

Dowell, Andrew; Wooldridge, Michael; McBurney, Peter

Working Paper

The Computational Difficulty of Bribery in Qualitative Coalitional Games

Nota di Lavoro, No. 100.2007

Provided in Cooperation with:

Fondazione Eni Enrico Mattei (FEEM)

Suggested Citation: Dowell, Andrew; Wooldridge, Michael; McBurney, Peter (2007) : The Computational Difficulty of Bribery in Qualitative Coalitional Games, Nota di Lavoro, No. 100.2007, Fondazione Eni Enrico Mattei (FEEM), Milano

This Version is available at:

<https://hdl.handle.net/10419/73897>

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.

The Computational Difficulty of Bribery in Qualitative Coalitional Games

Andrew J. Dowell, Michael Wooldridge and
Peter McBurney

NOTA DI LAVORO 100.2007

NOVEMBER 2007

CTN – Coalition Theory Network

Andrew Dowell, Michael Wooldridge and Peter McBurney,
Department of Computer Science, University of Liverpool

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=1032097>

The Computational Difficulty of Bribery in Qualitative Coalitional Games

Summary

Qualitative coalitional games (QCG) are representations of coalitional games in which self interested agents, each with their own individual goals, group together in order to achieve a set of goals which satisfy all the agents within that group. In such a representation, it is the strategy of the agents to find the best coalition to join. Previous work into QCGs has investigated the computational complexity of determining which is the best coalition to join. We plan to expand on this work by investigating the computational complexity of computing agent power in QCGs as well as by showing that insincere strategies, particularly bribery, are possible when the envy-freeness assumption is removed but that it is computationally difficult to identify the best agents to bribe.

Keywords: Bribery, Coalition Formation, Computational Complexity

JEL Classification: C63, C78

Address for correspondence:

Andrew Dowell
Department of Computer Science
University of Liverpool
Ashton Building
Ashton Street
Liverpool L69 3BX
UK
E-mail: adowell@liv.ac.uk

The Computational Difficulty of Bribery in Qualitative Coalitional Games ^{*}

Andrew Dowell[†] Michael Wooldridge and Peter McBurney.
Department of Computer Science, University of Liverpool, Ashton Building,
Ashton Street, Liverpool L69 3BX.

November 26, 2007

Abstract

Qualitative coalitional games (QCG) are representations of coalitional games in which self interested agents, each with their own individual goals, group together in order to achieve a set of goals which satisfy all the agents within that group. In such a representation, it is the strategy of the agents to find the best coalition to join. Previous work into QCGs has investigated the computational complexity of determining which is the best coalition to join. We plan to expand on this work by investigating the computational complexity of computing agent power in QCGs as well as by showing that insincere strategies, particularly bribery, are possible when the envy-freeness assumption is removed but that it is computationally difficult to identify the best agents to bribe.

1 Introduction

Coalition formation is an important aspect of group decision making within multi-agent systems and as such is a key issue in multi-agent research [18, 17]. Efforts have been undertaken regarding coalitional formation in an attempt to circumvent some of the computational problems associated with computing agent strategy, for example, computing the Shapley Value and the core solution. Such efforts have involved computing these concepts under different representations of these games. Consequently, there exist many representations of coalitional games including: marginal contribution nets [12]; multi-attribute coalitional games [13]; and weighted threshold games [6]. Marginal contribution nets are a compact representation for coalitional games which consist of rules of the syntactic form: *pattern* \rightarrow *value*, where a rule is said to apply to a group of agents if these agents meet the requirement of the *Pattern*. Under this representation, there exist algorithms for computing the Shapley value and the core. The Shapley value, in particular, can be computed in time linear in the size of the input.

^{*}Copyright 2007 ©All rights reserved.

[†]Corresponding author Email: adowell@liv.ac.uk

Multi-attribute coalitional games are games where the value of a coalition is measured by the attributes of the agents who belong to it. They are represented as a tuple $\langle Ag, M, A, \mathbf{a}, w \rangle$ where Ag is the set of agents, M is the set of attributes, $A \in \mathcal{R}^{m \times n}$ is the attribute matrix (where entry $A_{i,j}$ denotes the value of attribute i for agent a_j), $\mathbf{a} : \mathcal{R}^{m \times n} \times 2^N \rightarrow \mathcal{R}^m$ is the set of aggregators which take, as input, both a row of the attribute matrix and a coalition $C \subseteq Ag$ and outputs a vector of values and w is the aggregate value function which takes, as input, a vector of values and outputs a single real value ($w : \mathcal{R}^m \rightarrow \mathcal{R}$). This representation induces a coalitional game $\langle Ag, v \rangle$ where the value function is defined by $v(C) = w(\mathbf{a}(A, S))$ for any $C \subseteq Ag$. There exist positive results for this representation also, including that it does not require as much space as other representations do.

Weighted threshold games are coalitional games given by a set of agents Ag , their non-negative weights W and a threshold $\mathcal{T} \in \mathbb{Z}^+$ such that any coalition $C \subseteq Ag$ is winning (has value 1) if the sum of the weights of the agents in that coalition are greater than or equal to \mathcal{T} and is losing (has value 0) otherwise. They are represented in the form of a tuple $\langle Ag, W, \mathcal{T} \rangle$. Under this representation, determining if the core is non-empty can be done in polynomial time, where as computing the Shapley value is computationally difficult.

In cooperative goal-orientated multi-agent systems (GOMAS), where each individual agent has as set of goals they would like to achieve, agents may believe that they are more likely to achieve their goals by cooperating with other agents and forming coalitions, such that if the agents in the coalition were to act in a similar manner then each one of them should achieve at least one of their goals. Thus, in such a system, it is the strategy of each agent to find the best coalition to join. Qualitative coalitional games (QCG from now on) are representations of GOMAS and for this framework Wooldridge & Dunne [21] investigate how hard it is for an individual agent to compute which is the best coalition to join. These authors construct several decision problems which compute whether coalitions satisfy certain desirable criteria and compute the computational complexity of these problems. However, one criteria that they do not consider is the *power* of the agents within the coalitions, that is, the ability of the agents to influence the decision of the group they belong to. An agent can measure if they can influence the outcome within the group by computing if they display *critical defection*. An agent displays critical defection if the coalition they belong to is successful or winning but the same coalition with them removed is unsuccessful. In this way, it may be the case that the agents may want to join the coalitions in which they are more powerful since they can influence the overall decision making process of that group. Useful measures of an agents power are given by *The Banzhaf Power Index* and *The Banzhaf Score* [9]. The Banzhaf Score for an agent a_j (written θ_j) is the number of successful coalitions for which agent a_j is pivotal and The Banzhaf Index for an agent a_j , BZ_j is the ratio of the agent's Banzhaf Score to the sum of The Banzhaf Scores of every agent in the game. Intuitively, if an agent's Banzhaf Index equals zero then they contribute nothing to the achievement of any goals at all in the groups they belong to and can not influence the decision within them at all. Conversely if an agent's Banzhaf Index is exactly one then they are the only agent who contributes anything toward achieving any goals at all within the set of agents.

In addition to this, we will also show that, through extending the QCG framework

such that we can no longer assume envy-freeness, agents can adopt other insincere strategies regarding coalition formation. Through constructing new decision problems as well as using our complexity results from agent power we will then investigate how difficult it is for an agent to compute these insincere strategies. The rest of this paper will take the following form. In Section 2, we will define the QCG framework as well as Banzhaf Power before extending the QCG framework and defining the problems that compute these strategies and measuring their computational complexity. These results will be given in Section 4. We will then discuss other work that has been done which is related to our work as well as conclude in Section 5.

2 Qualitative Coalitional Games (QCG)

We begin by introducing the framework for the model of a qualitative coalitional game (QCG). This is defined as a $(n + 3)$ -tuple $\Gamma = \langle G, Ag, G_1, \dots, G_n, V \rangle$, where:

- $G = \{g_1, \dots, g_m\}$ is a set of possible goals,
- $Ag = \{a_1, \dots, a_n\}$ is a set of agents,
- $G_i \subseteq G$ is a set of goals for each agent $a_i \in Ag$ with the interpretation being that any of the goals G_i would satisfy a_i - but a_i is indifferent between the members of G_i , and
- $V : 2^{Ag} \rightarrow 2^{2^G}$ is a characteristic function, which for every coalition $C \subseteq Ag$ determines a set $V(C)$ of choices, the intended interpretation being that if $G' \in V(C)$, then one of the choices available to C is to bring about *all* the goals in G' simultaneously.

To ease the burden of calculating the set of choices $V(C)$ we adopt an approach, whereby function V is represented as a formula Ψ of propositional logic over the propositional variables Ag and G such that $\Psi[C, G'] = \top \iff G' \in V(C)$. Clearly, this computation can be performed in deterministic polynomial time. For such a function, we say that:

- A set of goals G' satisfies agent a_i if $G' \cap G_i \neq \emptyset$ (where \emptyset is the empty set),
- G' satisfies coalition C ($C \subseteq Ag$) if it satisfies every member of C .
- G' is feasible for coalition C if $\Psi[C, G'] = \top$.
- For a set of goals G' , coalition C is successful if and only if $\Psi[C, G'] = \top$ and G' satisfies every agent in coalition C .

In terms of QCGs, we define an agent to display critical defection in the following manner:

An agent a_j is said to display critical defection if for a set of goals $G' \subseteq G$ the coalition $C \cup \{a_j\}$ is successful but the coalition C is not successful.

A measure of an agent's critical defection is given by the Banzhaf Score [9].

Definition 1 *The Banzhaf Score for an agent a_j (written θ_j) is the number of successful coalitions for which agent a_j is pivotal.*

Definition 2 *The Banzhaf Index [20] for an agent a_j , BZ_j is the ratio of the agent's Banzhaf Score to the sum of The Banzhaf Scores of every agent in the game. Mathematically, this is expressed as*

$$BZ_i = \frac{\theta_i}{\sum_{j=1}^n \theta_j}.$$

Associated with The Banzhaf Index, is another measure of power - The Banzhaf Measure [9].

Definition 3 *The Banzhaf Measure for an agent a_j , BZ_j^* is the ratio of its Banzhaf Score to the number of coalitions to which it does not belong to. Mathematically this is expressed as:*

$$BZ_j^* = \frac{\theta_j}{2^{n-1}}.$$

3 When We Lose The Envy Freeness Assumption

It is assumed that the QCG system is envy-free, that is, each individual agent only wants to achieve any one of the goals in their individual goal set and achieving any one of these goals is not affected by the achievement of other goals not in their individual goal set. Thus, it is assumed that each agent adopts the strategy: "Which is the best coalition to join?"

However, we shall show that one can not always assume envy-freeness. We shall consider a situation where the accomplishment of goals in an agents individual goal set is influenced by the accomplishment of other goals not in this set.

To emphasize this point, we consider the following motivational example.

Example.

Suppose there exists a set of agents $Ag = \{a_1, \dots, a_n\}$ who have encountered an area of land at co-ordinates (x, y) . Suppose that a group of these agents wish to build a tower at $(x, y)(B)$, another group of agents desire to dig a ditch at $(x, y)(D)$, and another group of agents desire to farm the land at $(x, y)(F)$. Thus, this QCG has 3 goals $G = \{B, D, F\}$. These 3 goals are *incompatible* and can not all be achieved. If a tower is built then the land can not be farmed or dug. Conversely, if the land is farmed, then it can not be dug or build upon or if the land is dug, it can't be built or farmed upon. Thus, an agent who wants to achieve goal B can be thought of as wanting to achieve B and not wanting to see goals F and D achieved. Conversely, an agent who wants to either farm or build on the land can be

thought of as wanting to achieve goals B or F and not wanting to see goal D achieved.

An agent a_i who wants achieve B knows if D or F are accomplished then B can not be accomplished since the goals B , D and F are incompatible. The agent could, rather than ask themselves: “Which is the best coalition to join to achieve goal B ,” adopt the strategy: “Which is the best coalition to join to achieve goal B and how do I stop the goals D and F from also being achieved?” Thus, in addition to trying to find the best coalition to join, agents may try to stop or hinder the formation of successful coalitions which achieve goals that are incompatible with theirs. One way of accomplishing this is through *bribery*. This involves offering an agent who belongs to a successful coalition which achieves a particular goal set an incentive to leave this coalition.

In this way, when the goals are incompatible, one can not always assume envy-freeness in QCGs and when one can't always assume envy-freeness, insincere strategies can be adopted by the agents in the QCG.

The approaches to the problem of bribery in other work (see the section 5) ask the question : *Can bribery happen?* That is, how hard is it to bribe someone so that the outcome is affected? In this paper we ask the question: *Who can be bribed?* That is, how hard is it to identify agents whom bribing would change the outcome in the favour of the manipulator?

We propose that the manipulator agent a will target agents who display the following criteria:

- Agents who display *critical defection* [20]. That is, for a set of goals G' , the agents who belong to a successful coalition, such that, if they were to leave that coalition then it would be rendered unsuccessful. Conversely, the manipulator may want to identify agents who are not *free riders*. By avoiding free-riders, the manipulator will avoid agents who don't have the ability to influence the outcome of the group decision.
- Agents who are *veto players*. A veto player is a player who, for the set of goals G' , is present in every successful coalition that achieves at least one of the goals in G' . By identifying the veto players for a set of goals G' , they could identify the agents who belong to every successful coalition for G' and so veto players could be useful targets for bribery.

In this way, we can use our complexity results from computing agent power for computing if certain agents are appropriate to bribe.

In addition to the above criteria, an insincere agent may also wish to identify a successful coalition for a goal set G' in which every agent in that coalition displays critical defection. That is, every strict subset of this successful coalition is not successful. Wooldridge and Dunne proved that the problem of computing if there exists such a coalition is D^P -complete [21].

Wooldridge and Dunne also proved that, for 2 agents $a_i, a_j \in Ag$, determining if agent a_j is a veto player for the set of goals G_i is co-NP complete [21]. If agent a_j is a

veto player for the goal set G_i , then one can say that a_i is *dependent* on a_j to achieve the goals in G_i . Consequently, one can construct a directed graph, with the agents represented by vertices, such that, if agent a_i is dependent on agent a_j then there is an edge directed from vertex i to vertex j . Such a graph is called a *dependence* graph.

If a manipulator knows that the goal set of agent a_i consists of exactly the set of goals which are incompatible with theirs, then such a graph, could be useful for a manipulator agent to find the veto players for that goal set. With this in mind, we shall investigate the following decision problems.

Problem 1 Critical Defection.

Question: For a set of goals $G' \subseteq G$, does there exist a coalition $C \cup \{a_i\}$ (where $C \subseteq Ag \setminus \{a_i\}$) such that $C \cup \{a_i\}$ is a successful coalition but C is not.

Input: $\Gamma, G' \subseteq G$, agent a_i .

Output: ‘Yes’ if there exists a coalition $C \cup \{a_i\}$ such that $G' \cap G_j \neq \emptyset, \forall a_j \in C \cup \{a_i\}$ then $\Psi[C \cup \{a_i\}, G'] = \top$ and $\Psi[C, G'] = \perp$.

‘No’ otherwise.

Problem 2 Free Rider.

Question: For a set of goals G' , is it the case that for every successful coalition $C \cup \{a_i\}$, the defection of agent a_i is never critical?

Input: $\Gamma, G' \subseteq G$, agent a_i .

Output: “Yes” if for all coalitions $C \cup \{a_i\}$ such that $G' \cap G_j \neq \emptyset, \forall a_j \in C \cup \{a_i\}$ then it is never the case that $\Psi[C \cup \{a_i\}, G'] = \top$ and $\Psi[C, G'] = \perp$.

“No” Otherwise.

Problem 3 Banzhaf Score

Question: What is the value of the Banzhaf score for agent a_i - that is how many successful coalitions $C \cup \{a_i\}$ exist such that the defection of agent a_i is critical?

Input: Γ , agent a_i ,

Output: a numerical value.

Problem 4 Banzhaf measure:

Question: What is the value of the Banzhaf measure for agent a_i , that is what is the value of $\frac{\theta_i}{2^n - 1}$?

Input: Γ , agent a_i .

Output: a numerical value.

Problem 5 Banzhaf Index:

Question: What is the value of The Banzhaf Index for agent a_i , that is what is the value of $\frac{\theta_i}{\sum_{j=1}^n \theta_j}$?

Input: Γ , agent a_i .

Output: a numerical value.

Problem 6 Dependence Graph.

Input: Γ , directed graph $G = (V, E)$ where $|V| = |Ag|$, an injective mapping \mathcal{F} from V to Ag .

Question: For the injective mapping \mathcal{F} is G a dependence graph for Γ ?

Output: “Yes” if $\forall (i, j) \in E$, agent $\mathcal{F}^{-1}(i)$ is dependent on $\mathcal{F}^{-1}(j)$ (that is, $\mathcal{F}^{-1}(j)$ is a veto player for $\mathcal{F}^{-1}(i)$).

“No” Otherwise.

4 Computational Complexity Results.

We begin with our result for the **Critical Defection** problem.

Theorem 1 *The Critical Defection problem is NP-complete.*

Proof: Membership: The following non-deterministic algorithm can solve this problem: “Guess $C \subseteq Ag \setminus \{X\}$ and Verify that $G' \cap G_j \neq \emptyset$ for all agents $j \in C \cup \{X\}$ and that both $\Psi[C \cup \{X\}, G'] = \top$ and $\Psi[C, G'] = \perp$.” Since verifying that $G' \cap G_j \neq \emptyset$ for all agents $j \in C \cup \{X\}$ and that both $\Psi[C \cup \{X\}, G'] = \top$ and $\Psi[C, G'] = \perp$ can be performed in deterministic polynomial time then the **Critical Defection** problem can be solved using NP computation.

Hardness: Reduction from SAT [11]. We proceed as follows:

- $Ag = \{x_1, \dots, x_n, X\}$ where X does not appear in $\Phi(x_1, \dots, x_n)$.
- $X = a_i$
- $G = G_{x_i} = G_X = G' = \{g\}$ and,
- $\Psi = \Phi \wedge g \wedge X$.

We claim that

Φ is satisfiable $\Leftrightarrow X$ is pivotal for some coalition C

(\Rightarrow) Assume that $\Phi(x_1, \dots, x_n)$ is satisfiable. Then there exists a valuation $Z \subseteq \{x_1, \dots, x_n\}$ such that $\Phi(x_1, \dots, x_n)[Z] = \top$. Now, consider the valuation $Z_2 = Z \cup \{g, X\}$. By construction $\Psi[Z_2] = \top$; note that this tells us that $\{x_1, \dots, x_n, X\}$ is a successful coalition, since they have a feasible goal (i.e., g) which satisfies all members of the coalition. Now, $\Psi[Z_2 \setminus \{X\}] = \perp$; hence $\{x_1, \dots, x_n\}$ are not successful. Hence X displays critical defection in the coalition $\{x_1, \dots, x_n, X\}$ and X is a good target for bribery.

(\Leftarrow) Assume that X is pivotal for some coalition $C \subseteq Ag$. Then $\Psi[C, g] = \top$, and since $\Psi = \Phi(x_1, \dots, x_n) \wedge g \wedge X$, then Φ is satisfiable. ■

Thus, it is computationally difficult for an agent to identify a suitable agent to bribe. Consequently, an agent may also desire to identify who not to bribe. This was addressed in the **Free Rider** problem, for which we have the following complexity result:

Theorem 2 *The problem of Free Rider is co-NP-complete.*

Proof: We can prove co-NP-completeness by observing that this problem is the complement of the problem **Critical Defection**, which we proved to be NP-complete. ■

Thus, it is also computationally difficult to identify the “good” targets and eliminate the “bad” targets for bribery in a QCG.

Theorem 3 *The problems of computing the Banzhaf Score, Measure and Index are #P-complete.*

Proof: Banzhaf Score - counting problem associated with a NP-complete problem - #P-complete by definition.

Recall that the formula for The Banzhaf measure is given by:

$$BZ_i^* = \frac{\Theta_i}{2^{n-1}},$$

i.e. it is value of The Banzhaf Score divided by a constant 2^{n-1} . Calculating the value of the Banzhaf Score is #P-complete and dividing this value by a constant can be done in polynomial time. Thus, to show #P-completeness for this problem, we are required to show that $\#P^P = \#P$, which is trivial since both $\#P^P \subseteq \#P$ and $\#P \subseteq \#P^P$.

Recall that the formula for calculating **The Banzhaf Index** is given by:

$$BZ_i = \frac{\theta_i}{\sum_{j=1}^n \theta_j}.$$

Recall that computing the Banzhaf Score for agents a_i is #P-complete and that computing the Banzhaf score for every individual agent $a_j \in Ag$ is also #P-complete. This means that as well as being as hard as a known #P-complete problem, this problem also belongs to the complexity class #P. Thus, a non-deterministic Turing Machine M' can compute if each agent displays critical defection and the number of successful computations of M' can be counted. Suppose M' had access to a P oracle which could in one step compute the summation and division in the formula, then M'^P could compute the Banzhaf Index for agent a_i .

Therefore, since $\#P^P = \#P$, and since computing the Banzhaf Score is #P-complete, then computing the Banzhaf Index is also #P-complete. ■

Suppose now we are given the graph G , the function \mathcal{F} and the graph Γ (as defined in the input to problem 3), the question we ask ourselves is: How are G , \mathcal{F} and Γ related? Wooldridge *et al.* [22] suggest 2 ways: Soundness and completeness.

1. *Soundness*: G is sound with respect to the dependence relation if and only if for all vertices $(v_i, v_j) \in E$ then $\mathcal{F}(v_j)$ is a veto player for $\mathcal{F}(v_i)$.
2. *Completeness*: G is complete with respect to the dependence relation if and only if for all $a_i, a_j \in Ag$ such that a_i is a veto player for a_j then $(\mathcal{F}^{-1}(a_j), \mathcal{F}^{-1}(a_i)) \in E$.

Theorem 4 *Given G, \mathcal{F} and Γ the problem of computing if G is sound for Γ and \mathcal{F} with respect to the dependence relation is co-NP complete.*

Proof:

The complement problem to soundness asks: “Does there exist a pair of vertices (v_i, v_j) such that $\mathcal{F}(v_j)$ is not a veto player for $\mathcal{F}(v_i)$?” This problem can be solved using the following non-deterministic algorithm:

“For every pair of vertices (v_i, v_j) , guess a coalition $C \subseteq Ag \setminus \{\mathcal{F}(v_j)\}$ and a goal set $G' \subseteq G$. Verifying that $(v_i, v_j) \in E$, and either:

- $G' \cap G_{\mathcal{F}(v_j)} = \emptyset$ or,
- $\Psi[C, G_{\mathcal{F}(v_j)}] = \perp$, or
- $\mathcal{F}(v_i)$ is not in C ,

can be done in deterministic polynomial time.”

Thus the complement problem can be solved using NP computation. Since the complement problem to the problem of soundness belongs to NP, then the problem of soundness belongs to the class co-NP.

For each directed edge $(v_i, v_j) \in E$ computing $\mathcal{F}(v_i)$ and $\mathcal{F}(v_j)$ can be done in deterministic polynomial time. Thus the complexity of the problem of computing *soundness* is as hard as the problem of computing if $\mathcal{F}(v_j)$ is a veto player for $\mathcal{F}(v_i)$. This is co-NP complete from [21].

Therefore, the problem of computing soundness is co-NP-complete. ■

Theorem 5 *Given G, \mathcal{F} and Γ the problem of computing if G is complete for Γ and \mathcal{F} with respect to the dependence relation is co-NP complete.*

Proof: For a pair of agents $(a_i, a_j) \in Ag$ the problem of computing if a_j is a veto player for a_i is co-NP complete from [21]. For these agents, computing $(\mathcal{F}^{-1}(a_i), \mathcal{F}^{-1}(a_j))$ can be done in deterministic polynomial time, as can verifying if $(\mathcal{F}^{-1}(a_i), \mathcal{F}^{-1}(a_j)) \in E$.

Since $\text{co-NP}^P = \text{co-NP}$ [14] then the problem of computing *completeness* is also co-NP complete ■

Both theorems 4 and 5 allow us to construct the following theorem:

Theorem 6 *The **Dependence Graph** problem is co-NP complete.*

Proof: Showing that G is the dependence graph is equivalent to showing that G is both sound and complete. Let L_1 be the co-NP complete language that computes if G is sound and let L_2 the co-NP complete language that computes if G is complete. Consequently, $L = L_1 \cap L_2$ is the language which computes if G is both sound and complete and therefore the dependence graph. Therefore this problem belongs to the class co-NP

We prove completeness by observing that for an edge $v_i, v_j \in E$ then the problem of computing if agent $\mathcal{F}(v_j)$ is a veto player for agent $\mathcal{F}(v_i)$ is co-NP complete. Since there are a polynomial number of edges then we can conclude that computing the **Dependence Graph** problem is as hard as computing the co-NP complete problem *veto player*.

Therefore, the **Dependence Graph** problem is co-NP complete. ■

In this way, it is computationally difficult for an agent to compute if bribery is possible.

5 Related Work

Much work has been undertaken into investigating insincere strategies adopted by agents within multi-agent systems ([3, 4, 5, 7, 8]). Much of this work has focused on manipulation of voting procedure, that is, agents acting selfishly to achieve an outcome that is most desirable to them and not necessarily to the other agents or to the system as a whole.

Surprisingly, there has been very little work addressing the computational issues regarding bribery in voting procedures and much of the work focuses on whether bribery is possible. Faliszewski *et al.* [8] address the issue of bribery by asking the question: Can one agent change the outcome by changing (at most) the preference lists of k agents. Proccacia *et al.* [16] address bribery from the point of view of unregistered voters entering and changing the outcome when the procedure was applied to registered voters only.

Regarding bribery in coalition formation, much work has not been directly undertaken into looking at bribery. Abbink *et al.* [1] construct an experimental bribery game which investigates the influence of certain characteristics over corruption (e.g. bribery). One result they conclude is that through enforcing high penalties on those caught acting insincerely reduces the level of corruption. Additional work regarding bribery includes investigating into coalition formation in the presence of transfers and externalities, however, we have found no existing literature directly linking bribery and externalities. Much of the work into coalition formation in the presence of transfers and , that is known to the authors, focuses on computing stability and equilibrium in such environments [19, 2]. Surprisingly little work has also been undertaken looking at the computational complexity of computing insincere strategy in coalition formation, particularly bribery, leaving a lot of scope for future work on the topic.

6 Conclusions

Our results show that for an individual agent, computing the best coalition to join, in terms of agent power, is computationally intractable. This, unfortunately, is consistent with the results in [21] where they also show that, generally, it is computationally difficult to find the best coalition to join. Thus, as further work, one could look into constructing algorithms which make the process of finding the best coalitions to join less difficult.

Our results also show that one can not always assume envy-freeness in the QCG framework but that, in the situations where this condition fails to hold, computing if insincere strategy is possible (particularly the process of identifying suitable agents to bribe) is computationally difficult. Compared to other domains, for example, in weighted threshold games the process of computing if there is an agent who displays critical defection is NP-complete and computing the Banzhaf Index is #P-complete [15]. Thus, it is just as hard to compute these on a weighted threshold domain as it is on a QCG domain. However, there are some computational problems with computing the Banzhaf index on a weighted threshold domain, for example, the computational process displays many logical paradoxes and fails to satisfy certain postulates [10]. This tarnishes the credibility of using this index in a weighted threshold domain. No such computational complexity results are known yet for marginal contribution net and multi-attribute coalitional game representations.

References

- [1] K. Abbink, B. Irenblusch, and E. Renner. An experimental bribery game. *The Journal of Law, Economics, and Organization.*, 18(2):428 – 454, 2002.
- [2] F. Bloch. Sequential formation of coalitions in games with externalities and fixed payoff division. *Games and Economic Behaviour.*, 14:90–123, 1996.
- [3] V. Conitzer and T. Sandholm. Complexity of manipulating elections with few candidates. In *In proceedings of the 18th National Conference on Artificial Intelligence*, pages 314–319, Edmonton, Canada, 2002.
- [4] V. Conitzer and T. Sandholm. Vote elicitation: complexity and strategy-proofness. In *In Proceedings of the 18th National Conference on Artificial Intelligence*, pages 392–397, Edmonton, Canada, 2002.
- [5] V. Conitzer and T. Sandholm. Universal voting protocol tweaks to make manipulation hard. In *In Proceedings of the 18th International Joint Conference on Artificial Intelligence*, pages 781–788, Acapulco, Mexico, 2003.
- [6] E. Elkind, L. Goldberg, P. Goldberg, and M. Wooldridge. Computational complexity of weighted threshold games. In *Twenty-Second Conference on Artificial Intelligence (AAAI-07)*, Vancouver, BC, Canada, 2007.

- [7] E. Elkind and H. Lipmaa. Hybrid voting protocols and hardness of manipulation. In U. Endriss and J.Lang, editors, *Computational Social Choice 2006*, pages 234–248, Amsterdam, Netherlands, 2006. Instiute for Logic, Language and Computation.
- [8] P. Faliszewski, E. Hemaspaandra, and L. Hemaspaandra. The complexity of bribery in elections. In U. Endriss and J.Lang, editors, *Computational Social Choice 2006*, pages 192–203, Amsterdam, Netherlands, 2006. Instiute for Logic, Language and Computation.
- [9] D. Felsenthal and M. Machover. Postulates and paradoxes of relative voting power - a critical re-appraisal. *Theory and Decision*, 38(2):195–229, 1995.
- [10] D. Felsenthal and M. Machover. *The Measurement of Voting Power: Theory, Practice, Problems and Paradoxes*. Edward Elgar, Masachussettes, USA, 1998.
- [11] M. Garey and D. Johnson. *Computers and Intractability - A Guide to The Theory of NP-Completeness*. WH Freeman, New York, USA, 1979.
- [12] S. Leong and Y. Shoham. Marginal contribution nets: A complact representation scheme for coalitional games. *ACM EC-06*, 2006.
- [13] S. Leong and Y. Shoham. Multi-attribute coalitional games. *ACM EC-06*, 2006.
- [14] C. Papadimitriou. *Computational Complexity*. Addison, Wesley, Longman, California, USA, 1995.
- [15] K. Prasad and J. Kelly. NP-completeness of some problems concerning voting games. *International Journal of Game Theory*, 19(1):1–9, 1990.
- [16] A. Procaccia, J. Rosenschein, and A. Zohar. Multi-winner elections: complexity of manipulation, control and winner-determination. In *The Twentieth International Joint Conference on Artificial Intelligence (IJCAI 2007)*, pages 1476–1481, Hyderabad, India, 2007.
- [17] T. Rahwan and N. Jennings. Distributing coalitional value calculations among cooperating agents. In *Proceedings of 25th National Conference on AI (AAAI)*, pages 152–157, Pittsburgh, USA, 2005.
- [18] T. Rahwan, S. Ramchurn, V. Dang, A. Giovannucci, and N. Jennings. Near-optimal anytime coalition structure generation. In *Proceedings of 20th International Joint Conference on Artificial Intelligence (IJCAI)*, page In press, Hyderabad, India, 2007.
- [19] M. Saiz, E. Hendrix, and N.Oliman. On the computation of stability in multiple coalition formation games. *Computational Economics.*, 28(3):251–275, 2006.
- [20] A. Taylor. *Mathematics and Politics - Strategy, Voting, Power and Proof*. Springer, New York, USA, 1995.

- [21] M. Wooldridge and P. Dunne. On the computational complexity of qualitative coalitional games. *Artificial Intelligence*, 158(1):27 – 73, 2004.
- [22] M. Wooldridge, P. Dunne, and S. Parsons. On the complexity of linking and deductive and abstract argument systems. In *Proceedings of the Twenty First National Conference on Artificial Intelligence (AAAI-06)*, Boston MA, 2006.

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.htm>

<http://www.ssrn.com/link/feem.html>

<http://www.repec.org>

<http://agecon.lib.umn.edu>

<http://www.bepress.com/feem/>

NOTE DI LAVORO PUBLISHED IN 2007

NRM	1.2007	<i>Rinaldo Brau, Alessandro Lanza, and Francesco Pigliaru: <u>How Fast are Small Tourism Countries Growing? The 1980-2003 Evidence</u></i>
PRCG	2.2007	<i>C.V. Fiorio, M. Florio, S. Salini and P. Ferrari: <u>Consumers' Attitudes on Services of General Interest in the EU: Accessibility, Price and Quality 2000-2004</u></i>
PRCG	3.2007	<i>Cesare Dosi and Michele Moretto: <u>Concession Bidding Rules and Investment Time Flexibility</u></i>
IEM	4.2007	<i>Chiara Longo, Matteo Manera, Anil Markandya and Elisa Scarpa: <u>Evaluating the Empirical Performance of Alternative Econometric Models for Oil Price Forecasting</u></i>
PRCG	5.2007	<i>Bernardo Bortolotti, William Megginson and Scott B. Smart: <u>The Rise of Accelerated Seasoned Equity Underwritings</u></i>
CCMP	6.2007	<i>Valentina Bosetti and Massimo Tavoni: <u>Uncertain R&D, Backstop Technology and GHGs Stabilization</u></i>
CCMP	7.2007	<i>Robert Küster, Ingo Ellersdorfer, Ulrich Fahl (lxxx): <u>A CGE-Analysis of Energy Policies Considering Labor Market Imperfections and Technology Specifications</u></i>
CCMP	8.2007	<i>Mònica Serrano (lxxx): <u>The Production and Consumption Accounting Principles as a Guideline for Designing Environmental Tax Policy</u></i>
CCMP	9.2007	<i>Erwin L. Corong (lxxx): <u>Economic and Poverty Impacts of a Voluntary Carbon Reduction for a Small Liberalized Developing Economy: The Case of the Philippines</u></i>
CCMP	10.2007	<i>Valentina Bosetti, Emanuele Massetti, and Massimo Tavoni: <u>The WITCH Model. Structure, Baseline, Solutions</u></i>
SIEV	11.2007	<i>Margherita Turvani, Aline Chiabai, Anna Alberini and Stefania Tonin: <u>Public Policies for Contaminated Site Cleanup: The Opinions of the Italian Public</u></i>
CCMP	12.2007	<i>M. Berrittella, A. Certa, M. Enea and P. Zito: <u>An Analytic Hierarchy Process for The Evaluation of Transport Policies to Reduce Climate Change Impacts</u></i>
NRM	13.2007	<i>Francesco Bosello, Barbara Buchner, Jacopo Crimi, Carlo Giupponi and Andrea Povellato: <u>The Kyoto Protocol and the Effect of Existing and Planned Measures in the Agricultural and Forestry Sector in the EU25</u></i>
NRM	14.2007	<i>Francesco Bosello, Carlo Giupponi and Andrea Povellato: <u>A Review of Recent Studies on Cost Effectiveness of GHG Mitigation Measures in the European Agro-Forestry Sector</u></i>
CCMP	15.2007	<i>Massimo Tavoni, Brent Sohngen, and Valentina Bosetti: <u>Forestry and the Carbon Market Response to Stabilize Climate</u></i>
ETA	16.2007	<i>Erik Ansink and Arjan Ruijs: <u>Climate Change and the Stability of Water Allocation Agreements</u></i>
ETA	17.2007	<i>François Gusdorf and Stéphane Hallegatte: <u>Compact or Spread-Out Cities: Urban Planning, Taxation, and the Vulnerability to Transportation Shocks</u></i>
NRM	18.2007	<i>Giovanni Bella: <u>A Bug's Life: Competition Among Species Towards the Environment</u></i>
IEM	19.2007	<i>Valeria Termini and Laura Cavallo: <u>"Spot, Bilateral and Futures Trading in Electricity Markets. Implications for Stability"</u></i>
ETA	20.2007	<i>Stéphane Hallegatte and Michael Ghil: <u>Endogenous Business Cycles and the Economic Response to Exogenous Shocks</u></i>
CTN	21.2007	<i>Thierry Bréchet, François Gerard and Henry Tulkens: <u>Climate Coalitions: A Theoretical and Computational Appraisal</u></i>
CCMP	22.2007	<i>Claudia Kettner, Angela Köppl, Stefan P. Schleicher and Gregor Thenius: <u>Stringency and Distribution in the EU Emissions Trading Scheme –The 2005 Evidence</u></i>
NRM	23.2007	<i>Hongyu Ding, Arjan Ruijs and Ekko C. van Ierland: <u>Designing a Decision Support System for Marine Reserves Management: An Economic Analysis for the Dutch North Sea</u></i>
CCMP	24.2007	<i>Massimiliano Mazzanti, Anna Montini and Roberto Zoboli: <u>Economic Dynamics, Emission Trends and the EKC Hypothesis New Evidence Using NAMEA and Provincial Panel Data for Italy</u></i>
ETA	25.2007	<i>Joan Canton: <u>Re dealing the Cards: How the Presence of an Eco-Industry Modifies the Political Economy of Environmental Policies</u></i>
ETA	26.2007	<i>Joan Canton: <u>Environmental Taxation and International Eco-Industries</u></i>
CCMP	27.2007	<i>Oscar Cacho and Leslie Lipper (lxxxii): <u>Abatement and Transaction Costs of Carbon-Sink Projects Involving Smallholders</u></i>
CCMP	28.2007	<i>A. Caparrós, E. Cerdá, P. Ovando and P. Campos (lxxxii): <u>Carbon Sequestration with Reforestations and Biodiversity-Scenic Values</u></i>
CCMP	29.2007	<i>Georg E. Kindermann, Michael Obersteiner, Ewald Rametsteiner and Ian McCallum (lxxxii): <u>Predicting the Deforestation-Trend Under Different Carbon-Prices</u></i>

CCMP	30.2007	<i>Raul Ponce-Hernandez (lxxxii): <u>A Modelling Framework for Addressing the Synergies between Global Conventions through Land Use Changes: Carbon Sequestration, Biodiversity Conservation, Prevention of Land Degradation and Food Security in Agricultural and Forested Lands in Developing Countries</u></i>
ETA	31.2007	<i>Michele Moretto and Gianpaolo Rossini: <u>Are Workers' Enterprises Entry Policies Conventional</u></i>
KTHC	32.2007	<i>Giacomo Degli Antoni: <u>Do Social Relations Affect Economic Welfare? A Microeconomic Empirical Analysis</u></i>
CCMP	33.2007	<i>Reyer Gerlagh and Onno Kuik: <u>Carbon Leakage with International Technology Spillovers</u></i>
CCMP	34.2007	<i>Richard S.J. Tol: <u>The Impact of a Carbon Tax on International Tourism</u></i>
CCMP	35.2007	<i>Reyer Gerlagh, Snorre Kverndokk and Knut Einar Rosendahl: <u>Optimal Timing of Environmental Policy: Interaction Between Environmental Taxes and Innovation Externalities</u></i>
SIEV	36.2007	<i>Anna Alberini and Alberto Longo: <u>Valuing the Cultural Monuments of Armenia: Bayesian Updating of Prior Beliefs in Contingent Valuation</u></i>
CCMP	37.2007	<i>Roeland Bracke, Tom Verbeke and Veerle Dejonckheere: <u>What Distinguishes EMAS Participants? An Exploration of Company Characteristics</u></i>
CCMP	38.2007	<i>E. Tzouvelekas, D. Vouvaki and A. Xepapadeas: <u>Total Factor Productivity Growth and the Environment: A Case for Green Growth Accounting</u></i>
CCMP	39.2007	<i>Klaus Keller, Louise I. Miltich, Alexander Robinson and Richard S.J. Tol: <u>How Overconfident are Current Projections of Anthropogenic Carbon Dioxide Emissions?</u></i>
CCMP	40.2007	<i>Massimiliano Mazzanti and Roberto Zoboli: <u>Environmental Efficiency, Emission Trends and Labour Productivity: Trade-Off or Joint Dynamics? Empirical Evidence Using NAMEA Panel Data</u></i>
PRCG	41.2007	<i>Veronica Ronchi: <u>Populism and Neopopulism in Latin America: Clientelism, Trade Union Organisation and Electoral Support in Mexico and Argentina in the '90s</u></i>
PRCG	42.2007	<i>Veronica Ronchi: <u>The Neoliberal Myth in Latin America: The Cases of Mexico and Argentina in the '90s</u></i>
CCMP	43.2007	<i>David Anthoff, Cameron Hepburn and Richard S.J. Tol: <u>Equity Weighting and the Marginal Damage Costs of Climate Change</u></i>
ETA	44.2007	<i>Bouwse R. Dijkstra and Dirk T.G. Rübhelke: <u>Group Rewards and Individual Sanctions in Environmental Policy</u></i>
KTHC	45.2007	<i>Benno Torgler: <u>Trust in International Organizations: An Empirical Investigation Focusing on the United Nations</u></i>
CCMP	46.2007	<i>Enrica De Cian, Elisa Lanzi and Roberto Roson: <u>The Impact of Temperature Change on Energy Demand: A Dynamic Panel Analysis</u></i>
CCMP	47.2007	<i>Edwin van der Werf: <u>Production Functions for Climate Policy Modeling: An Empirical Analysis</u></i>
KTHC	48.2007	<i>Francesco Lancia and Giovanni Prarolo: <u>A Politico-Economic Model of Aging, Technology Adoption and Growth</u></i>
NRM	49.2007	<i>Giulia Minoia: <u>Gender Issue and Water Management in the Mediterranean Basin, Middle East and North Africa</u></i>
KTHC	50.2007	<i>Susanna Mancinelli and Massimiliano Mazzanti: <u>SME Performance, Innovation and Networking Evidence on Complementarities for a Local Economic System</u></i>
CCMP	51.2007	<i>Kelly C. de Bruin, Rob B. Dellink and Richard S.J. Tol: <u>AD-DICE: An Implementation of Adaptation in the DICE Model</u></i>
NRM	52.2007	<i>Frank van Kouwen, Carel Dieperink, Paul P. Schot and Martin J. Wassen: <u>Interactive Problem Structuring with ICZM Stakeholders</u></i>
CCMP	53.2007	<i>Valeria Costantini and Francesco Crespi: <u>Environmental Regulation and the Export Dynamics of Energy Technologies</u></i>
CCMP	54.2007	<i>Barbara Buchner, Michela Catenacci and Alessandra Sgobbi: <u>Governance and Environmental Policy Integration in Europe: What Can We learn from the EU Emission Trading Scheme?</u></i>
CCMP	55.2007	<i>David Anthoff and Richard S.J. Tol: <u>On International Equity Weights and National Decision Making on Climate Change</u></i>
CCMP	56.2007	<i>Edwin van der Werf and Sonja Peterson: <u>Modeling Linkages Between Climate Policy and Land Use: An Overview</u></i>
CCMP	57.2007	<i>Fabien Priour: <u>The Environmental Kuznets Curve in a World of Irreversibility</u></i>
KTHC	58.2007	<i>Roberto Antonietti and Giulio Cainelli: <u>Production Outsourcing, Organizational Governance and Firm's Technological Performance: Evidence from Italy</u></i>
SIEV	59.2007	<i>Marco Percolo: <u>Urban Transport Policies and the Environment: Evidence from Italy</u></i>
ETA	60.2007	<i>Henk Folmer and Pierre von Mouche: <u>Linking of Repeated Games. When Does It Lead to More Cooperation and Pareto Improvements?</u></i>
CCMP	61.2007	<i>Arthur Riedacker (lxxx): <u>A Global Land Use and Biomass Approach to Reduce Greenhouse Gas Emissions, Fossil Fuel Use and to Preserve Biodiversity</u></i>
CCMP	62.2007	<i>Jordi Roca and Mònica Serrano: <u>Atmospheric Pollution and Consumption Patterns in Spain: An Input-Output Approach</u></i>
CCMP	63.2007	<i>Derek W. Bunn and Carlo Fezzi (lxxx): <u>Interaction of European Carbon Trading and Energy Prices</u></i>
CTN	64.2007	<i>Benjamin Golub and Matthew O. Jackson (lxxxiii): <u>Naïve Learning in Social Networks: Convergence, Influence and Wisdom of Crowds</u></i>
CTN	65.2007	<i>Jacob K. Goeree, Arno Riedl and Aljaž Ule (lxxxiii): <u>In Search of Stars: Network Formation among Heterogeneous Agents</u></i>
CTN	66.2007	<i>Gönül Doğan, M.A.L.M. van Assen, Arnout van de Rijt, and Vincent Buskens (lxxxiii): <u>The Stability of Exchange Networks</u></i>
CTN	67.2007	<i>Ben Zissimos (lxxxiii): <u>Why are Trade Agreements Regional?</u></i>
CTN	68.2007	<i>Jacques Drèze, Michel Le Breton, Alexei Savvateev and Shlomo Weber (lxxxiii): <u>«Almost» Subsidy-free Spatial Pricing in a Multi-dimensional Setting</u></i>
CTN	69.2007	<i>Ana Babus (lxxxiii): <u>The Formation of Financial Networks</u></i>

CTN	70.2007	<i>Andrea Galeotti and Sanjeev Goyal</i> (lxxxiii): <u>A Theory of Strategic Diffusion</u>
IEM	71.2007	<i>Francesco Bosello, Enrica De Cian and Roberto Roson</i> : <u>Climate Change, Energy Demand and Market Power in a General Equilibrium Model of the World Economy</u>
ETA	72.2007	<i>Gastón Giordana and Marc Willinger</i> : <u>Fixed Instruments to Cope with Stock Externalities An Experimental Evaluation</u>
KTHC	73.2007	<i>Oguzhan Dincer and Eric Uslaner</i> : <u>Trust and Growth</u>
CCMP	74.2007	<i>Fei Teng and Alun Gu</i> : <u>Climate Change: National and Local Policy Opportunities in China</u>
KTHC	75.2007	<i>Massimiano Bucchi and Valeria Papponetti</i> : <u>Research Evaluation as a Policy Design Tool: Mapping Approaches across a Set of Case Studies</u>
SIEV	76.2007	<i>Paolo Figini, Massimiliano Castellani and Laura Vici</i> : <u>Estimating Tourist Externalities on Residents: A Choice Modeling Approach to the Case of Rimini</u>
IEM	77.2007	<i>Irene Valsecchi</i> : <u>Experts and Non-experts</u>
CCMP	78.2007	<i>Giuseppe Di Vita</i> : <u>Legal Families and Environmental Protection: is there a Causal Relationship?</u>
KTHC	79.2007	<i>Roberto Antonietti and Giulio Cainelli</i> : <u>Spatial Agglomeration, Technology and Outsourcing of Knowledge Intensive Business Services Empirical Insights from Italy</u>
KTHC	80.2007	<i>Iacopo Grassi</i> : <u>The Music Market in the Age of Download</u>
ETA	81.2007	<i>Carlo Carraro and Alessandra Sgobbi</i> : <u>Modelling Negotiated Decision Making: a Multilateral, Multiple Issues, Non-Cooperative Bargaining Model with Uncertainty</u>
CCMP	82.2007	<i>Valentina Bosetti, Carlo Carraro, Emanuele Massetti and Massimo Tavoni</i> : <u>International Energy R&D Spillovers and the Economics of Greenhouse Gas Atmospheric Stabilization</u>
CCMP	83.2007	<i>Sjak Smulders and Edwin van der Werf</i> : <u>Climate Policy and the Optimal Extraction of High- and Low-Carbon Fossil Fuels</u>
SIEV	84.2007	<i>Benno Torgler, Bruno S. Frey and Clevo Wilson</i> : <u>Environmental and Pro-Social Norms: Evidence from 30 Countries</u>
KTHC	85.2007	<i>Elena Bellini, Ugo Gasparino, Barbara Del Corpo and William Malizia</i> : <u>Impact of Cultural Tourism upon Urban Economies: An Econometric Exercise</u>
NRM	86.2007	<i>David Tomberlin and Garth Holloway</i> : <u>Trip-Level Analysis of Efficiency Changes in Oregon's Deepwater Trawl Fishery</u>
CTN	87.2007	<i>Pablo Revilla</i> : <u>Many-to-One Matching when Colleagues Matter</u>
IEM	88.2007	<i>Hipòlit Torró</i> : <u>Forecasting Weekly Electricity Prices at Nord Pool</u>
ETA	89.2007	<i>Y. Hossein Farzin</i> : <u>Sustainability and Optimality in Economic Development: Theoretical Insights and Policy Prospects</u>
NRM	90.2007	<i>P. Sarfo-Mensah and W. Oduro</i> : <u>Traditional Natural Resources Management Practices and Biodiversity Conservation in Ghana: A Review of Local Concepts and Issues on Change and Sustainability</u>
NRM	91.2007	<i>Lorenzo Pellegrini</i> : <u>The Rule of The Jungle in Pakistan: A Case Study on Corruption and Forest Management in Swat</u>
NRM	92.2007	<i>Arjan Ruijs</i> : <u>Welfare and Distribution Effects of Water Pricing Policies</u>
ETA	93.2007	<i>Jean-Marie Grether, Nicole A. Mathys and Jaime de Melo</i> : <u>Trade, Technique and Composition Effects: What is Behind the Fall in World-Wide SO2 Emissions 1990-2000?</u>
PRCG	94.2007	<i>Bernardo Bortolotti, Carlo Cambini, Laura Rondi and Yossi Spiegel</i> : <u>Capital Structure and Regulation: Does Ownership Matter?</u>
CCMP	95.2007	<i>Valentina Bosetti, Carlo Carraro, Emanuele Massetti and Massimo Tavoni</i> : <u>Optimal Energy Investment and R&D Strategies to Stabilise Greenhouse Gas Atmospheric Concentrations</u>
CCMP	96.2007	<i>Xavier Pautrel</i> : <u>Pollution, Health and Life Expectancy: How Environmental Policy Can Promote Growth</u>
KTHC	97.2007	<i>Roberto Antonietti and Davide Antonioli</i> : <u>Production Offshoring and the Skill Composition of Italian Manufacturing Firms: A Counterfactual Analysis</u>
CTN	98.2007	<i>Miyuki Nagashima and Rob Dellink</i> : <u>Technology Spillovers and Stability of International Climate Coalitions</u>
ETA	99.2007	<i>Eftichios S. Sartzetakis and Panagiotis D. Tsigaris</i> : <u>Uncertainty and the Double Dividend Hypothesis</u>
CTN	100.2007	<i>Andrew J. Dowell, Michael Wooldridge and Peter McBurney</i> : <u>The Computational Difficulty of Bribery in Qualitative Coalitional Games</u>

(lxxxix) This paper was presented at the EAERE-FEEM-VIU Summer School on "Computable General Equilibrium Modeling in Environmental and Resource Economics", held in Venice from June 25th to July 1st, 2006 and supported by the Marie Curie Series of Conferences "European Summer School in Resource and Environmental Economics".

(lxxxix) This paper was presented at the Workshop on "Climate Mitigation Measures in the Agro-Forestry Sector and Biodiversity Futures", Trieste, 16-17 October 2006 and jointly organised by The Ecological and Environmental Economics - EEE Programme, The Abdus Salam International Centre for Theoretical Physics - ICTP, UNESCO Man and the Biosphere Programme - MAB, and The International Institute for Applied Systems Analysis - IIASA.

(lxxxix) This paper was presented at the 12th Coalition Theory Network Workshop organised by the Center for Operation Research and Econometrics (CORE) of the Université Catholique de Louvain, held in Louvain-la-Neuve, Belgium on 18-20 January 2007.

2007 SERIES

CCMP	<i>Climate Change Modelling and Policy</i> (Editor: Marzio Galeotti)
SIEV	<i>Sustainability Indicators and Environmental Valuation</i> (Editor: Anil Markandya)
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: Matteo Manera)
CSR	<i>Corporate Social Responsibility and Sustainable Management</i> (Editor: Giulio Sapelli)
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>