The Economics of Scientific Misconduct

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This article presents a model of the research and publication process that analyzes why scientists commit fraud and how fraud can be detected and prevented. In the model, authors are asymmetrically informed about the success of their projects and can fraudulently manipulate their results. We show, first, that the types of scientific frauds that are observed are unlikely to be representative of the overall amount of malfeasance; also, star scientists are more likely to misbehave but less likely to be caught than average scientists. Second, a reduction in fraud verification costs may not lead to a reduction of misconduct episodes but rather to a change in the type of research that is performed. Third, a strong "publish or perish" pressure may reduce, and not increase, scientific misconduct because it motivates more scrutiny. Finally, a more active role of editors in checking for misconduct does not always provide additional deterrence. (*JEL* A14, D82, K42, O31, Z13)

1. Introduction

Never have the fame and disgrace of a scientist received more attention than in the case of Woo-Suk Hwang. The biomedical researcher rose to fame in 2004 thanks to a series of breakthroughs in the field of stem-cell research. In a number of articles in top journals, he claimed that he had created human

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embryonic stem cells through cloning—a discovery that made him the most esteemed stem-cell scientist in the world and a national hero in South Korea, his home country. The scientific and health-related consequences of his findings were predicted to be enormous and so was their economic potential. The reexamination of his findings by other scholars, however, revealed that Hwang's results had been fraudulently reported. Most of the cell lines were faked, and pictures of allegedly different cells were found to be photos of the same cell. Hwang eventually admitted to various lies and frauds and was indicted for misconduct, ethical violations, and embezzlement (Kolata 2005; Fifield and Cookson 2006; Reuters 2006).

Contemporaneously to Hwang committing his frauds, major cases of scientific misconduct were shaking other disciplines. The findings published by Jan Hendrik Schön (in over 40 articles only in 2001), at Bell Laboratories, on organic transistors, which could have spelled the end of the entire silicon chip industry, were found to be almost entirely fabricated (Beasley et al. 2002; Goss 2002a, 2002b; BBC 2004; Ossicini 2007). Twenty years of medical research by Eric Poehlman on the benefits of hormone therapy to prevent obesity were discarded when the researcher was found to have fabricated most of his results and had excluded evidence on the risks of hormone therapy. Poehlman was the first academic scientist to be given prison time for falsifying data in grant submissions (Chang 2004; CBS 2005; Office of Research Integrity [ORI] 2005; Kintisch 2006).

History is also rich in examples of misconduct in many scientific fields. The discovery of "defensive enzymes" by the Swiss biochemist Emil Abderhalden in the early 1900s, on which a number of medical tests were developed,[1] began to be questioned in the 1920s, but his work was revealed to be fraudulent only in 1998 (Deichmann and Müller-Hill 1998). Defensive enzymes, simply, do not exist. Several instances of negligence and misconduct were also found in the work immunologist Jacques Benveniste on the effectiveness of homeopathy (Maddox et al. 1988). The research of two of the most prominent psychologists of the 20th century, Bruno Bettelheim and Cyril Burt, turned out to be faked for the most part. The work of Bettelheim showing that a major cause of child autism was the lack of mothers' affection was based on fabricated evidence. Similarly, the studies by Burt of twins reared apart, showing that about three quarters of an individual's intelligence are inherited, were found to be fraudulent. Evidence of fraud by these two scholars emerged only after their death and after their studies had affected generations of psychologists, parents, children, educators, and policymakers (Kamin 1974; Hearnshaw 1979; Joynson 1989; Pollak 1997).[2]

1. 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.

2. For example, proposals were advanced in the United Kingdom and the United States to discontinue programs that helped lower class children since the accomplishments of these program, according to Burt's findings, would have been very limited.

These cases offer a grim and worrisome image of the scientific community, and unfortunately, rather than being just a few "bad apples" that are promptly discovered through the standard self-correcting mechanisms within the scientific community, they are examples of a larger phenomenon. Scientific misconduct appears to be a pervasive phenomenon, a systemic characteristic of the scientific community rather than a matter of a few episodes of misbehavior. Reports of different types of malfeasance—such as data fabrication, falsification, and plagiarism—abound. Judson (2004) and Pozzi and David (2007) document a steady flow of new cases opened, and allegations confirmed, at the US ORI over the past decade. Swazey et al. (1993) report that about 10% of the scientists responding to their surveys have witnessed episodes of scientific misconduct. Martinson et al. (2005) find that, whereas only few scientists admit having explicitly fabricated or "cooked up" data, up to 10%–15% of scientists admit 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 (see also Evans 2002).

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. Decisions about one's health or education, as well as business choices, depend also on the findings from scientific research. Even a handful of fraudulently produced results, if not detected promptly, can spur entire lines of research and endanger whole scientific fields as well as society at large. Scientific fraud is therefore not just an internal matter of the scientific community: it is a social problem that scientists need to address.

Scholars in the natural and biomedical sciences, and more recently also in the social sciences, have shown awareness of the problem and its deleterious consequences.[3] A common agreement is that scientific fraud needs to be reduced to a minimum if not eliminated, given the negative effects of even a few cases going undetected. Several proposals to better detect and deter fraud, with the aim to minimize its occurrence and the likelihood of it going unnoticed, have been advanced. These proposals include incentivizing replication (Dewald et al. 1986; Hamermesh 2007), softening the competitive pressure among scientists since harsh rivalry for priority in publication is seen as conducive to dishonest practices (List 1985; Abelson 1990; Giles 2007), and a more active role of referees and editors in checking not only for novelty and rigor but also for fraudulent practices (Rossner 2006). Some experiments have been tried, or are currently in progress, to implement these proposals at some

3. In the natural sciences, see, for example, Abelson (1990), LaFollette (1992), Judson (2004), 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. In the social sciences and most notably in economics, see among others Bailey et al. (2001), Enders and Hoover (2004b), Glaeser (2006), and Arce et al. (2008).

journals (Dewald et al. 1986; Rossner 2006; Hamermesh 2007; *Nature Immunology* 2007).

The current understanding of scientific misconduct, however, is limited. Analyses are largely based on reports about researchers who have been *found committing* frauds[4] and especially on high-profile cases, such as those described above. Although suggestive, these accounts offer only a limited picture of the problem. More broadly, the current debate lacks a theoretical background that clarifies the underlying incentives of scientists to undertake fraudulent behavior and the incentives of their peers to detect these practices. A rigorous model of scientific fraud 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 policies to reduce misconduct. The aim of this article is to elaborate such a model.

We study malfeasance in the research and publication process through a dynamic game of incomplete information that reproduces some of the main features of how the scientific community operates. In the first stage of the game, a scientist decides what type of research to undertake, that is, more or less radical research. 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 an article to a journal but only after committing some fraudulent behavior[5]—otherwise, reviewers will immediately spot the failure of the project. If the article is accepted and published, a potential reader of the article decides whether to thoroughly check the article—in which case any fraud is spotted—or not. The author of the article 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 scientist's research, for example, the success of the scientist reduces her room for contributions if she is competing in the same field.

The model derives a number of results on how different parameters affect the probability of committing frauds and on the likelihood that these frauds will go undetected after being published.

We show, first, that the types of scientific frauds that are observed are not representative of the overall amount of malfeasance in science. In particular, the probability of detecting misconduct is higher for radical research,

4. 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 frauds. See, for example, Dyck et al. (2007).

5. We are assuming that there are no "innocent mistakes." In other words, we assume that it is always possible to discern an honest mistake from a fraud. See Nath et al. (2006) for an empirical analysis of the incidence of mistakes and fraudulent activities in science.

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 article is higher for a star. Claiming the discovery of radical findings, or being a young scholar who would benefit greatly from publishing research, attracts higher scrutiny from peers, thus discouraging dishonest behavior in the first place. These results imply that there may be a good deal of frauds of which the scientific community is not aware and of a different nature than the ones that are in fact discovered and reported. Even if the result that more radical, innovative findings are less likely to be faked is reassuring, the potentially larger amount of faked "incremental" research going undiscovered can have major negative consequences. For example, research that is incremental from a scientific viewpoint might have important social consequences. Also, the allocation of research funds and promotion decisions are often based on limited advancements rather than major breakthroughs by scientists.

Second, we derive that policies such as facilitating replication and data sharing, softening the "publish or perish" paradigm, and involving journals' editorial boards in checking for frauds do not necessarily elicit virtuous behaviors and may in fact increase malfeasance. A reduction in the costs of checking for frauds may lead to a change in the type of research that is performed (i.e., more or less innovative) rather than to a reduction of misconduct. A stronger pressure to publish in order to obtain promotions and funds may reduce, and not increase, scientific misconduct as it stimulates more monitoring. Finally, a more active role of editors in policing misconduct (modeled as an additional layer of verifications, before an article is published) does not always provide additional deterrence as it crowds out the incentives of readers to check.

Previous attempts have been made to model the research and publication process, with consideration for misconduct. Wible (1998) treats the publication process as a one-person decision problem rather than a multi-agent game as in our model. Hoover (2006) and Arce et al. (2008) have proposed game-theoretic analyses of plagiarism, and survey evidence from economics has been provided by Enders and Hoover (2004a,b) and Hoover (2006). We focus, in contrast, on fabrication and falsification of data. Plagiarism, which is third in frequency, behind fabrication and falsification, as instance of misconduct, has its own specificities that our model does not aim to capture. Glaeser (2006) discusses the problem of data mining in empirical economics research. These existing articles are not focused on the informational asymmetries between the different actors involved in the publication process nor do they analyze the questions at the center of our article—what types of research and researchers are more likely to be fraudulent, and what is the impact of frequently proposed policies to limit misconduct in science. A framework similar to ours is developed by Mialon and Mialon (2002), who consider an author-reviewer game to analyze the decision of a scientist of how innovative to be. In this model, the relation between the author and the reader-reviewer is more similar to a principal-agent relation than to one among peers. Whereas Mialon and Mialon stress the role of readers and referees as evaluators, we focus more on the fact that authors and readers both complement and compete with each other, and the success of an author bears a positive or negative externality on a reader. These externalities are critical in determining the incentives of the reader to engage in a thorough check of an article.

More generally, our article contributes to a recent stream of economic analyses of the operating of academia and the scientific community, which has focused on issues such as the allocation of research projects between universities and companies, the commercialization of academic research, and the allocation of authority within universities (see, e.g., Jensen and Thursby 2001; Masten 2006; Aghion et al. 2008; Lacetera 2009a, 2009b).

As for the structure of the model in this article, it relates to several streams of literature. First, the model bears similarities with the "costly state verification" class of models, initiated by Townsend (1979). In these models, a principal can overcome a condition of asymmetric information, by verifying the agents' declarations at a cost (examples include tax payments, employer-employee relationships, and financial contracts). The main focus of this literature is to determine the optimal contract between the principal and the agent, given the auditing technology. In our context, no contract is in place, and the focus is instead on the private incentives of verification by the reader. Second, the model relates to the literature on law enforcement, started by Becker (1968). With this literature, we share the view that the severity and likelihood of punishment deter crime (in our case, scientific misconduct). Most of the work in this area has had optimal punishment as primary concern (Garoupa 1997), and a decision theory perspective has been adopted. On the contrary, we adopt a game-theoretic framework and focus on the incentives both to commit fraud and to monitor. With this setup, the effects of proposed policies for reducing frauds can be assessed. Within the law enforcement literature, the game-theoretic approach makes our model close to the class of "inspection games" (Tsebelis 1989; Andreozzi 2004). In the basic inspection game, one player decides whether to inspect the other player, who in turn decides whether to infringe a rule. The common assumptions on the payoffs are such that these games do not have pure strategies equilibria but only mixed strategy Nash equilibria. As shown in the analysis that follows, for some values of the parameters the game in this article has (semi-separating) equilibria with similar properties to those of inspection games. There are, however, a number of differences as well. First, our application allows for more general payoffs such that pure-strategy equilibria can be sustained as well. Second, we consider a first stage, where the type of activity is chosen. Third, in our game the inspector observes a signal (i.e., the publication) associated to the norm infringement with a probability that is, in turn, endogenously determined.

The remainder of the article is structured as follows. Section 2 develops the publication game, which is then solved in Section 3. In Section 4, the implications of the results are derived and discussed. Section 5 concludes. All proofs are gathered in Appendix A.

2. 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 articles to journals. These articles are evaluated by the scientists' peers. The game is represented in extensive form in Figure 1. A detailed description of the setup follows.

2.1 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.

2.2 Actions, Timing, and Information

The game has five stages. In the first stage, A decides whether to undertake a "radical" research project (action r), which can potentially lead to major novel results, or to undertake "incremental" research (action i), which might lead to minor improvements to the existing knowledge. The choice of the type of research is perfectly observed. This initial choice mimics more closely the research process in the natural sciences, where the researcher must choose the line of research and sink the corresponding, and possibly very large, investments (setting up a laboratory, hiring postdocs, etc.). However, also in the social sciences some projects may require large ex ante commitment. Think, for example, of an experimental study in economics or psychology or a major data collection effort.

In the second stage, N chooses whether the project is successful (*succ*) or not (*fail*). The probabilities of success of a radical and of an incremental project

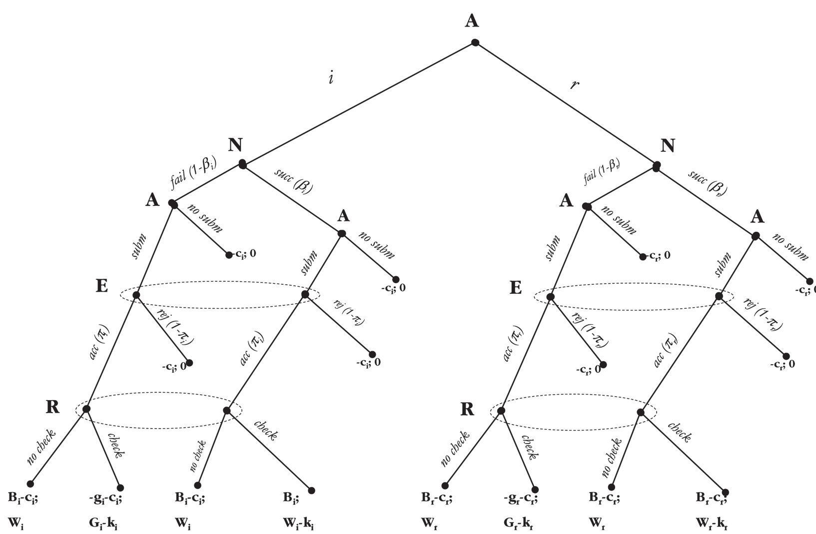

Figure 1. Game Tree for the Publication Game.

are, respectively, β_r and β_i. We can reasonably assume that succeeding in radical research is more difficult, that is, $\beta_r \leqslant \beta_i$. The outcome of the project is observed only by the author A who, in the third stage, decides whether to submit an article resulting from the research (*subm*) or not to submit (*no subm*). If the project failed, and the author submits the article as it is, it would never be published. Therefore, sending the article is equivalent to not submitting it at all. However, the author can decide to fake the results of the research and send an article thus faked.

In the fourth stage, E accepts the article for publication with some probability $\pi_j \in (0,1)$ $(j = r, i)$. E is therefore modeled just as a probability distribution with no active role. This choice is not too restrictive for our aims since journal editors and reviewers are not expected to check for misconduct. 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.[6] In an extension of the model below (Section 4.3), we also consider the effect of having misconduct checks performed by editors before publication.

The fifth stage occurs only if the manuscript is published. The reader R decides whether to check the article or not.[7] The *check* action summarizes different behaviors. The reader, for instance, 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 article. The cases described in Section 1 provide examples of 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 (assuming that the detection of frauds is uncertain would not affect qualitatively the results). 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.

2.3 Payoffs

Performing research has a cost for the author. Call the cost of performing radical research c_r and the cost of performing incremental research c_i. Successful

6. 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 two potentially distinct figures: the editor and the reviewers. Editors and reviewers may have partially different attitudes toward an article. For example, an editor may be very keen to publish an allegedly groundbreaking article in his journal. The reviewer 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. However, for our purposes, the relative role of editors and referees and their motivations for acceptance are irrelevant. The important assumption is that π_j is independent from the occurrence of frauds.

7. We focus on one major way frauds are discovered: through actions initiated by peer researchers reading articles after their publications. We do not consider one other form in which malfeasance can be discovered, that is, by collaborators, students, or supervisors of a researcher, who have witnessed the fraud and "blow the whistle."

research also generates a benefit for A if the research is published: B_r and B_i. This benefit summarizes reputational gains, career advancements, and possibly monetary rewards. Although not crucial for most of our results, it is reasonable to assume that, in general, radical research not only conveys higher (or no lower) recognitions but also is more costly to perform, that is, $B_r \geqslant B_i$ and $c_r \geqslant c_i$.

The success of A's research generates a return of W_j ($j = r, i$) for R. This return may be positive or negative. The reader 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 might also derive disutility from the success of A's research since 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 k_r for radical research and k_i for incremental research. These costs can be seen as a function of the time and effort spent in thorough scrutiny. Again, if we assume that radical research is harder to perform than incremental research, then it may also be harder to check for frauds, so that $k_r \geqslant k_i$. However, checking costs may also have other determinants. For example, a young scholar questioning the work of a higher reputation peer might have problems in publishing her own work and obtaining recognitions and promotions.[8]

If caught cheating, A bears a disutility g_j ($j = r, i$). This disutility can be a loss of reputation, or even legal and monetary costs, as the cases reported in Section 1 testify.[9] In contrast, the reader receives a reward if she detects cheating. For example, the reader can publish articles that contradict A's results, thus obtaining additional recognition (Boffey 1988). Call this reward G_j ($j = r, i$). Table 1 summarizes the model's notation.

3. Analysis

3.1 The Equilibria in Each Subgame

We solve for the perfect Bayesian-Nash equilibria of the game. There are two proper subgames, each starting after A chooses whether to undertake radical or incremental research. The payoffs of the two subgames are different, but

8. In 1986, Margot O'Toole, a postdoctoral researcher at MIT, questioned the results in an article 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 her academic career soon after, even though most of her claims turned out to be correct. Whereas Baltimore never admitted to fraud and was cleared of the accusations (some of his collaborators, however, were not), he admitted to have discredited O'Toole, thus causing damage to her (Okie 1988; LaFollette 1992; Judson 2004).

9. 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 happened in the cases of Cyril Burt and Bruno Bettelheim.

Table 1. Summary of the Notation Used in the Model

Players	
A	Author
N	Nature
E	Editor/referee (basic game), editor (active editor game)
Ref	Referee (active editor game)
R	Reader
Moves	
r, i	Choices by A of incremental versus radical research
$fail, succ$	Failure or success of the project, as determined by nature
acc, rej	Acceptance or rejection of the article by E (basic game) or by Ref (active editor game)
$check, no\ check$	Choice of checking or not checking an article for fraud—by R (basic game) and by either R or E (or both) (active editor game)
Probabilities	
β_i, β_r	Probabilities of success of an incremental or radical project
π_i, π_r	Probabilities of acceptance by the referee of an incremental or radical project
γ	Probability that E checks an article for misconduct (active editor game)
Payoffs parameters	
$B_i, B_r \in (0, +\infty)$	Benefit for A from his article being published and not checked (or checked and found clean), for incremental and radical research
$c_i, c_r \in (0, +\infty)$	Cost to perform incremental or radical research
$g_i, g_r \in (0, +\infty)$	Penalty to A from his article being detected as fraudulent
$W_i, W_r \in (-\infty, +\infty)$	Benefit for R from A's article being published and not checked (or checked and found clean), for incremental and radical research
$k_i, k_r \in (0, +\infty)$	Cost for R to check an incremental or radical article for misconduct
$G_i, G_r \in (0, +\infty)$	Benefit to R from A's article being detected as fraudulent

the two subgames are otherwise identical in their structure. We analyze only one of these subgames and omit the subscripts r and i for notational simplicity (subscripts will be omitted also elsewhere in the article, whenever this does not lead to any loss of clarity). We also name each subgame after the action chosen by A. For example, the r game is the subgame following the choice by A to perform radical research. After having analyzed the subgames, we proceed backwards and consider the first move by A, that is, 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, where 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 the project is unsuccessful.

An equilibrium in each subgame is given by a four-tuple composed by (a) the action chosen by A if the project is successful, (b) the action chosen by A if the project fails, (c) the action chosen by R, and (d) 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 3.1. There is no separating equilibrium where A chooses *subm* if the project is successful and chooses *no subm* if the project is not successful.

Given Lemma 3.1, the following Proposition 3.1 characterizes the equilibria of each subgame. In addition, the proposition reports, for each type of equilibrium, the probabilities that fraudulent articles are written, are published, are published without being caught, are published and are caught, and are checked when, instead, they are not fraudulent. These probabilities are also reported in Tables 2–4 below.

Proposition 3.1. The subgames r and i have the following equilibria:

1. A pooling equilibrium (*subm*, *subm*; *nocheck*; β_j) for $G_j \leqslant W_j + \frac{k_j}{1-\beta_j}$, $j = r, i$.
   (a) In a pooling equilibrium, the probability that a fraudulent article is written and submitted, P_{subm_j} $(j = r, i)$, is $(1-\beta_j)$. The probability that a fraudulent article is submitted and published, $P_{(subm,acc)_j}$, is $\pi_j(1-\beta_j)$, and is equal to the probability that a fraudulent article is submitted, published, and not caught, $P_{(subm,acc,nc)_j}$. The probability that a fraudulent article is submitted, published, and caught, $P_{(subm,acc,c)_j}$, is zero, and so is the probability that a nonfraudulent article, if published, goes under a check by the reader.
2. A semi-separating equilibrium $\left(subm \text{ with probability } p_j = 1;\ subm \text{ with probability } p_j = \frac{\beta_j}{1-\beta_j}\frac{k_j}{G_j-W_j-k_j};\ check \text{ with probability } q_j = \frac{B_j}{B_j+g_j};\ \frac{\beta_j}{\beta_j+p_j(1-\beta_j)}\right)$ if $G_j > W_j + \frac{k_j}{1-\beta_j}$, $j = r, i$.
   (a) In a semi-separating equilibrium, the probability that a fraudulent article is written and submitted, P_{subm_j} $(j = r, i)$, is $(1-\beta_j)p_j = \frac{\beta k_j}{G_j-W_j-k_j}$. The probability that a fraudulent article is submitted and published, $\mathrm{P}_{(subm,acc)_j}$, is $\pi_j(1-\beta_j)p_j = \frac{\pi_j\beta_j k_j}{G_j-W_j-k_j}$. The probability that a fraudulent article is submitted, published, and caught, $\mathrm{P}_{(subm,acc,c)_i}$, is

Table 2. Probability That a Fraudulent article Is Submitted, Published, and Not Caught

Type of research	Pooling equilibrium	Semi-separating equilibrium
r	$\pi_r(1-\beta_r)$	$\frac{\pi_r\beta_r k_r}{G_r-W_r-k_r}\frac{g_r}{B_r+g_r}$
i	$\pi_i(1-\beta_i)$	$\frac{\pi_i\beta_i k_i}{G_i-W_i-k_i}\frac{g_i}{B_i+g_i}$

Table 3. Probability That a Fraudulent article Is Submitted, Published, and Caught

Type of research	Pooling equilibrium	Semi-separating equilibrium
r	0	$\frac{\pi_r\beta_r k_r}{G_r - W_r - k_r}\frac{B_r}{B_r+g_r}$
i	0	$\frac{\pi_i\beta_i k_i}{G_i - W_i - k_i}\frac{B_i}{B_i+g_i}$

$\frac{\pi_j\beta_j k_j}{G_j-W_j-k_j}\frac{B_j}{B_j+g_j}$. Finally, the probability that a nonfraudulent article is submitted, published, and goes under a check is $\frac{\pi_j\beta_j B_j}{B_j+g_j}$. The probability that a fraudulent article is submitted, published, and not caught, $\mathrm{P}_{(subm,acc,nc)_j}$, is $\pi_j(1-\beta_j)p_j(1-q_j) = \frac{\pi_j\beta_j k_j}{G_j-W_j-k_j}\frac{g_j}{B_j+g_j}$. We have the following comparative statics on $\mathrm{P}_{(subm,acc,nc)_j}$:

$$\frac{\partial P_{(subm,acc,nc)_j}}{\partial \pi_j}, \frac{\partial P_{(subm,acc,nc)_j}}{\partial \beta_j}, \frac{\partial P_{(subm,acc,nc)_j}}{\partial g_j}, \frac{\partial P_{(subm,acc,nc)_j}}{\partial k_j}, \frac{\partial P_{(subm,acc,nc)_j}}{\partial W_j} > 0;$$
$$\frac{\partial P_{(subm,acc,nc)_j}}{\partial G_j}, \frac{\partial P_{(subm,acc,nc)_j}}{\partial B_j} < 0.$$

Proposition 3.1 implies that the equilibrium is pooling (and scrutiny is never performed) if (a) the "net" benefits from fraud detection $G-W$ are low; (b) the cost k of performing a check is high; and (c) the probability of research project success β is high (since this implies that R checks a successful article with high probability). 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 3.1, finally, has a straightforward corollary.

Corollary 3.1. In any equilibrium of the publication game, fraud occurs with positive probability.

3.2 The Choice of the Type of Research and the Equilibrium of the Whole Game

By backward induction, A chooses the type of research to perform in order to maximize his expected payoff, whose derivation is immediate. If the equilibrium is pooling, then checks never occur, and the payoff of the author A is simply $\pi B - c$. If the equilibrium is semi-separating, in case of failure (which occurs with probability $1-\beta$) A is made indifferent between submitting a article and not submitting, with the latter action yielding a payoff of 0.

Table 4. Probability That a Nonfraudulent article Is Submitted, Published, and Checked

Type of research	Pooling equilibrium	Semi-separating equilibrium
r	0	$\frac{\pi_r\beta_r B_r}{B_r+g_r}$
i	0	$\frac{\pi_i\beta_i B_i}{B_i+g_i}$

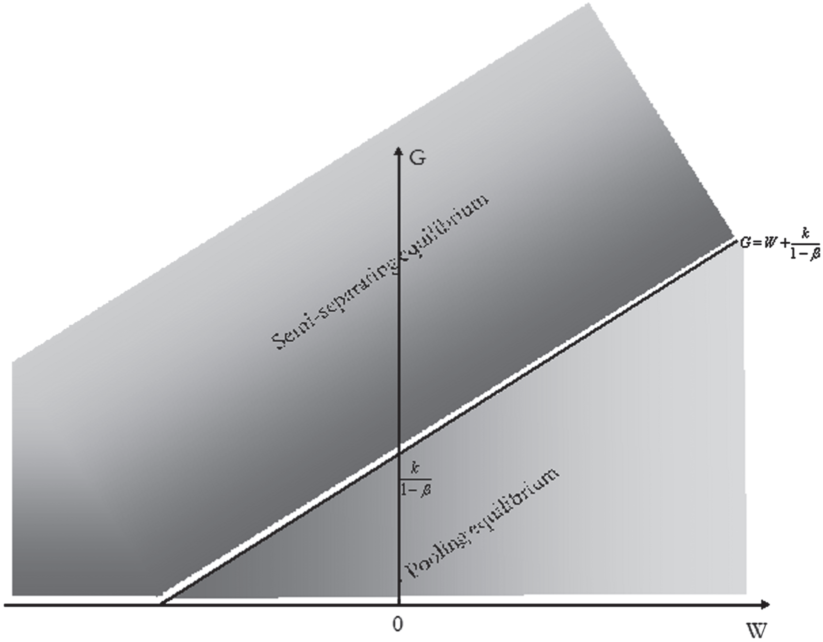

Figure 2. Parameter Space for Each of the Two Types of Equilibria in Each Proper Subgame (subscripts have been omitted).

Therefore, the payoff of A is $\pi\beta B - c$. An equilibrium of the whole game is expressed by a five-tuple composed by (a) the choice of the type of research by A (r or i); (b) the action chosen by A (*subm* or *no subm*) if the project is successful; (c) the action chosen by A (*subm* or *no subm*) if the project is a failure; (d) the action chosen by R (*check* or *no check*)—if the equilibrium of the relevant subgame is semi-separating, also the probability of each action by A and R is reported; and (e) the posterior belief by R on the success or failure of the project. Table 5 below describes the conditions under which different equilibria of the whole game emerge. The table has four parts (1, 2, 3, and 4), each of which has two subcases (a and b). The subcases a and b show the conditions under which A will choose radical or incremental research.

4. Implications

In this section, we 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 comprehensive) of frauds that go undetected. Then, we derive a series of results and predictions that qualify, and in some cases contradict, current proposals and adopted policies to deter scientific fraud.

Table 5. The Equilibria of the Full Game

Conditions	Equilibrium
1. $G_r \leqslant W_r + \dfrac{k_r}{1-\beta_r}$ and $G_i \leqslant W_i + \dfrac{k_i}{1-\beta_i}$	
1.a $\pi_r B_r - c_r > \pi_i B_i - c_i$	$(r$; *subm*, *subm*; *no check*; $\beta_r)$
1.b $\pi_r B_r - c_r \leqslant \pi_i B_i - c_i$	$(i$; *subm*, *subm*; *no check*; $\beta_i)$
2. $G_r \leqslant W_r + \dfrac{k_r}{1-\beta_r}$ and $G_i > W_i + \dfrac{k_i}{1-\beta_i}$	
2.a $\pi_r B_r - c_r > \pi_i \beta_i B_i - c_i$	$(r$; *subm*, *subm*; *no check*; $\beta_r)$
2.b $\pi_r B_r - c_r \leqslant \pi_i \beta_i B_i - c_i$	$\big(i$; *subm* with probability $p_i = 1$; *subm* with probability $p_i = \frac{\beta_i}{1-\beta_i} \frac{k_i}{G_i - W_i - k_i}$; *check* with probability $q_i = \frac{B_i}{B_i + g_i}$; $\frac{\beta_i}{\beta_i + p_i(1-\beta_i)}\big)$
3. $G_r > W_r + \dfrac{k_r}{1-\beta_r}$ and $G_i \leqslant W_i + \dfrac{k_i}{1-\beta_i}$	
3.a $\pi_r \beta_r B_r - c_r > \pi_i B_i - c_i$	$\big(r$; *subm* with probability $p_r = 1$; *subm* with probability $p_r = \frac{\beta_r}{1-\beta_r} \frac{k_r}{G_r - W_r - k_r}$; *check* with probability $q_r = \frac{B_r}{B_r + g_r}$; $\frac{\beta_r}{\beta_r + p_r(1-\beta_r)}\big)$
3.b $\pi_r \beta_r B_r - c_r \leqslant \pi_i B_i - c_i$	$(i$; *subm*, *subm*; *no check*; $\beta_i)$
4. $G_r > W_r + \dfrac{k_r}{1-\beta_r}$ and $G_i > W_i + \dfrac{k_i}{1-\beta_i}$	
4.a $\pi_r \beta_r B_r - c_r > \pi_i \beta_i B_i - c_i$	$\big(r$; *subm* with probability $p_r = 1$; *subm* with probability $p_r = \frac{\beta_r}{1-\beta_r} \frac{k_r}{G_r - W_r - k_r}$; *check* with probability $q_r = \frac{B_r}{B_r + g_r}$; $\frac{\beta_r}{\beta_r + p_r(1-\beta_r)}\big)$
4.b $\pi_r \beta_r B_r - c_r \leqslant \pi_i \beta_i B_i - c_i$	$\big(i$; *subm* with probability $p_i = 1$; *subm* with probability $p_i = \frac{\beta_i}{1-\beta_i} \frac{k_i}{G_i - W_i - k_i}$; *check* with probability $q_i = \frac{B_i}{B_i + g_i}$; $\frac{\beta_i}{\beta_i + p_i(1-\beta_i)}\big)$

4.1 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 types of research that are more likely to be caught if fraudulent and the types of research that are more likely to be fraudulently produced. To see this, assume first that $G_i \leqslant W_i + \frac{k_i}{1-\beta_i}$ and $G_r > W_r + \frac{k_r}{1-\beta_r}$. This implies that a pooling equilibrium for incremental research and a semi-separating equilibrium for radical research are played. In this case, the probability that a fraudulent article with incremental research is submitted, accepted, and caught is zero, which is lower than the probability of a radical fraudulent article to be caught—this probability is strictly positive. The probability that a fraudulent incremental research article is published at all, however, may be higher or lower than the corresponding probability for radical research article. It will be higher if

$$\pi_i(1-\beta_i) > \frac{\pi_r \beta_r k_r}{G_r - W_r - k_r}. \tag{1}$$

The inequality holds when β_r is sufficiently low. In this case, we observe that misconduct is more likely to be discovered in radical research, whereas being more common in incremental research.

Suppose now that semi-separating equilibria exist for both types of research $\left(G_i > W_i + \frac{k_i}{1-\beta_i} \text{ and } G_r > W_r + \frac{k_r}{1-\beta_r}\right)$. In this case, the probability that a fraudulent article is submitted and published is higher for incremental research if

$$\frac{\pi_i \beta_i k_i}{G_i - W_i - k_i} > \frac{\pi_r \beta_r k_r}{G_r - W_r - k_r}, \tag{2}$$

whereas the probability that a fraudulent article is submitted, published, and caught is higher for radical research if

$$\frac{\pi_i \beta_i k_i}{G_i - W_i - k_i} \frac{B_i}{B_i + g_i} > \frac{\pi_r \beta_r k_r}{G_r - W_r - k_r} \frac{B_r}{B_r + g_r}. \tag{3}$$

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

Example 4.1. Assume $G_r = 49$, $G_i = 43$, $W_r = 12$, $W_i = 40$, $k_r = 12$, $k_i = 6$, $g_r = 70$, $g_i = 40$, $\pi_r = 0.5$, $\pi_i = 0.2$, $\beta_r = 0.4$, and $\beta_i = 0.4$. Thus, $G_r = 49 > W_r + \frac{k_r}{1-\beta_r} = 32$, $G_i = 43 < W_i + \frac{k_i}{1-\beta_i} = 50$, $\pi_i(1-\beta_i) = 0.12$, and $\frac{\pi_r \beta_r k_r}{G_r - W_r - k_r} = 0.09$.

Assume further that $B_r = 89$, $B_i = 15$, $c_r = 5$, and $c_i = 2$. Then, $\pi_r \beta_r B_r - c_r = 12.8 > \pi_i B_i - c_i = 1$, a semi-separating equilibrium with radical research is played, and the probability of an article being faked and published is $\frac{\pi_r \beta_r k_r}{G_r - W_r - k_r} = 0.09$.

Assume now, instead, that $B_i = 80$. Then, $\pi_r \beta_r B_r - c_r = 12.8 < \pi_i B_i - c_i = 14$; a pooling equilibrium with incremental research is played. The probability of an article being faked and published is $0.12 > 0.09$, and since this a pooling equilibrium prevails, faked published articles are never checked—but are more frequent than in the previous case, where, in addition, the probability of detection is greater than zero.

Going beyond the specific numerical example, more generally in fields where the premium from radically advancing knowledge is very high as compared with providing incremental improvements, scientists not only would be more willing to invest in radical research on the one hand but also will be more scrutinized since their high-powered incentives would be anticipated to generate a temptation to cheat. Where, instead, scientists are only marginally less rewarded for minor contributions, they may be not only more likely to undertake incremental projects, more likely to misbehave, but also less likely to be scrutinized. Comparing fields of these two different types, one would observe a lot of "policing" in the former ones and might mistakenly conclude that these are the fields where more misconduct actually takes place.

The model can also be used to predict scientific misconduct in relation to the characteristics of scientists. We point to a further discrepancy between observed (detected) and actual amount and types of fraud. Whereas 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 compared with an average scientist, as follows: he is more likely to succeed in a project, that is, he has a higher β; he has a higher g because the loss of reputation is higher; his B is lower, if B is meant to be the "utility" of a marginal publication, compared with an average, less known scientist; and he has a high π, that is, stars are more likely to have an article 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. If one assumes that $G-W$ is more dependent on the type of research (e.g., $G_r > G_i$) than on the reputation of the scientist before the article is published, the assumption on β implies that the conditions $G^{\mathrm{s}} \leqslant W^{\mathrm{s}} + \frac{k}{1-\beta^{\mathrm{s}}}$ and $G^{\mathrm{a}} > W^{\mathrm{a}} + \frac{k}{1-\beta^{\mathrm{a}}}$ will be true for a large set of values of k.[10] 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 an article of the average scientist than of the star. However, the probability of submitting and publishing a faked article is higher for a star if

$$\pi^{\mathrm{s}}(1-\beta^{\mathrm{s}}) > \frac{\pi^{\mathrm{a}}\beta^{\mathrm{a}}k}{G^{\mathrm{a}}-W^{\mathrm{a}}-k}\,\frac{g^{\mathrm{a}}}{B^{\mathrm{a}}+g^{\mathrm{a}}}. \tag{4}$$

Note that our assumption on β implies that both $(1-\beta^{\mathrm{s}})$ and β^{a} are low. We also assumed that B^{a} is high and g^{a} is low and that $\pi^{\mathrm{s}} > \pi^{\mathrm{a}}$. Hence, inequality (4) will be satisfied for large sets of values of G^{a}, W^{a}, and k. 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 articles in the first place. At the same time, articles 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.

It could be claimed, however, that prominent scholars are also subject to other, indirect forms of scrutiny that may lead to unveiling malfeasance. For example, articles by well-known scientists are more likely to be used in the classroom for replication exercises, and students might catch a fraud in this

10. One could argue that questioning a star's results provides higher visibility and, then, is associated to higher values of G. However, it can also be harmful, for example, for a young scholar who might have problems in publishing her own work and obtaining recognitions. At the end of Section 2, we reported the case of Margot O'Toole and proposed to model the potential harm as an increase in the verification cost k. A priori, it is not clear which effect (more visibility or more harm) we should expect to prevail.

process. These additional controls might function as deterrent for otherwise less-controlled star scientists.[11] In an extension of the model along these lines (details are available upon request), we find that this is actually the case when $W > 0$, that is, when the reader benefits from a publication by the author. In this case, if the reader does not check and a fraud is discovered by the additional layer of checks (occurring after the reader has seen the published article), then the reader gives up both G, that is, the benefit from catching a fraud, and W, the benefit from the publication found (by others) to be fraudulent. In contrast, if $W < 0$ (i.e., R and A are competitors) and if the probability of other scrutinies (e.g., by students doing replication exercises) is not too high even for star scientists (so that we always get semi-separating equilibria), the reader's incentives to check are reduced by the additional layer of checks; this is because R can avoid the loss from A's publication without incurring in the checking cost. Furthermore, in this case, the net effect of these additional controls on the probability of discovering a fraud by a star turns out to be negative.

4.1.1 Comment: "Real" Frauds and "Real" Cheaters Are Not as They Appear

On the one hand, this first set of results conform with most of the available accounts on (detected) scientific frauds. Most fraud stories, such as those reported in Section 1, describe fraud 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 yet established a strong reputation. Not having a strong reputation made them less credible in the eyes of their peers, thus motivating scrutiny. Conversely, the fraudulent works performed by prominent, established scientists, as in the cases of Bruno Bettelheim, Cyril Burt, and Emil Abderhalden, were largely overlooked while the perpetrators were alive, and allegations of frauds emerged only after their deaths.

On the other hand, however, these results point to some pitfalls of relying on *observed* frauds in order to understand the overall phenomenon of scientific misconduct. We show that there 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. As found by Furman et al. (2009), (observed) retractions are more likely for high-profile (or highly cited) articles as these articles generate more interest and, consequently, more scrutiny.

The "good news" 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 originate from apparently marginal discoveries. Research results that the

11. We thank a referee for making this observation.

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 (see, e.g., Surowiecki 2007). Also, decisions on promotions and allocation of funds are not necessarily based on breakthrough research but rather often on more modest advancements. 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 the types 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 focused on less-known researchers (postdocs, junior faculty), whereas the scientific community already generates, without the need for interventions, the right incentives for these classes of researchers to be scrutinized.

4.2 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.

4.2.1 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, authors should be required to share their data with their peers as a condition to publish on a given journal. A number of journals require the authors of accepted articles to make their data available online and to provide any additional material of potential relevance in order to fully understand an article. In economics, for example, this is the current policy at a few journals, following an earlier experiment at the *Journal of Money, Credit and Banking* (Ashenfelter et al. 1986; Dewald et al. 1986). Similar experiments were tried at *Empirical Economics* and *Labour Economics*, where a section of each issues was dedicated, for a few years, to replication works (Hamermesh 2007). Or, techniques could be developed to check for frauds more easily (Hill 1999; Giles 2006; Sorokina et al. 2006).

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 proposition.

Proposition 4.1.

1. A reduction in checking costs k_j $(j = r, i)$ never leads to a higher probability of undiscovered fraud if it does not induce a change in the type of research.
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 examples clarify these results. In the first example, a reduction in verification costs leads the author to shift from incremental to radical research, whereas in the second example, the shift is from radical to incremental research. In both cases, the reduction in checking costs increases the probability of undetected fraud.[12]

Example 4.2. Figure 3 below reports an example of a reduction in checking costs that leads to an increase in the likelihood of an article being fraudulent, submitted, accepted, and not caught (the parameter values are reported in the figure caption). The graph represents the (k_r, k_i) space and focuses on the region where $k_r \geqslant k_i$. Consider the points in region A. In this area, $\frac{\pi_r \beta_r k_r}{G_r - W_r - k_r} \frac{g_r}{B_r + g_r} > \pi_i(1-\beta_i)$ and $G_r > W_r + \frac{k_r}{1-\beta_r}$—equivalently, $\frac{(B_r+g_r)(G_r-W_r)[\pi_i(1-\beta_i)]}{\pi_r\beta_r g_r + \pi_i(1-\beta_i)(B_r+g_r)} < k_r < (G_r - W_r)(1-\beta_r)$. Furthermore, $G_i \leqslant W_i + \frac{k_i}{1-\beta_i}$—equivalently, $k_i \geqslant (G_i - W_i)(1-\beta_i)$. The parameters are also such that $\pi_i B_i - c_i > \pi_r \beta_r B_r - c_r$. As a consequence, A chooses incremental research and a pooling equilibrium is played (as from point 3.b of Table 5). The likelihood of an article being fraudulent, submitted, accepted, and not caught is $\pi_i(1-\beta_i)$ (see Table 2). In region B, the only condition that changes with respect to region A is that $G_i > W_i + \frac{k_i}{1-\beta_i}$—equivalently, $k_i < (G_i - W_i)(1-\beta_i)$. The figure is drawn for parameter values such that $\pi_i \beta_i B_i - c_i < \pi_r \beta_r B_r - c_r$. The author A therefore chooses radical research and a semi-separating equilibrium is played (as from point 4.a in Table 5). The likelihood of an article being fraudulent, submitted, accepted, and not caught is $\frac{\pi_r \beta_r k_r}{G_r - W_r - k_r} \frac{g_r}{B_r + g_r}$. Since $\frac{\pi_r \beta_r k_r}{G_r - W_r - k_r} \frac{g_r}{B_r + g_r} > \pi_i(1-\beta_i)$ for this set

12. Proposition 4.1 might seem in contradiction with the results in Section 4.1. There, we showed that fraud is more likely to go undetected in incremental research, whereas in this proposition it might be the case that a shift from incremental to radical research increases undetected fraud. However, note first, as Examples 4.2 and 4.3 show, Proposition 4.1 is valid in both directions, that is, for a shift from radical to incremental research and vice versa. The key driver of this result is that a change in checking costs might alter the overall nature of the game, and this will lead in turn to an increase in the probability of undetected fraud. The result in Section 4.1 on a higher likelihood of undetected fraud characterizing incremental research is valid keeping verification costs constant. Moreover, the result is valid even if there is no change in the type of equilibrium played in the subgames, with incremental or radical research.

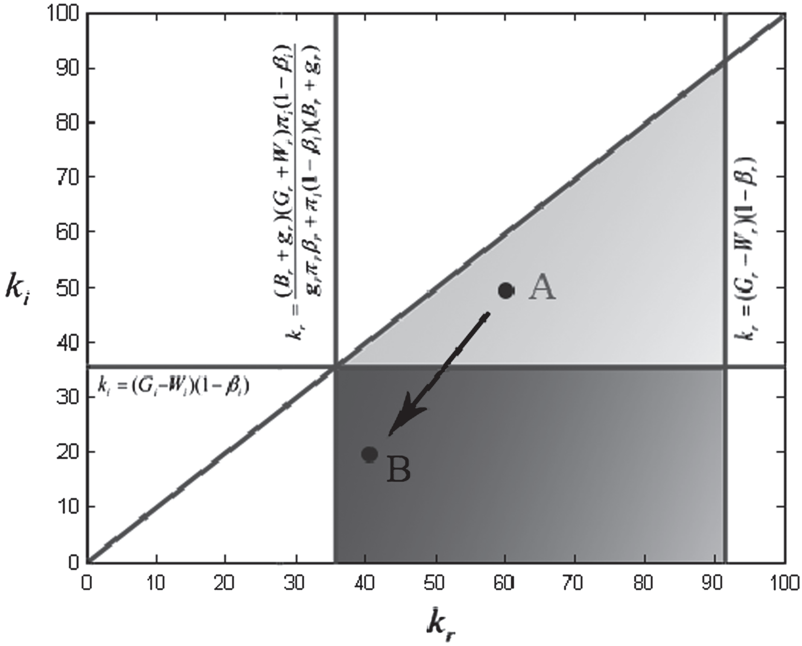

Figure 3. Example of a Reduction in Checking Costs That Leads to an Increase in the Likelihood of an article Being Fraudulent, Submitted, Accepted, and Not Caught. The x Axis Represents Values of k_r and the y Axis Values of k_i. The Figure Is Drawn for the Following Set of Other Values of the Parameters: $G_r = 85$, $G_i = 62$, $W_r = -36$, $W_i = -25$,$B_r = 89$, $B_i = 65$, $c_r = 16$, $c_i = 1$, $g_r = 84$, $\pi_r = 0.96$, $\pi_i = 0.12$, $\beta_r = 0.24$, $\beta_i = 0.59$.

of parameter values, and since region B lies below region A, a reduction of both k_r and k_i can lead to an increase in the rate of committed and undetected fraud.

Example 4.3. The following example describes an environment in which a reduction of verification costs leads the author to shift from radical to incremental research, with, again, an increase in the likelihood of undetected frauds. Assume $G_r = 30$, $G_i = 10$, $W_r = 22$, $W_i = 15$, $k_r = 5$, $k_i = 2$, $\pi_r = 0.4$, $\pi_i = 0.6$, $\beta_r = 0.4$, and $\beta_i = 0.55$. Thus, $G_r = 30 < W_r + \frac{k_r}{1-\beta_r} = 30.3$ and$G_i = 10 < W_i + \frac{k_i}{1-\beta_i} = 19.4$: the equilibrium is pooling in both subgames i and r. Assume further that $B_r = 80$, $B_i = 40$, $c_r = 12$, and $c_i = 10$. Then, $\pi_r B_r - c_r = 20 > \pi_i B_i - c_i = 14$, so that a pooling equilibrium with radical research is played. The probability of an article being faked and published is $\pi_r(1-\beta_r) = 0.24$. Assume now that verification costs are reduced as follows: $k_r = 4$ and $k_i = 1$. Then, $G_r = 30 > W_r + \frac{k_r}{1-\beta_r} = 28.6$, $G_i = 10 < W_i + \frac{k_i}{1-\beta_i} = 17.2$, and $\pi_r\beta_r B_r - c_r = 0.8 < \pi_i B_i - c_i = 14$. Therefore, a pooling equilibrium with incremental research is played. The probability of an article being faked and published (and not caught) is now $\pi_i(1-\beta_i) = 0.27 > 0.24$.

4.2.2 Misconduct and the "Publish or Perish" Imperative. It is frequently claimed that high-powered incentives to scientists may be conducive to fraud. The high benefits from publishing articles and outcompeting rivals (in winner-takes-all competitions for funds or careers) would make scientists more prone to misbehavior (List 1985; Abelson 1990; Hartemink 2000; Giles 2007).

In our model, the benefits from publications are captured by B and $G-W$. A strong pressure to publish can be represented by a high benefit from publications, B. If a particular research area or topic is "hot" in a given period, publishing on that particular topic will give higher recognition, therefore attracting more competition among scientists, all else equal.[13] Similarly, in a field where publications give high prestige to authors, it is reasonable to assume that the return from discovering a fraud (G) and the loss from others' publications ($-W$) are higher.[14] 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. In particular, we show that, under certain circumstances, a reinforcement of the "publish or perish" paradigm can lead to a reduction in undiscovered frauds. We derive the following proposition.

Proposition 4.2.

1. An increase in the "publish or perish" imperative (i.e., an increase in B_j and $G_j - W_j$, $j = r, i$) never leads to a higher probability of undiscovered fraud if it does not induce a change in the type of research.
2. If the author A changes the type of research following an increase in the "publish or perish" imperative, then the probability of an undiscovered fraud can increase.

This proposition implies that the claim that the "publish or perish" pressure is conducive to more fraud is not necessarily borne out. This pressure can actually serve as a powerful mechanism to deter fraud as it increases the incentives of peers to scrutinize each other's work. This is due both to the increase in the

13. We are assuming, in this section, that changes in the value of B are not necessarily accompanied by changes in other parameters. In particular, some types of research might convey high prestige because they are hard to perform. If this is the case, then increments in B should be accompanied by increases in the costs of performing research and, consequently, in the costs of checking for misconduct. Whereas the cost of performing research by the author A does not affect the probability of committing or discovering frauds (see Proposition 3.1), an increase in the verification cost k actually weakens the effect of an increase of $G-W$. We thank a referee for having raised this point.

14. The types of misconduct on which we are focusing in this article, namely data fabrication and falsification, may in fact convey recognition also to the researchers who spot the fraud. If these types of fraud are discovered by a peer scientist while reading and examining a published article, then the scientist can submit an article for publication, based on the spotted fraud (see, e.g., the case of Deichman and Muller-Hill (1998) on unveiling Abelhanrden's frauds). For other forms of fraud, such as plagiarism, it is less realistic to assume that a scientist who discovers it might receive recognition.

reward from discovering fraud and to the anticipation of the author's higher temptation to cheat.

4.2.3 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. Stiffer penalties would deter scientists 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 game above, the parameter g represents the cost, which can be pecuniary or not, suffered by A if a fraudulent article is discovered. This parameter appears as relevant only in a semi-separating equilibrium, affecting the probability of discovering a fraudulent article. Notice that an increase in g increases the probability that a fraudulent article 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 and not submitting a faked article by A.[15]

4.2.4 Comment: Deterrence Policies Can Backfire. A series of counterintuitive insights emerge from these 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 and the author does not change the type of research, the "intuitive" result is obtained, where the overall chance of undetected frauds is reduced. However, the reduction in checking costs can modify the type of research activities scientists undertake in the first place. In turn, these changes in the type of research can lead to a higher likelihood of undetected fraud.

The model also qualifies the claim that a major cause of misbehavior in science is represented by an excessive pressure to publish and "outcompete" peer scientists. In fact, the reader is aware of the author's high-powered incentives to publish, and this stimulates more monitoring, thus deterring frauds. One might observe more cases of fraud in fields where the "publish or perish" imperative is stronger, 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* pressure to publish certain findings is conducive to misconduct. Consider again the role of replication. The limited recognition for replication works that characterizes the scientific community (Dewald et al. 1986, Hamermesh 2007) can also be seen as a limit to the pressure to publish

15. This result replicates the main conclusion from the literature on "inspection games" (see Tsebelis 1989).

and compete with other scientists in a given field. Once a result has been found by a scientist, he establishes a sort of "monopoly" over it, thus reducing the incentives of peers to do research in that same area.[16]

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 tendency to invest in this kind of research, at the sacrifice of time and resources spent on genuinely novel activities. The reduction in the occurrence of frauds or in the likelihood of malfeasance going undetected should therefore be weighted against these possible distortions. An example of these risks is given by Walter W. Stewart and Ned Feder, two scientists at the National Institutes of Health who, in the 1980s, gained notoriety and recognition for having unveiled several 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 (LaFollette 1992).

4.3 An Active Role for Editors?

As previously noticed, neither editors nor referees are typically required to control for the truth of the findings reported in the manuscripts they receive. Suspicions of fraud most often emerge after an article is published. Colleagues and collaborators of an author, or, most frequently, readers of an article, contact the editor of the journal and express their concerns. The editor then contacts 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 boards in the attempt to deter and reduce fraud. At *Nature Immunology*, for example, one 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. We show, however, that they do not necessarily imply additional deterrence power: in fact, they might increase the probability of undetected fraud by crowding out the incentives of readers to check. We extend the game as follows. Referees are still assumed to have no role in checking for frauds. Now, however, editors and referees are separated agents. If an article is passed by a referee, then the editor, with some probability γ, performs a check before publication.[17] This is a

16. Engaging in activities aimed at questioning existing works can even be detrimental to a scientist's career, as the case of the MIT postdoctoral student Margot O'Toole suggests (see footnote 8 above).

17. The separation of referees and editors is made for expository reasons. The identity of who makes the ultimate acceptance decision is irrelevant as long as the probability of acceptance does not depend on the occurrence of frauds.

commitment by the editor: he has no choice but performing the random check.[18] Since the editor does not act strategically, his 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 with the practices in the aforementioned journals, where the identity of the checked articles is kept secret.

This version of the game presents some similarities with the model of plagiarism developed by Arce et al. (2008). Like ours, in their game editors may play an active role in the verification process, and there is some uncertainty on whether they would do so. In Arce et al., the uncertainty is in terms of the "type" of editors; in our model, consistent with the policies at some journals, the probability of checks is known, but readers do not know if the check has taken place. In both models, the probability of the editor's check plays a key role in the incentives to cheat. A major difference in our model is that the actions by the editor and the reader are substitutes, whereas in Arce et al. the editor is the sole agent in charge of sanctioning misbehavior. The initial stage in our model where authors decide the type of research adds a further dimension to the publication game proposed here, which will have an impact on the effectiveness of having active editors.

A full analysis of this extended game is reported in Appendix A. Here, we report the main results and comment on them. We focus on the impact of variations in γ, our measure of the degree to which editors participate in checking for frauds. We consider in particular the effects of an increase in this parameter.

Proposition 4.3.

1. If $\gamma \geqslant \frac{B_j}{B_j+g_j}$ $(j=i,r)$, then there is no fraud in equilibrium.
2. Consider each proper subgame (i,r). Suppose $1-\frac{k_j\beta_j}{(G_j-W_j-k_j)(1-\beta_j)} \leqslant \gamma < \frac{B_j}{B_j+g_j}$, $j=r,i$, both before and after an increase of γ. Then, the probability that frauds are not discovered decreases if γ increases.
3. Consider each proper subgame (i,r). Suppose $\gamma < \min\left(1-\frac{k_j\beta_i}{(G_j-W_j-k_j)(1-\beta_j)}, \frac{B_j}{B_j+g_j}\right)$, $j=r,i$, both before and after an increase of γ. Then, the probability that frauds are not discovered increases if γ increases.

18. 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 article 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 articles are checked, some frauds can go undetected. Second, in the case of both *Nature Immunology* and *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.

4. Consider each proper subgame (i,r). Suppose that initially $\gamma = \gamma' < \min\left(1\text{-}\frac{k_j\beta_j}{(G_j-W_J-k_j)(1-\beta_j)}, \frac{B_j}{B_j+g_j}\right)$, $j = r,i$, and then γ increases up to γ'', such that $1 - \frac{k_j\beta_j}{(G_j-W_J-k_j)(1-\beta_j)} < \gamma'' < \frac{B_j}{B_j+g_j}$. Then, the probability that a fraud is not discovered increases with the increase of γ from γ' to γ''.

With respect to the whole game, variations in γ can actually lead to a change in the type of research performed by A. Similarly to the case of a reduction in checking costs, such changes may induce changes in the probability that a fraud is committed and discovered, and, in particular, an increase in γ can induce an increase in the probability that a fraud is committed and not caught. Further details and examples are reported in Appendix A.

4.3.1 Comment: Check a Lot or Do Not Check At All.

Point 1 of Proposition 4.3 shows a major difference between this extended game with active editors and the basic game described previously: for a sufficiently high probability of the preliminary, additional check to be performed, each proper subgame has a separating equilibrium, where no fraud is performed and only "truly" successful articles are submitted by the author A. Taken together, points 1 and 2 of Proposition 4.3 depict "expected" scenarios where the scrutiny by an additional actor reduces the overall chance of undetected frauds. Points 3 and 4 of the proposition, in contrast, show that also the opposite can be true. When R observes a published article, she 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 article.

We conclude that an active role of editors into checking for misconduct unambiguously leads to a lower chance of fraudulent articles being left unchecked only when such an involvement is large. If the involvement is only on a small scale (i.e., only on a small share of articles 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 articles published and not scrutinized. The benefits from a large-scale involvement of journals in prepublication checks for fraud will need to be weighted against such costs as additional personnel, time, and delays in publication.

5. Conclusions

The objective of this article 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 abound of scientists who falsified, fabricated, or plagiarized findings and were still able to publish and get recognition from them. The scientific community is a complex, self-regulating institution where several actors interact in different forms—as competitors, complementors, and evaluators. Little is known about how the same institutional features that lead to knowledge creation also lead to the fabrication of fake information. We built a game-theoretic model of the research and publication process that captures some of the main characteristics of the scientific community and also allows authors to commit fraud.

The model shows, first, that 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, inducing an increase in undetected misbehavior. Also, adding layers of control for misconduct—for example, through a direct involvement of a journal's 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 fraud of which the scientific community is not aware, 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 the pressure to publish, and involving journals' editorial boards into checking for frauds, do not necessarily elicit the expected virtuous behaviors.

Some limits of the model have been reported and discussed in the article. Further extensions are possible. In the current version of the model, for example, the success or failure of the project does not depend on the effort spent by the author, or by scientists ability, which in fact are 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, and these, in turn, may also be determined by the scientist-specific level of ability, unobserved by the reader. Changing the probability of success would affect monitoring incentives and consequently the decision of whether to commit fraud or not. Another avenue for extensions concerns the behavioral assumptions. In the model, scientists are "selfish" and have no ethical concerns. Although the sociological literature is controversial on the issue, it can be argued that scientists derive utility also from producing knowledge *honestly* and not only from the publication of any results. An interpretation of our result is that, if ethical concerns are limited or nonexistent, then fraud is an inherent characteristic of the scientific community. Cheating, moreover, can also be seen as the result of "compulsive" behavior and not as the outcome of rational choice, as in the model in this article.[19]

19. Schrand and Zechman (2008) provide evidence of a relationship between irrational beliefs of managers (as expressed by overconfidence) and financial fraud.

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. For example, increasing recognition for replication works can deviate some scientists toward these activities, thus not only making existing knowledge more reliable but also slowing down the creation of new knowledge. Also, the existence of multiple readers potentially checking for misconduct may create a free rider problem since the checking cost is individual, whereas the benefits of discovering a fraud are social. Finally, just as competition among scientists may affect the propensity to cheat and the likelihood of discovering frauds, competition among journals might also play a role. For example, if journals compete to publish a particularly "hot" piece of research, checks for fraud might become lenient, thus affecting, in turn, the behavior of scientists and peer-readers.

The analysis in this article, finally, offers insights for empirical research on scientific fraud. We highlight that empirical works based on detected fraud might overestimate frauds in certain types of research and scientists and overestimate others. Studies such as Furman et al. (2009) offer findings in line with the type of biases that the model in this article predicts—in particular, that retractions are more likely for high-profile (or highly cited) articles since these articles generate more interest. In order to properly test for the extent of scientific misconduct, and for some of the predictions of our model—for example, on the impact of a reduction in replication cost, on the extent of fraud in disciplines and lines of research more or less radical or with more or less competitive pressure, and on the impact of multiple layers of checks that include also editorial board—data collection effort should rely on samples that potentially include nonfraudulent works too. This could be achieved, for example, through anonymous surveys asking about the respondents's conduct as well as suspicious conducts the respondents have witnessed (as in Swazey et al. 1993; Bailey et al. 2001; Martinson et al. 2005); through the analysis and comparison of investigations by authorities (e.g. the ORI) with and without findings (as in Pozzi and David 2007); or through the collection of data from a large set of articles for replication exercises (as in Dewald et al. 1986).

Appendix A: Proofs

Proof of Lemma 3.1. 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 checking dominates checking. However, anticipating this, A has an incentive to deviate when the project turns out to be a failure, that is, A will submit also when the project fails. □

Proof of Proposition 3.1. We first prove the existence of a 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 (subscripts are omitted)

$$\beta W+(1-\beta)W \geqslant \beta(W-k)+(1-\beta)(G-k), \tag{A1}$$

from which we obtain the result.[20]

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 randomize. Indeed, if R chooses *check*, then A has no incentive to submit in case of failure: he would be caught cheating with probability 1. Thus, *no subm* would dominate *subm*. In other words, the two options would 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 the checking probability q so as to make A indifferent between submitting and not submitting, when the project is unsuccessful:

$$\pi[q(-g-c)+(1-q)(B-c)]+(1-\pi)[-c]=-c, \tag{A2}$$

from which we obtain $q=\frac{B}{B+g}$. 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:

$$\mu(W-k)+(1-\mu)(G-k)=\mu(W)+(1-\mu)(W), \tag{A3}$$

where $\mu = \text{prob(project is successful|article published)}$ $= \frac{\text{prob(article publ|proj succ)}\times\text{prob(proj succ)}}{\text{prob(article publ| proj succ)}\times\text{prob(proj succ)}+\text{prob(article publ| proj not succ)}\times\text{prob(proj not succ)}}$ $=\frac{\pi*\beta}{\pi*\beta+\pi p(1-\beta)}$. Substituting into (A3), we obtain $p=\frac{\beta}{1-\beta}\frac{k}{G-W-k}$.

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

The calculations, for each type of equilibrium, of the probabilities that fraudulent articles are written, are published, are published without being caught, are published and are caught, and are checked when, instead, they are not fraudulent (as reported in the proposition and in Tables 2–4 above) derive straightforwardly. □

Proof of Proposition 4.1. Suppose there is no change in the type of research chosen in equilibrium, following a reduction in checking costs. Three cases

20. In the case where expression (A1) holds with equality, we assume that the indifference case is included into the pooling equilibrium. In contrast to the semi-separating equilibrium, the pooling equilibrium is robust with respect to a (small) probability of ethical behavior, that is, A does not submit an article when it is not successful, even if this action is profitable. A formal proof of this result is available upon request.

need to be considered:

1. 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.
2. The equilibrium moves from pooling to semi-separating. The probability of undiscovered misconduct moves from $\pi(1-\beta)$ to $\pi(1-\beta)p(1-q)$. Since p and q are smaller than 1, then $\pi(1-\beta)p(1-q) < \pi(1-\beta)$.
3. The equilibrium is semi-separating before and after the reduction in checking costs. It can be seen from Proposition 3.1 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 $G_r > W_r + \frac{k_r}{1-\beta_r}$, $G_i \leqslant W_i + \frac{k_i}{1-\beta_i}$, and $\pi_i B_i - c_i > \pi_r \beta_r B_r - c_r$. This means that equilibrium falls in region 3.b of Table 5: an incremental type of research is chosen, and a pooling equilibrium is played. Consider now a reduction in both k_r and k_i such that $G_r \leqslant W_r + \frac{k_r}{1-\beta_r}$ and $G_i \leqslant W_i + \frac{k_i}{1-\beta_i}$. The author A may switch to a radical type of research since there are values of the parameters for which both $\pi_i B_i - c_i > \pi_r \beta_r B_r - c_r$ and $\pi_i \beta_i B_i - c_i < \pi_r \beta_r B_r - c_r$ 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 article is submitted, published, and not caught is higher after the reduction in the checking costs if

$$\frac{\mu \pi_r \beta_r k_r}{G_r - W_r - k_r} \frac{g_r}{B_r + g_r} > \pi_i(1-\beta_i). \tag{A4}$$

Inequality (A4) is satisfied if the probability of success of radical research is sufficiently high and if a radical research article is more likely to accepted than an incremental article. □

Proof of Proposition 4.2. Consider first the case in which the choice of research type is unaffected after the increase in the intensity of "publish or perish" imperative. In this case, three situations may occur:

1. The equilibrium is pooling before and after the increase.
2. The equilibrium moves from pooling to semi-separating.
3. The equilibrium is semi-separating before and after the increase.

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 3.1 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 Table 5 $\left(\text{i.e., } G_r \leqslant W_r + \frac{k_r}{1-\beta_r}, G_i \leqslant W_i + \frac{k_i}{1-\beta_i}, \text{ and } \pi_i B_i - c_i \geqslant \pi_r B_r - c_r\right)$. 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 conduct radical research (i.e., an increase in both B_r and $G_r - W_r$), which moves the equilibrium from region 1 to region 3 as described in Table 5 ($G_r > W_r + \frac{k_r}{1-\beta_r}$ and $G_i \leqslant W_i + \frac{k_i}{1-\beta_i}$). If the increase in B_r 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 configurations of the parameters, the probability of undiscovered fraud may increase. □

Proof of Proposition 4.3. In order to prove this proposition, we fully develop the game with an active editor game introduced in Section 4.3. The full game is represented in Figure 4.

We first analyze separately the two proper subgames starting when nature N moves, and we then deal with the whole publication game thus modified. The main difference from the case without checks by the editor is that, now, a separating equilibrium exists when the checking probability by E is sufficiently high. Consider the following proposition. □

Proposition A.1. The subgames r and i have the following equilibria:

1. A separating equilibrium (*subm*, *no subm*; *no check*; 1) for $\gamma \geqslant \frac{B_j}{B_j+g_j}$, $j = r, i$.
2. A pooling equilibrium (*subm*, *subm*; *no check*; β) for $1 - \frac{k_j\beta_j}{(G_j-W_j-k_j)(1-\beta_j)} \leqslant \gamma < \frac{B_j}{B_j+g_j}$, $j = r, i$.

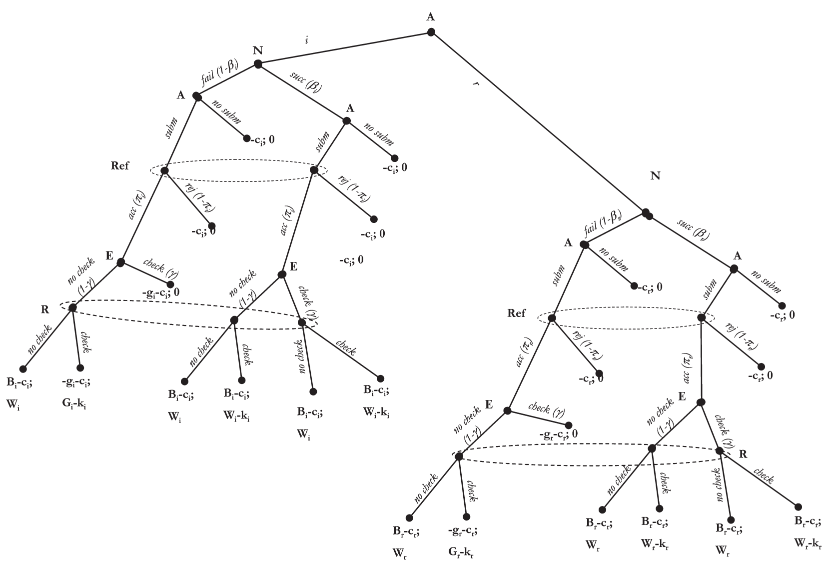

Figure 4. Game with Random Checks by the Editor.

3. A semi-separating equilibrium $\left(subm\right.$ with probability $p_j = 1$ if the project is successful; *subm* with probability $p_j = \frac{\beta_j}{1-\beta_j}\frac{k_j}{(G_j-W_j-k_j)(1-\gamma)}$ if the project is unsuccessful; *check* with probability $q_j = \frac{B_j}{B_j+g_j}\frac{1}{1-\gamma} - \frac{\gamma}{1-\gamma}$; $\left.\frac{\beta_j}{\beta_j+p_j(1-\beta_j)(1-\gamma)}\right)$ exists for $\gamma < \min\left(1-\frac{k_j\beta_j}{(G_j-W_J-k_j)(1-\beta_j)}, \frac{B_j}{B_j+g_j}\right)$, $j = r, i$.

Proof. We prove, in sequence, the existence of a separating, pooling, and semi-separating equilibrium. Subscripts are omitted. First, A prefers not to submit a faked article if $\pi\gamma(-g)+\pi(1-\gamma)B-c < -c$, from which the condition on the existence of a separating equilibrium follows. 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 observes an article being published, she excludes that the article is faked and that 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 not 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

$$W \geqslant \frac{\beta}{\beta+(1-\gamma)(1-\beta)}(W-k)+\frac{(1-\beta)(1-\gamma)}{\beta+(1-\gamma)(1-\beta)}(G-k) \tag{A5}$$

or $\gamma \geqslant 1-\frac{k\beta}{(G-W-k)(1-\beta)}$. 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 semi-separating equilibrium. R chooses the checking probability q so as to make A indifferent between submitting and not submitting, when the project is unsuccessful:

$$\pi\gamma(-g)+\pi(1-\gamma)\left[q(-g)+(1-q)(B)\right]-c = -c \tag{A6}$$

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

$$\mu(W-k)+(1-\mu)(G-k) = \mu(W)+(1-\mu)(W), \tag{A7}$$

where $\mu = \text{prob}(\text{project is successful}|\text{article published})$

$$= \frac{\text{prob(article publ| proj succ)}\times\text{prob(proj succ)}}{\text{prob(article publ| proj succ)}\times\text{prob(proj succ)}+\text{prob(article publ| proj not succ)}\times\text{prob(proj not succ)}}$$

$$= \frac{\pi*\beta}{\pi*\beta+\pi p(1-\beta)(1-\gamma)}.$$

Substituting into (A7), we obtain the probability that A submits a faked article to be $p = \frac{\beta}{1-\beta}\frac{k}{(G-W-k)(1-\gamma)}$. In order for q to be positive, it must be that $\gamma < \frac{B}{B+g}$. For q to be within the unit interval, it must be that $B-\gamma(g+B) < (1-\gamma)(g+B)$ or, equivalently, $g > 0$, which is true by assumption. In order for p to be positive, G has to be large enough, that is, $G > W+k$. Also, in order for p to have positive and meaningful values, that is, within the unit interval,

Table 6. Probability That a Fraudulent article Is Submitted, Published, and Not Caught

Type of research	Pooling equilibrium	Semi-separating equilibrium
r	$\pi_r(1-\gamma)(1-\beta_r)$	$\frac{\pi_r\beta_r k_r}{(G_r-W_j-k_r)}\frac{g_r}{B_r+g_r}\frac{1}{1-\gamma}$
i	$\pi_i(1-\gamma)(1-\beta_i)$	$\frac{\pi_i\beta_i k_i}{(G_i-W_j-k_i)}\frac{g_i}{B_i+g_i}\frac{1}{1-\gamma}$

we need $\frac{\beta}{1-\beta}\frac{k}{(G-W-k)(1-\gamma)}<1$. Equivalently, $\gamma<1-\frac{k\beta}{(G-W-k)(1-\beta)}$. Therefore, a semi-separating equilibrium also requires that $\gamma<1-\frac{k\beta}{(G-W-k)(1-\beta)}$. □

The probability that fraudulent articles are written and published without being caught and the probability that they are written, published, and caught are reported in Tables 6 and 7 (the probability is obviously 0 if the equilibrium is separating since frauds are never committed). Notice that, for $\gamma=0$ (i.e., there is no check by the editor), we obtain the probabilities for the baseline game, as reported in Tables 2 and 3 above.

By backward induction, the author A chooses the type of research to perform, in order to maximize his expected payoff. If the equilibrium is separating, an article is never submitted in case of failure (which occurs with probability $1-\beta$). Therefore, the payoff of A is $\pi\beta B-c$. The same payoff accrues to A if the equilibrium is semi-separating since in case of failure A is made indifferent between submitting an article and not submitting. If the equilibrium is pooling, check (by the editor) occurs with probability γ. In case of failure and check, A does not obtain the benefit B and receives the punishment g instead. Therefore, the payoff of A is $\pi[\beta B+(1-\beta)((1-\gamma)B-\gamma g)]-c=\pi[B-\gamma(1-\beta)(B+g)]-c$.

We now derive the following proposition, whose proof is immediate given the results and propositions above.

Proposition A.2.

1. If $\max\left\{1-\frac{k_r\beta_r}{(G_r-W_r-k_r)(1-\beta_r)},1-\frac{k_i\beta_i}{(G_i-W_i-k_i)(1-\beta_i)}\right\}\leqslant\gamma<\min\left\{\frac{B_r}{g_r+B_r},\frac{B_i}{g_i+B_i}\right\}$, A chooses radical research if $\pi_r(B_r-\gamma(1-\beta_r)(B_r+g_r))-c_r>\pi_i(B_i-\gamma(1-\beta_i)(B_i+g_i))-c_i$, incremental otherwise. The subgames have pooling equilibria.
2. If $1-\frac{k_r\beta_r}{(G_r-W_r-k_r)(1-\beta_r)}\leqslant\gamma<\frac{B_r}{g_r+B_r}$ and $\gamma<\min\left\{\frac{B_i}{g_i+B_i},1-\frac{k_i\beta_i}{(G_i-W_i-k_i)(1-\beta_i)}\right\}$,

Table 7. Probability That a Fraudulent article Is Submitted, Published, and Caught

Type of research	Pooling equilibrium	Semi-separating equilibrium
r	$\pi_r(1-\beta_r)\gamma$	$\frac{\pi_r\beta_r k_r}{(G_r-W_j-k_r)}\frac{B_r}{B_r+g_r}\frac{1}{1-\gamma}$
i	$\pi_i(1-\beta_i)\gamma$	$\frac{\pi_i\beta_i k_i}{(G_i-W_j-k_i)}\frac{B_i}{B_i+g_i}\frac{1}{1-\gamma}$

A chooses radical research (with pooling on *subm*) if $\pi_r(B_r - \gamma(1-\beta_r)(B_r + g_r)) - c_r > \pi_i\beta_i B_i - c_i$, incremental otherwise (with a semi-separating equilibrium).

3. If $\gamma < \min\left\{\frac{B_r}{g_r+B_r}, 1 - \frac{k_r\beta_r}{(G_r-W_r-k_r)(1-\beta_r)}\right\}$ and $1 - \frac{k_i\beta_i}{(G_i-W_i-k_i)(1-\beta_i)} \leqslant \gamma < \frac{B_i}{g_i+B_i}$, A chooses radical research (with a semi-separating equilibrium) if $\pi_r\beta_r B_r - c_r > \pi_i(B_i - \gamma(1-\beta_i)(B_i + g_i)) - c_i$, incremental otherwise (with pooling on *subm*).
4. If $\gamma < \min\left\{\frac{B_r}{g_r+B_r}, 1 - \frac{k_r\beta_r}{(G_r-W_r-k_r)(1-\beta_r)}\right\}$ and $\gamma < \min\left\{\frac{B_i}{g_i+B_i}, 1 - \frac{k_i\beta_i}{(G_i-W_i-k_i)(1-\beta_i)}\right\}$, A chooses radical research if $\pi_r\beta_r B_r - c_r > \pi_i\beta_i B_i - c_i$, incremental otherwise. The subgames have semi-separating equilibria.
5. If $\gamma \geqslant \max\left\{\frac{B_r}{g_r+B_r}, \frac{B_i}{g_i+B_i}\right\}$, A chooses radical research if $\pi_r\beta_r B_r - c_r > \pi_i\beta_r B_i - c_i$, incremental otherwise, with separating equilibria and no fraud occurring.
6. If $\gamma \geqslant \frac{B_r}{g_r+B_r}$ and $1 - \frac{k_i\beta_i}{(G_i-W_i-k_i)(1-\beta_i)} \leqslant \gamma < \frac{B_i}{g_i+B_i}$, A chooses radical research (separating) if $\pi_r\beta_r B_r - c_r > \pi_i(B_i - \gamma(1-\beta_i)(B_r + g_r)) - c_i$, incremental (pooling) otherwise.
7. If $\gamma \geqslant \frac{B_r}{g_r+B_r}$ and $\gamma < \min\left\{\frac{B_i}{g_i+B_i}, 1 - \frac{k_i\beta_i}{(G_i-W_i-k_i)(1-\beta_i)}\right\}$, A chooses radical research (separating) if $\pi_r\beta_r B_r - c_r > \pi_i\beta_i B_i - c_i$, incremental (semi-separating) otherwise.
8. If $1 - \frac{k_r\beta_r}{(G_r-W_r-k_r)(1-\beta_r)} \leqslant \gamma < \frac{B_r}{g_r+B_r}$ and $\gamma \geqslant \frac{B_i}{g_i+B_i}$, A chooses radical research (pooling) if $\pi_r(B_r - \gamma(1-\beta_r)(B_r + g_r)) - c_r > \pi_i\beta_i B_i - c_i$, incremental (separating) otherwise.
9. If $\gamma < \min\left\{\frac{B_r}{g_r+B_r}, 1 - \frac{k_r\beta_r}{(G_r-W_r-k_r)(1-\beta_r)}\right\}$ and $\gamma \geqslant \frac{B_i}{g_i+B_i}$, A chooses radical research (semi-separating) if $\pi_r\beta_r B_r - c_r > \pi_i\beta_i B_i - c_i$, incremental (separating) otherwise.

We can now prove Proposition 4.3 reported in the main text. First, if $\gamma \geqslant \frac{B_j}{B_j+g_j}$, the subgames have a separating equilibrium where no failed article is submitted. Second, if $1 - \frac{k\beta_j}{(G_j-W_J-k_j)(1-\beta_j)} \leqslant \gamma < \frac{B_j}{B_j+g_j}$ 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 $\pi_j(1-\beta_j)\gamma_j$ (see Table 6), from which point 2 of Proposition 4.3 follows. Third, if $\gamma < \min\left(1 - \frac{k\beta_j}{(G_j-W_j-k_j)(1-\beta_j)}, \frac{B_j}{B_j+g_j}\right)$ before and after the increase, then the subgames are played in semi-separating equilibria. It is immediate to verify that $\frac{\partial q}{\partial \gamma} < 0$, so that an increase in γ leads to a reduction in the checking probability by R. This effect more than compensates for the direct, fraud-reducing effect of an increase of γ, so that the overall probability that a faked article goes unchecked increases, as can be seen from Table 6 above. This proves point 3 of the proposition. Finally, to prove point 4, note the following. From point 3, we know that the probability that a fraud is not discovered is increasing in γ, when the equilibrium is semi-separating. Then, if such a probability is smaller than the corresponding probability associated to pooling equilibria for values of γ close to the lower bound for the existence of semi-separating equilibria, that is, when $\gamma \to 1 - \frac{k_j\beta_j}{(G_j - W_j - k_j)(1-\beta_j)}$, then this probability will always be smaller. The limit value of the probability is equal to $\pi_j(1-\beta_j)\frac{g_j}{g_j+B_j}$, which is smaller than $\pi_j(1-\beta_j)(1-\gamma'')$ since $\gamma'' < \frac{B_j}{B_j+g_j}$.

In order to see how an increase in γ can induce an increase in the probability that a fraud is committed and not caught via a change in the type of research, consider the following numerical example.

Example A.1. Assume $G_r = 10$, $G_i = 6$, $W_r = 6$, $W_i = 3$, $k_r = 2$, $k_i = 1$, $g_r = 2$, $g_i = 1$, $\pi_r = 0.5$, $\pi_i = 0.5$, $\beta_r = 0.4$, $\beta_i = 0.6$, $B_r = 20$, $B_i = 6$, $c_r = 3$, $c_i = 1$. If $\gamma = 0.2$, the equilibrium implies radical research with semi-separating equilibrium since $1 - \frac{k_i\beta_i}{(G_i-W_i-k_i)(1-\beta_i)} = 0.25$, $1 - \frac{k_r\beta_r}{(G_r-W_r-k_r)(1-\beta_r)} = 0.33$, $\frac{B_r}{B_r+g_r} = 0.91$, $\frac{B_i}{B_i+g_i} = 0.86$, and $\pi_r\beta_r B_r - c_r = 1 > \pi_i\beta_i B_i - c_i = 0.8$. If γ increases such that $\gamma = 0.3$, then the equilibrium is with incremental research (and pooling) since $\pi_r\beta_r B_r - c_r = 1 < \pi_i(B_i - \gamma(1-\beta_i)(B_i+g_i)) - c_i = 1.58$. Now, note that, if $\gamma = 0.2$, then the probability that a fraud is not discovered is $\frac{\pi_r\beta_r k_r}{(G_r-W_r-k_r)}\frac{g_r}{B_r+g_r}\frac{1}{1-\gamma} = 0.023$, whereas if $\gamma = 0.3$, the probability is $\pi_i(1-\beta_i)(1-\gamma) = 0.14 > 0.023$.

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