A Few Bad Apples Are Enough. An Agent-Based Peer Review Game

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***Abstract*—Following previous agent-based research on peer review, this paper presents a game theory-inspired model that looks at peer review as a cooperation dilemma. We tested different scientist behaviours and network topologies in order to understand their implications on the quality, efficiency and type of resource distribution in the science system. We tested random, scale-free and small world networks connecting scientists and three types of referee behaviour: self-interested (providing unreliable opinion), normative referees (providing reliable opinion) and conformist reviewers (conforming to other referees' behaviour). Preliminary results indicate that differences in the combination of referee behaviour have significant impact on the quality of the process and that the percentage of conformists is one of the most crucial model parameters.**

I. Introduction

PEER review is recently under the spotlight. Cases of misconduct [1], [2], proofs of biased referee behaviour [3] and studies about the process quality and scientists' satisfaction [4] called for reconsideration of the quality and sustainability of this important institution, especially in periods of explosion of online journals and publications.

Previous examples of applications of agent-based models have testified to the advantages of looking at the internal mechanisms of peer review, e.g., scientist behaviour at the micro level [5], [6].

This paper proposes a game theory-inspired approach that looks at peer review as a cooperation problem with network externalities, with room for strategic and normative behaviour and reciprocal influence by all scientists involved.

This approach brings a theoretical basis to previous work and a more realistic modelling, in which the efforts and the resources are limited, and so the strategic behaviours make more sense.

This work was supported by the European Network for Social Intelligence (SINTELNET, FP7-ICT-2009-C Project No. 286370, www.sintelnet.eu).

II. The peer review game

We assumed that peer review was a cooperation dilemma where players can take on two different roles, authors and referees. Following [5], each player $i \in \{1,\ldots,n\}$ had a certain amount of resources R_i that could be seen as productivity, available time, funds, human resources, etc. according to academic status, position, experience, and scientific achievement.

They could choose how much to invest in writing articles and reviewing. We assumed that this investment had a cost $c>0$ independently of the player's role, given that both activities (writing and reviewing) have a cost on resources.

In case of publication, authors received a benefit $b>c$, since publishing usually leads to achieve resources in a scientist's career (such as getting grants, funding for attending conferences, developing projects, hiring researchers, etc.).

On the other hand, reviewers do not receive any benefit, since we understand that the reviewing activity does not produce any profit in terms of consumable resources.

The game assumed continuous investment choices, mimicking successive rounds of the publication process.

We defined e^s_i, $e^r_i \in [0, 1]$ as the efforts made for submitting and reviewing respectively. Then, we assumed that the cost of both submitting and reviewing articles was proportional to these efforts. In the simplest form, we had $c^s_i = e^s_i c$ and $c^r_j = e^r_j c$.

The author's submission quality was given by

$$Q^s_i = e^s_i R_i \quad (1)$$

while the quality of the review performed by a reviewer $j \in \{1,\ldots,n\} \mid j \neq i$ was:

$$Q^r_j = e^r_j R_j \quad (2)$$

We assumed the peer review game had a certain publication threshold (T).

A review was considered fair, i.e., reflecting the true value of the paper, if $Q^r_j \geq T$.

If the review was fair, a given submission was accepted if $Q^s_i \geq T$ and the published author received the publication benefit. Otherwise, if the submission was rejected, the author got nothing. Note that the condition $Q^s_i \geq T$ meant that authors with higher resources could meet the publication threshold more easily (i.e., with lower effort).

If the review was unfair, the paper was accepted with probability 0.5, which meant that the expected utility of the submission was $\frac{1}{2}b$.

In each period, costs were subtracted and benefits were added to the authors' and referees' own resources, which lead to the period payoff table shown in Table 1.

TABLE I.
PEER REVIEW GAME FOR AUTHOR *I* SUBMITTING A PAPER HAVING *J* AS REFEREE

		Referee	
		$Q^r_j \geq T$	$Q^r_j < T$
Author	$Q^s_i \geq T$	$b - c^s_i, - c^r_j$	$\frac{1}{2}b - c^s_i, - c^r_j$
	$Q^s_i < T$	$- c^s_i, - c^r_j$	$\frac{1}{2}b - c^s_i, - c^r_j$

The equilibrium of the game was as follows: referees had a dominant strategy of putting a zero effort ($e^r_j = 0$) in their review. Knowing this, the best response for authors was to set $e^s_i = 0$ in turn, leading to a unique equilibrium of the game where only low quality were produced and publication was at random.

III. THE AGENT-BASED MODEL

We built an agent-based model that implemented the peer review game by adding behavioural heterogeneity. We assumed one type of agent, namely scientists.

In each time step, agents played twice, once as author and once as referee. The role order was random and couples changed with roles, meaning that the same two agents were unlikely to play together twice in the same time step.

A fixed global resource R was divided among scientists following an individual resource share that varied at the beginning of each time step. Thus, the resource available for each scientist i was R_i.

The benefit received in case of publication was given by b, where b was a parameter of the model.

The basic cost of both producing a submission and reviewing was the parameter c, which was multiplied by the effort.

The effort for reviewing articles depended on three types of referee behaviour, i.e., self-interest, normativism and conformism:

- Self-interested referees did not contribute to the quality of peer review by putting little effort in reviewing ($e^r_j = 0.5$), trying to save resources for publishing.
- Normative referees were intrinsically motivated by Mertonian norms of scientist conduct [7], e.g., they always put a great effort in reviewing in order to provide pertinent judgment so intentionally contributing to the quality of peer review ($e^r_j = 0.75$).
- Conformists were referees whose effort depended on the behaviour of other scientists which they were connected with. While self-interested and altruists were not influenced by others' behaviour, conformists were sensitive to social influence. They commiserated their effort by looking at the average effort by their connected scientists.

We manipulated the initial combination of self-interested, normative and conformists in order to understand interaction effects among these types of behaviour. As it is known in behavioural game theory, the combination of heterogeneous behaviour over time can have dramatic implications for the aggregate level of cooperation [8].

Furthermore, we assumed that scientists were connected in networks, which defined the neighbourhoods affecting the behaviour of conformists. We tested different network topologies, by initializing the system with random, small-world and scale-free networks [9]. These topologies have been tested by previous studies to reproduce co-authorship networks of scientists.

IV. RESULTS

Preliminary results by implementing the proposed model in NetLogo indicated that different behavioural combinations could dramatically affect the quality of peer review.

While the percentage of self-interested referees in the population could condition cooperative equilibria, we found that also the presence of a significant number of conformists could have negative effects. This is especially evident in conjunction with the presence of a minimal number of self-interested and small world network topologies.

V. FUTURE WORK

This model represents a first step in an ongoing research on peer review processes under the scope of the New Frontiers of Peer Review (PEERE) COST action.

It is known that reputation is crucial in science dynamics, although it is not implemented in the presented model. Further steps are the inclusion of reputation mechanisms that reflect better the real scientific world in the long term, in order to study the effects on the system, and the validation of the model against real-world data and other game-theory models [10].

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