

Calvó-Armengol, Antoni; Ilkiliç, Rahmi

Working Paper

Pairwise-Stability and Nash Equilibria in Network Formation

Nota di Lavoro, No. 34.2005

Provided in Cooperation with:

Fondazione Eni Enrico Mattei (FEEM)

Suggested Citation: Calvó-Armengol, Antoni; Ilkiliç, Rahmi (2005) : Pairwise-Stability and Nash Equilibria in Network Formation, Nota di Lavoro, No. 34.2005, Fondazione Eni Enrico Mattei (FEEM), Milano

This Version is available at:

<http://hdl.handle.net/10419/74247>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Pairwise-Stability and Nash Equilibria in Network Formation

Antoni Calvó-Armengol and Rahmi İlkiliç

NOTA DI LAVORO 34.2005

MARCH 2005

CTN – Coalition Theory Network

Antoni Calvó-Armengol, *Universitat Autònoma de Barcelona,*
Université de Toulouse Sciences Sociales and CEPR
Rahmi İlkiliç, *Universitat Autònoma de Barcelona*

This paper can be downloaded without charge at:

The Fondazione Eni Enrico Mattei Note di Lavoro Series Index:
<http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm>

Social Science Research Network Electronic Paper Collection:
<http://ssrn.com/abstract=677995>

Pairwise-Stability and Nash Equilibria in Network Formation

Summary

Suppose that individual payoffs depend on the network connecting them. Consider the following simultaneous move game of network formation: players announce independently the links they wish to form, and links are formed only under mutual consent. We provide necessary and sufficient conditions on the network link marginal payoffs such that the set of pairwise stable, pairwise-Nash and proper equilibrium networks coincide, where pairwise stable networks are robust to one-link deviations, while pairwise-Nash networks are robust to one-link creation but multi-link severance. Under these conditions, proper equilibria in pure strategies are fully characterized by one-link deviation checks.

Keywords: Network formation, Pairwise-stability, Proper equilibrium

JEL Classification: C62, C72, D85, L14

We thank Jordi Massó for helpful conversations. The first author gratefully acknowledges the financial support from the Spanish Ministry of Education through grant BEC2002-02130, the Fundación Ramón Areces, and the Barcelona Economics Program of CREA. The second author acknowledges the financial support from IGSOE. All errors belong to the authors.

This paper was presented at the 10th Coalition Theory Network Workshop held in Paris, France on 28-29 January 2005 and organised by EUREQua.

Address for correspondence:

Antoni Calvó-Armengol
Department of Economics
UAB, Edifici B
08193 Bellaterra
Barcelona
Spain
Email: antoni.calvo@uab.es

1 Introduction

When individual payoffs depend on an underlying network of bilateral links, self-interested players may want to manipulate the network structure at their advantage. A model of network formation needs to specify how players set up links with each other, together with a network equilibrium concept compatible with this process. In recent years, different network formation procedures and network stability concepts have been proposed. This paper aims at wedging a bridge between the different stability notions proposed. We relate pairwise-stability, a prominent network equilibrium concept due to Jackson and Wolinsky (1996), to proper equilibrium, a non-cooperative refinement due to Myerson (1978).

Pairwise-stability is a network equilibrium concept that dispenses from any procedure of network formation. By definition, pairwise stable networks are robust to one-link deviations. Such one-link deviations are either promoted by single players in isolation (in the case of link-cutting), or at the coordinated initiative of pairs of players (in the case of link-creation). Pairwise-stability is a weak equilibrium notion, often interpreted as a necessary condition for network stability,¹ introduced initially to document the inherent tension between stability and efficiency in a network context. Pairwise-stability is also extensively used for positive purposes due to its computational (relative) simplicity, and to its ability to generate sharp predictions in many contexts.²

Myerson (1991) proposes a simultaneous move game of network formation, where players announce non-cooperatively the links they wish to form and the network that forms results from the collection of these announcements. This game is simple and intuitive. When networks are directed and links need not be reciprocated, standard Nash equilibrium analysis is informative about the geometry of endogenous network architectures.³ Instead, when networks are undirected and link creation requires the mutual consent of the two involved parties, a coordination problem arises. The game displays a multiplicity of Nash equilibria.⁴ This coordination problem results from the multidimensionality of the strategy spaces and the requirement of mutual consent. It is thus a feature of the network formation process itself. Allowing for bilateral moves solves the coordination problem satisfactorily, as no mutually beneficial link is now left aside. We call pairwise-Nash networks the Nash equilibrium outcomes that fulfill this added (coalitional-move) requirement.⁵

Our first result shows that pairwise-stability and pairwise-Nash equilibrium are two sides of the same token when joint-links marginal returns and single-link marginal returns to currently existing links are of the same sign, whenever the sum of the latter is non-negative. We call this condition

¹Most likely, any equilibrium notion should, at least, check for one-link deviations.

²See Jackson (2003) for an exhaustive and recent survey on these issues.

³Bala and Goyal (2000) offers an analysis of Nash directed networks.

⁴For instance, the empty network is always a Nash equilibrium outcome (when nobody announces any link).

⁵The set of pairwise-Nash networks is thus at the intersection of the set of Nash equilibrium outcomes and the set of pairwise stable networks. See Goyal and Joshi (2002), Bloch and Jackson (2004) and Calvó-Armengol (2004) for definitions and applications of this equilibrium notion.

α -convexity. Under this condition, robustness to unilateral or to multilateral link severance are equivalent. Many existing models in the literature fulfill this condition, including the connections model, the co-author model, models of information transmission on the network and oligopoly markets, among others.

Pairwise-Nash equilibrium, though, suffers from a serious conceptual drawback. Although intended to be a non-cooperative equilibrium notion, bilateral and coordinated players moves are explicitly allowed (as part of the equilibration process). Note that the process through which pairs of players might coordinate on their strategies' announcements is left unspecified. To avoid such *ad hoc* coalitional moves, we focus on proper equilibrium, a Nash refinement due to Myerson (1978). In a proper equilibrium, players best respond to perturbations of their opponents' strategies, where perturbations are ordered so that more costly mistakes are made with less probability.⁶

We provide necessary and sufficient conditions on marginal payoffs such that pairwise-Nash equilibria and proper equilibria coincide. This condition is twofold. First, network payoffs must be link-responsive, that is, the returns to any link are never zero. This is a mild requirement: network payoffs with exogenous parameters are (often) generically link-responsive. Second, joint-links marginal returns and single-link marginal returns to currently existing links are of the same sign whenever the sum of the latter is non-positive, and whenever not only players use their discretion to cut existing links, but also to create new ones. We call this condition β -strong concavity. More precisely, β -strong concavity need only hold for those links not in the network and for which the involved parties have conflicting interests in their creation (that is, one player would gain whereas the other would lose). This condition thus trivially holds in networks where absent links are not formed because neither player consents in its creation.

More precisely, link-responsiveness is enough to guarantee that any proper equilibrium network in pure strategies is also a pairwise-Nash equilibrium. Reciprocally, assuming that payoffs are link-responsive, all pairwise-Nash networks can be supported by proper equilibrium strategies if and only if β -strong concavity holds on the set of missing links that generate conflicting interests. The proof for the second inclusion is constructive, and is sketched below.

Consider some pairwise-Nash network and an equilibrium strategy that supports it. In this network, some links may not be formed by lack of mutual consent, even though it may be of the interest of one of the two parties to create them. Now, modify the equilibrium strategy so that, the interested parties systematically announce such (extra) links. Note that, at equilibrium, any such players taken in isolation are in fact indifferent between announcing and not announcing any of these links (which are not formed anyway). Yet, the network equilibrium strategy at hand may exploit the network payoff externalities in some intricate way that does require some of these announcements not to be effective (in the equilibrium strategy that supports it). The condition for β -strong

⁶Ordered mistakes differ by, at least, one order of magnitude. This hierarchy of mistakes distinguishes properness from trembling-hand perfection.

concavity is equivalent to stating that the strategy where all these extra announcements are made yields the same equilibrium network. This condition is met for a variety of models, including the connections model and information transmission. In particular, this shows that α -concavity and β -strong concavity are perfectly compatible with one another.

With this new equilibrium pure strategy profile, we construct a completely mixed strategy profile by allowing players to make mistakes on link announcements. When mistakes vanish, the mixed profile converges to the equilibrium one. Mistakes are chosen so that links absent from the network for which neither of the two parties agree on their creation are announced with a (tremble) probability one order of magnitude higher than any other tremble. We show that this mixed strategy profile induces a quasi-perfect equilibrium in any extensive form equivalent⁷ of the simultaneous move game of link formation. We then rely on an extensive form characterization of properness by Van Damme (1984) and Mailath, Samuelson and Swinkels (1997) to establish the relationship between proper and pairwise-Nash equilibrium. Incidentally, our analysis also sheds light on the extensive form approach to network formation (and corresponding extensive form equilibrium refinements), pioneered by Aumann and Myerson (1988).

Section 2 describes networks, payoffs and defines α -convexity and β -strong concavity. Section 3 introduces network formation games and stability concepts. Section 4 contains the main results and some examples. The proofs of the main results are gathered in Section 5.

2 Network payoffs

Networks $N = \{1, \dots, n\}$ is a set of players.

Players on N are connected by a network g , a collection of direct links. Let $ij \in g$ be a direct link between players i and j in g . We focus on undirected networks, where $ij \in g$ is equivalent to $ji \in g$.

Let g^N denotes the complete network where each player $i \in N$ is directly linked to any other player $j \in N \setminus \{i\}$. Then, $\mathcal{G} = \{g \subseteq g^N\}$ is the set of undirected networks on N .

Let $g \in \mathcal{G}$ and $ij \in g$ a *link*. For all $ij \notin g$, $g + ij$ is the network obtained by adding the new link ij to g . Similarly, for all $ij \in g$, $g - ij$ is the network obtained by eliminating the current link ij from g .

Network payoffs A network payoff function is a mapping $u : \mathcal{G} \rightarrow \mathbb{R}^N$ that assigns to each network g a payoff $u_i(g)$ for each player $i \in N$. Some examples are provided below.

Link marginal payoffs Let $g \in \mathcal{G}$. For all player $i \in N$ and link $ij \in g$, we denote by:

$$m_{ij}u_i(g) = u_i(g) - u_i(g - ij)$$

⁷Both with complete and incomplete information.

the marginal payoff accruing to i from the link ij in the network g . Given a collection of current links $ij_1, \dots, ij_\ell \in g$ of player i in g , the marginal joint value of these links accruing to i in g is:

$$m_{ij_1, \dots, ij_\ell} u_i(g) = u_i(g) - u_i(g - ij_1 - \dots - ij_\ell).$$

Consider now some new direct link $ij \notin g$ of player i , absent from g . Then, $m_{ij} u_i(g + ij)$ is the marginal payoff accruing to i from the new link ij added to g , and the joint marginal value of a collection of new links $ij_1, \dots, ij_\ell \notin g$ is $m_{ij_1, \dots, ij_\ell} u_i(g + ij_1 + \dots + ij_\ell)$.

α -convexity and β -strong concavity in new links The following definitions documents two possible features displayed by link marginal payoffs.

Let u be a network payoff function, $\mathcal{A} \subseteq \mathcal{G}$ and $\alpha \geq 0$.

Definition 1 *Let $i \in N$. Then, u_i is α -convex on \mathcal{A} if and only if, for all $g \in \mathcal{A}$ and $ij_1, \dots, ij_\ell \in g$, we have:*

$$m_{ij_1, \dots, ij_\ell} u_i(g) \geq \alpha \sum_{p=1}^{\ell} m_{ij_p} u_i(g). \quad (1)$$

u is α -convex on \mathcal{A} if and only if u_i is α -convex on \mathcal{A} for each $i \in N$.

The condition for α -convexity states that the joint marginal value of a group of links already in the network is higher than the sum of the marginal values of each single link, scaled by α . The case $\alpha = 1$ corresponds to convexity. α -convexity is a property that applies to marginal payoff returns from existing links only.⁸

Let $g \in \mathcal{G}$. For all $i \in N$, let $g_i = \{ij \in g\}$ be the set of direct links stemming from i in g , and $\bar{g}_i = \{ij \notin g\}$ the set of i 's missing direct links in g . Let $\gamma_i \subseteq \bar{g}_i$ be a subset of i 's missing links in g , and $\beta > 0$.

Definition 2 *Let $i \in N$. Then, u_i is β -strongly concave in own new links on γ_i if and only if, for all $ij_{\ell+1}, \dots, ij_{\ell+\ell'} \in g$ and $ij_1, \dots, ij_\ell \in \gamma_i$, we have:*

$$m_{ij_1, \dots, ij_\ell} u_i(g + ij_1 + \dots + ij_\ell - ij_{\ell+1} - \dots - ij_{\ell+\ell'}) \leq \beta \sum_{p=1}^{\ell} m_{ij_p} u_i(g + ij_p). \quad (2)$$

Suppose first that $\gamma_i = \emptyset$. Then, β -strong concavity states that the joint marginal value of a group of links already in the network is higher than the sum of the marginal values of each single link, scaled by β . The case $\beta = 1$ corresponds to concavity. When $\gamma_i = \emptyset$, β -strong concavity is simply the dual of α -convexity.

Suppose now that $\gamma_i \neq \emptyset$. Then, β -strong concavity compares the joint-links marginal value of current links to the sum of their single-link marginal values, both in the original network g and

⁸Given that marginal link values are only computed for links already in the network, a more precise (but introverted) wording would be α -convexity in own current links. We keep α -convexity for short.

in every supernetwork of g where subsets of links in γ_i are added. β -strong concavity is thus a stronger version of β -concavity that allows for link addition for the comparison of marginal payoffs.⁹

Note that α -convexity on \mathcal{A} implies α' -convexity on \mathcal{A} , for all $\alpha > \alpha' \geq 0$, and similarly for β -strong concavity, for all $\beta' > \beta > 0$. In fact, both conditions are equivalent to a sign preserving condition for joint-link marginal payoffs versus the sum of single-link marginal payoffs. Formally, for all $x \in \mathbb{R}$, let:

$$\omega(x) = \begin{cases} +1, & \text{if } x > 0 \\ 0, & \text{if } x = 0 \\ -1, & \text{if } x < 0 \end{cases}.$$

Proposition 1 *Let $\mathcal{A} \subseteq \mathcal{G}$, $\alpha \geq 0$ and $i \in N$. Then, u_i is α -convex on \mathcal{A} if and only if, for all $ij_1, \dots, ij_\ell \in g$ and $g \in \mathcal{A}$:*

$$\omega\left(\sum_{p=1}^{\ell} m_{ij_p} u_i(g)\right) \geq 0 \text{ implies } \omega(m_{ij_1, \dots, ij_\ell} u_i(g)) \geq 0.$$

Let $\gamma_i \subseteq \bar{g}_i$ and $\beta > 0$. Then, u_i is β -strongly concave in own new links on γ_i if and only if, for all $ij_1, \dots, ij_\ell \in \gamma_i$ and $ij_{\ell+1}, \dots, ij_{\ell+\ell'} \in g_i$:

$$\begin{aligned} \omega\left(\sum_{p=1}^{\ell} m_{ij_p} u_i(g + ij_p)\right) &\leq 0 \text{ implies} \\ \omega(m_{ij_1, \dots, ij_\ell} u_i(g + ij_1 \dots + ij_\ell - ij_{\ell+1} \dots - ij_{\ell+\ell'})) &\leq \omega\left(\sum_{p=1}^{\ell} m_{ij_p} u_i(g + ij_p)\right). \end{aligned}$$

3 Network equilibrium

In what follows, we first define *pairwise-stability*, due to Jackson and Wolinsky (1996), and often interpreted as a necessary condition for network equilibrium.¹⁰

We then formulate a simultaneous move game of network formation due to Myerson (1991). This game is simple and intuitive, but generally displays a multiplicity of Nash equilibria. To accommodate this fact, we define *pairwise-Nash equilibrium*, a variation of Nash equilibrium where players are allowed to deviate by pairs.¹¹

Finally, we recall the definition of *proper equilibrium*, a Nash equilibrium refinement for simultaneous move games introduced by Myerson (1978).

⁹ Again, a more precise wording for this condition on marginal payoffs would be β -strong concavity in own current links and own new links in γ_i .

¹⁰ See also Jackson and Watts (2002) for a dynamic foundation of pairwise-stability.

¹¹ See Bloch and Jackson (2004), Calvó-Armengol (2004) and Goyal and Joshi (2002) for applications of this concept. See also Dutta and Mutuswami (1997) and Jackson and van den Nouweland (2000) for alternatives to pairwise stability and Nash equilibrium that allow for coalitional moves.

Pairwise-stability Pairwise stable networks are robust to one-link deviations, where link severance is unilateral, while link creation is bilateral and under mutual consent of the two involved players.

Definition 3 A network $g \in \mathcal{G}$ is pairwise stable with respect to the network payoff function u if and only if, for all $ij \in g$, both $m_{ij}u_i(g) \geq 0$ and $m_{ij}u_j(g) \geq 0$, while for all $ij \notin g$, if $m_{ij}u_i(g + ij) > 0$, then $m_{ij}u_j(g + ij) < 0$, for all $i \in N$.

We denote by $PS(u)$ the set of pairwise stable networks with respect to u .

A simultaneous move game of network formation This game is due to Myerson (1991).¹² The set of players is N . All players $i \in N$ simultaneously announce the direct links they wish to form. Formally, $S_i = \{0, 1\}^{n-1}$ is i 's set of pure strategies. Let $s_i = (s_{i1}, \dots, s_{i,i-1}, s_{i,i+1}, \dots, s_{in}) \in S_i$. Then, $s_{ij} = 1$ if and only if i wants to set up a direct link with $j \neq i$ (and thus $s_{ij} = 0$, otherwise). We assume that mutual consent is needed to create a direct link, that is, ij is created if and only if $s_{ij}s_{ji} = 1$.

Let $S = S_1 \times \dots \times S_n$. A pure strategy profile $s = (s_1, \dots, s_n) \in S$ induces an undirected network $g(s)$.

Let $\Sigma_i = \Delta(\{0, 1\}^{n-1})$ be i 's set of mixed strategies, where $\Delta(\{0, 1\}^{n-1})$ denotes the set of probability distributions over $\{0, 1\}^{n-1}$. A mixed strategy $\sigma_i \in \Sigma_i$ is thus a joint (multivariate Bernoulli) distribution that allows for rich correlation patterns in individual link announcements. In particular, given a mixed strategy σ_i , i announces a link with j with marginal probability.¹³

$$\sigma_i(s_{ij} = 1, \cdot) = \sum_{s \in \{0, 1\}^{n-1}; s_{ij}=1} \sigma_i(s)$$

Let $\Sigma = \Sigma_1 \times \dots \times \Sigma_n$. A mixed strategy $\sigma = (\sigma_1, \dots, \sigma_n) \in \Sigma$ generates a probability distribution over \mathcal{G} , a random graph.¹⁴

Pairwise-Nash equilibrium A pure strategy profile $s^* = (s_1^*, \dots, s_n^*)$ is a Nash equilibrium of the game of network formation if and only if $u_i(g(s^*)) \geq u_i(g(s_i, s_{-i}^*))$, for all $s_i \in S_i$ and $i \in N$. Nash equilibrium, though, is too weak an equilibrium concept to single out equilibrium networks. For instance, the empty network is always a Nash equilibrium.¹⁵ Building upon pairwise-stability,

¹²To quote Myerson: "Now consider a link-formation process in which each player independently writes down a list of players with whom he wants to form a link (...) and the payoff allocation is (...) for the graph that contains a link for every pair of players who have named each other." (p. 448)

¹³Note that, for $n \geq 3$, the collection of such marginal probabilities does not define univocally a mixed strategy. Fréchet (1951) gives an early and thorough account of the relationship between joint distributions (here, mixed strategies on the collection of all link announcements) and marginals (here, single link probabilities) when $n = 3$.

¹⁴See Jackson and Rogers (2004) for a relation between random graphs and individual incentives.

¹⁵When nobody announces any link.

we further require that any mutually beneficial link be formed at equilibrium. Pairwise-Nash equilibrium networks are robust to bilateral commonly agreed one-link creation, and to unilateral multi-link severance.

Definition 4 *A network $g \in \mathcal{G}$ is a pairwise-Nash equilibrium network with respect to the network payoff function u if and only if there exists a Nash equilibrium strategy profile s^* that supports g , that is, $g = g(s^*)$, and, for all $ij \notin g$, if $m_{ij}u_i(g + ij) > 0$, then $m_{ij}u_j(g + ij) < 0$, for all $i \in N$.*

We denote by $PNE(u)$ the set of pairwise-Nash equilibrium networks with respect to u .

Proper equilibrium

Definition 5 *A strategy profile $\sigma \in \Sigma$ is proper if there exists a sequence of completely mixed equilibrium strategy profiles $\{\sigma^{\varepsilon_t}\}_{t \in \mathbb{N}}$ with limit σ such that, for all $i \in N$, $s'_i, s''_i \in S_i$, and $t \in \mathbb{N}$ we have:*

$$Eu_i(s'_i, \sigma_{-i}^{\varepsilon_t}) > Eu_i(s''_i, \sigma_{-i}^{\varepsilon_t}) \text{ implies that } \sigma_i^{\varepsilon_t}(s''_i) \leq \varepsilon_t \cdot \sigma_i^{\varepsilon_t}(s'_i).$$

This refinement is due to Myerson (1978). In a proper equilibrium, players best respond to perturbations of their opponents' strategies, where costly mistakes are made with less probability. This hierarchy of mistakes differentiates properness from trembling-hand perfection. Myerson (1978) showed that every game has a proper equilibrium. We denote by $PRE(u)$ the set of proper Nash equilibrium networks *in pure strategies* with respect to u .¹⁶

4 The results

We first provide necessary and sufficient conditions on the payoff function u for the set of pairwise stable networks and the set of pairwise-Nash equilibrium networks to coincide. We latter characterize the equivalence between pairwise-Nash equilibrium networks and proper equilibrium networks.

Pairwise stable and pairwise-Nash equilibrium networks

Theorem 1 *$PS(u) = PNE(u)$ if and only if u is α -convex on $PS(u)$, for some $\alpha \geq 0$.*

¹⁶We want to establish necessary and sufficient conditions such that the set of pairwise stable, pairwise-Nash and proper equilibrium networks coincide. Given that both pairwise-stability and pairwise-Nash networks are only defined for pure strategies (that is, deterministic networks), we restrict attention to proper equilibria in pure strategies. Myerson (1978) shows that any finite normal form game has a proper equilibria. Given our restriction to pure strategies, existence is not warranted here. See Jackson and Watts (2001) for a perspective on the existence of pairwise stable networks.

The proof derives from the simple observation that, when payoffs are α -convex on $PS(u)$ for some $\alpha \geq 0$, if a player does not benefit from severing any single link, then he does not gain from cutting any group of links simultaneously. Robustness to unilateral or to multilateral link severance are equivalent when marginal payoffs from existing links satisfy (1) on some particular set.

Pairwise-Nash and proper equilibrium networks We now define link-responsive network payoffs functions.

Definition 6 *The network payoff function u is link-responsive if and only if $m_{ij_1, \dots, ij_\ell} u_i(g) \neq 0$, for all $i \in N$, $ij_1, \dots, ij_\ell \in g$, and $g \in \mathcal{G}$.*

Link-responsiveness states that no link removal or addition is innocuous for the players directly involved. Network payoff functions that depend on some exogenous set of parameters (e.g., a constant marginal-link cost) are generically link-responsive..

For all $g \in \mathcal{G}$ and u , let $\nu_i(g, u) = \{ij \notin g : m_{ij} u_i(g + ij) \leq 0\}$ be the set of i 's direct links not in g with non-positive marginal returns.

Theorem 2 *Suppose that u is link-responsive. Then, $PNE(u) = PRE(u)$ if and only if u_i is β -strongly concave in own new links on $\nu_i(g, u)$, for all $i \in N$ and $g \in PNE(u)$, for some $\beta > 0$.*

Link-responsiveness is enough for any proper equilibrium network to be pairwise-Nash, while β -strong concavity on $\nu_i(g, u)$ is needed to sustain pairwise-Nash equilibria as proper. Consider some pairwise-Nash equilibrium g , and s an equilibrium strategy profile that supports it. Now, modify the profile s the following way. For each single link not in g , say $ij \notin g$, if one of the two parties involved agrees to create such a link, say i ,¹⁷ then modify s by letting i announce this link, that is, set $s_{ij} = 1$. The new strategy profile obtained from this procedure is still an equilibrium strategy that supports g if and only if the condition in Theorem 2 holds.

With this new equilibrium pure strategy profile, we construct a completely mixed strategy profile by allowing players to make mistakes on link announcements. When mistakes vanish, the mixed profile converges to the equilibrium one. Mistakes are chosen so that links (not in g) for which neither of the two parties agree on their creation are announced with a (tremble) probability one order of magnitude higher than any other tremble probability on any other link announcement. This mixed strategy profile induces a quasi-perfect equilibrium in any extensive form equivalent of the simultaneous move game of link formation.¹⁸ We finally invoke a result by Mailath, Samuelson and Swinkels (1997) who provide an extensive form characterization of properness by means of quasi-perfect equilibrium strategies.

¹⁷That is, $m_{ij} u_i(g + ij) > 0$.

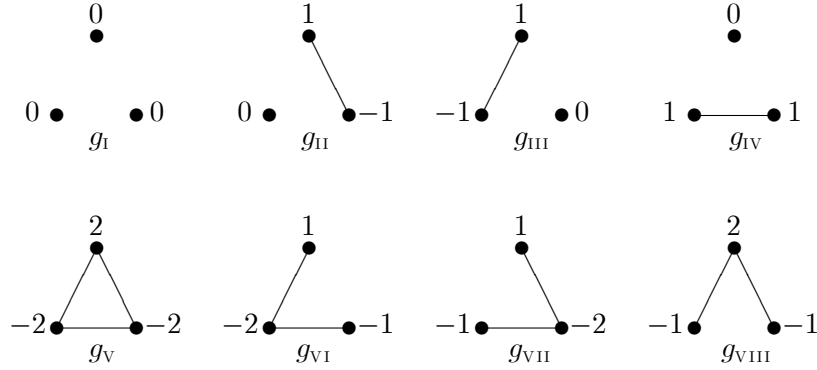
¹⁸Quasi-perfection, a notion due to van Damme (1984), requires that, with the limit strategy, players are best-responding at all information sets to each element of the sequence of perturbed strategies. Quasi-perfection also forces players to ignore their perturbations in their own strategies.

When links absent from the network are such that no player consents in their creation, then $\nu_i(g, u) = \emptyset$, for all $i \in N$, and any pairwise-Nash equilibrium outcome is proper. In particular, when the complete network is a pairwise-Nash equilibrium outcome, it is also proper.

Corollary 1 *Let $g \in PNE(u)$. Suppose that, for all $ij \notin g$, we have $m_{ij}u_i(g + ij) < 0$ and $m_{ij}u_j(g + ij) < 0$. Then, $g \in PRE(u)$.*

In what follows, we first show with an example that trembling-hand perfect equilibrium outcomes need not be pairwise-Nash, even when the conditions in Theorem 2 hold. This justifies the need to resort to proper equilibrium, a refinement that differs from trembling-hand by imposing a hierarchy on trembles related to the relative cost values associated with these mistakes.

Example (trembling-hand networks need not be pairwise-Nash) Let $N = \{1, 2, 3\}$ and consider the network payoffs defined below:



Denote by 1 the player at the top, and by 2 and 3 the players at the bottom, and let $S_1 = \{(s_{12}, s_{13}) \in \{0, 1\}^2\}$, $S_2 = \{(s_{21}, s_{23}) \in \{0, 1\}^2\}$ and $S_3 = \{(s_{31}, s_{32}) \in \{0, 1\}^2\}$. The only pairwise-Nash equilibrium network is g_{IV} . The network payoff function u is link-responsive and satisfies (2). The empty network g_I is a trembling-hand network for the pure strategy $s^* = ((1, 1), (0, 0), (0, 0))$ in which player 1 announces all the links, and players 2 and 3 do not announce any link. This strategy s^* is the limit of the sequence of best-replying trembles of the perturbed game, where:

$$\begin{aligned} \sigma_1^\varepsilon((0, 0)) &= \sigma_1^\varepsilon((1, 0)) = \sigma_1^\varepsilon((0, 1)) = \varepsilon, \sigma_1^\varepsilon((1, 1)) = 1 - 3\varepsilon \\ \sigma_2^\varepsilon((1, 0)) &= \sigma_2^\varepsilon((0, 1)) = \sigma_2^\varepsilon((1, 1)) = \varepsilon, \sigma_2^\varepsilon((0, 0)) = 1 - 3\varepsilon \\ \sigma_3^\varepsilon((1, 0)) &= \sigma_3^\varepsilon((0, 1)) = \sigma_3^\varepsilon((1, 1)) = \varepsilon, \sigma_3^\varepsilon((0, 0)) = 1 - 3\varepsilon \end{aligned}$$

Next, we apply our results to the connections model and the co-author model, both due to Jackson and Wolinsky (1996), and to a model of information transmission due to Calvó-Armengol (2004).

Example (connections model) This model is due to Jackson and Wolinsky (1996). Suppose that network payoffs are given by:

$$u_i(g) = \sum_{j \in N} \delta^{d_{ij}(g)} - cn_i(g),$$

for some $\delta \in (0, 1)$, where $n_i(g) = \#g_i$ and $d_{ij}(g)$ is the geodesic distance between i and j . As marginal link costs are constant, we focus on link marginal gross returns. As an agent might be connected indirectly to another agent through several paths, the number of indirect connections lost under multiple link cutting would be greater than the sum of the losses over links, when each is cut individually. Hence, as is shown in Lemma 2 in Section 5, the connections model is 1-convex for all the networks. Next, note that u satisfies (2) for the complete network and for stars on the cost ranges where these are pairwise stable (resp. $c < \delta - \delta^2$ and $\delta - \delta^2 < c < \delta$).¹⁹ This is a consequence of Corollary 1, as peripheral players in the star network get a negative return from any direct link with one another. Note also that u is generically link-responsive. Therefore, stars and the complete network are (generically) proper equilibria when $c < \delta - \delta^2$ and $\delta - \delta^2 < c < \delta$, respectively.

Example (co-author model) This model is due to Jackson and Wolinsky (1996). Suppose that network payoffs are given by:

$$u_i(g) = \left(1 + \frac{1}{n_i(g)}\right) \sum_{ij \in g} \frac{1}{n_j(g)},$$

if $\#g_i \geq 1$, and $u_i(g) = 0$, otherwise. Then, straight calculations show that u is $2/n^3$ -convex in own current links on \mathcal{G} . The set of pairwise stable and pairwise-Nash equilibrium networks thus coincide. Pairwise stable networks consist on a sequence of fully connected networks such that, if we order this sequence by components' sizes, the square of the size of any component is smaller than the next size in this sequence.²⁰ It is plain that any player in a component gains by cutting current links with its component mates and rewiring with players in components of smaller size. Such links, though, are not formed because it is not in the interest of the latter (the players in the components of smaller size) to consent to this rewiring process. In fact, (2) does not hold, and pairwise stable networks are not proper (except for the complete network, which is pairwise stable, pairwise-Nash and proper).

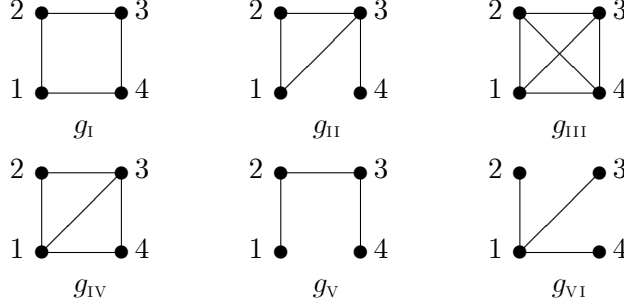
Example (information transmission) This model is due to Calvó-Armengol (2004). Suppose that network payoffs are given by:

$$u_i(g) = 1 - \prod_{j \in N} p_{ji}(g) - cn_i(g),$$

¹⁹See Proposition 2 in Jackson and Wolinsky (1996).

²⁰See Proposition 4 in Jackson and Wolinsky (1996).

where $p_{ji}(g) \in (0, 1)$, for all $i, j \in N$. In this case, u is 1-convex in own current links on \mathcal{G} , and the set of pairwise stable and pairwise-Nash equilibrium networks coincide.²¹ Note that u is generically link-responsive. Let $N = \{1, 2, 3, 4\}$: There are six different connected networks on N :



When the p_{ij} 's take a particular expression,²² g_I , g_{II} and g_{III} are the only pairwise stable networks, each for some cost range. Corollary 1 implies that only g_I and g_{III} are (generically) proper on the cost ranges where these are pairwise stable (and only there).

5 Main proofs

Proof of Proposition 1 Derives from the fact that \mathcal{G} is a finite set.

Proof of Theorem 1 First, it is clear that $PNE(u) \subseteq PS(u)$. Hence, if $PS(u) = \emptyset$, the result follows. Suppose now that $PS(u) \neq \emptyset$, and let $g^* \in PS(u)$. Define:

$$\phi(g^*, u) \in \min \{m_{ij}u_i(g^*) : ij \in g, i \in N\}.$$

Pairwise-stability implies that $\phi(g^*, u) \geq 0$. Suppose that u is α -convex in own current links on $PS(u)$ for some $\alpha \geq 0$. Then, (1) implies that $m_{ij_1, \dots, ij_\ell}u_i(g^*) \geq \alpha\phi(g^*, u) \geq 0$, for all $ij_1, \dots, ij_\ell \in g^*$ and $i \in N$. Moreover, by definition of pairwise-stability, if $m_{ij}u_i(g^* + ij) > 0$, then $m_{ij}u_j(g^* + ij) < 0$, for all $ij \notin g^*$ and $i \in N$. Therefore, $g^* \in PNE(u)$.

Now, suppose that there exists $g^* \in PS(u)$ such that, for all $\alpha \geq 0$, (1) does not hold for g^* . Then, for some $i \in N$, there exists $ij_1, \dots, ij_\ell \in g^*$ such that $m_{ij_1, \dots, ij_\ell}u_i(g^*) < 0$, implying that $g^* \notin PNE(u)$. ■

²¹This results from Claim 2 in Calvó-Armengol (2004).

²²Let $u_i(g) = 1 - b \prod_{ij \in g} q(n_j(g)) - cn_i(g)$, where

$$q(n_j(g)) = \frac{1 - (1 - c)^{n_j(g)}}{cn_j(g)}.$$

This is i 's expected payoff for a stochastic process of information transmission in the network. Then, g_I , g_{II} and g_{III} are the unique pairwise-stable networks for some cost ranges (see Calvó-Armengol 2004).

Proof of Theorem 2 We decompose the proof in two parts. Proposition 2 establishes that $PRE(u) \subseteq PNE(u)$ when u is link-responsive. Suppose that u is link-responsive. Proposition 3 then shows that $PNE(u) \subseteq PRE(u)$ if and only if u is u_i is β -strongly concave in own new links on $\nu_i(g, u)$, for all $i \in N$ and $g \in PNE(u)$, for some $\beta > 0$.

Proposition 2 *If the network payoff u is link-responsive, then $PRE(u) \subseteq PNE(u)$.*

Proof. Let u be link-responsive. We show that $g \notin PNE(u)$ implies that $g \notin PRE(u)$.

Let g^* be a Nash equilibrium outcome such that $m_{ij}u_i(g^* + ij) > 0$ and $m_{ij}u_j(g^* + ij) \geq 0$, for some $ij \notin g^*$. Then, $g^* \notin PNE(u)$. Suppose that $g^* \in PRE(u)$, and let s^* be a pure strategy proper equilibrium that supports it. Then, $g^* = g(s^*)$. Let $\{\sigma^{\varepsilon t}\}_{t \in \mathbb{N}}$ be a sequence of completely mixed strategy profiles such that $\lim_{t \rightarrow +\infty} \sigma^{\varepsilon t}(s^*) = 1$, and $\sigma^{\varepsilon t}$ is an ε_t -proper equilibrium of the link formation game with network payoffs u , for all $t \in \mathbb{N}$.

Given that s^* is also a Nash equilibrium strategy and that $ij \notin g^*$, necessarily, $s_{ij}^* = s_{ji}^* = 0$.

For all $j \neq i$, define $e(ij) = (0, \dots, s_{ij} = 1, 0, \dots, 0)$. In $e(ij)$, player i only announces the link with j . Let $s'_i = s_i^* \vee e(ij)$. In s'_i , player i announces exactly the same links than in s_i^* plus an extra link with player j . This extra link is not reciprocated by player j in s^* .

For all $t \in \mathbb{N}$, define:

$$\Delta_i(s'_i, s_i^*; \sigma^{\varepsilon t}_{-i}) = Eu_i(g(s'_i, \sigma^{\varepsilon t}_{-i})) - Eu_i(g(s_i^*, \sigma^{\varepsilon t}_{-i})) = \sum_{\tilde{s}_{-i} \in S_{-i}} \sigma^{\varepsilon t}_{-i}(\tilde{s}_{-i}) \Delta_i(s'_i, s_i^*; \tilde{s}_{-i}), \quad (3)$$

where $\Delta_i(s'_i, s_i^*; \tilde{s}_{-i}) = u_i(g(s'_i, \tilde{s}_{-i})) - u_i(g(s_i^*, \tilde{s}_{-i}))$. For all \tilde{s}_{-i} such that $\tilde{s}_{ji} = 0$, we have $g(s'_i, \tilde{s}_{-i}) = g(s_i^*, \tilde{s}_{-i})$, and $\Delta_i(s'_i, s_i^*; \tilde{s}_{-i}) = 0$. Therefore,

$$\Delta_i(s'_i, s_i^*; \sigma^{\varepsilon t}_{-i}) = \sum_{\tilde{s}_{-i} \in S_{-i}: \tilde{s}_{ji}=1} \sigma^{\varepsilon t}_{-i}(\tilde{s}_{-i}) \Delta_i(s'_i, s_i^*; \tilde{s}_{-i}).$$

Let $\tilde{s}_{-i} \in S_{-i}$ such that $\tilde{s}_{ji} = 1$. Let $\tilde{g} = g(s_i^*, \tilde{s}_{-i})$. Note that $\tilde{g}_{ij} = 0$, and that $g(s'_i, \tilde{s}_{-i}) = \tilde{g} + ij$. Also, $s_{ik} = 0$ implies that $\tilde{g}_{ik} = 0$. Define $\mathcal{G}(s_i^*) = \{g \in \mathcal{G} : s_{ik}^* = 0 \Rightarrow g_{ik} = 0\}$. It is readily checked that

$$\mathcal{G}(s_i^*) = \{g(s_i^*, \tilde{s}_{-i}) : \tilde{s}_{-i} \in S_{-i}, \tilde{s}_{ji} = 1\}.$$

Therefore, we can write:

$$\Delta_i(s'_i, s_i^*; \sigma^{\varepsilon t}_{-i}) = \sum_{\tilde{g} \in \mathcal{G}(s_i^*)} \mu_{\varepsilon t}(\tilde{g}) m_{ij} u_i(\tilde{g} + ij),$$

where

$$\mu_{\varepsilon t}(\tilde{g}) = \sum_{\substack{\tilde{s}_{-i} \in S_{-i}: \tilde{s}_{ji}=1 \\ g(s_i^*, \tilde{s}_{-i}) = \tilde{g}}} \sigma^{\varepsilon t}_{-i}(\tilde{s}_{-i}).$$

Given that the mixed strategy profiles $\sigma^{\varepsilon t}$, $t \in \mathbb{N}$ have full support, $\mu_{\varepsilon t}(\tilde{g}) \neq 0$, for all $\tilde{g} \in \mathcal{G}(s_i^*)$ and $t \in \mathbb{N}$. Therefore, $\Delta_i(s_i', s_i^*; \sigma_{-i}^{\varepsilon t}) > 0$ is equivalent to

$$m_{ij}u_i(g^* + ij) + \sum_{\tilde{g} \in \mathcal{G}(s_i^*), \tilde{g} \neq g^*} \frac{\mu_{\varepsilon t}(\tilde{g})}{\mu_{\varepsilon t}(g^*)} m_{ij}u_i(\tilde{g} + ij) > 0.$$

Since $\Delta_i(s_i', s_i^*; \sigma_{-i}^{\varepsilon t})$ is continuous in $\sigma_{-i}^{\varepsilon t}$, and given that $m_{ij}u_i(g^* + ij) > 0$, it suffices to show that $\lim_{t \rightarrow +\infty} \mu_{\varepsilon t}(\tilde{g})/\mu_{\varepsilon t}(g^*) = 0$, for all $\tilde{g} \in \mathcal{G}(s_i^*), \tilde{g} \neq g^*$. Note that $\lim_{t \rightarrow +\infty} \sigma_{-i}^{\varepsilon t}(\tilde{s}_{-i}) = 0$, for all $\tilde{s}_{-i} \in S_{-i}$ such that $\tilde{s}_{ji} = 1$. Therefore, $\lim_{t \rightarrow +\infty} \mu_{\varepsilon t}(\tilde{g}) = 0$, for all $\tilde{g} \in \mathcal{G}(s_i^*)$, including $\tilde{g} = g^*$. Establishing that

$$\lim_{t \rightarrow +\infty} \frac{\mu_{\varepsilon t}(\tilde{g})}{\mu_{\varepsilon t}(g^*)} = 0, \text{ for all } \tilde{g} \in \mathcal{G}(s_i^*), \tilde{g} \neq g^*,$$

is thus equivalent to showing that the rate of convergence of $\mu_{\varepsilon t}(\tilde{g}), \tilde{g} \neq g^*$ is at least one order of magnitude higher than that of $\mu_{\varepsilon t}(g^*)$. This is implied by properness, as detailed below.

For each $k \in N$, we partition the strategy set S_k into two disjoint sets S_k^+ and S_k^- where:

$$\begin{cases} S_k^+ = \{s_k \in S_k : u_k(g(s_k, s_{-k}^*)) \geq u_k(g^*)\} \\ S_k^- = \{s_k \in S_k : u_k(g(s_k, s_{-k}^*)) < u_k(g^*)\} \end{cases}.$$

It is plain that $S_k = S_k^+ \cup S_k^-$ and that $S_k^+ \cap S_k^- = \emptyset$. Given that u is link-responsive and that s^* is a Nash equilibrium strategy supporting g^* , we have $g(s_k', s_{-k}^*) = g^*$, for all $s_k' \in S_k^+$. Moreover, as $\lim_{t \rightarrow +\infty} \sigma^{\varepsilon t} = s^*$, and given that each player's expected payoff is continuous in the vector of other players' (completely) mixed strategies, there exists some t_k such that, for all $t \geq t_k$, we have $u_k(g(s_k^+, \sigma_{-k}^{\varepsilon t})) < u_k(g(s_k^-, \sigma_{-k}^{\varepsilon t}))$, for all $s_k^+ \in S_k^+$ and $s_k^- \in S_k^-$. Given that $\{\sigma^{\varepsilon t}\}_{t \in \mathbb{N}}$ is a sequence of ε_t -proper equilibria, this implies that, for all $t \geq t_k$, $s_k^+ \in S_k^+$ and $s_k^- \in S_k^-$ we have $\sigma_k^{\varepsilon t}(s_k^-) \leq \varepsilon_t \cdot \sigma_k^{\varepsilon t}(s_k^+)$. Note, also, that $s_j' \in S_j^+$. Define:

$$\begin{cases} \mathcal{G}' = \{g \in \mathcal{G}(s_i^*) : g \neq g^*, g = g(\tilde{s}_j, s_{-j}^*), \tilde{s}_j \in S_j, \tilde{s}_{ji} = 1\} \\ \mathcal{G}'' = \{g \in \mathcal{G}(s_i^*) : g \neq g^*, g = g(s_i^*, \tilde{s}_{-i}), \tilde{s}_{-i} \in S_{-i}, \tilde{s}_{ji} = 1, \tilde{s}_k \neq s_k^* \text{ for some } k \neq j\} \end{cases}.$$

In words, \mathcal{G}' is the set of networks derived from g^* under s^* where only player j makes a mistake (including always the announcement of the link ij), whereas \mathcal{G}'' uncovers all the networks where at least some other player (besides j) makes a mistake. Clearly, $\mathcal{G}(s_i^*) \setminus g^* = \mathcal{G}' \cup \mathcal{G}''$. Let $\tilde{g} \in \mathcal{G}'$. Then,

$$\mu_{\varepsilon t}(\tilde{g}) = \sigma_{-i-j}^{\varepsilon t}(s_{-i-j}^*) \sum_{\substack{\tilde{s}_j \in S_j : \tilde{s}_{ji}=1 \\ g(\tilde{s}_j, s_{-j}^*) = \tilde{g}}} \sigma_j^{\varepsilon t}(\tilde{s}_j).$$

But, for all $\tilde{s}_j \in S_j$ such that $g(\tilde{s}_j, s_{-j}^*) \in \mathcal{G}'$, necessarily, $\tilde{s}_j \in S_j^-$, implying in turn that $\sigma_j^{\varepsilon t}(\tilde{s}_j) \leq \varepsilon_t \sigma_j^{\varepsilon t}(s_j')$, for all $t \geq t_j$. Therefore, for all $t \geq t_j$, we have $\mu_{\varepsilon t}(\tilde{g}) \leq K(\tilde{g}) \varepsilon_t \sigma_{-i}^{\varepsilon t}(s_{-i}')$, where $K(\tilde{g}) = \#\{\tilde{s}_j \in S_j : \tilde{s}_{ji} = 1, g(\tilde{s}_j, s_{-j}^*) = \tilde{g}\} \geq 1$. Then, given that

$$\mu_{\varepsilon t}(g) = \sigma_{-i}^{\varepsilon t}(s_{-i}') + \sum_{\substack{\tilde{s}_{-i} \in S_{-i} \setminus \{s_{-i}'\} \\ \tilde{s}_{ji}=1, g(s_i^*, \tilde{s}_{-i}) = \tilde{g}}} \sigma_{-i}^{\varepsilon t}(\tilde{s}_{-i}),$$

we have

$$\frac{\mu_{\varepsilon_t}(\tilde{g})}{\mu_{\varepsilon_t}(g)} \leq K(\tilde{g})\varepsilon_t \frac{1}{1 + \sum_{\substack{\tilde{s}_{-i} \in S_{-i} \setminus \{s'_{-i}\}: \\ \tilde{s}_{ji}=1, g(s_i^*, \tilde{s}_{-i})=\tilde{g}}} \frac{\sigma_{-i}^{\varepsilon_t}(\tilde{s}_{-i})}{\sigma_{-i}^{\varepsilon_t}(s'_{-i})}}.$$

But, any $\tilde{s}_{-i} \in S_{-i}$ such that $\tilde{s}_{-i} \neq s'_{-i}$ and $\tilde{s}_{ji} = 1$ contains at least one additional mistake with respect to s'_{-i} , implying that $\sigma_{-i}^{\varepsilon_t}(\tilde{s}_{-i})/\sigma_{-i}^{\varepsilon_t}(s'_{-i}) \rightarrow 0$ as $t \rightarrow +\infty$, for any such strategy profile, which implies in turn that $\lim_{t \rightarrow +\infty} \mu_{\varepsilon_t}(\tilde{g})/\mu_{\varepsilon_t}(g^*) = 0$.

Let now $\tilde{g} \in \mathcal{G}''$. Let $\tilde{s}_{-i} \in S_{-i}$ such that $g = g(s_i^*, \tilde{s}_{-i})$. Define $L = \{k \neq j : \tilde{s}_k \neq s_k^*\}$. By definition, $L \neq \emptyset$. Now, $\sigma_{-i}^{\varepsilon_t}(\tilde{s}_{-i}) = \sigma_j^{\varepsilon_t}(\tilde{s}_j)\sigma_L^{\varepsilon_t}(\tilde{s}_L)\sigma_{-i-j-L}^{\varepsilon_t}(s_{-i-j-L}^*)$ and, thus,

$$\begin{aligned} \frac{\sigma_{-i}^{\varepsilon_t}(\tilde{s}_{-i})}{\mu_{\varepsilon_t}(g)} &\leq \frac{\sigma_j^{\varepsilon_t}(\tilde{s}_j)\sigma_L^{\varepsilon_t}(\tilde{s}_L)\sigma_{-i-j-L}^{\varepsilon_t}(s_{-i-j-L}^*)}{\sigma_j^{\varepsilon_t}(s'_j)\sigma_{-i-j}^{\varepsilon_t}(s_{-i-j}^*) + \sum_{\substack{\tilde{s}_{-i} \in S_{-i} \setminus \{s'_{-i}\}: \\ \tilde{s}_{ji}=1, g(s_i^*, \tilde{s}_{-i})=\tilde{g}}} \sigma_{-i}^{\varepsilon_t}(\tilde{s}_{-i})} \\ &\leq \frac{\sigma_L^{\varepsilon_t}(\tilde{s}_L)\sigma_j^{\varepsilon_t}(\tilde{s}_j)}{\sigma_L^{\varepsilon_t}(s_L^*)\sigma_j^{\varepsilon_t}(s'_j)} \frac{1}{1 + \sum_{\substack{\tilde{s}_{-i} \in S_{-i} \setminus \{s'_{-i}\}: \\ \tilde{s}_{ji}=1, g(s_i^*, \tilde{s}_{-i})=\tilde{g}}} \frac{\sigma_{-i}^{\varepsilon_t}(\tilde{s}_{-i})}{\sigma_{-i}^{\varepsilon_t}(s'_{-i})}}. \end{aligned}$$

Now, $\lim_{t \rightarrow +\infty} \sigma_L^{\varepsilon_t}(\tilde{s}_L) = 0$, $\lim_{t \rightarrow +\infty} \sigma_L^{\varepsilon_t}(s_L^*) = 1$, and

$$\lim_{t \rightarrow +\infty} \frac{\sigma_j^{\varepsilon_t}(\tilde{s}_j)}{\sigma_j^{\varepsilon_t}(s'_j)} = \begin{cases} 1, & \text{if } \tilde{s}_j = s'_j \\ 0, & \text{otherwise} \end{cases},$$

implying that $\lim_{t \rightarrow +\infty} \mu_{\varepsilon_t}(\tilde{g})/\mu_{\varepsilon_t}(g^*) = 0$.

But then, given that σ^{ε_t} is an ε_t -proper equilibrium, there exists some T such that $\sigma_i^{\varepsilon_t}(s_i^*) \leq \varepsilon_t \sigma_i^{\varepsilon_t}(s'_i)$, for all $t \geq T$, implying that $\lim_{t \rightarrow +\infty} \sigma_i^{\varepsilon_t}(s_i^*) = 0$, which is a contradiction. ■

Proposition 3 *Suppose that u is link-responsive. Then, $PNE(u) \subseteq PRE(u)$ if and only if u_i is β -strongly concave in own new links on $\nu_i(g, u)$, for all $i \in N$ and $g \in PNE(u)$, for some $\beta > 0$.*

Proof. Let u be link-responsive. Suppose first that u_i is β -strongly concave in own new links on $\nu_i(g, u)$, for all $i \in N$ and $g \in PNE(u)$, for some $\beta > 0$. Let $g^* \in PNE(u)$, and denote by $S^{-1}(g^*) \subseteq S$ the set of all pure strategy Nash equilibrium profiles that support g^* . Let $s' \in S^{-1}(g^*)$. Recall that $\nu_i(g^*, u) = \{ij \notin g^* : m_{ij}u_i(g^* + ij) < 0\}$ and $\bar{g}_i^* \setminus \nu_i(g^*, u) = \{ij \notin g^* : m_{ij}u_i(g^* + ij) > 0\}$.²³ Given that g^* is a pairwise-Nash equilibrium outcome, necessarily $ij \in \bar{g}_i^* \setminus \nu_i(g^*, u)$ implies that $m_{ij}u_j(g^* + ij) < 0$ (as, otherwise, creating the currently missing link ij would be profitable for both i and j). For all $i \in N$, let $s_i^* = s'_i \vee \cup_{ij \in \bar{g}_i^* \setminus \nu_i(g^*, u)} e(ij)$. By definition, $s_{ij}^* = 0$ if and only if $ij \in \nu_i(g^*, u)$. Indeed, suppose that $ij \notin \nu_i(g^*, u)$. Then, either $ij \in g_i$ and $s'_{ij} = 1$, implying that $s_{ij}^* = 1$. Or $ij \in \bar{g}_i^* \setminus \nu_i(g^*, u)$, in which case $s'_{ij} = 0$ but, by construction, $s_{ij}^* = 1$. By β -strong

²³Note that the strict inequality derives from link-responsiveness.

concavity, s^* is still a pure strategy Nash equilibrium profile that supports g^* , that is, $s^* \in S^{-1}(g^*)$ and $g^* = g(s^*)$.

For all $t \in \mathbb{N}$, $t \neq 0$, define the following marginal probabilities:

$$\sigma^{*t}(s_{ij} = 1, \cdot) = \begin{cases} \frac{1}{t}, & \text{if } ij \in \nu_i(g^*, u) \\ 1 - \frac{1}{t^2}, & \text{otherwise} \end{cases}.$$

Given that $s_{ij}^* = 0$ if and only if $ij \in \nu_i(g^*, u)$ (and, thus, $s_{ij}^* = 1$, otherwise) these marginal probabilities for each single link announcement are just a tremble away from the pure strategy link announcement in s^* . Tremble probabilities for links $ij \notin \nu_i(g^*, u)$ are one order of magnitude higher than trembles for links $ij \in \nu_i(g^*, u)$.²⁴ Under the marginal distribution, each single link ij follows a Bernoulli process with probability $\sigma^{*t}(s_{ij} = 1, \cdot)$. Denote by σ^{*t} the (independent) product of such marginal probabilities. By construction, this is a multivariate Bernoulli process that constitutes a completely mixed strategy such that $\lim_{t \rightarrow +\infty} \sigma^{*t}(s^*) = 1$.

For each player $k \in N$, we partition the strategy set $S_k \setminus \{s_k^*\}$ into two disjoint sets S_k^- and S_k^\neq defined as follows:

$$\begin{cases} S_k^\neq = \{s_k \neq s_k^* : g(s_k, s_{-k}^*) \neq g^*\} \\ S_k^- = \{s_k \neq s_k^* : g(s_k, s_{-k}^*) = g^*\} \end{cases}.$$

It is plain that $S_k = S_k^\neq \cup S_k^-$ and that $S_k^\neq \cap S_k^- = \emptyset$. We now distinguish two cases.

First, let $s'_i \in S_k^\neq$. Then, by link-responsiveness of the network payoff function u , and given that s_i^* is a best-response to s_{-i}^* , we have $u_i(g^*) > u_i(g(s'_i, s_{-i}^*))$. Using the notations in (3) we get:

$$\Delta_i(s_i^*, s'_i; \sigma_{-i}^t) = \sigma_{-i}^t(s_{-i}^*) [u_i(g^*) - u_i(g(s'_i, s_{-i}^*))] + \sum_{\tilde{s}_{-i} \neq s_{-i}^*} \sigma_{-i}^t(\tilde{s}_{-i}) [u_i(g(s_i^*, \tilde{s}_{-i})) - u_i(g(s'_i, \tilde{s}_{-i}))].$$

But, $\lim_{t \rightarrow +\infty} \sigma_{-i}^t(s_{-i}^*) = 1$ whereas $\lim_{t \rightarrow +\infty} \sigma_{-i}^t(\tilde{s}_{-i}) = 0$, for all $\tilde{s}_{-i} \neq s_{-i}^*$. Therefore, there exists some $T'_i > 0$ such that, for all $t \geq T_1$, we have $Eu_i(g(s_i^*, \sigma_{-i}^{*t})) > Eu_i(g(s'_i, \sigma_{-i}^{*t}))$, for all $s'_i \in S_k^\neq$.

Second, let $s'_i \in S_k^-$. Now, by definition, $g(s'_i, s_{-i}^*) = g^*$, and we get:

$$\Delta_i(s_i^*, s'_i; \sigma_{-i}^t) = \sum_{\tilde{s}_{-i} \neq s_{-i}^*} \sigma_{-i}^t(\tilde{s}_{-i}) [u_i(g(s_i^*, \tilde{s}_{-i})) - u_i(g(s'_i, \tilde{s}_{-i}))],$$

and all the probability weights $\sigma_{-i}^t(\tilde{s}_{-i})$ now converge to zero as $t \rightarrow +\infty$. We control for the sign of $\Delta_i(s_i^*, s'_i; \sigma_{-i}^t)$ by looking at the rates of convergence of the different probabilities.

²⁴If $\nu_i(g^*, u) = \emptyset$, for all $i \in N$ then, necessarily, $\bar{g}_i^* = \emptyset$, for all $i \in N$ (as, otherwise, link creation would be strictly profitable for any pair of players not yet linked in g^*), implying that g^* is the complete network, which is a proper equilibrium under link-responsiveness for the following reasons. First, given that $\{\sigma^{*t}\}$ have full support, the expected payoffs accruing to each player under σ^{*t} are a continuous function of the trembles. Second, any link cutting is strictly harmful for every player (from link-responsiveness and the fact that the network is a pairwise-Nash equilibrium). Therefore, by continuity on the size of the trembles, it is strictly optimal not to cut any link for small enough trembles. Therefore, we assume throughout that $\nu_i(g^*, u) \neq \emptyset$ for at least some $i \in N$. In words, there is some tremble over (at least) one link one order of magnitude higher than some other trembles on other links (that is, trembles are not all of the same order of magnitude).

Suppose first that $ij \in g^*$ for all $j \in N$, that is, player i is fully directly connected in g^* . Then, $S_k^- = \emptyset$, and we are done.

Suppose, on the contrary, that $ij \notin g^*$ for some $j \in N$. Take one such link ij . Then, we distinguish two cases. Either $m_{ij}u_i(g^* + ij) < 0$ and $s_{ij}^* = 0$, or $m_{ij}u_i(g^* + ij) > 0$. In this latter case, by definition of s^* , we have $s_{ij}^* = 1$.

Recall also that $m_{ij}u_i(g^*) > 0$, for all $ij \in g^*$. For all such links, by definition of s^* , we have $s_{ij}^* = 1$.

Take $\tilde{s}_{-i} \neq s_{-i}^*$. Now, $u_i(g(s_i^*, \tilde{s}_{-i})) \neq u_i(g(s_i', \tilde{s}_{-i}))$ if and only if (by link-responsiveness) $g(s_i^*, \tilde{s}_{-i}) \neq g(s_i', \tilde{s}_{-i})$, which is equivalent to the fact that \tilde{s}_{-i} is reciprocating at least one link that is announced in s_i' but that is not announced in s_i^* . Formally, there exists at least one $ij \notin g^*$ such that $s_{ij}^* \tilde{s}_{ji} = 0$ but $s_{ij}' \tilde{s}_{ji} = 1$, equivalent to $s_{ij}^* = 0$ and $s_{ij}' = \tilde{s}_{ji} = 1$. Necessarily, for any such link, $m_{ij}u_i(g^* + ij) < 0$. Also, given that, $g(s_i', s_{-i}^*) = g^*$, this link ij is not announced in s_{-i}^* as, otherwise, $g(s_i', s_{-i}^*)$ and g^* would differ for at least this link. Therefore, it is also true that $m_{ij}u_j(g^* + ij) < 0$. Then, by definition, $\sigma_{-i}^{*t}(\tilde{s}_{ji}) = 1/t$.

More generally, let \widehat{S}_{-i} be the set of strategy profiles $\tilde{s}_{-i} \neq s_{-i}^*$ such that $\tilde{s}_{ji} = 1$ for some $ij \notin g^*$, $m_{ij}u_i(g^* + ij) < 0$ and $m_{ij}u_j(g^* + ij) < 0$, and $\tilde{s}_{kl} = s_{kl}^*$, otherwise. In words, \widehat{S}_{-i} is the set of strategy profile for i 's opponents that differ from s_{-i}^* only for one link which corresponds to a mistake of probability $1/t$. Given that any other strategy profile $\tilde{s}_{-i} \in \widehat{S}_{-i}$, $\tilde{s}_{-i} \neq s_{-i}^*$, differs from s_{-i}^* from either more than one mistake (with probability at most $1/t$ each) or from only one mistake of probability $1/t^2$, we have:

$$\Delta_i(s_i^*, s_i'; \sigma_{-i}^t) = \sum_{\tilde{s}_{-i} \in \widehat{S}_{-i}} \frac{1}{t} [u_i(g(s_i^*, \tilde{s}_{-i})) - u_i(g(s_i', \tilde{s}_{-i}))] + o\left(\frac{1}{t}\right).$$

Let $\tilde{s}_{-i} \in \widehat{S}_{-i}$. Then, $u_i(g(s_i^*, \tilde{s}_{-i})) - u_i(g(s_i', \tilde{s}_{-i})) = -m_{ij}u_i(g^* + ij)$ for some $ij \notin g^*$ such that $m_{ij}u_i(g^* + ij) < 0$. Therefore, there exists some $T_i'' > 0$ such that, for all $t \geq T_i''$, we have:

$$\sum_{\tilde{s}_{-i} \in \widehat{S}_{-i}} \frac{1}{t} [u_i(g(s_i^*, \tilde{s}_{-i})) - u_i(g(s_i', \tilde{s}_{-i}))] + o(1) > 0, \text{ for all } s_i' \in S_i^-,$$

equivalent to $Eu_i(g(s_i^*, \sigma_{-i}^{*t})) > Eu_i(g(s_i', \sigma_{-i}^{*t}))$, for all $s_i' \in S_i^-$. Let now $T = \max\{T_i', T_i'' : i \in N\}$. Then, for all $i \in N$ and for all $t \geq T$, s_i^* is a strict best response to σ_{-i}^{*t} . Formally,

$$Eu_i(g(s_i^*, \sigma_{-i}^{*t})) > Eu_i(g(s_i', \sigma_{-i}^{*t})), \text{ for all } s_i' \in S_i, t \geq T \text{ and } i \in N. \quad (4)$$

We first introduce a definition. Consider a normal form game $\gamma = (N, S, u)$ with an extensive form equivalent Γ . The extensive form is characterized by a set of histories H , a function P that assigns to each non-terminal history a player in N , a partition \mathcal{I}_i of $\{h \in H : P(h) = i\}$. The set of actions available after the non-terminal history h to $P(h)$ is denoted by $A(h)$, and we assume that $h, h' \in \mathcal{I}_i$ implies that $A(h) = A(h')$.

Definition 7 (Van Damme, 1984) A sequence $\{\sigma^{\varepsilon_t}\}_{t \in \mathbb{N}}$ of completely mixed strategies in γ with limit σ induces a quasi-perfect equilibrium in Γ if, for the corresponding sequence of completely mixed behavior strategies ξ^{ε_t} with limit ξ , for all $i \in N$ and for all information set $h \in H$ such that $P(h) = i$, contingent on having reached h , there exists some T such that:

$$Eu_i(\xi_i, \xi_{-i}^{\varepsilon_t}) \geq Eu_i(\xi_i', \xi_{-i}^{\varepsilon_t}), \text{ for all } \xi_i' \text{ and } t \geq T.$$

Let $\Gamma(u)$ be any extensive form game equivalent to the simultaneous move game of link formation with network payoffs u . We prove the following result.

Lemma 1 The sequence $\{\sigma^{*t}\}_{t \in \mathbb{N}}$ with limit s^* induces a quasi-perfect equilibrium in $\Gamma(u)$.

Proof. Denote by ξ^{*t} the behavioral strategies induced by σ^{*t} , for all $t \in \mathbb{N}$. This behavioral strategies generate a probability distribution over the set of terminal nodes to which we associate a probability distribution over networks in \mathcal{G} denoted by $\pi^{*t} \in \Delta(\mathcal{G})$. If $\mu^{*t} \in \Delta(\mathcal{G})$ denote the probability distribution on \mathcal{G} induced by σ^{*t} , it is plain that $\pi^{*t} \in O(\mu^{*t})$, when $t \rightarrow +\infty$. In words, the probabilities assigned to any single network on \mathcal{G} by π^{*t} and by σ^{*t} are of the same order of magnitude. Then, by (4) there exists some $T > 0$ such that, for all $t \geq T$, we have $Eu_i(\xi_i^*, \xi_{-i}^{*t}) \geq Eu_i(\xi_i', \xi_{-i}^{*t})$, for all ξ_i' , and for all i . \square

Therefore, when u_i is β -strongly concave in own new links on $\nu_i(g, u)$, for all $i \in N$ and $g \in PNE(u)$, for some $\beta > 0$, we can construct a sequence $\{\sigma^{*t}\}$ that induces a quasi-perfect equilibrium in any extensive form equivalent to Myerson's simultaneous move game in network formation. By the extensive form characterization of properness by Mailath, Samuelson and Swinkels (1997), we conclude that this sequence sustains a proper equilibrium in the original normal form game.²⁵

Suppose now that β -strong concavity does not hold for some i . Then, using the arguments in the proof of Theorem 1 we prove, mutatis mutandis, that, for any sequence of completely mixed strategy profiles $\{\sigma^{\varepsilon_t}\}$ converging to s^* , there always exists a strategy $s_i' \neq s_i^*$ yielding strictly higher payoffs against $\sigma_{-i}^{\varepsilon_t}$ than s_i^* . \blacksquare

Lemma 2 The connections model is 1-convex.

Proof. Let $ij \in g$.

First note that $d_{ik}(g) \leq d_{ik}(g - ij)$ for all $k \in N$. Let

$$\Delta_{ij}(g) = \{k \in N : d_{ik}(g) < d_{ik}(g - ij)\}.$$

In particular, $j \in \Delta_{ij}(g)$. Then,

$$m_{ij}u_i(g) = \sum_{k \in \Delta_{ij}(g)} [\delta^{d_{ik}(g)} - \delta^{d_{ik}(g-ij)}] - c.$$

²⁵See Proposition 1 in Mailath et al. (1997).

Let $il \in g$, where $l \neq j$. Define $\Delta_{ij,il}(g) = \{k \in N : d_{ik}(g) < d_{ik}(g - ij - il)\}$. Then,

$$m_{ij,il}u_i(g) = \sum_{k \in \Delta_{ij}(g)} [\delta^{d_{ik}(g)} - \delta^{d_{ik}(g-ij-il)}] - 2c.$$

Note the following.

First, $\Delta_{ij}(g) \cup \Delta_{il}(g) \subset \Delta_{ij,il}(g)$. Indeed, for all $k \in \Delta_{ij}(g)$, we have $d_{ik}(g) < d_{ik}(g - ij) \leq d_{ik}(g - ij - il)$. Idem for $\Delta_{il}(g)$.

Second, $\Delta_{ij}(g) \cap \Delta_{il}(g) = \emptyset$. Indeed, let $k \in \Delta_{ij}(g) \cap \Delta_{il}(g)$. Then, both l and j are on (two different) shortest paths in g between i and k . Consider the sortest path in g between i and k that crosses through l . This path still exists in $g - ij$, implying that $d_{ik}(g) = d_{ik}(g - ij)$, in contradiction with $k \in \Delta_{ij}(g)$.

Third, $\delta^{d_{ik}(g)} - \delta^{d_{ik}(g-ij-il)} \geq \delta^{d_{ik}(g)} - \delta^{d_{ik}(g-ij)}$, as $d_{ik}(g - ij) \leq d_{ik}(g - ij - il)$. Similarly for $\delta^{d_{ik}(g)} - \delta^{d_{ik}(g-il)}$.

Altogether, this implies that $m_{ij,il}u_i(g) \geq m_{ij}u_i(g) + m_{il}u_i(g)$. ■

References

- [1] R. Aumann and R.B. Myerson, Endogenous formation of links between players and coalitions: an application of the Shapley value, in A. Roth (ed.) *The Shapley Value*, Cambridge University Press (1988) 175-191.
- [2] V. Bala and S. Goyal, A noncooperative model of network formation, *Econometrica* **68** (2000) 1181-1230.
- [3] F. Bloch and M.O. Jackson, The formation of networks with transfers among players, Caltech, 2004.
- [4] A. Calvó-Armengol, Job contact networks, *Journal of Economic Theory* **115** (2004) 191-206.
- [5] B. Dutta and S. Mutuswami, Stable networks, *Journal of Economic Theory* **76** (1997) 322-344.
- [6] M. Fréchet, Sur les tableaux de corrélation dont les marge sont données, *Annales de l'Université de Lyon* **14** (1951) 53-77.
- [7] S. Goyal and S. Joshi, Unequal connections, Essex University, 2002.
- [8] M.O. Jackson, A survey of models of network formation: stability and efficiency, Caltech, 2003, forthcoming in *Group Formation in Economics; Networks, Clubs and Coalitions*, edited by Gabrielle Demange and Myrna Wooders, Cambridge University Press.
- [9] M.O. Jackson and A. Wolinsky, A strategic model of social and economic networks, *Journal of Economic Theory* **71** (1996) 44-74.

- [10] M.O. Jackson and A. Watts, The existence of pairwise stable networks, *Seoul Journal of Economics* **14** (2001) 299-321.
- [11] M.O. Jackson and A. Watts, The evolution of social and economic networks, *Journal of Economic Theory* **106** (2002) 265-295.
- [12] M.O. Jackson and A. van den Nouweland, Strongly stable networks, *Games and Economic Behavior* (forthcoming).
- [13] M.O. Jackson and B. Rogers, Search and random attachment in the formation of large networks, Caltech, 2004.
- [14] G.J. Mailath, L. Samuelson L. and J.M. Swinkels, How proper is sequential equilibrium? *Games and Economic Behavior* **18** (1997) 193-218.
- [15] R.B. Myerson, Refinements of the Nash equilibrium concept, *International Journal of Game Theory* **7** (1978) 73-80.
- [16] R.B. Myerson, *Game Theory: Analysis of Conflict*, Harvard University Press, 1991.
- [17] E. van Damme, A relation between perfect equilibria in extensive form games and proper equilibria in normal form games, *International Journal of Game Theory* **13** (1984) 1-13.

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

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

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

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

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

NOTE DI LAVORO PUBLISHED IN 2005

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

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

2005 SERIES

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