeria COSTANTINI, Francesco GRACCEVA, Anil MARKANDYA and Giorgio VICINI*: Market-Based Options for Security of Energy Supply
IEM	118.2004	*David FISK*: Transport Energy Security. The Unseen Risk?
IEM	119.2004	*Giacomo LUCIANI*: Security of Supply for Natural Gas Markets. What is it and What is it not?
IEM	120.2004	*L.J. de VRIES and R.A. HAKVOORT*: The Question of Generation Adequacy in Liberalised Electricity Markets
KTHC	121.2004	*Alberto PETRUCCI*: Asset Accumulation, Fertility Choice and Nondegenerate Dynamics in a Small Open Economy
NRM	122.2004	*Carlo GIUPPONI, Jaroslaw MYSIAK and Anita FASSIO*: An Integrated Assessment Framework for Water Resources Management: A DSS Tool and a Pilot Study Application
NRM	123.2004	*Margaretha BREIL, Anita FASSIO, Carlo GIUPPONI and Paolo ROSATO*: Evaluation of Urban Improvement on the Islands of the Venice Lagoon: A Spatially-Distributed Hedonic-Hierarchical Approach
ETA	124.2004	*Paul MENSINK*: Instant Efficient Pollution Abatement Under Non-Linear Taxation and Asymmetric Information: The Differential Tax Revisited
NRM	125.2004	*Mauro FABIANO, Gabriella CAMARSA, Rosanna DURSI, Roberta IVALDI, Valentina MARIN and Francesca PALMISANI*: Integrated Environmental Study for Beach Management:A Methodological Approach
PRA	126.2004	*Irena GROSFELD and Iraj HASHI*: The Emergence of Large Shareholders in Mass Privatized Firms: Evidence from Poland and the Czech Republic
CCMP	127.2004	*Maria BERRITTELLA, Andrea BIGANO, Roberto ROSON and Richard S.J. TOL*: A General Equilibrium Analysis of Climate Change Impacts on Tourism
CCMP	128.2004	*Reyer GERLAGH*: A Climate-Change Policy Induced Shift from Innovations in Energy Production to Energy Savings
NRM	129.2004	*Elissaios PAPYRAKIS and Reyer GERLAGH*: Natural Resources, Innovation, and Growth
PRA	130.2004	*Bernardo BORTOLOTTI and Mara FACCIO*: Reluctant Privatization
SIEV	131.2004	*Riccardo SCARPA and Mara THIENE*: Destination Choice Models for Rock Climbing in the Northeast Alps: A Latent-Class Approach Based on Intensity of Participation
SIEV	132.2004	*Riccardo SCARPA Kenneth G. WILLIS and Melinda ACUTT*: Comparing Individual-Specific Benefit Estimates for Public Goods: Finite Versus Continuous Mixing in Logit Models
IEM	133.2004	*Santiago J. RUBIO*: On Capturing Oil Rents with a National Excise Tax Revisited
ETA	134.2004	*Ascensión ANDINA DÍAZ*: Political Competition when Media Create Candidates' Charisma
SIEV	135.2004	*Anna ALBERINI*: Robustness of VSL Values from Contingent Valuation Surveys
CCMP	136.2004	*Gernot KLEPPER and Sonja PETERSON*: Marginal Abatement Cost Curves in General Equilibrium: The Influence of World Energy Prices
ETA	137.2004	*Herbert DAWID, Christophe DEISSENBERG and Pavel ŠEVČIK*: Cheap Talk, Gullibility, and Welfare in an Environmental Taxation Game
CCMP	138.2004	*ZhongXiang ZHANG*: The World Bank's Prototype Carbon Fund and China
CCMP	139.2004	*Reyer GERLAGH and Marjan W. HOFKES*: Time Profile of Climate Change Stabilization Policy
NRM	140.2004	*Chiara D'ALPAOS and Michele MORETTO*: The Value of Flexibility in the Italian Water Service Sector: A Real Option Analysis
PRA	141.2004	*Patrick BAJARI, Stephanie HOUGHTON and Steven TADELIS* (lxxi): Bidding for Incompete Contracts
PRA	142.2004	*Susan ATHEY, Jonathan LEVIN and Enrique SEIRA* (lxxi): Comparing Open and Sealed Bid Auctions: Theory and Evidence from Timber Auctions
PRA	143.2004	*David GOLDREICH* (lxxi): Behavioral Biases of Dealers in U.S. Treasury Auctions
PRA	144.2004	*Roberto BURGUET* (lxxi): Optimal Procurement Auction for a Buyer with Downward Sloping Demand: More Simple Economics
PRA	145.2004	*Ali HORTACSU and Samita SAREEN* (lxxi): Order Flow and the Formation of Dealer Bids: An Analysis of Information and Strategic Behavior in the Government of Canada Securities Auctions
PRA	146.2004	*Victor GINSBURGH, Patrick LEGROS and Nicolas SAHUGUET* (lxxi): How to Win Twice at an Auction. On the Incidence of Commissions in Auction Markets
PRA	147.2004	*Claudio MEZZETTI, Aleksandar PEKEČ and Ilia TSETLIN* (lxxi): Sequential vs. Single-Round Uniform-Price Auctions
PRA	148.2004	*John ASKER and Estelle CANTILLON* (lxxi): Equilibrium of Scoring Auctions
PRA	149.2004	*Philip A. HAILE, Han HONG and Matthew SHUM* (lxxi): Nonparametric Tests for Common Values in First-Price Sealed-Bid Auctions
PRA	150.2004	*François DEGEORGE, François DERRIEN and Kent L. WOMACK* (lxxi): Quid Pro Quo in IPOs: Why Bookbuilding is Dominating Auctions
CCMP	151.2004	*Barbara BUCHNER and Silvia DALL'OLIO*: Russia: The Long Road to Ratification. Internal Institution and Pressure Groups in the Kyoto Protocol's Adoption Process
CCMP	152.2004	*Carlo CARRARO and Marzio GALEOTTI*: Does Endogenous Technical Change Make a Difference in Climate Policy Analysis? A Robustness Exercise with the FEEM-RICE Model
PRA	153.2004	*Alejandro M. MANELLI and Daniel R. VINCENT* (lxxi): Multidimensional Mechanism Design: Revenue Maximization and the Multiple-Good Monopoly
ETA	154.2004	*Nicola ACOCELLA, Giovanni Di BARTOLOMEO and Wilfried PAUWELS*: Is there any Scope for Corporatism in Stabilization Policies?
CTN	155.2004	*Johan EYCKMANS and Michael FINUS*: An Almost Ideal Sharing Scheme for Coalition Games with Externalities
CCMP	156.2004	*Cesare DOSI and Michele MORETTO*: Environmental Innovation, War of Attrition and Investment Grants

CCMP	157.2004	*Valentina BOSETTI, Marzio GALEOTTI and Alessandro LANZA*: How Consistent are Alternative Short-Term Climate Policies with Long-Term Goals?
ETA	158.2004	*Y. Hossein FARZIN and Ken-Ichi AKAO*: Non-pecuniary Value of Employment and Individual Labor Supply
ETA	159.2004	*William BROCK and Anastasios XEPAPADEAS*: Spatial Analysis: Development of Descriptive and Normative Methods with Applications to Economic-Ecological Modelling
KTHC	160.2004	*Alberto PETRUCCI*: On the Incidence of a Tax on PureRent with Infinite Horizons
IEM	161.2004	*Xavier LABANDEIRA, José M. LABEAGA and Miguel RODRÍGUEZ*: Microsimulating the Effects of Household Energy Price Changes in Spain

NOTE DI LAVORO PUBLISHED IN 2005

CCMP	1.2005	*Stéphane HALLEGATTE*: Accounting for Extreme Events in the Economic Assessment of Climate Change
CCMP	2.2005	*Qiang WU and Paulo Augusto NUNES*: Application of Technological Control Measures on Vehicle Pollution: A Cost-Benefit Analysis in China
CCMP	3.2005	*Andrea BIGANO, Jacqueline M. HAMILTON, Maren LAU, Richard S.J. TOL and Yuan ZHOU*: A Global Database of Domestic and International Tourist Numbers at National and Subnational Level
CCMP	4.2005	*Andrea BIGANO, Jacqueline M. HAMILTON and Richard S.J. TOL*: The Impact of Climate on Holiday Destination Choice
ETA	5.2005	*Hubert KEMPF*: Is Inequality Harmful for the Environment in a Growing Economy?
CCMP	6.2005	*Valentina BOSETTI, Carlo CARRARO and Marzio GALEOTTI*: The Dynamics of Carbon and Energy Intensity in a Model of Endogenous Technical Change
IEM	7.2005	*David CALEF and Robert GOBLE*: The Allure of Technology: How France and California Promoted Electric Vehicles to Reduce Urban Air Pollution
ETA	8.2005	*Lorenzo PELLEGRINI and Reyer GERLAGH*: An Empirical Contribution to the Debate on Corruption Democracy and Environmental Policy
CCMP	9.2005	*Angelo ANTOCI*: Environmental Resources Depletion and Interplay Between Negative and Positive Externalities in a Growth Model
CTN	10.2005	*Frédéric DEROIAN*: Cost-Reducing Alliances and Local Spillovers
NRM	11.2005	*Francesco SINDICO*: The GMO Dispute before the WTO: Legal Implications for the Trade and Environment Debate
KTHC	12.2005	*Carla MASSIDDA*: Estimating the New Keynesian Phillips Curve for Italian Manufacturing Sectors
KTHC	13.2005	*Michele MORETTO and Gianpaolo ROSSINI*: Start-up Entry Strategies: Employer vs. Nonemployer firms
PRCG	14.2005	*Clara GRAZIANO and Annalisa LUPORINI*: Ownership Concentration, Monitoring and Optimal Board Structure
CSRM	15.2005	*Parashar KULKARNI*: Use of Ecolabels in Promoting Exports from Developing Countries to Developed Countries: Lessons from the Indian LeatherFootwear Industry
KTHC	16.2005	*Adriana DI LIBERTO, Roberto MURA and Francesco PIGLIARU*: How to Measure the Unobservable: A Panel Technique for the Analysis of TFP Convergence
KTHC	17.2005	*Alireza NAGHAVI*: Asymmetric Labor Markets, Southern Wages, and the Location of Firms
KTHC	18.2005	*Alireza NAGHAVI*: Strategic Intellectual Property Rights Policy and North-South Technology Transfer
KTHC	19.2005	*Mombert HOPPE*: Technology Transfer Through Trade
PRCG	20.2005	*Roberto ROSON*: Platform Competition with Endogenous Multihoming
CCMP	21.2005	*Barbara BUCHNER and Carlo CARRARO*: Regional and Sub-Global Climate Blocs. A Game Theoretic Perspective on Bottom-up Climate Regimes
IEM	22.2005	*Fausto CAVALLARO*: An Integrated Multi-Criteria System to Assess Sustainable Energy Options: An Application of the Promethee Method
CTN	23.2005	*Michael FINUS, Pierre v. MOUCHE and Bianca RUNDSHAGEN*: Uniqueness of Coalitional Equilibria
IEM	24.2005	*Wietze LISE*: Decomposition of CO2 Emissions over 1980–2003 in Turkey
CTN	25.2005	*Somdeb LAHIRI*: The Core of Directed Network Problems with Quotas
SIEV	26.2005	*Susanne MENZEL and Riccardo SCARPA*: Protection Motivation Theory and Contingent Valuation: Perceived Realism, Threat and WTP Estimates for Biodiversity Protection
NRM	27.2005	*Massimiliano MAZZANTI and Anna MONTINI*: The Determinants of Residential Water Demand Empirical Evidence for a Panel of Italian Municipalities
CCMP	28.2005	*Laurent GILOTTE and Michel de LARA*: Precautionary Effect and Variations of the Value of Information
NRM	29.2005	*Paul SARFO-MENSAH*: Exportation of Timber in Ghana: The Menace of Illegal Logging Operations
CCMP	30.2005	*Andrea BIGANO, Alessandra GORIA, Jacqueline HAMILTON and Richard S.J. TOL*: The Effect of Climate Change and Extreme Weather Events on Tourism
NRM	31.2005	*Maria Angeles GARCIA-VALIÑAS*: Decentralization and Environment: An Application to Water Policies
NRM	32.2005	*Chiara D.ALPAOS, Cesare DOSI and Michele MORETTO*: Concession Length and Investment Timing Flexibility
CCMP	33.2005	*Joseph HUBER*: Key Environmental Innovations
CTN	34.2005	*Antoni CALVÓ-ARMENGOL and Rahmi İLKILIÇ* (lxxii): Pairwise-Stability and Nash Equilibria in Network Formation
CTN	35.2005	*Francesco FERI* (lxxii): Network Formation with Endogenous Decay
CTN	36.2005	*Frank H. PAGE, Jr. and Myrna H. WOODERS* (lxxii): Strategic Basins of Attraction, the Farsighted Core, and Network Formation Games

CTN	37.2005	*Alessandra CASELLA and Nobuyuki HANAKI* (lxxii): Information Channels in Labor Markets. On the Resilience of Referral Hiring
CTN	38.2005	*Matthew O. JACKSON and Alison WATTS* (lxxii): Social Games: Matching and the Play of Finitely Repeated Games
CTN	39.2005	*Anna BOGOMOLNAIA, Michel LE BRETON, Alexei SAVVATEEV and Shlomo WEBER* (lxxii): The Egalitarian Sharing Rule in Provision of Public Projects
CTN	40.2005	*Francesco FERI*: Stochastic Stability in Network with Decay

(lxv) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications” organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003
(lxvi) This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation” organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, August 28-29, 2003
(lxvii) This paper has been presented at the international conference on “Tourism and Sustainable Economic Development – Macro and Micro Economic Issues” jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003
(lxviii) This paper was presented at the ENGIME Workshop on “Governance and Policies in Multicultural Cities”, Rome, June 5-6, 2003
(lxix) This paper was presented at the Fourth EEP Plenary Workshop and EEP Conference “The Future of Climate Policy”, Cagliari, Italy, 27-28 March 2003
(lxx) This paper was presented at the 9th Coalition Theory Workshop on "Collective Decisions and Institutional Design" organised by the Universitat Autònoma de Barcelona and held in Barcelona, Spain, January 30-31, 2004
(lxxi) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by Fondazione Eni Enrico Mattei and Consip and sponsored by the EU, Rome, September 23-25, 2004
(lxxii) This paper was presented at the 10th Coalition Theory Network Workshop held in Paris, France on 28-29 January 2005 and organised by EUREQua.

2004 SERIES	
CCMP	*Climate Change Modelling and Policy* (Editor: Marzio Galeotti)
GG	*Global Governance* (Editor: Carlo Carraro*)*
SIEV	*Sustainability Indicators and Environmental Valuation* (Editor: Anna Alberini)
NRM	*Natural Resources Management* (Editor: Carlo Giupponi)
KTHC	*Knowledge, Technology, Human Capital* (Editor: Gianmarco Ottaviano)
IEM	*International Energy Markets* (Editor: Anil Markandya)
CSRM	*Corporate Social Responsibility and Sustainable Management* (Editor: Sabina Ratti)
PRA	*Privatisation, Regulation, Antitrust* (Editor: Bernardo Bortolotti)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)
CTN	*Coalition Theory Network*

2005 SERIES	
CCMP	*Climate Change Modelling and Policy* (Editor: Marzio Galeotti)
SIEV	*Sustainability Indicators and Environmental Valuation* (Editor: Anna Alberini)
NRM	*Natural Resources Management* (Editor: Carlo Giupponi)
KTHC	*Knowledge, Technology, Human Capital* (Editor: Gianmarco Ottaviano)
IEM	*International Energy Markets* (Editor: Anil Markandya)
CSRM	*Corporate Social Responsibility and Sustainable Management* (Editor: Sabina Ratti)
PRCG	*Privatisation Regulation Corporate Governance* (Editor: Bernardo Bortolotti)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)
CTN	*Coalition Theory Network*