

# The Economics of Scientific Misconduct<sup>t\*</sup>

Nicola Lacetera  
Case Western Reserve University<sup>†</sup>

Lorenzo Zirulia  
University of Bologna<sup>‡</sup>  
CESPRI, Bocconi University

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## Abstract

The types of scientific frauds that are observed are unlikely to be representative of the overall amount of malfeasance in science. Star scientists are more likely to misbehave, but less likely to be caught than average scientists. A reduction in the costs of checking for frauds may lead to a change in the type of research that is performed (e.g. more or less innovative) rather than to a reduction of misconduct episodes. Contrary to conventional wisdom, an increase in competition between scientists may reduce, and not increase, scientific misconduct, as it stimulates more monitoring. A more active role of editors in checking for misconduct does not always provide additional deterrence. These claims derive from a game-theoretic model of the publication process, where authors are asymmetrically informed about the success of their projects, and can fraudulently manipulate their results. In evaluating a paper, the author's peers have incentives to perform a thorough scrutiny since they are competitors of the author, but also have disincentives to do so as users or complementors of that particular research. The magnitude and sign of the utility that scientists receive from a peer's success crucially determine their incentives to detect fraud, as well as the decision of a researcher to commit fraud in the first place.

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<sup>†</sup>Department of Economics, Weatherhead School of Management, Case Western University, Cleveland, OH, USA. Email: nxl51@case.edu.

<sup>‡</sup>Department of Economics, University of Bologna, Italy. Center of Research on Innovation and Internationalization (CESPRI), Bocconi University, Milano, Italy. Email: lorenzo.zirulia@unibocconi.it.

## Introduction

In the first half of the 1900s, the Swiss biochemist Emil Abderhalden published hundreds on article on what he called "defensive enzymes". Subsequently, numerous scientists developed several tests based on the existence of defensive enzymes. These included pregnancy tests, the diagnosis of some forms of cancer, and tests for psychiatric disorders. Researchers in Nazi concentration camps used Abderhalden's theories to "prove" the superiority of the Aryan race. Large amounts of public and private monies were granted to Abderhalden and his collaborators. A few researchers in the 1920s began to question the validity and replicability of Abderhalden's experiments, but his work was revealed to be largely fraudulent only in 1998 (Deichmann and Müller-Hill 1998). Defensive enzymes, simply, do not exist.

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In 1988, the scientific journal *Nature* agreed to publish an article of the immunologist Jacques Benveniste with positive evidence of the effectiveness of homeopathy. Most investigators were unable to replicate the results, and identified several forms of negligence and misconduct (Maddox 1988, Park 1997, Fisher 1999).

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The experimental work of child psychologist Bruno Bettelheim suggested that a major cause of child autism was bad parenting, and in particular the lack of affection of mothers towards their children. These findings affected generations of psychologists, parents, and children. However, after Bettelheim's death in 1990, most of the evidence on the relation between parenting and autism he produced was found to be non-existent and almost entirely fabricated (Pollak 1997).

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When he won the Otto-Klung-Weberbank Prize for Physics in 2001 at age 31, Jan Hendrik Schön, a rising star physicist at Bell Labs, was churning one article every eight days. His research on organic transistors promised to be revolutionary and to have major impacts in several scientific fields, including the development of nanotechnology. Some observers speculated that Schön's discoveries could spell the end of the entire silicon chip industry, since traditional chips would be substituted by organic transistors. Several other physicists, however, begun to question his work after finding anomalies in the data on a number of his published articles. Evidence of Schön's scientific misconduct was found in at least sixteen papers. Whole data sets were reused in a number of different experiments, and some graphs were found to have been produced using mathematical functions. Several journals withdrew Schön's articles, Bell Labs fired him, and he was deprived of his doctorate by the University of Konstanz in 2004 (Goss Levi 2002a, 2002b, Bell Labs 2002, BBC 2004).

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The biomedical scientist Woo-Suk Hwang rose to fame in 2004 thanks to a series of breakthroughs in the field of stem cell research. The novelty and relevance of his alleged findings led several scholars to investigate further into their solidity and accuracy. Hwang's results were found to have been fraudulently reported. Most of the cell lines object of his research turned out to have been faked, and pictures of allegedly different cells were found to be photos of the same cell. Hwang admitted to various lies and frauds.<sup>1</sup> On May 12, 2006, he was indicted on embezzlement and bioethics law violations (Kolata 2005, Fifield and Cookson 2006).

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Eric Poehlman, a scientist in the field of human obesity and aging, was accused of scientific misconduct and on March 17, 2005 he pleaded guilty to the charges, acknowledging falsifying 17 grant applications to the National Institutes of Health and fabricating data in 10 of his papers. He had theorized that menopause makes women lose muscle and gain fat, and causes health problems that hormones could help fix. Millions of women were prescribed hormone therapy by their doctors, only to learn afterwards that its health benefits were never proved and there were risks involved instead. The government prosecutors stated that Dr. Poehlman had defrauded agencies out of \$2.9 million. Investigations on the scientist began after one his collaborators revealed that Poehlman was fabricating data in his laboratory. On June 28, 2006, Poehlman was ordered to serve a year and a day in prison for using falsified data in federal research grants. He also paid a \$180,000 fine, and was barred for life from receiving federal research funding. It was the first case where an academic scientist was given prison time for falsifying data in grant submissions (Chang 2004, Office of Research Integrity 2005, CBS 2005, Kintisch 2006).

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On the one hand, these "vignettes" offer a grim image of the scientific community, and indeed a very worrisome one. Knowledge is a key asset that allows individuals to improve their socioeconomic status, companies to succeed in the marketplace, and countries to grow and prosper. Scientific research is a major process through which knowledge is generated. Such decisions as business strategies, as well as decisions about one's health or child education, depend also on the findings from scientific research, as published in professional journals and divulged through the media. If false and fabricated results are generated and published, the negative consequences on social welfare can be major. Scientific fraud is therefore not just an internal matter for the scientific community, but a greater problem that social scientist need to address.

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<sup>1</sup>He also admitted that he spent private donations for research to pay the Russian mafia for mammoth tissues, to be used to clone extinct species (Reuters 2006).

On the other hand, if scientific malfeasance was limited to a few high-profile cases and a few "bad apples", and these were promptly discovered through the standard procedures and self-correcting mechanisms within the scientific community, then the concerns would be largely unjustified. But is this the case? The existing evidence offers a less comforting picture. Reports of different types of misconduct – such as data fabrication, falsification, mining, and plagiarism – abound in any scientific discipline. Freeland Judson (2004) and Pozzi and David (2007) document a steady flow of new cases opened and allegations confirmed at the US Office of Research Integrity (ORI) over the past decade. Swazey et al. (1993) document that about 10% of the scientists responding to their surveys have witnessed episodes of scientific misconduct. Martinson et al. (2005) find that, while only few scientists admit having explicitly fabricated or "cooked up" data, up to 10-15% of scientists admitted to have performed such behaviors as omitting data that did not conform to their *ex ante* theories, without any solid logical basis for their choice.

Scientific misconduct, therefore, appears as a pervasive phenomenon, a systemic characteristic of the scientific community rather than a matter of a few episodes of misbehavior. Especially in the natural sciences, scholars are showing great awareness of the problem. Several proposals to deter malfeasance in science have been advanced. These proposals include making replication easier and more rewarded, and softening competition among scientists, since harsh rivalry for priority in publication is seen as conducive to dishonest practices.<sup>2</sup>

The current understanding of this phenomenon, however, is still very limited. For example, analyses are largely based on reports and accounts about researchers who have been *found committing* frauds,<sup>3</sup> and especially on "high profile" cases, such as some of those described above. As much as these accounts are suggestive, they offer only a limited picture of the problem. More broadly, the current debate lacks a theoretical background of the underlying incentives of scientists to undertake fraudulent behavior in their research, and the incentives of their peers to detect these behaviors. Elaborating such a theory would allow for more founded predictions of the kinds of research and of researchers that are more likely to engage in fraudulent behavior, and of the impact of different policy proposals to reduce misconduct. In this paper, a theory of scientific malfeasance is proposed.

The research and publication process is analyzed as a dynamic game of incomplete information that reproduces the main features of the operating of the scientific community.<sup>4</sup> In the

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<sup>2</sup>See for example Freeland Judson 2004, Council of Science Editors 2005, Fuller 2006, and the Special Issue of *Nature* on January 18, 2007. Moreover, in 2007 the ORI and the European Science Foundation have organized the First World Conference on Research Integrity.

<sup>3</sup>See Pozzi and David (2007) for a recent descriptive account of malfeasance in science, based on discovered cases. Similar analyses, based on detected cases, have been performed with regard to other types of misconduct, such as financial fraud. See for example Dyck et al. (2007).

<sup>4</sup>Previous attempts to model the research and publication process, with consideration for misconduct, include Wible 1998 and Glaeser 2006. These studies treat the process as a one-person decision problem rather than a multi-agent game. Glaeser's paper, moreover, is exclusively focussed on the analysis of empirical research in

first stage of the game, a scientist decides what type of research to undertake, i.e., more or less radical. The research is successful with some probability. The scientist then decides whether to submit the results of the project for publication. If the project failed, the scientist can still submit a paper to a journal, but only after committing some fraudulent behavior<sup>5</sup> – otherwise, reviewers will immediately spot the failure of the project. If the paper is accepted and published, a potential reader of the article decides whether to thoroughly check the paper – in which case any fraud is spotted – or just to read it lightly. The author of the paper receives a benefit if the manuscript is published. If he committed fraud and the fraud is detected, in contrast, the scientist has negative utility. As for the reader, on the one hand she may enjoy an advance of science and may benefit from a specific result having been found. This result, for example, might legitimate the field of research of the reader, and be complementary to her own work. On the other hand, the reader may also derive disutility from the success of a third scientist's research. The success of the scientist reduces her room for contributions. She can therefore be a competitor.

The model shows, first, that there may be a divergence between the probability that a certain kind of fraud is committed and the probability that it is discovered. In particular, if the reward from radical research is high, the probability of detecting misconduct is higher for radical research, although frauds are more common in incremental research; similarly, it is more likely that fraud is discovered in the work of a scientist with a lower reputation than in the work of a star, even if the probability to publish a fraudulent paper is higher for a star.

A second set of results qualify and even contradict some of the conventional wisdom and proposed policies to deter fraud in science. First, we consider the effects of reducing the costs of checking for misconduct by an author's peers. We show that, if a reduction in checking costs does not induce a change in the type of research an author undertakes (e.g. radical versus incremental), then the likelihood that misconduct goes undetected decreases. In contrast, the probability of undetected fraud may increase if the author changes the type of research. Second, we assess whether excessive competition in the scientific arena, as frequently claimed, can be among the causes of fraudulent behavior. In this case, we show that an increase in competition between scientists may reduce scientific misconduct, instead of increasing it. This occurs because competition also increases the benefits from checking and therefore the overall intensity of scrutiny.

A third set of results derive from an extension of the model to consider a more active role by a journal's editorial boards in deterring misconduct. Our model implies that additional checks by journals' editorial boards before publication do deter misconduct in some circumstances,

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Economics. Mialon and Mialon (2003) analyze the decision of a scientist on how innovative to be, within an author-reviewer game.

<sup>5</sup>We are assuming there are no "innocent mistakes". Better said, we assume that it is always possible to discern an honest mistake from a fraud.

especially when the likelihood of these additional checks to be performed is very high. In other cases, these additional controls can instead backfire and be conducive to more misconduct. For, readers may check less frequently in response, and authors may change the type of research they perform, thus changing the equilibrium of the publication game, including the propensity to commit frauds.

These results appear as consistent with the anecdotal evidence on scientific malfeasance in that, for example, accounts of misconduct often concern (allegedly) pathbreaking research by scientists "on the rise". The results, however, posit numerous caveats on the definition of policies to deter fraud. First, policy implications on scientific misconduct should not be based on *detected* frauds, since the "wrong", minoritarian types of actual fraud and of scientists might be targeted, through policies that are not appropriate for deterring the majority of (undetected) frauds. Second, several provisions typically assumed to reduce fraudulent behavior might actually backfire and lead to a higher, instead of lower, incidence of misconduct. These include the reduction of replication costs, the containment of competition among researchers, and the involvement of multiple layers of detection both before and after publication.

Section 1 develops the publication game, which is then solved in Section 2. In Section 3, the implications of the results are derived and discussed. Section 4 concludes.

## 1 The publication game

We introduce a game-theoretic model of the publication process, where scientists perform research whose results they can also fake, and they send papers to journals. These papers are evaluated by the scientists' peers. The game is represented in extensive form in Figure 1. A detailed description of the set up follows. Table 6 in Appendix A provides a summary of the notation adopted in the model.

**Players** There are four players: the author of an article, (A), "nature" (N), an editor-reviewer (E), and a reader of the article (R) if the article is published.

**Actions, timing, and information structure** The game has five stages. In the first stage, the author A decides whether to undertake a "radical" research project (action *rad*), which can potentially lead to major novel results, or to undertake incremental research (action *incr*), which might lead to minor improvements to the existing knowledge.

In the second stage, nature (N) chooses whether the project is successful (*succ*) or not (*fail*). The probabilities of success of a radical and of an incremental project are, respectively,  $\beta_{rad}$  and  $\beta_{incr}$ . The outcome of the project is observed only by the author.

In the third stage, the author A decides whether to submit a paper resulting from the research (*subm*), or not to submit (*no subm*). If the project failed, and the author submits the paper as

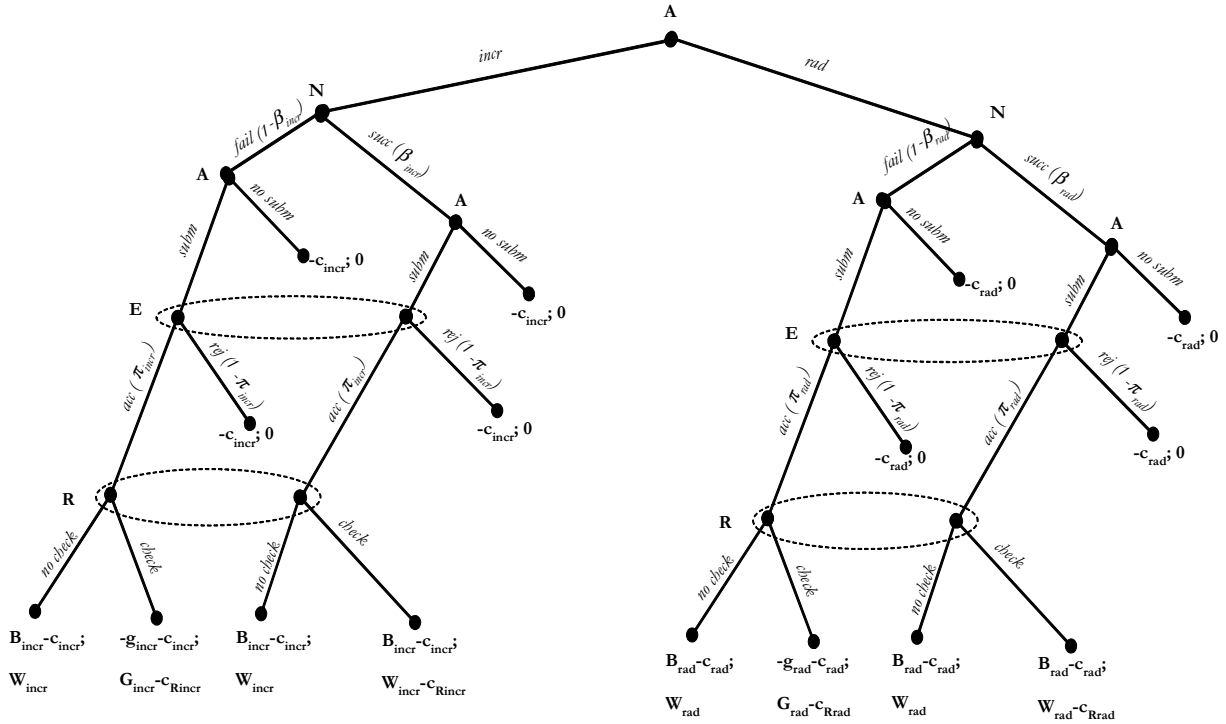


Figure 1: Game tree for the publication game. Players and payoffs are reported in bold types. Actions are in italics. The dotted ellipses represent information sets. The notation is described below, and summarized in Table 6 in Appendix A.

it is, it would never be published. Therefore, sending the paper is equivalent to not submitting it at all. However, the author can decide to fake the results of the research and send a paper thus faked.<sup>6</sup>

In the fourth stage, the editor-reviewer E, with some probability  $\pi_i \in (0, 1)$  ( $i = rad, incr$ ) accepts the paper for publication. The editor-reviewer E is therefore modeled just as a probability distribution with no active role. This choice is not too restrictive for our aims. Journal editors and reviewers are not expected to check for misconduct, for example they are not required to ask the authors for the raw data. Most actions aimed at checking for frauds occur after the publication of a study. Editors may come to play a role then, but typically not before publication.<sup>7</sup> In an extension of the model below (Section 3.3), we also consider the effect of

<sup>6</sup>The success or failure of the project does not depend on the effort spent by the author, which in fact is not modeled in the game. This is clearly a limitation, as one could argue that by exerting higher effort and care, a scientist reduces the chances of failure. We are interested, however, not as much in the determinants of success of a project, as in the incentives that scientists have to commit fraud, and of their peers to check for these frauds. The decision of whether to commit fraud or not may be seen as not related to the amount of effort spent in the research. In this respect, the exclusion of effort from the model is not too restrictive.

<sup>7</sup>The information we gathered on this topic from conversations with editors at some major scientific journals are consistent with these claims. See also LaFollette (1992) and Hamermesh (2007). Note also that we are merging

having misconduct checks been performed also by editors before publication.

The fifth stage occurs only if the manuscript is published. The reader R decides whether to check the paper or not. The *check* action summarizes different behaviors. The reader may request the raw data to the author and try to replicate the study, or she may try to build a similar experiment. The reader can also try to build on the original study, and, through her own work, she may find discrepancies in the original paper. The cases described in the Introduction provide examples on how a scientist's peers or even collaborators scrutinize the work of a researcher. If the check is performed, cheating (if occurred) is detected with certainty.

The reader cannot tell whether the author has committed fraud unless she performs a thorough check. Only the probability distribution over success versus failure, and over the behavior of the editor-referee E, is common knowledge. The choice of the type of research is perfectly observed.

**Payoffs** Performing research has a cost for the author. Call the cost of performing radical research  $c_{rad}$ , and the cost of performing incremental research  $c_{incr}$ . Performing research also generates a benefit for A, if the research is published:  $B_{rad}$  and  $B_{incr}$ . This benefit summarizes reputational gains, career advancements, and possibly monetary rewards.

The success of A's research generates a return of  $W_i$  ( $i=rad, incr$ ) for the reader R. These returns may be positive or negative. R may enjoy an advance of science. Also, she may benefit from a certain result being published: this result might contribute to legitimating the field of research the reader is also working on, and may be complementary to her work and findings – the reader, too, is a member of the scientific community. R can also derive disutility from the success of A's research. R and A can be competitors, so that a success of A reduces the room for contributions by R. The reader also bears some costs if she plays *check*. Call these costs  $c_{R_{rad}}$  for radical research and  $c_{R_{incr}}$  for incremental research. These costs can be seen as a function of the time and effort spent in a thorough scrutiny. They can also have other determinants. For example, a young scholar questioning the work of a higher-reputation peer might have problems in having her own work published and in obtaining recognitions and promotions.<sup>8</sup>

If caught cheating, A bears a disutility  $g_i$  ( $i=rad, incr$ ). This cost can be seen as a loss

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two potentially distinct figures: the editor and the reviewers. Editors and reviewers may have partially different attitudes toward a paper. For example, an editor may be very keen to publish an allegedly ground breaking article in his journal. The reviewer, instead, might decide to be tougher on potentially more innovative research, and she may also have a negative return from a competitor making a major leap in a field. Numerous studies, however, show that in most of the cases editors follow the opinions of the referees, and try to build consensus (or reduce discrepancies) among different referees (see Rothwell and Martyn 2000). Interviews with editors at a few leading scientific journals confirmed this behavior. For these reasons, merging editors and referees does not appear as an unacceptable simplification.

<sup>8</sup>In 1986 Margot O'Toole, a postdoctoral researcher at MIT, questioned the results in a paper of the Nobel Prize winner David Baltimore. After this episode, both supporters and detractors of O'Toole's initiatives deemed her career as "ruined". She, in fact, abandoned the academic career soon after, even though her claims turned out to be correct (Okie 1988, LaFalette 1992, Freeland Judson 2004).

of reputation, or even as legal and monetary costs, as the cases reported in the Introduction testify.<sup>9</sup> By contrast, the reader receives a reward if she detects cheating. For example the reader can publish papers that contradict A's results, thus obtaining additional recognition (Boffrey 1988). Call this reward  $G_i$  ( $i=rad, incr$ ).

## 2 Analysis

### 2.1 The equilibria in each subgame

We solve for the Perfect Bayesian Nash Equilibria of the game. There are two proper subgames, each starting after the author A chooses whether to undertake radical or incremental research. The payoffs of the two subgames are different, but the two subgames are otherwise identical in their structure. We analyze only one of these subgames, and omit the subscripts *rad* and *incr* for notational simplicity. We also name each subgame after the action chosen by A. So, for example, the *rad* game is the subgame following the choice by A to perform radical research. After having analyzed the subgames, we consider the first move by A – the decision of the type of research.

Since submitting dominates not submitting when the project is successful, three types of equilibria may exist in each subgame:

1. Separating equilibrium, in which A submits when the project is successful, and does not submit otherwise.
2. Pooling equilibrium, where A chooses *subm*, regardless of the success or failure of the project.
3. Semi-separating equilibrium, where A randomizes over *subm* and *no subm* if project is unsuccessful.

An equilibrium in each subgame is given by a four-tuple composed by i) the action chosen by A if the project is successful; ii) the action chosen by A if the project is a failure; iii) the action chosen by R and iv) the posterior belief of R on the success or failure of the project. We begin the characterization of the equilibria in each subgame with the following lemma:

**Lemma 2.1.1** *There is no separating equilibrium where A chooses "subm" if the project is successful, and chooses "no subm" if the project is not successful.*

**Proof.** *By contradiction. Assume A is separating and consider R's response. R updates her beliefs on the success of the project, and attributes probability 1 to success. In this case, not*

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<sup>9</sup>In some cases, scientists caught cheating "disappear" from the scientific community (Odling-Smee et al. 2007). Still in other cases, evidence of fraud in the work of a scientist is found after his death, as it happened for the child psychologist Bruno Bettelheim.

checking dominates checking. However, anticipating this,  $A$  has an incentive to deviate when the project turns out to be a failure, i.e.  $A$  will submit also when the project fails. ■

Given Lemma 2.1.1, the following proposition can be stated. The proof of this proposition, as well as the proofs of all of the other results in the paper, is in Appendix B.

**Proposition 2.1** *The subgames "rad" and "incr" have the following equilibria:*

1. A pooling equilibrium (subm, subm; no check;  $\beta$ ) for  $G_i \leq W_i + \frac{cR_i}{1 - \beta_i}$ ,  $i = rad, incr$ .
2. A semi-separating equilibrium (subm with probability  $p_i = 1$ ; subm with probability  $p_i = \frac{\beta_i}{1 - \beta_i} \frac{cR_i}{G_i - W_i - cR_i}$ ; check with probability  $r_i = \frac{B_i}{B_i + g_i}; \frac{\beta_i}{\beta_i + p_i(1 - \beta_i)}$ ) if  $G_i > W_i + \frac{cR_i}{1 - \beta_i}$ ,  $i = rad, incr$ .

The parameter sets that make each equilibrium existing are mutually exclusive and constitute a partition of the whole parameter space. Figure 2 represents qualitatively the regions where different equilibria occur. Proposition 2.1 has a straightforward corollary:

**Corollary 2.1.1** *In any equilibrium of the publication game, fraud occurs with positive probability.*

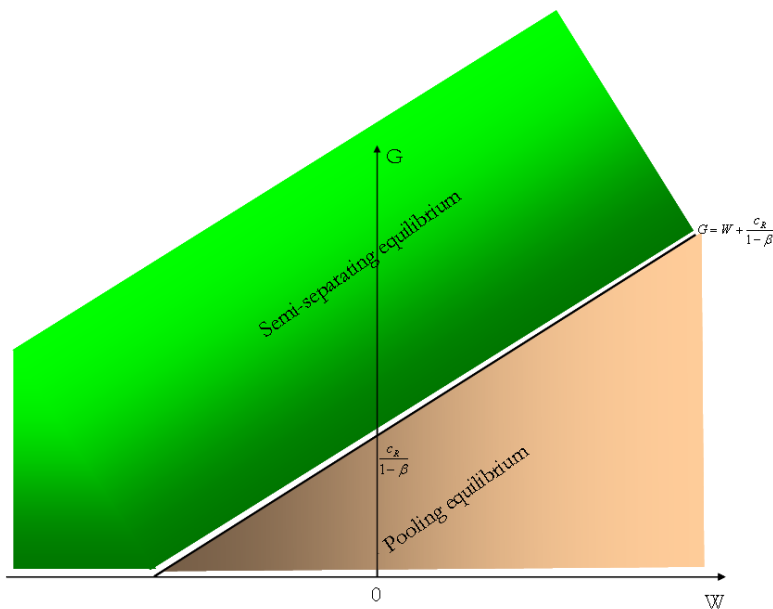


Figure 2: Parameter space for each of the two types of equilibria in each proper subgame (subscripts have been omitted).

## 2.2 Detected and undetected misconduct

For each of the two subgames, and for each of the two types of equilibria, we can calculate the probability that fraudulent papers are written, are published, are published without being caught, are published and are caught, and are checked when, instead, they are not fraudulent. The following propositions and tables derive straightforwardly from the previous results.

**Proposition 2.2** *In a pooling equilibrium, the probability that a fraudulent paper is written and submitted,  $P_{subm_i}$  ( $i = rad, incr$ ) is  $(1 - \beta_i)$ . The probability that a fraudulent paper is submitted and published,  $P_{(subm,acc)_i}$  is  $\pi_i(1 - \beta_i)$ , and is equal to the probability that a fraudulent paper is submitted, published, and not caught,  $P_{(subm,acc,nc)_i}$ . The probability that a fraudulent paper is submitted, published, and caught,  $P_{(subm,acc,c)_i}$  is zero, and so is the probability that a non-fraudulent paper, if published, goes under a check by the reader.*

**Proposition 2.3** *In a semi-separating equilibrium the probability that a fraudulent paper is written and submitted,  $P_{subm_i}$  ( $i = rad, incr$ ) is  $(1 - \beta_i)p_i = \frac{\beta c_{R_i}}{G_i - W_i - c_{R_i}}$ . The probability that a fraudulent paper is submitted and published,  $P_{(subm,acc)_i}$  is  $\pi_i(1 - \beta_i)p_i = \frac{\pi_i \beta_i c_{R_i}}{G_i - W_i - c_{R_i}}$ . The probability that a fraudulent paper is submitted, published, and caught,  $P_{(subm,acc,c)_i}$  is  $\frac{\pi_i \beta_i c_{R_i}}{G_i - W_i - c_{R_i}} \frac{B_i}{B_i + g_i}$ . Finally, the probability that a non-fraudulent paper is submitted, published, and goes under a check is  $\frac{\pi_i \beta_i B_i}{B_i + g_i}$ . The probability that a fraudulent paper is submitted, published, and not caught,  $P_{(subm,acc,nc)_i}$ , is  $\pi_i(1 - \beta_i)p_i(1 - r_i) = \frac{\pi_i \beta_i c_{R_i}}{G_i - W_i - c_i} \frac{g_i}{B_i + g_i}$ . We have the following comparative statics on  $P_{(subm,acc,nc)_i}$ :*

$$\frac{\partial P_{(subm,acc,nc)_i}}{\partial \pi_i}, \frac{\partial P_{(subm,acc,nc)_i}}{\partial \beta_i}, \frac{\partial P_{(subm,acc,nc)_i}}{\partial g_i}, \frac{\partial P_{(subm,acc,nc)_i}}{\partial c_{R_i}}, \frac{\partial P_{(subm,acc,nc)_i}}{\partial W_i} > 0;$$

$$\frac{\partial P_{(subm,acc,nc)_i}}{\partial G_i}, \frac{\partial P_{(subm,acc,nc)_i}}{\partial B_i} < 0.$$

		pooling eq.	semi-separating eq.
Type of research:	rad	$\pi_{rad}(1 - \beta_{rad})$	$\frac{\pi_{rad} \beta_{rad} c_{Rrad}}{G_{rad} - W_{rad} - c_{Rrad}} \frac{g_{rad}}{B_{rad} + g_{rad}}$
	incr	$\pi_{incr}(1 - \beta_{incr})$	$\frac{\pi_{incr} \beta_{incr} c_{Rincr}}{G_{incr} - W_{incr} - c_{Rincr}} \frac{g_{incr}}{B_{incr} + g_{incr}}$

Table 1: Probability that a fraudulent paper is submitted, published, and not caught

		pooling eq.	semi-separating eq.
Type of research:	rad	0	$\frac{\pi_{rad} \beta_{rad} c_{Rrad}}{G_{rad} - W_{rad} - c_{Rrad}} \frac{B_{rad}}{B_{rad} + g_{rad}}$
	incr	0	$\frac{\pi_{incr} \beta_{incr} c_{Rincr}}{G_{incr} - W_{incr} - c_{Rincr}} \frac{B_{incr}}{B_{incr} + g_{incr}}$

Table 2: Probability that a fraudulent paper is submitted, published, and caught

		<i>pooling eq.</i>	<i>semi-separating eq.</i>
<b>Type of research:</b>	<i>rad</i>	0	$\frac{\pi_{rad}\beta_{rad}B_{rad}}{B_{rad}+g_{rad}}$
	<i>incr</i>	0	$\frac{\pi_{incr}\beta_{incr}B_{incr}}{B_{incr}+g_{incr}}$

Table 3: Probability that a non-fraudulent paper is submitted, published, and checked

### 2.3 The choice of the type of research and the equilibrium of the whole game

By backward induction, the author A chooses the type of research to perform, in order to maximize his expected payoff. An equilibrium in the whole game is five-tuple composed by: i) the choice of the type of research by A (*rad* or *incr*); ii) the action chosen by A if the project is successful; iii) the action chosen by A if the project is a failure (*sub* or *no subm*); iv) the action chosen by R (*check* or *no check*); and v) the posterior belief by R on the success or failure of the project. Proposition 2.4 below is divided in four points (1, 2, 3 and 4), each of which has two subcases (a and b). The four points follow Proposition 2.1 above and show the conditions under which a pooling or semi-separating equilibrium for each proper subgame will occur, given the type of research. For each point, the subpoints a and b show the conditions under which A will choose radical or incremental research. The proof of this proposition follows immediately from the previous results.

#### Proposition 2.4

1. If  $G_{rad} \leq W_{rad} + \frac{c_{Rrad}}{1 - \beta_{rad}}$  and  $G_{incr} \leq W_{incr} + \frac{c_{Rincr}}{1 - \beta_{incr}}$  :
  - (a) If  $\pi_{rad}B_{rad} - c_{rad} > \pi_{incr}B_{incr} - c_{incr}$ , then the equilibrium of the game is (*rad*; *subm*, *subm*; *no check*;  $\beta_{rad}$ );
  - (b) If  $\pi_{incr}B_{incr} - c_{incr} \geq \pi_{rad}B_{rad} - c_{rad}$  then the equilibrium of the game is (*incr*; *subm*, *subm*; *no check*;  $\beta_{incr}$ ).
2. If  $G_{rad} \leq W_{rad} + \frac{c_{Rrad}}{1 - \beta_{rad}}$  and  $G_{incr} > W_{incr} + \frac{c_{Rincr}}{1 - \beta_{incr}}$  :
  - (a) If  $\pi_{rad}B_{rad} - c_{rad} > \pi_{incr}\beta_{incr}B_{incr} - c_{incr}$  then the equilibrium of the game is (*rad*; *subm*, *subm*; *no check*;  $\beta_{rad}$ );
  - (b) If  $\pi_{incr}\beta_{incr}B_{incr} - c_{incr} \geq \pi_{rad}B_{rad} - c_{rad}$  then the equilibrium of the game is (*incr*; *subm* with probability  $p_{incr} = 1$ ; *subm* with probability  $p_{incr} = \frac{\beta_{incr}}{1 - \beta_{incr}} \frac{c_{Rincr}}{G_{incr} - W_{incr} - c_{Rincr}}$ ; *check* with probability  $r_{incr} = \frac{B_{incr}}{B_{incr} + g_{incr}}; \frac{\beta_{incr}}{\beta_{incr} + p_{incr}(1 - \beta_{incr})}$ ).
3. If  $G_{rad} > W_{rad} + \frac{c_{Rrad}}{1 - \beta_{rad}}$  and  $G_{incr} \leq W_{incr} + \frac{c_{Rincr}}{1 - \beta_{incr}}$  :

- (a) If  $\pi_{rad}\beta_{rad}B_{rad} - c_{rad} > \pi_{incr}B_{incr} - c_{incr}$ , then the equilibrium of the game is (rad; subm with probability  $p_{rad}=1$ ; subm with probability  $p_{rad} = \frac{\beta_{rad}}{1-\beta_{rad}} \frac{c_{Rrad}}{G_{rad}-W_{rad}-c_{Rrad}}$ ; check with probability  $r_{rad} = \frac{B_{rad}}{B_{rad}+g_{rad}}; \frac{\beta_{rad}}{\beta_{rad}+p_{rad}(1-\beta_{rad})}$ );
- (b) If  $\pi_{incr}B_{incr} - c_{incr} \geq \pi_{rad}\beta_{rad}B_{rad} - c_{rad}$ , then the equilibrium of the game is (incr; subm, subm; no check, no check;  $\beta_{incr}$ ).
4. If  $G_{rad} > W_{rad} + \frac{c_{Rrad}}{1-\beta_{rad}}$  and  $G_{incr} > W_{incr} + \frac{c_{Rincr}}{1-\beta_{incr}}$  :
- (a) If  $\pi_{rad}\beta_{rad}B_{rad} - c_{rad} > \pi_{incr}\beta_{incr}B_{incr} - c_{incr}$ , then the equilibrium of the game is (rad; subm with probability  $p_{rad}=1$ ; subm with probability  $p_{rad} = \frac{\beta_{rad}}{1-\beta_{rad}} \frac{c_{Rrad}}{G_{rad}-W_{rad}-c_{Rrad}}$ ; check with probability  $r_{rad} = \frac{B_{rad}}{B_{rad}+g_{rad}}; \frac{\beta_{rad}}{\beta_{rad}+p_{rad}(1-\beta_{rad})}$ );
- (b) If  $\pi_{incr}\beta_{incr}B_{incr} - c_{incr} \geq \pi_{rad}\beta_{rad}B_{rad} - c_{rad}$ , then the equilibrium of the game is (incr; subm with probability  $p_{incr}=1$ ; subm with probability  $p_{incr} = \frac{\beta_{incr}}{1-\beta_{incr}} \frac{c_{Rincr}}{G_{incr}-W_{incr}-c_{Rincr}}$ ; check with probability  $r_{incr} = \frac{B_{incr}}{B_{incr}+g_{incr}}; \frac{\beta_{incr}}{\beta_{incr}+p_{incr}(1-\beta_{incr})}$ ).

### 3 Implications

We now study how the probabilities of committing a fraud, of being discovered and of not being discovered, are affected by variations of the main parameters of the model. We show that observed cases of frauds are unlikely to be representative (not to mention all comprehensive) of frauds that go undetected. The analysis also generate a series of claims and predictions that qualify and in some cases contradict current proposals and adopted policies to deter scientific fraud. The findings are presented in three sets, one for each of the following subsections. A discussion of the findings and their implications concludes each of the three subsections.

#### 3.1 Types of fraudulent research and of fraudulent scientists

A first question we pose concerns the relationship between the extent of scientific misconduct and the type of research that is performed. We show that for an economically significant range of parameter values, there may be a mismatch between the type of research that are more likely to be caught if fraudulent, and the type of research that are more likely to actually be fraudulently produced. To see this, assume first that  $G_{incr} \leq W_{incr} + \frac{c_{Rincr}}{1-\beta_{incr}}$  and  $G_{rad} > W_{rad} + \frac{c_{Rrad}}{1-\beta_{rad}}$ . This implies that a pooling equilibrium for incremental research and a semi-separating equilibrium for radical research are played. The conditions are more likely to be satisfied if the benefits from discovering frauds in radical research ( $B_{rad}$ ) are high (while they are low for incremental research), and the probability of a ground breaking project to be successful ( $\beta_{rad}$ ) is low (while is high for an incremental project). In this case, the probability that a fraudulent paper with incremental research is submitted, accepted and caught is zero, which is lower than the probability of a radical fraudulent paper to be caught – this probability is strictly

positive. The probability that a fraudulent incremental research paper is published, however, may be higher or lower than the corresponding probability for radical research paper. It will be higher if:

$$\pi_{incr}(1 - \beta_{incr}) > \frac{\pi_{rad}\beta_{rad}c_{Rrad}}{G_{rad} - W_{rad} - c_{Rrad}} \quad (1)$$

Inequality (1) is more likely to be satisfied if  $B_{rad}$  is high, i.e. when benefits from radical research are particularly high. If the inequality holds, we observe scientific misconduct more likely to be discovered in radical research, while being more common in incremental research.

Suppose now that semi-separating equilibria exist for both types of research ( $G_{incr} \leq W_{incr} + \frac{c_{R_{incr}}}{1 - \beta_{incr}}$  and  $G_{rad} \leq W_{rad} + \frac{c_{R_{rad}}}{1 - \beta_{rad}}$ ). In this case, the probability that a fraudulent paper is submitted and published is higher for incremental research if:

$$\frac{\pi_{inc}\beta_{inc}c_{Rinc}}{G_{inc} - W_{inc} - c_{Rinc}} > \frac{\pi_{rad}\beta_{rad}c_{Rrad}}{G_{rad} - W_{rad} - c_{Rrad}}, \quad (2)$$

while the probability of fraudulent paper is submitted, published and caught is higher for incremental research if:

$$\frac{\pi_{inc}\beta_{inc}c_{Rinc}}{G_{inc} - W_{inc} - c_{Rinc}} \frac{B_{inc}}{B_{inc} + g_{inc}} > \frac{\pi_{rad}\beta_{rad}c_{Rrad}}{G_{rad} - W_{rad} - c_{Rrad}} \frac{B_{rad}}{B_{rad} + g_{rad}}. \quad (3)$$

If benefits from publishing radical research are much higher than benefits from publishing incremental research, the probability that a fraudulent paper is submitted and published may be higher for incremental research, while the probability of being caught is higher for radical research. The following numerical example further clarifies these claims.

**Example 3.1** Assume  $G_{rad} = 49$ ;  $G_{incr} = 43$ ;  $W_{rad} = 12$ ;  $W_{incr} = 40$ ;  $c_{Rrad} = 12$ ;  $c_{R_{incr}} = 6$ ;  $B_{rad} = 89$ ;  $g_{rad} = 70$ ;  $\pi_{rad} = .5$ ;  $\pi_{incr} = .2$ ;  $\beta_{rad} = .4$ ;  $\beta_{incr} = .4$ . Then  $G_{rad} = 49 > W_{rad} + \frac{c_{R_{rad}}}{1 - \beta_{rad}} = 32$ ;  $G_{incr} = 43 < W_{incr} + \frac{c_{R_{incr}}}{1 - \beta_{incr}} = 50$ ; and  $\pi_{incr}(1 - \beta_{incr}) = .12 > \frac{\pi_{rad}\beta_{rad}c_{Rrad}}{G_{rad} - W_{rad} - c_{Rrad}} = .09$ . Assume further that  $B_{incr} = 15$ ,  $c_{incr} = 2$ ,  $c_{rad} = 5$ . Then,  $\pi_{rad}\beta_{rad}B_{rad} - c_{rad} = 12.8 > \pi_{incr}B_{incr} - c_{incr} = 1$ ; a semi-separating equilibrium with radical research is played and the probability of a paper being faked and published is .09. Assume now, instead, that  $B_{incr} = 60$ . Then,  $\pi_{rad}\beta_{rad}B_{rad} - c_{rad} = 12.8 < \pi_{incr}B_{incr} - c_{incr} = 14$ ; a pooling equilibrium with incremental research is played. The probability of a paper being faked and published is  $.12 > .09$ .

The model can also be used to predict scientific misconduct in relation to the characteristics of scientists. We point to a further source of mismatch between observed (detected) and actual amount and types of fraud. While high-reputation scientists are more likely to misbehave, average scientists are more likely to be caught. We might therefore observe more fraudulent cases by those categories of scientists who are less likely to commit them.

Characterize a high-reputation or "star" scientist as one more likely to succeed in a project, i.e. having a high  $\beta$ ; as one having a higher  $g$ , because the loss of reputation is higher, and a lower  $B$ , if  $B$  is meant to be the "utility" of a marginal publication, compared to an average, less known scientist.; and as one having a high  $\pi$ , i.e. stars are more likely to have a paper passed by a referee. Indicate the parameters referring to the star with the superscript  $s$ , and those referred to the average scientist with the superscript  $a$ . Assume finally that both types of scientists choose the same type of research. One could assume that  $G - W$  is more depending on the type of research (e.g.  $G_{rad} > G_{inc}$ ) rather than on the reputation of the scientist *before* the paper is published. If that is the case, the assumption on  $\beta$  on imply that the conditions  $G^s \leq W^s + \frac{c_R}{1-\beta^s}$  and  $G^a > W^a + \frac{c_R}{1-\beta^a}$  will be true for a large set of values of  $c_R$  (we omit the *rad/incr* subscript since we assume the scientists choose the same type of research). Therefore, we have a pooling equilibrium for the star scientist and a semi-separating equilibrium for the average scientist. It will therefore be more likely for a reader to discover a fraud in the paper by the average scientist than by the star. However, the probability of submitting and get a faked paper published is higher for a star if:

$$\pi^s(1 - \beta^s) \geq \frac{\pi^a \beta^a c_R}{G^a - W^a - c_R} \frac{g^a}{B^a + g^a}, \quad (4)$$

Our assumption on  $\beta$  implies that both  $(1 - \beta^s)$  and  $\beta^a$  are low. However, we also assumed that  $B^a$  is high and  $g^a$  is low, and that  $\pi^s > \pi^a$ . Hence, inequality (4) will be satisfied for large set of  $G^a, W^a$  and  $c_R$ .

The intuition behind this result is that average, unknown scientists have more to gain from a fraud. As a consequence, they are under stricter scrutiny by peers. This reduces their incentive to submit fraudulent papers in the first place. At the same time, papers by star scientists are not checked because, *ex ante*, their probability of success is higher, they have less gain at the margin and the penalty if caught (i.e. loss in reputation) is higher.

### 3.1.1 Comment: "real" frauds and "real" cheaters are not as they seem

On the one hand, this first set of results conform with most of the available accounts on (detected) scientific fraud. Most fraud stories, such as those reported in the Introduction, describe frauds as being committed in the attempt to generate pathbreaking advances in science. Most fraudulent researchers, moreover, were described as being "on the rise". The frauds were committed (and then discovered) when they had not had not yet established a strong reputation. Not having a strong reputation made them less credible in the eyes of their peers and motivated further scrutiny.

On the other hand, however, these results point to some pitfalls of excessively relying on *observed* frauds in order to understand the overall phenomenon of scientific misconduct. We show that here may be a divergence between the probability that a certain kind of fraud is discovered

and the probability that it is committed. A whole set of equilibria, where authors commit fraud and readers do not check (the pooling equilibria) is not captured by empirical analyses. A "good news" from the model is that major advances in science are more closely scrutinized, so that fraud is more likely to be detected – and as a consequence, less likely to be committed in the first place. Undetected fraud in incremental research, however, should not be undervalued. Entirely new areas of research may have origin from apparently marginal discoveries. Research results that the scientific community would consider marginal improvements, for example on drug delivery methods or side effects of drugs, may have major impact on people's lives.<sup>10</sup> Finally, the scientific communities of several countries are relatively isolated and recognition is based on local, less prominent journals. Arguably, the overall scrutiny on these articles will be less strict (Marušić 2007), thus paving the way to more undetected frauds.

As a consequence, policy implications on scientific misconduct based on *detected* fraudulent behavior can be misleading, in terms of both the types of research and of researchers these policies would address. Policies might be tailored to the types of research that are less likely to be fraudulent – for example by focusing only on some journals or fields. The attention might be too focused on larger scientific communities, thus neglecting local communities where fraud may be more pervasive. Or, policies might be focussed on less known researchers (post-docs, junior faculty), while the scientific community already generates, without the need for interventions, the right incentives for these classes of researchers to be scrutinized.

## 3.2 Policy experiments

Several scholars as well as the popular press have advocated a series of interventions and reforms of the scientific community that would deter scientific misconduct. Some of these proposed policies correspond to changes in the parameters of our model. The analysis that follows assesses the effects of these changes.

### 3.2.1 Misconduct and checking costs

High costs of replicating the results in an article are indicated among the main causes of the occurrence of frauds. It is perceived that, over time, cheating has become easier (e.g. thanks to the ease of modifying electronic images), but the costs of checking have increased. Data should be made more easily available, it is claimed. For example if authors should be required to share their data with their peers as a condition to publish on a given journal. A few journals require the authors of accepted papers to make their data available online, and to provide any additional material of potential relevance to fully understand a paper (Hamermesh 2007). Or, techniques could be developed to check for frauds more easily (Hill 1999, Sorokina et al. 2006, Giles 2006).

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<sup>10</sup>A few recent examples on how frauds in these areas can have serious consequences are in Surowiecki (2007).

When we fully consider the strategic behavior of both authors and their peers, however, we can show that a reduction in checking costs does not necessarily lead to less misconduct. This claim is formalized in the following corollaries (proofs are in Appendix B).

**Corollary 3.2.1** *A reduction in checking costs  $c_{Ri}$  ( $i = \text{rad}, \text{incr}$ ) never leads to a higher probability of undiscovered fraud if it does not induce a change in the type of research.*

**Corollary 3.2.2** *If the author A changes the type of research following a reduction in checking costs, then the probability of an undiscovered fraud can increase.*

The following numerical and graphical example clarifies these results.

**Example 3.2** *Figure 3 below reports an example of a reduction in checking costs that leads to an increase in the likelihood of a paper being fraudulent, submitted, accepted, and not caught. The graph represents the  $(c_{R_{\text{rad}}}, c_{R_{\text{incr}}})$  space and focuses on the region where  $c_{R_{\text{rad}}} \geq c_{R_{\text{incr}}}$ . Consider the points in region A. In this area,  $\frac{\pi_{\text{rad}}\beta_{\text{rad}}c_{R_{\text{rad}}}}{G_{\text{rad}}-W_{\text{rad}}-c_{R_{\text{rad}}}} \frac{g_{\text{rad}}}{B_{\text{rad}}+g_{\text{rad}}} > \pi_{\text{incr}}(1 - \beta_{\text{incr}})$  and  $G_{\text{rad}} > W_{\text{rad}} + \frac{c_{R_{\text{rad}}}}{1 - \beta_{\text{rad}}}$  – equivalently,  $\frac{(B_{\text{rad}}+g_{\text{rad}})(G_{\text{rad}}-W_{\text{rad}})[\pi_{\text{incr}}(1-\beta_{\text{incr}})]}{\pi_{\text{rad}}\beta_{\text{rad}}g_{\text{rad}}+\pi_{\text{incr}}(1-\beta_{\text{incr}})(B_{\text{rad}}+g_{\text{rad}})} < c_{R_{\text{rad}}} < (G_{\text{rad}}-W_{\text{rad}})(1-\beta_{\text{rad}})$ . Furthermore,  $G_{\text{incr}} \leq W_{\text{incr}} + \frac{c_{R_{\text{incr}}}}{1 - \beta_{\text{incr}}}$  – equivalently,  $c_{R_{\text{incr}}} \geq (G_{\text{incr}} - W_{\text{incr}})(1 - \beta_{\text{incr}})$ . The parameters are also such that  $\pi_{\text{incr}}B_{\text{incr}} - c_{\text{incr}} > \pi_{\text{rad}}\beta_{\text{rad}}B_{\text{rad}} - c_{\text{rad}}$ . As a consequence, A chooses incremental research and a pooling equilibrium is played (as from point 3.b of Proposition 2.4). The likelihood of a paper being fraudulent, submitted, accepted, and not caught is  $\pi_{\text{incr}}(1 - \beta_{\text{incr}})$  (see Table 1 at page 11 above). In region B, the only condition that changes with respect to region A is that  $G_{\text{incr}} > W_{\text{incr}} + \frac{c_{R_{\text{incr}}}}{1 - \beta_{\text{incr}}}$  – equivalently,  $c_{R_{\text{incr}}} < (G_{\text{incr}} - W_{\text{incr}})(1 - \beta_{\text{incr}})$ . The figure is drawn for parameter values such that  $\pi_{\text{incr}}\beta_{\text{incr}}B_{\text{incr}} - c_{\text{incr}} < \pi_{\text{rad}}\beta_{\text{rad}}B_{\text{rad}} - c_{\text{rad}}$ . The author A therefore chooses radical research and a semi-separating equilibrium is played (as from point 4.a of Proposition 2.4). The likelihood of a paper being fraudulent, submitted, accepted, and not caught is  $\frac{\pi_{\text{rad}}\beta_{\text{rad}}c_{R_{\text{rad}}}}{G_{\text{rad}}-W_{\text{rad}}-c_{R_{\text{rad}}}} \frac{g_{\text{rad}}}{B_{\text{rad}}+g_{\text{rad}}}$ . Since  $\frac{\pi_{\text{rad}}\beta_{\text{rad}}c_{R_{\text{rad}}}}{G_{\text{rad}}-W_{\text{rad}}-c_{R_{\text{rad}}}} \frac{g_{\text{rad}}}{B_{\text{rad}}+g_{\text{rad}}} > \pi_{\text{incr}}(1 - \beta_{\text{incr}})$  for this set of parameter values, and since region B lies below region A, a reduction of both  $c_{R_{\text{rad}}}$  and  $c_{R_{\text{incr}}}$  can lead to an increase in the rate of committed and undetected fraud.*

### 3.2.2 Misconduct and competition among scientists

It is frequently claimed that high powered incentives to scientists may be conducive to fraud. The high benefits from publishing papers and outcompeting rivals (in a winner-takes-all competition) makes scientists more prone to misbehave (List 1985, Abelson 1990, Giles 2007). Again, our model shows that this claim is not necessarily borne out: more competition can actually serve as a powerful mechanism to deter fraud, as it increases the incentives of peers for scrutinizing each other's work.

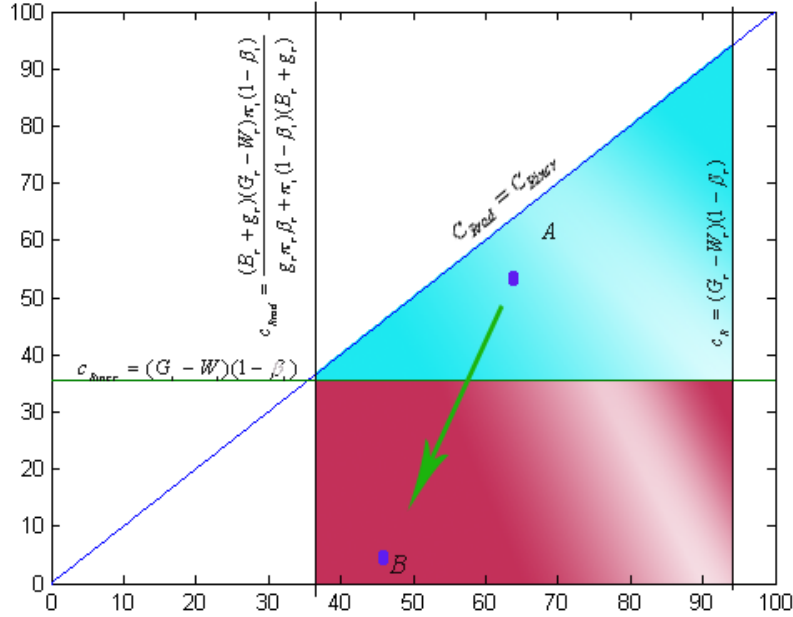


Figure 3: Example of a reduction in checking costs that leads to an increase in the likelihood of a paper being fraudulent, submitted, accepted, and not caught. The x-axis represent values of  $c_{Rrad}$ , and the y-axis values of  $c_{Rincr}$ . The figure is drawn for the following set of other values of the parameters:  $G_{rad}= 85$ ;  $G_{incr}= 62$ ;  $W_{rad}= -36$ ;  $W_{incr}= -25$ ;  $B_{rad}= 89$ ;  $B_{incr}= 65$ ;  $c_{rad} = 16$ ;  $c_{incr} = 1$ ;  $g_{rad}= 84$ ;  $\pi_{rad}= .96$ ;  $\pi_{incr}= .12$ ;  $\beta_{rad}= .24$ ;  $\beta_{incr}= .59$ .

In the game, the benefits from publications, and more generally the intensity of competition among scientists, are captured by  $B$  (the author's incentives) and  $G - W$ . If the intensity of competition is high,  $A$ 's benefit from publications ( $B$ ) will be high; the same is for the return from discovering a fraud ( $G$ ) and the loss from others' publications ( $-W$ ). The comparative statics for these parameters, just as in the previous exercises, crucially depend on whether the type of research chosen by authors changes or not. Our results are formalized in the following corollaries.

**Corollary 3.2.3** *An increase in competition (i.e. an increase in  $B_i$  and  $G_i - W_i$ ,  $i= rad, incr$ ) never leads to a higher probability of undiscovered fraud if it does not induce a change in the type of research.*

**Corollary 3.2.4** *If the author  $A$  changes the type of research following an increase in competition, then the probability of an undiscovered fraud can increase.*

### 3.2.3 Misconduct and the penalties of being caught

Another frequently proposed remedy against misconduct in science is to strengthen the severity of the penalties for those scientists who are caught committing fraud. This would deter scien-

tists from misbehaving. In fact, as mentioned above, penalties can be as severe as leading to imprisonment. However, just as the increased absolute value of the punishment should deter an author from cheating, this could also reduce the incentives for peers to check, countervailing the deterrence effect. In the publishing game above, the parameter  $g$  represents the cost, which can be pecuniary or not, suffered by  $A$  if a fraudulent paper is discovered. This parameter appears as relevant only in a semi-separating equilibrium, affecting the probability of discovering a fraudulent paper. The derivative sign is negative, i.e. a increase in  $g$  increases the probability that a fraudulent paper is not caught. This apparently counterintuitive result is due to the fact that, if  $g$  is high, then a lower probability of checking by  $R$  is required to generate the indifference between submitting a faked paper or not by  $A$ .

### 3.2.4 Comment: deterrence policies can backfire

A series of counterintuitive insights emerge from this second set of results. Of key importance in the model are the multiple roles played by a scientist's peers. They are users, competitors, and evaluators at the same time. These different positions correspond to different benefits and costs. We show that, if checking published results becomes easier, this can modify the *type* of research activities scientists undertake in the first place. In turn, fraudulent activities will concentrate in some types of research.

The model also qualifies the claim that a major cause of misbehavior in science is represented by an excess of competition among researchers. High-powered competition can stimulate more monitoring, thus deterring frauds. One might observe more cases of fraud in more competitive fields, but, as pointed out above, this does not mean that the *overall* amount of fraud is greater. This just says that fraud is more likely to be caught, thus deterring scientists to misbehave in the first place. In fact, it may well be that *too little* competition is conducive to misconduct. Several scholars have pointed out that replication of existing results is too poorly rewarded by the scientific community. In Economics, for example, Hamermesh (2007) documents a decline in the number of journals that have a section dedicated to commentaries of previous works. This limited recognition for replication can be seen as a limit to competition. Once a result has been found by a scientist, he establishes a sort of "monopoly" over it. Any subsequent work that just replicates this result is considered unworthy of recognition.<sup>11</sup>

Establishing higher rewards for works that replicate existing findings and could possibly detect misconduct episodes thus emerges as a powerful device to deter fraud. The cost of such a policy might be an excessive incentive to invest in this kind of research instead of engaging in genuinely novel activities. In the late 1980s, for example, Walter W. Stewart and Ned Feder, two scientists at NIH, gained notoriety and some scientific recognition for having unveiled several

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<sup>11</sup>Engaging in activities aimed at questioning existing works can even be detrimental to a scientist's career, as the case of the MIT post-doctoral students Margot O'Toole witnesses ( see footnote 8 at page 8 above).

cases of misconduct. The two scholars engaged in these "checking activities" almost on a full-time basis, at the cost of a poor productivity in the generation of new research.<sup>12</sup>

### 3.3 An active role for Editors?

As previously noticed, neither editors nor referees are typically required to control for the truth of findings in the manuscripts they receive. Suspicions of fraud most often emerge after a paper is published. Colleagues and collaborators of an author, or most frequently, readers of an article contact the editor of the journal to express their concerns. Only then do editorial boards have a role. They take part in a control process that can involve the organization where the author works and possibly also public agencies (LaFollette 1992). The model as described so far represents this state of affairs. However, a few major journals have recently implemented practices that imply a greater involvement of editorial board in the attempt to deter and reduce fraud. At *Nature Immunology*, for example, an article is randomly selected among those accepted for publication before each issue is released, and goes through additional controls. A similar procedure, concerning every accepted manuscript, had been previously introduced at the *Journal of Cell Biology* (Rossner 2006, *Nature Immunology* 2007).

In what follows, we attempt to replicate these editorial innovations by extending the publication game. Referees are still assumed to have no role in checking for frauds. Now, however, editors and referees are separated agents. If a paper is accepted by a referee (called Ref), the editor E, with some probability  $\gamma$ , performs a check before publication. This is a commitment by the editor: he has no choice but performing the random check.<sup>13</sup> The editor, therefore, does not act strategically; hence her payoffs are irrelevant. As for the information structure, imperfect information is assumed by the reader on whether the editor has performed the check. This is consistent, for example, with the practices in the aforementioned journals, where the identity of the checked papers is kept secret. The full game in extended form is represented in Figure 4. We first analyze the two proper subgames starting when nature N moves separately, and then deal with the whole publication game thus modified. The analysis mirrors that of Section 2 above. We focus on the peculiarities of this case, and leave the derivations and proofs of the results to Appendix B below.

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<sup>12</sup>See Boffey 1988, Greenberg 1988, Okie 1988, LaFollette 1992.

<sup>13</sup>Both at *Nature Immunology* and at the *Journal of Cell Biology*, for example, this is a clearly stated editorial policy, with no discretion allowed. Notice also that, differently from the practice at *Nature Immunology*, checks are supposed to be run on each and every accepted paper at the *Journal of Cell Biology*, before publication. However, it is still reasonable to include such a case in the model's version developed here, where the probability of checking can also be less than one. First, in the model what matters is the probability of checking and spotting a fraud. Even when all papers are checked, some frauds can go undetected. Second, both in the case of *Nature Immunology* and the *Journal of Cell Biology*, these checks are largely focused on image manipulation only (Rossner 2006). Therefore, other types of frauds can go undetected. Conversations with journal editors confirmed that only some frauds can be detected with the methods and resources currently in use.

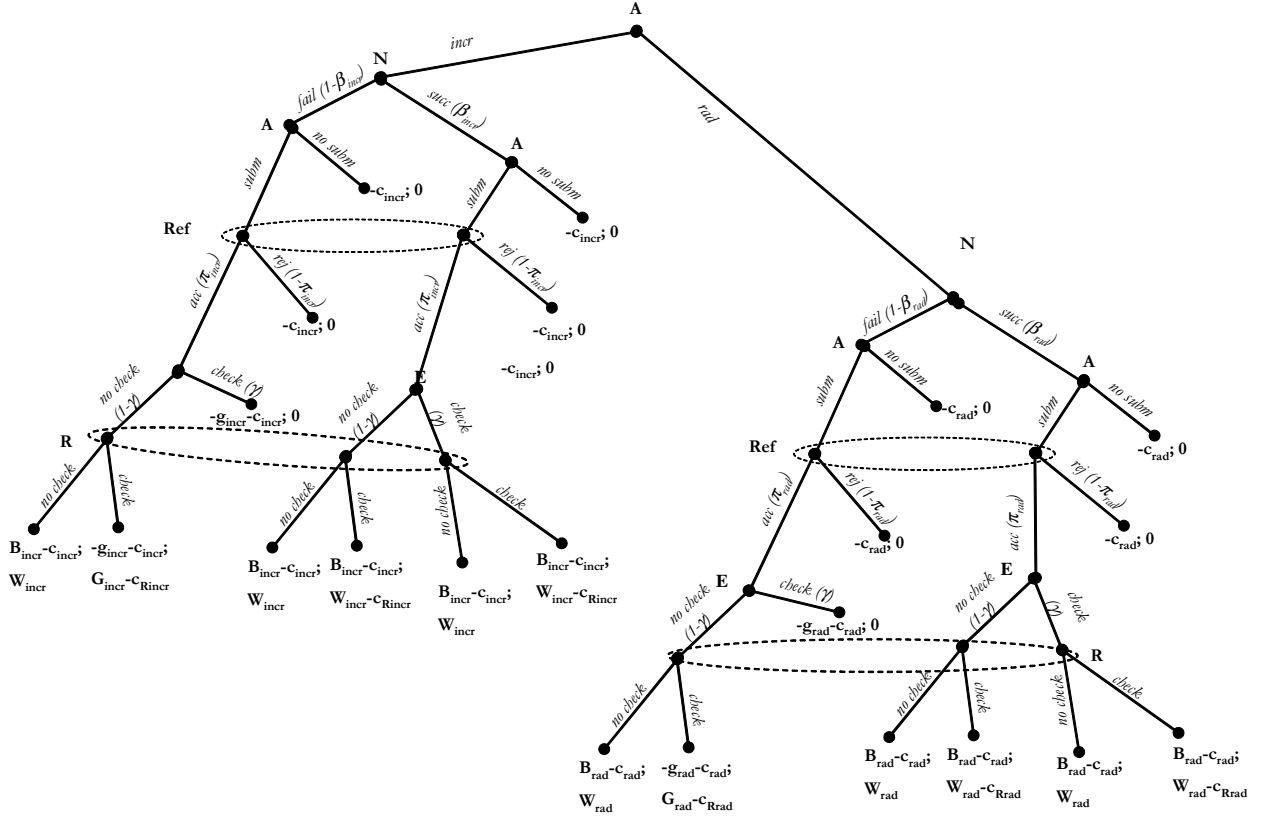


Figure 4: Game with random checks by the editor.

### 3.3.1 Equilibria of the proper subgames

The main difference from the case without check by the editor is that, now, a separating equilibrium exists when the checking probability by E is sufficiently high. Consider the following proposition.

**Proposition 3.1** *The subgames "rad" and "incr" have the following equilibria:*

1. A separating equilibrium (subm, no subm; no check; 1) for  $\gamma \geq \frac{B_i}{B_i + g_i}$
2. A pooling equilibrium (subm, subm; no check;  $\beta$ ) for  $1 - \frac{(1-\beta_i)W_i + c_{Ri}\beta_i}{(G_i - c_{Ri})(1-\beta_i)} \leq \gamma < \frac{B_i}{B_i + g_i}$ ,  $i = rad, incr$ .
3. A semi-separating equilibrium (subm with probability  $p=1$  if project is successful; subm with probability  $p_i = \frac{\beta_i}{1-\beta_i} \frac{c_i}{(G_i - c_{Ri})(1-\gamma) - W_i}$  if the project is unsuccessful; check with probability  $r = \frac{B_i}{B_i + g_i} \frac{1}{1-\gamma} - \frac{\gamma}{1-\gamma} \frac{\beta_i}{\beta_i + p_i(1-\beta_i)(1-\gamma)}$ ) exists for  $\gamma < \min(1 - \frac{(1-\beta_i)W_i + c_{Ri}\beta_i}{(G_i - c_{Ri})(1-\beta_i)}, \frac{B_i}{B_i + g_i})$ ,  $i = rad, incr$ .

### 3.3.2 Detected and undetected misconduct

The probability that fraudulent papers are written and published without being caught, and that they are written, published and caught are reported in the following tables. Notice that, for  $\gamma = 0$  (i.e. no check by the editor), we obtain the probabilities for the basic game, as reported in tables 1, 2, and 3 at page 11 above.

		<i>pooling eq.</i>	<i>semi-separating eq.</i>
<b>Type of research:</b>	<i>rad</i>	$\pi_{rad}(1-\gamma)(1-\beta_{rad})$	$\frac{\pi_{rad}\beta_{rad}c_{rad}}{(G_{rad}-c_{Rrad})(1-\gamma)-W_{rad}} \frac{g_{rad}}{B_{rad}+g_{rad}}$
	<i>incr</i>	$\pi_{incr}(1-\gamma)(1-\beta_{incr})$	$\frac{\pi_{incr}\beta_{incr}c_{incr}}{(G_{incr}-c_{Rincr})(1-\gamma)-W_{incr}} \frac{g_{incr}}{B_{incr}+g_{incr}}$

Table 4: Probability that a fraudulent paper is submitted, published, and not caught

		<i>pooling eq.</i>	<i>semi-separating eq.</i>
<b>Type of research:</b>	<i>rad</i>	$\pi_{rad}(1-\beta_{rad})\gamma$	$\frac{\pi_{rad}\beta_{rad}c_{rad}}{(G_{rad}-c_{Rrad})(1-\gamma)-W_{rad}} \frac{B_{rad}-\gamma(B_{rad}+g_{rad})}{B_{rad}+g_{rad}}$
	<i>incr</i>	$\pi_{incr}(1-\beta_{incr})\gamma$	$\frac{\pi_{incr}\beta_{incr}c_{incr}}{(G_{incr}-c_{Rincr})(1-\gamma)-W_{incr}} \frac{B_{incr}-\gamma(B_{incr}+g_{incr})}{B_{incr}+g_{incr}}$

Table 5: Probability that a fraudulent paper is submitted, published and caught

### 3.3.3 The choice of the type of research and the equilibrium of the whole game

By backward induction, the author A chooses the type of research to perform, in order to maximize his expected payoff. We derive the following Proposition, whose proof is immediate given the results and propositions above.

#### Proposition 3.2

1. If  $\max \left\{ 1 - \frac{(1-\beta_{rad})W_{rad}+c_{Rrad}\beta_{rad}}{(G_{rad}-c_{Rrad})(1-\beta_{rad})}, 1 - \frac{(1-\beta_{incr})W_{incr}+c_{Rincr}\beta_{incr}}{(G_{incr}-c_{Rincr})(1-\beta_{incr})} \right\} \leq \gamma < \min \left\{ \frac{B_{rad}}{g_{rad}+B_{rad}}, \frac{B_{incr}}{g_{incr}+B_{incr}} \right\}$ , A chooses radical research if  $\pi_{rad}(B_{rad}-\gamma(1-\beta_{rad})(B_{rad}+g_{rad}))-c_{rad} > \pi_{incr}(B_{incr}-\gamma(1-\beta_{incr})(B_{incr}+g_{incr}))-c_{incr}$ , incremental otherwise. The subgames have pooling equilibria.
2. If  $1 - \frac{(1-\beta_{rad})W_{rad}+c_{Rrad}\beta_{rad}}{(G_{rad}-c_{Rrad})(1-\beta_{rad})} \leq \gamma < \frac{B_{rad}}{g_{rad}+B_{rad}}$  and  $\gamma < \min \left\{ \frac{B_{incr}}{g_{incr}+B_{incr}}, 1 - \frac{(1-\beta_{incr})W_{incr}+c_{Rincr}\beta_{incr}}{(G_{incr}-c_{Rincr})(1-\beta_{incr})} \right\}$ , A chooses radical research (with pooling on subm) if  $\pi_{rad}(B_{rad}-\gamma(1-\beta_{rad})(B_{rad}+g_{rad}))-c_{rad} > \pi_{incr}\beta_{incr}B_{incr}-c_{incr}$ , incremental otherwise (with a semi-separating equilibrium).
3. If  $\gamma < \min \left\{ \frac{B_{rad}}{g_{rad}+B_{rad}}, 1 - \frac{(1-\beta_{rad})W_{rad}+c_{Rrad}\beta_{rad}}{(G_{rad}-c_{Rrad})(1-\beta_{rad})} \right\}$  and  $1 - \frac{(1-\beta_{incr})W_{incr}+c_{Rincr}\beta_{incr}}{(G_{incr}-c_{Rincr})(1-\beta_{incr})} \leq \gamma < \frac{B_{incr}}{g_{incr}+B_{incr}}$ , A chooses radical research (with a semi-separating equilibrium) if  $\pi_{rad}\beta_{rad}B_{rad}-c_{rad} > \pi_{incr}(B_{incr}-\gamma(1-\beta_{incr})(B_{incr}+g_{incr}))-c_{incr}$ , incremental otherwise (with pooling on submit).

4. If  $\gamma < \min \left\{ \frac{B_{rad}}{g_{rad}+B_{rad}}, 1 - \frac{(1-\beta_{rad})W_{rad}+c_{Rrad}\beta_{rad}}{(G_{rad}-c_{Rrad})(1-\beta_{rad})} \right\}$  and  $\gamma < \min \left\{ \frac{B_{incr}}{g_{incr}+B_{incr}}, 1 - \frac{(1-\beta_{incr})W_{incr}+c_{Rincr}\beta_{incr}}{(G_{incr}-c_{Rincr})(1-\beta_{incr})} \right\}$ , A chooses radical research if  $\pi_{rad}\beta_{rad}B_{rad} - c_{rad} > \pi_{incr}\beta_{incr}B_{incr} - c_{incr}$ , incremental otherwise. The subgames have semi-separating equilibria.
5. If  $\gamma \geq \max \left\{ \frac{B_{rad}}{g_{rad}+B_{rad}}, \frac{B_{incr}}{g_{incr}+B_{incr}} \right\}$ , A chooses radical research if  $\pi_{rad}\beta_{rad}B_{rad} - c_{rad} > \pi_{incr}\beta_{rad}B_{incr} - c_{incr}$ , incremental otherwise, with separating equilibria and no fraud occurring.
6. If  $\gamma \geq \frac{B_{rad}}{g_{rad}+B_{rad}}$  and  $1 - \frac{(1-\beta_{incr})W_{incr}+c_{Rincr}\beta_{incr}}{(G_{incr}-c_{Rincr})(1-\beta_{incr})} \leq \gamma < \frac{B_{inc}}{g_{inc}+B_{inc}}$ , A chooses radical research (separating) if  $\pi_{rad}\beta_{rad}B_{rad} - c_{rad} > \pi_{inc}(B_{inc} - \gamma(1 - \beta_{inc})(B_{rad} + g_{rad})) - c_{inc}$ , incremental (pooling) otherwise.
7. If  $\gamma \geq \frac{B_{rad}}{g_{rad}+B_{rad}}$  and  $\gamma < \min \left\{ \frac{B_{incr}}{g_{incr}+B_{incr}}, 1 - \frac{(1-\beta_{incr})W_{incr}+c_{Rincr}\beta_{incr}}{(G_{incr}-c_{Rincr})(1-\beta_{incr})} \right\}$ , A chooses radical research (separating) if  $\pi_{rad}\beta_{rad}B_{rad} - c_{rad} > \pi_{incr}\beta_{incr}B_{incr} - c_{incr}$ , incremental (semi-separating) otherwise.
8. If  $1 - \frac{(1-\beta_{rad})W_{rad}+c_{Rrad}\beta_{rad}}{(G_{rad}-c_{Rrad})(1-\beta_{rad})} \leq \gamma < \frac{B_{rad}}{g_{rad}+B_{rad}}$  and  $\gamma \geq \frac{B_{incr}}{g_{incr}+B_{incr}}$ , A chooses radical research (pooling) if  $\pi_{rad}(B_{rad} - \gamma(1 - \beta_{rad})(B_{rad} + g_{rad})) - c_{rad} > \pi_{incr}\beta_{incr}B_{incr} - c_{incr}$ , incremental (separating) otherwise.
9. If  $\gamma < \min \left\{ \frac{B_{rad}}{g_{rad}+B_{rad}}, 1 - \frac{(1-\beta_{rad})W_{rad}+c_{Rrad}\beta_{rad}}{(G_{rad}-c_{Rrad})(1-\beta_{rad})} \right\}$  and  $\gamma \geq \frac{B_{incr}}{g_{incr}+B_{incr}}$ , A chooses radical research (semi-separating) if  $\pi_{rad}\beta_{rad}B_{rad} - c_{rad} > \pi_{incr}\beta_{incr}B_{incr} - c_{incr}$ , incremental (separating) otherwise.

### 3.3.4 Comment: check a lot or not check at all?

Based on these results, we can analyze and discuss the impact of variations in  $\gamma$ , our measure of the degree to which editors participate in checking for frauds. We consider in particular the effect an increase of this parameter. We can show that an increase in  $\gamma$  does not necessarily lead to a reduction in scientific misconduct. Consider the following corollaries of Propositions 3.1 and 3.2 above (proofs in Appendix B).

**Corollary 3.3.1** *If  $\gamma \geq \frac{B_i}{B_i+g_i}$  ( $i=incr, rad$ ), then there is no fraud in equilibrium.*

**Corollary 3.3.2** *Consider each proper subgame in isolation. Suppose  $1 - \frac{(1-\beta_i)W_i+c_{Ri}\beta_i}{(G_i-c_{Ri})(1-\beta_i)} \leq \gamma < \frac{B_i}{B_i+g_i}$ ,  $i = rad, incr$ , both before and after an increase of  $\gamma$ . Then, the probability that frauds are discovered increases, following an increase in  $\gamma$ .*

**Corollary 3.3.3** *Consider each proper subgame. Suppose  $\gamma < \min(1 - \frac{(1-\beta_i)W_i+c_{Ri}\beta_i}{(G_i-c_{Ri})(1-\beta_i)}, \frac{B_i}{B_i+g_i})$ ,  $i = rad, incr$ , both before and after an increase of  $\gamma$ . Then, the increase in  $\gamma$  leads to an increase in the probability that a faked paper goes unchecked.*

**Corollary 3.3.4** Consider each proper subgame. Suppose that initially  $\gamma = \gamma' < \min(1 - \frac{(1-\beta_i)W_i+c_R\beta_i}{(G_i-c_{R_i})(1-\beta_i)}, \frac{B_i}{B_i+g_i})$ ,  $i = rad, incr$ , and an increase in  $\gamma = \gamma'$  is such that  $1 - \frac{(1-\beta_i)W_i+c_R\beta_i}{(G_i-c_{R_i})(1-\beta_i)} < \gamma'' < \frac{B_i}{B_i+g_i}$ . Then, the probability that a fraud is not caught increases if:

$$\frac{\pi\beta c_R}{(G - c_R)(1 - \gamma') - W} \frac{g}{B + g} < \pi(1 - \beta)(1 - \gamma''). \quad (5)$$

Corollaries 3.3.1 and 3.3.2 depict "expected" scenarios where the scrutiny by an additional actor reduces the overall chance of undetected frauds. Corollaries 3.3.3 and 3.3.4, in contrast, show that also the opposite can be true. Corollary 3.3.3, for example, says that when  $R$  observes a published paper, he cannot exclude that the editor has actually checked it. This reduces the incentives to check for  $R$ , since  $R$  faces the risk of a "double check" of a successful paper.

With respect to the whole game, from Proposition 3.2 we see that variations in  $\gamma$  can actually lead to a change in the type of research performed by  $A$ . Such changes may induce changes in the probability that a fraud is committed and discovered. Similarly to the case of a reduction in checking costs by  $R$ , an increase in  $\gamma$  can induce an increase in the probability that a fraud is committed and not caught via a change in the type of research. Consider a variation in  $\gamma$  that moves the equilibrium from region 4 (both subgames with semi-separating equilibria) to region 3 (subgame  $rad$  with a semi-separating equilibrium, subgame  $incr$  with a pooling equilibrium) in 3.2. Since

$$\pi_{inc}(B_{inc} - \gamma(1 - \beta_{inc})(B_{rad} + g_{rad})) - c_{inc} > \pi_{inc}\beta_{inc}B_{inc} - c_{inc}, \quad (6)$$

when  $\gamma < \frac{B_{inc}}{g_{inc}+B_{inc}}$  the author  $A$  may switch from radical to incremental research. In this case, the probability that frauds are committed not discovered increases if:

$$\pi_{incr}(1 - \beta_{incr}) > \frac{\pi_{rad}\beta_{rad}c_{Rrad}}{(G_{rad} - c_{Rrad})(1 - \gamma) - c_{Rrad}} \frac{g_{rad}}{B_{rad} + g_{rad}} \quad (7)$$

This is the case whenever  $B_{rad}$  is sufficiently high.

We conclude that an active role of editors into checking for misconduct unambiguously leads to a lower chance of fraudulent papers being left unchecked only when such an involvement is large. If the involvement is only on a small scale (e.g. only on a small share of papers or only for some specific types of frauds), then the checking activities by journals may crowd out the incentive to thoroughly check by readers, and lead to an overall increase of the chances of having fraudulent papers published and not scrutinized. The benefits from a large scale involvement of journal in pre-publication check for fraud will need to be weighted against such costs as additional personnel, time, and possibly delays in publication.

## 4 Conclusion

The objective of this paper was to provide a framework for the study of scientific misconduct. Fraud in science occurs and is a major problem. Individuals, firms and governments increasingly rely on scientific knowledge for their welfare. They operate under the assumption that this knowledge has been honestly and truthfully generated. Nonetheless, examples of scientists who falsified, fabricated or plagiarized their findings, and were still able to publish and get recognition from them (before being found out) abound. The scientific community is a complex, self-regulating institution where several actors interact in different forms – as competitors, complementors, and evaluators. Little is known on how those same institutional features that lead to knowledge creation also lead to the fabrication of fake information. With this paper, we hope to have made progress towards an understanding of these phenomena. We built a game-theoretic model of the research and publication process that captures these main characteristics of the scientific community, and also allows authors to commit fraud.

The model generates three sets of results. First, the types of research that are more likely to be fraudulent, and the type of scientists that are more likely to commit fraud, are different from the type of research and scientists that are discovered as fraudulent. Second, some policies aimed at reducing undetected fraud, such as a reduction in the costs of replicating other scientists' research and softening competition among researchers, can backfire and induce an increase in undetected misbehavior. Third, adding layers of control for misconduct, for example through a direct involvement journals; editorial staff in policing for misconduct before publication, does not necessarily increase the overall amount of detection and prevention of misconduct.

These results imply that there may be a good deal of frauds the scientific community is not aware of, and most of these frauds are of a different nature than the ones that are in fact discovered. We may therefore have only a limited and distorted sense of the amount and type of scientific misconduct, if we rely on reports and anecdotes of scientists who were, indeed, caught cheating. In addition, policies deemed to unequivocally discourage frauds, such as facilitating replication and data sharing, softening competition, and involving journals' editorial boards into checking for frauds, do not necessarily elicit the expected virtuous behaviors.

Some limits of the model, together with their discussions, have been reported in the paper already. Further extensions are possible. One avenue for extensions concerns the behavioral assumptions. In the model, scientists are "selfish" and have no ethical concerns. While the sociological literature is controversial on the issue, it can be argued that scientists derive utility from producing knowledge honestly, and not only from the publication of any results.<sup>14</sup> An interesting interpretation of our result is that, if ethical concerns are limited or non-existent, then fraud is an inherent characteristic of the scientific community. Cheating, moreover, can

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<sup>14</sup>Appendix C below can be seen as an attempt to include ethical concerns into the current set up.

also be seen as a "compulsive" behavior, and not as the outcome of a rational choice. The model could also be improved in order to draw clearer normative conclusions. We do not completely consider, for example, the costs required to implement some policies that deter frauds. An involvement of journals' editorial boards into checking for frauds may require more personnel, more time, and possibly delays in publication. Similarly, increasing recognition for replication works can deviate some scientists toward these activities, thus making existing knowledge more reliable but also slowing down the creation of new knowledge.

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## A Notation

<b>Players</b>	
$A$	Author
$N$	Nature
$E$	Editor/referee (basic game), Editor (extended game)
$Ref$	Referee (extended game)
$R$	Reader
<b>Moves</b>	
$rad, incr$	Choices by A of incremental vs. radical research
$fail, succ$	Failure or success of the project, as determined by Nature
$acc, rej$	Acceptance or rejection of the paper by E (basic game), or by ref (extended game)
$check, no\ check$	Choice of whether checking or not checking a paper for fraud – by R (basic game), and by either R or E (or both) (extended game)
<b>Probabilities</b>	
$\beta_{incr}, \beta_{rad}$	Probabilities of success of an incremental or radical project
$\pi_{incr}, \pi_{rad}$	Probabilities of acceptance by the referee of an incremental or radical project
$\gamma$	Probability that E checks a paper for misconduct (extended game)
<b>Payoffs parameters</b>	
$B_{incr}, B_{rad} \in (0, +\infty)$	Benefit for A from his paper being published and not checked (or checked and found clean), for incremental and radical research
$c_{incr}, c_{rad} \in (0, +\infty)$	Cost to perform incremental or radical research
$g_{incr}, g_{rad} \in (0, +\infty)$	Penalty to A from his paper being detected as fraudulent
$W_{incr}, W_{rad} \in (-\infty, +\infty)$	Benefit for R from A's paper being published and not checked (or checked and found clean), for incremental and radical research
$c_{Rincr}, c_{Rrad} \in (0, +\infty)$	Cost for R to check an incremental or radical paper for misconduct
$G_{incr}, G_{rad} \in (0, +\infty)$	Benefit to R from A's paper being detected as fraudulent

Table 6: Summary of the notation used in the model

## B Proofs

**Proof of Proposition 2.1** We first prove the existence of the pooling equilibrium. The expected payoff of  $R$  from not checking is higher than the payoff from checking, given the posterior beliefs of  $R$ . Since  $R$  assumes pooling by  $A$ , she does not update her beliefs on the state of nature. Therefore, the best response to pooling on *subm* is *no check* if and only if:

$$\beta W + (1 - \beta)W \geq \beta(W - c_R) + (1 - \beta)(G - c_R) \quad (8)$$

from which we obtain the result.<sup>15</sup>

<sup>15</sup>In the the case where expression (8) holds with equality, we assume that the indifference case is included into the pooling equilibrium. Appendix C below offers a more technical explanation for this choice.

Second, consider the conditions for the existence of a semi-separating equilibrium. Notice, first, that in order to have a semi-separating equilibrium, both A and R must randomize. If R chooses *check*, then A has no incentive to submit in case of failure: he would be caught cheating with probability 1. *no subm* will dominate *subm*. In other words, the two options will not leave A indifferent for any mixing probability in the unit interval. If R does not check, then A has an incentive to pool on *subm* rather than randomizing.

The reader R chooses  $r$  so as to make A indifferent between submitting and not submitting, when the project is unsuccessful:

$$\pi [r(-g - c) + (1 - r)(B - c)] + (1 - \pi) [-c] = -c, \quad (9)$$

from which we obtain  $r = \frac{B}{B+g}$ . Consider now the indifference condition for R, which determines the mixing probability for A. R is indifferent between checking and not checking, given her (updated) beliefs on the success of the research, if the following condition holds:

$$\mu(W - c_R) + (1 - \mu)(-c_R + G) = \mu(W) + (1 - \mu)(W), \quad (10)$$

where  $\mu = \text{prob}(\text{project is successful} \mid \text{paper published})$

$$= \frac{\text{prob}(\text{paper publ} \mid \text{proj succ}) * \text{prob}(\text{proj succ})}{\text{prob}(\text{paper publ} \mid \text{proj succ}) * \text{prob}(\text{proj succ}) + \text{prob}(\text{paper publ} \mid \text{proj not succ}) * \text{prob}(\text{proj not succ})} = \frac{\pi * \beta}{\pi * \beta + \pi p (1 - \beta)}.$$

Substituting into (10), we obtain  $p = \frac{\beta}{1 - \beta} \frac{c_R}{G - W - c}$ .

In order for  $p$  to be non negative, G has to be such that  $G > W + c_R$ . Also, in order for  $p$  to have positive and meaningful values, i.e. within the unit interval, it must be that  $\frac{\beta}{1 - \beta} \frac{c}{G - W - c} < 1$ . Equivalently:  $(1 - \beta)(W - G) < -c$ , or  $G > W + \frac{c_R}{1 - \beta}$ .

**Proof of Corollaries 3.2.1 and 3.2.2** Suppose there is no change in the type of research chosen in equilibrium, following a reduction in checking costs. Three cases need to be considered:

i) The equilibrium of the proper subgame is pooling before and after the reduction in checking costs. In this case, the probability of undiscovered misconduct does not change, as it is  $\pi(1 - \beta)$  before and after the change in checking costs.

ii) The equilibrium moves from pooling to semi-separating. The probability of undiscovered misconduct moves from  $\pi(1 - \beta)$  to  $\pi(1 - \beta)p(1 - r)$ . Since  $p$  and  $r$  are smaller than 1, then  $\pi(1 - \beta)p(1 - r) < \pi(1 - \beta)$ .

iii) The equilibrium is semi-separating before and after the reduction in checking costs. It can be seen from Proposition 2.3 that the probability of undiscovered fraud decreases.

To see how the probability of an undiscovered fraud can actually increase following a reduction in checking costs, assume first that  $G_{rad} > W_{rad} + \frac{c_{R_{rad}}}{1 - \beta_{rad}}$ ,  $G_{incr} \leq W_{incr} + \frac{c_{R_{incr}}}{1 - \beta_{incr}}$  and  $\pi_{incr} B_{incr} - c_{incr} > \pi_{rad} \beta_{rad} B_{rad} - c_{rad}$ . This means that equilibrium falls in region 3.b of Proposition 2.4 above (page 12): an incremental type of research is chosen, and a pooling equilibrium is played. Consider now a reduction in both  $c_{R_{rad}}$  and  $c_{R_{incr}}$  such that  $G_{rad} \leq W_{rad} + \frac{c_{R_{rad}}}{1 - \beta_{rad}}$  and  $G_{incr} \leq W_{incr} + \frac{c_{R_{incr}}}{1 - \beta_{incr}}$ .

A may switch to a radical type of research, since there are values of the parameters for which both  $\pi_{incr}B_{incr} - c_{incr} > \pi_{rad}\beta_{rad}B_{rad} - c_{rad}$  and  $\pi_{incr}\beta_{incr}B_{incr} - c_{incr} < \pi_{rad}\beta_{rad}B_{rad} - c_{rad}$  are true. If this happens, we move from a pooling equilibrium in which incremental research is chosen to a semi-separating equilibrium in which a radical path is chosen. The probability that a fraudulent paper is submitted, published, and not caught is higher after the reduction in the checking costs if:

$$\frac{\pi_{rad}\beta_{rad}c_{Rrad}}{G_{rad} - W_{rad} - c_{Rrad}} \frac{g_{rad}}{B_{rad} + g_{rad}} > \pi_{incr}(1 - \beta_{incr}) \quad (11)$$

Inequality (11) is satisfied if the probability of success of radical research is sufficiently high and if radical research paper is more likely to accepted than an incremental paper.

**Proof of Corollaries 3.2.3 and 3.2.4** Consider first the case in which the choice of research type is unaffected after the increase in the intensity of competition. In this case, three situations may occur:

- i) The equilibrium is pooling before and after the increase in competition.
- ii) The equilibrium moves from pooling to semi-separating.
- iii) The equilibrium is semi-separating before and after the increase in competition.

In the first two cases, the reasoning is the same as in the previous proof. In the third case, we see that the probability of undiscovered fraud decreases from Proposition 2.3 (page 11), since both  $\frac{\partial P_{(subm,acc,nc)}}{\partial(G-W)}$  and  $\frac{\partial P_{(subm,acc,nc)}}{\partial B}$  are negative.

In order to see the opposite effect at work, suppose that the equilibrium is in region 1.b in Proposition 2.4 (i.e.  $G_{rad} \leq W_{rad} + \frac{c_{Rrad}}{1 - \beta_{rad}}$ ,  $G_{incr} \leq W_{incr} + \frac{c_{Rincr}}{1 - \beta_{incr}}$  and  $\pi_{incr}B_{incr} - c_{incr} \geq \pi_{rad}B_{rad} - c_{rad}$ ). This means that an incremental type of research is chosen, and a pooling equilibrium is played. Consider now a significant increase in the incentives to conduce radical research (i.e. an increase in both  $B_{rad}$  and  $G_{rad} - W_{rad}$ ), which moves the equilibrium from region 1 to region 3 as described in Proposition 2.4 above ( $G_{rad} > W_{rad} + \frac{c_{Rrad}}{1 - \beta_{rad}}$  and  $G_{incr} \leq W_{incr} + \frac{c_{Rincr}}{1 - \beta_{incr}}$ ). Suppose that, before the change, incremental research was chosen. If the increase in  $B_{rad}$  is sufficiently high, a radical type of research will now be chosen. We move from a pooling equilibrium with incremental research, to a semi-separating equilibrium with radical research. We saw in the previous proof that, for some configuration of the parameters, the probability of undiscovered fraud may increase.

**Proof of Proposition 3.1** We prove, in sequence, the existence of a separating, pooling, and semi-separating equilibrium.

First, A prefers not to submit a faked paper if  $\pi\gamma(-g) + \pi(1 - \gamma)B - c < -c$ , from which the condition on the existence of a separating equilibrium follow.

With respect to the existence of a pooling equilibrium, we check first that the expected payoff of R from not checking is higher than the payoff from checking, given the posterior beliefs of R. If R observe a paper being published, she excludes that the paper is faked and the editor has checked it. This occurs with probability  $(1 - \beta)\gamma$ . Therefore, the probability that the research was successful, conditional on

the article having been published, is  $\frac{\beta}{1-(1-\beta)\gamma} = \frac{\beta}{\beta+(1-\gamma)(1-\beta)}$ . The probability that the research was successful, conditional on the article having been published, is  $\frac{(1-\beta)(1-\gamma)}{\beta+(1-\gamma)(1-\beta)}$ . Therefore, R does not check if

$$W \geq \frac{\beta}{\beta+(1-\gamma)(1-\beta)}(W - c_R) + \frac{(1-\beta)(1-\gamma)}{\beta+(1-\gamma)(1-\beta)}(G - c_R) \quad (12)$$

The condition  $\gamma < \frac{B}{B+g}$  derives from the result on the existence of a separating equilibrium.

Finally, consider the conditions for the existence of a semiseparating equilibrium. R chooses  $r$  so as to make A indifferent between submitting and not submitting, when the project is unsuccessful:

$$\pi\gamma(-g) + \pi(1-\gamma)[r(-g) + (1-r)(B)] - c = -c, \quad (13)$$

or:  $r = \frac{B}{B+g} \frac{1}{1-\gamma} - \frac{\gamma}{1-\gamma}$ . If the paper is faked and submitted, with probability  $\pi\gamma$  the paper is published and checked by the E. With probability  $\pi(1-\gamma)$ , the paper is published but not checked by E. In this case, with probability  $r$  there is a check by R, while with the complimentary probability there is no check. Consider now then the indifference condition for R. R is indifferent between checking and not checking if:

$$\mu(W - c_R) + (1-\mu)(-c_R + G) = \mu(W) + (1-\mu)(W), \quad (14)$$

where  $\mu = \text{prob}(\text{project is successful} \mid \text{paper published})$

$= \frac{\text{prob}(\text{paper publ} \mid \text{proj succ}) * \text{prob}(\text{proj succ})}{\text{prob}(\text{paper publ} \mid \text{proj succ}) * \text{prob}(\text{proj succ}) + \text{prob}(\text{paper publ} \mid \text{proj not succ}) * \text{prob}(\text{proj not succ})} = \frac{\pi * \beta}{\pi * \beta + \pi p (1-\beta)(1-\gamma)}$ .  
Substituting into (14), we obtain  $p = \frac{\beta}{1-\beta} \frac{c_R}{(G-c_R)(1-\gamma)-W}$ . In order for  $r$  to be non negative, it must be  $\gamma < \frac{B}{B+g}$ . For  $r$  to be within the unit interval, it must be  $B - \gamma(g + B) < (1-\gamma)(g + B)$ , or equivalently,  $g > 0$ , which is true by assumption. In order for  $p$  to be non negative, G has to be large enough, i.e.  $G > \frac{W}{1-\gamma} + c_R$ , or equivalently,  $\gamma < 1 - \frac{W+c_R}{G}$ . Also, in order for  $p$  to have positive and meaningful values, i.e. within the unit interval, we need  $\frac{\beta}{1-\beta} \frac{c_R}{(G-c_R)(1-\gamma)-W} < 1$ . Equivalently:  $c_R < \frac{(1-\beta)}{\beta+(1-\gamma)(1-\beta)}(G(1-\gamma) - W)$  or  $\gamma < 1 - \frac{(1-\beta)W+c_R\beta}{(G-c_R)(1-\beta)}$ . It turns out that this second condition is stricter than the first one, so that a semi-separating equilibrium requires  $\gamma < 1 - \frac{(1-\beta)W+c_R\beta}{(G-c_R)(1-\beta)}$ .

**Proof of Corollary 3.3.1** If  $\gamma \geq \frac{B_i}{B_i+g_i}$ , the subgames have a separating equilibrium where no failed paper is submitted.

**Proof of Corollary 3.3.2** If  $\min(1 - \frac{(1-\beta_i)W_i+c_R\beta_i}{(G_i-c_{R_i})(1-\beta_i)}, \frac{B_i}{B_i+g_i}) \leq \gamma < \frac{B_i}{B_i+g_i}$  before and after the increase, then the subgames are played in pooling equilibria. In this case, there is no check by A, and the overall probability that a fraud is discovered is  $\pi_i(1-\beta_i)\gamma_i$  (see Table 4), from which the corollary directly follows.

**Proof of Corollary 3.3.3** If  $\gamma < \min(1 - \frac{(1-\beta_i)W_i+c_R\beta_i}{(G_i-c_{R_i})(1-\beta_i)}, \frac{B_i}{B_i+g_i})$  before and after the increase, then the subgames are played in semi-separating equilibria. It is immediate to verify that  $\frac{\partial r}{\partial \gamma} < 0$ , so that an increase in  $\gamma$  leads to a reduction in the checking probability by R. This effect more than compensates

the direct, fraud-reducing effect of an increase of  $\gamma$ , so that the overall probability that a faked paper goes unchecked increases, as can be seen from Table 4 above.

**Proof of Corollary 3.3.4** We illustrate this corollary through the following numerical example:

**Example B.1** Suppose  $c_R = 1$ ,  $G = 5$ ,  $W = 2$ ,  $\beta = 0.5$  and  $\frac{g}{g+B} = 0.5$ . It must be  $\gamma < 0.5$  for a separating equilibrium not to be played. If  $\gamma' = 0.2$ , a semi-separating equilibrium is played. Then, for  $0.25 < \gamma'' < 0.5$ , the equilibrium becomes pooling and the probability that the fraud is not caught increases.

## C Ethic-based trembling equilibrium

In the basic set-up of the model we exclude the possibility that the author of the paper (A) behaves ethically, i.e. it does not submit a paper when it is not successful, even if this action is profitable. The aim of this section is to investigate the robustness of equilibria when there is a (small) probability that the author behaves ethically.

First, we consider the notion of ethic-perturbated game. In the original game, an equilibrium is defined by  $p_s$ , the probability of A submitting a paper which is successful (this probability being always equal to 1); by  $p_{ns}$ , the probability of A submitting a paper when it is not successful; by  $r$ , the probability of a checking by R; and, finally, by the update belief by R on A's action.

In the ethic-perturbated game, A submits an unsuccessful paper with probability  $p_{ns}(1 - \varepsilon)$ , where  $0 < \varepsilon < 1$ . This must be interpreted as follows. There is a probability  $\varepsilon$  that A is irrational, in the sense that he follows the rule of never submitting a faked paper, whatever are the payoffs. With the complementarity probability, instead, it is "rational".  $p_{ns}(\varepsilon)$  is the action by A. The checking probability by R is  $r(\varepsilon)$ . Both are in general function of the probability of an ethical behavior by A. Update beliefs are  $\frac{\beta}{\beta + p_{ns}(1-\varepsilon)(1-\beta)}$ .

**Definition 1** In the original game, a Perfect Bayesian Equilibrium is uniquely identified by  $p_{ns}^*$ ,  $r^*$  and  $\frac{\beta}{\beta + p_{ns}^*(1-\varepsilon)(1-\beta)}$ . Consider a decreasing sequence  $\varepsilon_k$ ,  $k = 1, 2, \dots, \infty$ , with  $\lim_{k \rightarrow \infty} \varepsilon_k = 0$ . In the perturbed game, a Perfect Bayesian Equilibrium is identified by a triple  $p_{ns}^*(\varepsilon)$ ,  $r^*(\varepsilon)$  and  $\frac{\beta}{\beta + p_{ns}^*(\varepsilon)(1-\varepsilon)(1-\beta)}$ . The PBE identified by  $p_{ns}^*$ ,  $r^*$  and  $\frac{\beta}{\beta + p_{ns}^*(1-\varepsilon)(1-\beta)}$  is an ethic-based trembling equilibrium (EBTE) if  $\lim_{k \rightarrow \infty} p_{ns}^*(\varepsilon_k) = p_{ns}^*$  and  $\lim_{k \rightarrow \infty} r^*(\varepsilon_k) = r^*$  for any sequence  $\varepsilon_k$ .

This definition has a clear interpretation. A Perfect Bayesian Equilibrium is a EBTE if small perturbations introduced by ethical (irrational) behavior do not lead to significant departure in the equilibrium of the original game.

If  $G < W + \frac{c_R}{1-\beta}$ , we are in the range of parameters where a pure strategy pooling equilibrium exists. In this range, in the perturbed game,  $p_{ns}^*(\varepsilon) = 1$  and  $r^*(\varepsilon) = 0$ . If R assumes pooling, it will decide

not to check if  $G < W + \frac{cR}{1 - \frac{\beta}{1 - \varepsilon(1 - \beta)}}$ , which is always true in the case we are considering. A will pool if R is not checking. In this case, it is obviously that  $\lim_{k \rightarrow \infty} r^*(\varepsilon_k) = r^*$  and  $\lim_{k \rightarrow \infty} p_{ns}^*(\varepsilon_k) = p_{ns}^*$ . Then, we have a EBTE.

If  $G > W + \frac{cR}{1 - \beta}$ , we are in the range of parameters where the equilibrium is semi-separating ( $p_{ns}^* < 1$ ). In the perturbed game, the indifference condition requires  $p_{ns}^*(\varepsilon) = \frac{p_{ns}^*}{1 - \varepsilon}$  while  $r^*(\varepsilon) = r^*$ . We clearly have  $\lim_{k \rightarrow \infty} r^*(\varepsilon_k) = r^*$  and  $\lim_{k \rightarrow \infty} p_{ns}^*(\varepsilon_k) = p_{ns}^*$ . The range of parameters for which a semi-separating PBE exists in the perturbed game is the same for which this type of equilibrium exist in the original game. Then, we have a EBTE in the original game.

If  $G = W + \frac{cR}{1 - \beta}$ , in any perturbed game R prefers not to check, if it assumes pooling. A will pool if R does not check. This implies that only  $r = 0$  is a EBTE. For  $r > 0$ , instead, we have  $r^*(\varepsilon) = 0 \forall \varepsilon > 0$ , and then  $\lim_{k \rightarrow \infty} r^*(\varepsilon_k) \neq r^*$ .

As a refinement, EBTE leads to a unique equilibrium for any value of the parameters. For  $G \leq W + \frac{cR}{1 - \beta}$ , the equilibrium is pooling. For  $G > W + \frac{cR}{1 - \beta}$ , the equilibrium is semi-separating.