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Incentives for Researchers: A Game-Theoretic Analysis of Scientific Misconduct

Bachelor Thesis

Submitted by

Rebecca Lee Emilie Dietrich

Supervisors: Elisabeth Schulte, Matthias Verbeck

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1. Fraud in Science

Scientists commit fraud. Not only (in)famous cases where these were revealed, but also surveys that aim for undetected fraud as well, document this.

Fanelli (2009) had the great idea to collect and compare all existing studies on scientific misconduct. The meta-analysis shows that between 0.3% and 4.9% of scientists admitted to have at least once fabricated, falsified or modified data or results; this gives a pooled weighted average of 1.97%. While that is the most serious form of misconduct, 33.7% admitted to have engaged in other questionable research practices. The figures for personally observed misconduct are even higher. Especially interesting for this topic is the examination of known cases of misconduct and their discoveries, one survey found that 29% of the cases that respondents personally knew of were never revealed.

A lot of researchers who committed fraud and whose detections later became publicly known are from fields of medical research. These include Woo-Suk Hwang, Eric Poehlman and Jacques Benveniste from (bio)medical research and the psychologists Bruno Bettelheim and Cyril Burt (see Lacetera and Zirulia 2011). This suggests taking a look at the statistics in these fields. John et al. (2012) estimate that 9% of psychologists have falsified data. Fang et al. (2012) examine article retractions in biomedical journals and find that fraud is the main reason with 43.4% of all retracted articles being fraudulent. Only 21.3% were retracted because of errors. Another alarming observation is the amount of times these retracted articles have been cited after were retracted, which is up to more than 750 times (Fang et al., 2012, p. 17032). This is (partly) due to the long time it takes until a fraudulent article is discovered and retracted. This amounts to 32.9 months on average for all retractions, fraudulent articles actually take the longest to be revealed with 46.8 months.

One of the most extreme cases to date is the one of biochemist Emil Abderhalden. He first published his discovery of so-called “defence enzymes“ in 1909; although in 1914 first contradicting results were published, it took until 1998, where Deichmann and Müller-Hill gave the public an impression of the entire extent of rejection, to completely reveal the fraud (Deichmann and Müller-Hill 1998). The scary thing about Abderhalden’s story is not solely the outstandingly long period his theory survived, but the influence it had in the meantime. While „defence enzymes“ were used by various institutes to test a number of things, the most disturbing application was in the concentration camp Auschwitz, where it was essentially used to separate “races“.

It is, therefore, pretty obvious that false published results can be harmful to society. They influence research in a way that causes it to be slowed down (Nosek et al. 2012). New, supposedly promising research fields open up, and this does not only cost the researchers themselves a lot, but also society as a whole. Though the overall harm cannot be quantified as it has numerous effects, some figures for the costs of retracting articles do exist. For example, Stern et al. (2014) calculate the direct financial costs of scientific articles that were retracted due to research misconduct, which is almost 400,000 US-Dollars per article in funds spent on the production of these articles. Freedman et al. (2015) calculate the irreproducibility rate for biomedical research at 50% and estimate that 28 Billion US-Dollars are spent every year on research that is irreproducible.

It should have become apparent by now how important addressing the problem of fraud in science is. The crucial question now is, given that a lot of fraudulent research exists and that frauds are being revealed from time to time, why do researchers commit scientific fraud?

The observation that scientists are prone to misbehavior is not new and may not be surprising to most people, but the question why exactly scientists decide to pervert the truth cannot be answered that easily. First of all, the nature and intrinsic purpose of science is to enlighten and advance humanity with discoveries and inventions. Truth, therefore, can be seen as a necessary condition for science. On the other hand, one could say that it lies in the human nature to deceive and betray. The publication process in science, too, is exposed to these forces.

A helpful tool to analyze the process is game theory. It can provide a theoretical background to determine the incentives researchers have to engage in fraudulent research themselves on the one hand, and to check their colleges' articles on the other hand. Modeling the publication process as a game to fully understand it is a necessary condition for evaluating proposed remedies against fraud.

In this work, I will first shed light on the publication process, as it is not necessarily common knowledge to every economist. Then, I analyze the publication process as a game with the help of Lacetera and Zirulia and the model they developed in their paper "The Economics of Scientific Misconduct" (2011). Considered aspects here are types of research and researchers and the so-called publish or perish imperative. Though Lacetera and Zirulia model the publication process quite extensively, in fact the game consists of four players acting in five stages, they do not consider the audience as a possibly influential factor. I therefore incorporate into my analysis the extensions of Verbeck (2018), who not only models audience size and structure but also approaches science as a public good which can raise the problem of free-riding among readers. After having strived to entirely understand the publication process and the forces at work, I will briefly investigate whether increasing the penalty for scientists who committed fraud, a commonly proposed remedy, could be effective from a game theoretic perspective. Altogether, I want to clarify as precisely as possible how underlying mechanisms work that lead scientists to engage in wrongful activities while (maybe) trying to uncover those of colleagues.

2. The Publication Process

Performing research for one publication typically takes several months (Björk Hedlund 2004). After having conducted the research, which can be own research as well as reviewing another researcher's work, the scientist will put it on paper. This is mostly done in the form of a journal article, a (doctoral) thesis or a book. The first draft, the manuscript, is then sent to a journal in order to be eventually published. The editor of the journal can either accept the manuscript right away and publish it, reject it, or she/he may return it for revision. Assessing the manuscript is usually not done by the editor, but by experts of the same field of research, who thereby engage in a peer review. Peer reviews are usually blind peer reviews, i.e. the identities of the referees are not revealed. These referees, which were picked by the editor, scrutinize the manuscript and return it with suggestions for improvement etc. to the editor. Referees are usually not being paid for their work, they are expected to be motivated enough by their interest as well as concern for their discipline (Engers and Gans 1998). The editor, in turn, does not have to adhere to their evaluations and is mostly interested in accepting the proper amount of papers (Ellison 2002a). Zietman (2017), however, observes a bias towards the selection of positive, eye-catching results.

In the case that the editor has returned the manuscript for revision, probably following the referee(s) recommendation, the author can improve and then resubmit it. Until the revised paper is published in the end it can take an astonishingly long time. Ellison (2002a) observed that accepting a paper for publication takes 20 to 30 months at the top economic journals. He identifies a trend that is neither limited to top journals nor to the field of economics, where articles become longer and are being increasingly revised (Ellison 2002b). But even after acception for publication, papers only enter the „queue for publishing“ (Björk Hedlund, 2004, p. 15), which can additionally defer publication for a whole year. Interested readers can then find the publication available through own subscription or (university) libraries's subscriptions. The relative unavailability due to the high subscription fees has led to more and more initiatives providing "open access“ in the recent past (Zietman 2017).

Scientists are paid by their universities, whose research projects are financed in large parts by public bodies (Congressional Budget Office, 2007). The sales of the publications do not nearly cover the costs of production of research, which accounts for 90% of what creating and publishing a typical journal paper costs (Björk Hedlund 2004).

While the scientific community is a rather global and homogenous phenomenon, consequences of scientific misconduct differ with respect to countries and their legislations. Even in one country, handling misconduct can vary from institution to institution. In general, fraud is not criminalized, at least if no misuse of public funds is involved. In the USA, the biggest producer of research, the Office of Research Integrity (ORI) was founded in 1985 and provides the administrative structures for the regulation of misconduct (Redman Caplan 2005). Universities there are required to have policies about scientific misconduct, which led to the first imprisonment of a researcher who committed scientific fraud (Tilden 2010), who was not the last. In Germany, on the contrary, battling the problem of fraudulent research began only in 1999 with the introduction of a committee that potential whistleblowers can turn to for help (Deutsche Forschungsgemeinschaft, n.d.). As late as 2011, german universities employed integrity officers. Also in 2011, Canada started a Tri-Agency Framework for Responsible Conduct of Research (Panel on Responsible Conduct of Research 2016). The United Kingdom followed in 2012 with a “concordat to support research integrity“ (Universities UK 2012), which universities can voluntarily take part in. In addition to universities taking action, All European Academies (ALLEA), which consists of learned societies, think tanks, or research performing organizations, is committed to research integrity (ALLEA n.d.). The first „European Code of Conduct for Research Integrity“ was published in 2011 and a revised edition in 2017. Primal measures have been adopted in the battle against scientific misconduct and one can see why there exists interest in decreasing the amount of fraudulent research.

3. Game-theoretic Literature on Scientific Misconduct

Research on scientific misconduct is naturally connected to detected cases of fraud, because these make people aware of the problem and lets them assess its scope. Understanding the reasons why scientists misbehave seems quite difficult without game theoretic methods, as the publication process closely resembles a game. It is a tournament in which scientists compete for recognition and fame, funds, job opportunities and publication spots (Stephan 2012). Still, the first approach to understand the underlying mechanisms in the publication process was not done with game theory but with decision theory. As an aspiring economist James R. Wible wondered why economics was not being applied to science, as he described it in 1998. Due to several, at the time recent cases of revealed fraud he then started to economically analyze the publication process with respect to misbehavior. Wible distinguishes two kinds of misconducts which he deals with respectively in two papers he published in 1991 and 1992. Replication failure describes what happens when research findings cannot be replicated due to the incentive structure in science where scientists devote their time to innovative research, which is more rewarding than to carefully record the details of past research, though that is essential for replication. In his analysis on the efficient use of time Wible developed an allocation-of-time-model based on Becker’s model (1965, 1971). The model suggests that a rational scientist produces both replicable and unreplicable research, depending on the opportunity costs of both activities. Fraud, being the other form of misconduct according to Wible, is a choice under uncertainty, with which one intentionally deceives others. To account for this different optimization problem, Wible applied Ehrlich’s (1973) model of decision making under uncertainty, which is part of the economics of crime literature, to fraud in science. The model, which is based on another model of Becker (1968), determines the optimal allocation of time between legitimate and fraudulent research. Dependent on the income of activities, the penalty for fraud and the probability that fraud is detected, Wible concludes that there will always be fraud, but much less than replication failure. The readers, who may detect fraud in scientific articles, are modeled solely as a probability distribution. This is referred to as the „Robinson Crusoe Fallacy“ (Tsebelis, 1989, p.77), a term invented by George Tsebelis, who saw the important mistakes resulting out of an inadequate use of the concept of probability. Applying his thoughts, the readers should have been modeled as rational players rather than just a probability. Tsebelis describes what is known as an inspection game, he uses a game theoretic approach in analyzing how to deter crime. In short, in an inspection game the inspected person can decide whether to infringe a rule, the inspector can rationally decide to inspect, which would lead to the discovery of the infringement, or he can refrain from inspecting. The inspected person would of course like to disobey the rules without getting caught. In equilibrium, both play mixed strategies, so that rules get broken, sometimes unnoticed. The important finding, from modeling the inspector as a rational player rather than as a probability distribution, is, that increasing the penalty would only alter the inspectors behavior, in a way that there is less inspection. The only effective policy in deterring crime is raising the inspectors incentives to engage in costly inspecting, while this does not affect the amount of inspections, it will decrease the amount of crime. Inspection games are especially useful for the understanding of scientific fraud, as they describe a lot of features of the publication process and employ game theory.The methods employed and results achieved by Wible and Tsebelis can be considered the foundation for the economic analysis of scientific misconduct.

Lacetera and Zirulia (2011) were the first ones to use game theory to depict and understand the publication process. They constructed a dynamic game in order to find out which types of researchers, high- or low-reputation, are more likely to engage in what type of research, incremental or radical, and commit scientific fraud. Moreover they evaluated the effect of common policy proposals. The game consists of five stages with four players; the author, nature, an editor and a reader. Particular assumptions are that nature and the editor decide based on probability distributions, so only the author and the reader are models as rational players, and that readers and editors detect fraud with certainty when checking. Fraud can only be committed when the research project failed, which is decided by nature. Lacetera and Zirulia found that independent from the equilibria, fraud always occurs. Furthermore they claim to have found that incremental research is more likely to be fraudulent, but fraudulent radical research is more likely to be detected. Also high-reputation scientists are more likely to commit fraud while average-scientists are more likely to get caught. The considered policies have ambiguous, none or negative effects on the occurrence of fraud. The only way to effectively deter crime would be editors checking articles before publication with a high probability.

A few years later, Lacetera and Zirulia developed together with Kiri a slightly simpler model of the publication game based on different assumptions. It places more attention on enhancing the reliability of scientific results by altering the incentives of scientists to check each others work. Their game involves only two players, a scientist and a colleague, who can decide to check the scientist's research. Unlike in Lacetera and Zirulia (2011), where nature decides with probability on the success of a project, here the quality of the paper is determined endogenously, depending on the effort spent by the scientist. An important difference here is the fact that low-quality, as opposed to the only other alternative high-quality, comprises not only outright fraud. Everything that contains mistakes or a significant lack of robustness is considered to be of low-quality. The game is one of imperfect information too, the colleague does not observe the effort choice. A notable aspect to mention here is that low effort leads to high-quality with some probability, while high effort always leads to high quality. Other remarkable features of the model are the expansion of the analysis by adding another colleague to better represent the property that science is a community and by infinitely repeating the game. The results are that in larger communities of inspectors crowding-out of incentives to check occurs, and that in a repeated interaction the scientists can collude, so that neither effort nor verification might take place. In general, Kiri et al. found same as Lacetera and Zirulia that in any equilibrium low-quality research will be present. Their evaluation of possible policies to further replication, though, is more promising.

Gall and Maniadis (2018) are so far the only ones to have found an equilibrium in which no misconduct occurs, but without the presence of an inspector. They as well took their turn at analyzing the publication game and they employed some interesting aspects. First of all, subject of their investigation are questionable research practices (QRP), which they classify into mild and severe QRP. So unlike both, Lacetera and Zirulia and Kiri et al., they include fraud such as the fabrication of data as well as mild misconduct e.g. practices such as rounding off p-values. QRP can be deployed by providing effort, where high effort leads to severe QRP. The probability to get one's article published then depends not only on the own effort but also on the competition's effort. Gall and Maniadis therefore incorporate into their analysis the intensity of competition and view misbehavior of scientists as a best response to their peers' respective misconduct. A checking player is not modeled here, the game is unlike the others not a dynamic, sequential game, since it consists of one stage in which the researchers decide simultaneously about their effort level. Of the four possible equilibria one features no QRP, one mild, one severe QRP and in the fourth one mixed strategies are played. It has the interesting property that increasing the effort costs for the two forms of QRP has different effects, respectively. Increasing the cost to perform mild QRP, through transparency requirements for example, decreases the overall amount of misconduct, because without mild QRP, severe QRP is not a reasonable option. Increasing the cost of severe misconduct, on the other hand, increases overall misbehavior. Like Lacetera and Zirulia and Kiri et al., Gall and Maniadis also investigate the effects of the pressure to publish on scientists' behavior. They find that a higher reward for publication increases severe QRP, but decreases mild QRP, so that overall misconduct is reduced. As an extension of their analysis researchers with different costs are considered, but this does not necessarily change the results.

The newest research on scientific misconduct was done by Verbeck (2018), who combines several features from Lacetera and Zirulia and Kiri et al. The basic model is similar to Lacetera and Zirulia's, but it consists of less stages and less players, only nature, who decides about the success of the research project, the author and readers are modeled here. Following Kiri et al., who already added another player to account for the scientific community, Verbeck considers a whole audience of size n. In his model, each reader detects fraud only with a probability, which is different form Lacetera and Zirulia and Kiri et al, where checking leads to the discovery of fraud with certainty. In equilibrium fraud occurs with positive probability. The effect of audience size is ambiguous, as for more readers the overall probability of detection increases, but at the same time the problem of free-riding becomes prominent, because detecting fraud constitutes a positive externality for the scientific community. In order to model the readership as realistically as possible Verbeck adds even more competition by spreading the gain from fraud detection among the successful readers, which further weakens the quality of research. Besides audience size, Verbeck also considers audience structure and changes the game so that some readers have higher incentives to check than others. This ideological diversity has positive effects on both occurrence and detection of fraud. Verbeck furthermore investigates the possible strategy of authors to increase readership size in order to decrease the amount of checking readers due to free-riding. This has rather negative effects on the quality of scientific research. Like Lacetera and Zirulia, Verbeck as well examines the case of a checking editor, whose presence might crowd out incentives for readers to check and therefore increase the volume of wrongful publications. Apart from the deception game, in which scientists commit fraud, Verbeck moreover considers the possibility that some errors in published research findings are genuine mistakes. In this approach, which is similar to Wible (1992) and Kiri et al. (2015), the author can always, after conducting research, decide to invest care and confirm the obtained results. Unlike Kiri et al., where low effort can also lead to high quality, only employing care leads to the detection of errors, and this with certainty. In one of the four equilibria of the game, no fraud occurs. All in all, Verbeck employs a lot of new ideas, with which he fills gaps in the research on scientific misconduct.

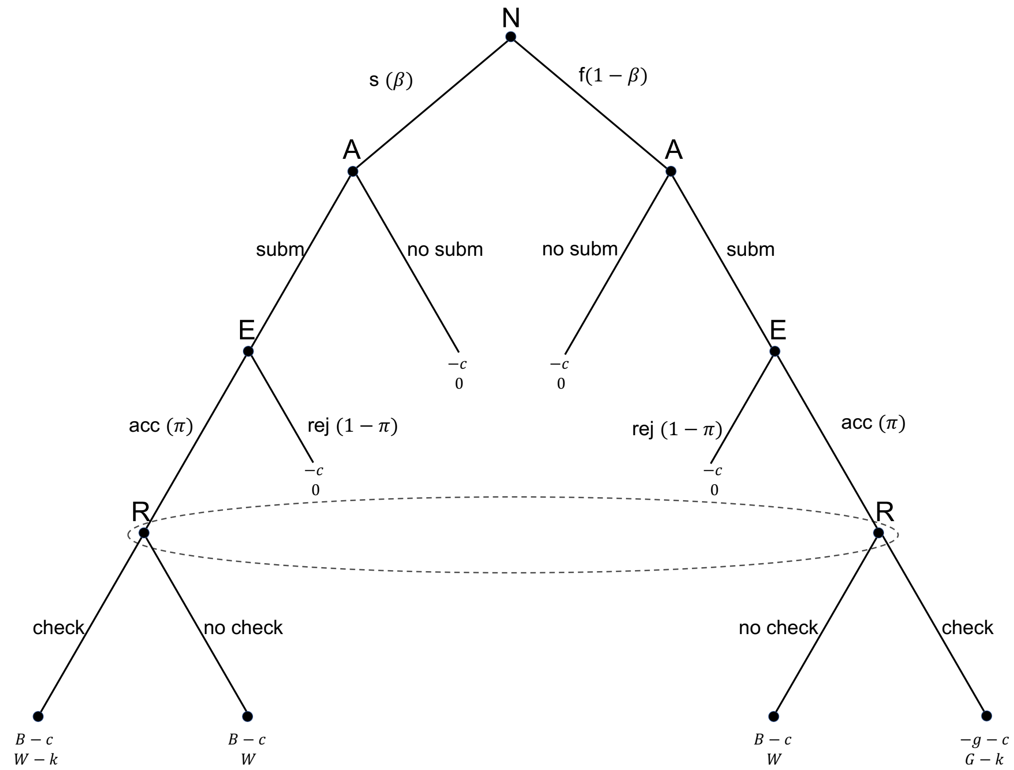
4. The Publication Game: Two Scientists

Policies to reduce scientific fraud are frequently demanded. Before one can even attempt to develop some, it is necessary to take an extensive look at the publication process and try to understand its underlying mechanisms. This necessity to profoundly investigate scientists' incentives has been recognized especially by Lacetera and Zirulia. In my attempt to capture the publication process as realistically as possible, I therefore use their model for explanation. Later on also the model of Verbeck will be used to further the analysis.

4.1 The Game

The publication process is a sequential game that consists of four stages, as depicted in figure 1. In the first step the success or failure of a research project is determined. Then the author decides whether to submit the paper to a journal whose editor decides upon its publication. In the last stage another scientist can decide whether to check the published results for errors, inconsistencies, etc.

Figure 1: Game tree publication game



Source: Based on Lacetera and Zirulia (2011)

The two rational players in this game are the two scientists, the author A and the reader R. The author can choose between submitting and not submitting his/her research results independent from the success of the project. That means that in case of failed research, submitting requires committing fraud. The author has to make the research look like a success, otherwise there is no point in submitting. A paper that is published and fraud is not detected by the reader is called a permanently published paper. For a permanently published paper the author receives a payoff of $B \in (0, +\infty)$. For the production of a paper he/she incurs cost $c \in (0, +\infty)$. In the case that the paper is revealed as fraudulent after publication, $g \in (0, +\infty)$ denotes the damage *A* experiences.

The reader decides in the last stage whether to check a published paper or not. R is assumed to find fraud, if present, with certainty. This would yield him/her a benefit of $G \in (0, +\infty)$, the costs for checking are denoted by $k \in (0, +\infty)$. A paper can be permanently published, if R does not check or if R checks a non-fraudulent paper. The effect of a permanently published paper on R can be positive or negative, this is described by $W \in (-\infty, +\infty)$.The editor E is solely modeled as a probability distribution that is known to all players. With probability $\pi \in (0,1)$ E will accept the paper for publication.

The game is originally one of incomplete information. The reader does not know which type of author he/she is confronted with, one whose project was successful or one whose project has failed, hence the two decision nodes constitute an information set for player R.[1] The reader can only form beliefs about the type of player. By introducing a player nature N, who chooses players from a set of possible players, the game of incomplete information can be transformed into a game of complete, but imperfect information.[2] The game can then be represented in extensive form. The probability that a research project is successful is $\beta \in (0,1)$, which is common knowledge. So unlike Kiri et al. and Wible, Lacetera and Zirulia assume that A cannot influence the success of his/her project, that also means that A is assumed to not make mistakes. The model is supposed to be rather intuitive following a description of the publication process. However, certain assumption will be discussed later.

4.2 Equilibria

Three types of perfect bayesian equilibria are possible here, separating, pooling and semi-separating equilibria. If there exists a separating equilibrium, it must be that in case of success the author submits and in the case of failure he/she does not, since submitting clearly dominates not submitting if the project is successful. After A's move the reader updates his/her beliefs such that submitting conveys the message that the project was successful. For R then not checking dominates checking. This gives A an incentive to deviate from the separating strategy in case of failure. Therefore, no separating equilibrium exists.

If there exists a pooling equilibrium, A must always submit. R cannot update his/her beliefs. Not checking is a best response if $\beta\pi W + (1-\beta)\pi W \geq \beta\pi(W-k) + (1-\beta)\pi(G-k)$, i.e., the expected payoff from not checking is at least as high as the expected payoff from checking. This can be transformed into $G \leq W + \frac{k}{1-\beta}$, if this condition holds, the pooling equilibrium will be played. Since A has no incentive to deviate from pooling on submitting, the pooling equilibrium exists in the form (subm, subm; no check), which describes the A's action if the project was successful, if the project was a failure and the action of R.

In a semi-separating equilibrium, one type of A plays a pure strategy while the other plays a mixed strategy. R will then only be able to imperfectly update his/her beliefs about A's type. If such an equilibrium exists here, it has to be that if the project is successful, A will always

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[1] There exists also an information set for player *E*, but since he/she is not a rational player and chooses an action according to a probability distribution, this information set is not of further interest.

[2] This is called the Harsanyi-transformation, developed by John C. Harsanyi (1967).

submit (pure strategy) and that if the project fails A randomizes over submitting and not submitting (mixed strategy) in order to make R indifferent between checking and not checking. After the editor accepts the paper and it is published, the reader does not know whether the research project was successful or not and the paper is therefore fraudulent. R can only form beliefs about the type of paper. R's belief that a published paper stems from a successful project is $\mu(success\,|\,pub) = \frac{\pi\beta}{\pi\beta + \pi p(1-\beta)}$, where $p \in (0,1)$ denotes the probability that A will choose submit in case of a failed project. R's belief that a published paper is based on a failed project is $\mu(fail\,|\,pub) = \frac{\pi p(1-\beta)}{\pi\beta + \pi p(1-\beta)}$. Then R's expected payoff of checking is

$E_R(check, pub) = \frac{\pi\beta}{\pi\beta + \pi p(1-\beta)}(W-k) + \frac{\pi p(1-\beta)}{\pi\beta + \pi p(1-\beta)}(G-k)$, $E_R(nocheck, pub)$ follows analogously. Equating the two and rearranging yields $p = \frac{\beta}{1-\beta}\frac{k}{G-W-k}$, the probability that A will submit when the project failed. A's action thus depends on the chance of success of the research project, the cost to check the paper, and the benefits for R if either the paper is revealed as fraudulent or not. Interesting here is that A's decision does not depend on A's own possible payoffs or costs but on the reader's. This exceptional effect is due to the dynamic character of the game, where one player's (expected) behavior influences that of the other's. Since p has to be smaller than 1, $G > W + \frac{k}{1-\beta}$ has to be true.[3] In order for the equilibrium to hold, A cannot have an incentive to deviate, i.e., R has to make A indifferent between submitting and not submitting with randomizing over checking and not checking. With probability $q \in (0,1)$ R will check the paper. The expected payoff that A receives from submitting a fraudulent paper in the case that the research project turned out to be a failure is $E_A(subm\,|\,fail) = (1-\pi)(-c) + \pi[q(-g-c) + (1-q)(B-c)]$. Equating this with $E_A(no\ subm\,|\,fail) = -c$ yields $q = \frac{B}{B+g}$. As before, the decision depends on the other player's payoffs, here the benefit A derives from permanent publication and the disutility if caught cheating. Noteworthy here is that while A's action in the case of a failed project depends on the probability of this project's success, R, who is not aware of the project's success, does not incorporate into his/her decision the probability that the project succeeds or fails. For the reader only the author's incentives matter. This type of equilibrium thus shares a lot of features with inspection game as described by Tsebelis (1989). The semi-separating equilibrium is of the form (subm, subm with $p = \frac{\beta}{1-\beta}\frac{k}{G-W-k}$; check with $q = \frac{B}{B+g}$).

Which equilibrium will be played depends on the relation of G to $W + \frac{k}{1-\beta}$. If G is higher, the semi-separating equilibrium is played, where A does not necessarily submit a fraudulent paper and R can check. If G, however, is lower, the pooling equilibrium will be played and A would always submit a paper and would never get caught for committing fraud. An important result is that although there is less fraud in the semi-separating equilibrium, misconduct oc-

[3] G also has to be higher than 0, from which it follows that G>W+k. Since k<k/(1-ß), the inequation stated above constitutes the binding condition.

curs in every equilibrium. Lacetera and Zirulia conclude that the pooling equilibrium will be played if the benefit from fraud detection G is low, the benefit, W, from not checking and the cost k to check are rather high, and the probability that a research project is successful is high. Then the readers will not check, because the expected payoff of scrutinizing the paper does not cover the cost, so authors can always, without incurring any risk, submit their fraudulent papers. The probabilities derived are presented in table 1.

Table 1: Probabilities of occurrence and detection of fraud

	Pooling equilibrium (subm, subm; no check)	Relation	Semi-separating equilibrium (subm, subm with $p = \frac{\beta}{1-\beta}\frac{k}{G-W-k}$, check with $q = \frac{B}{B+g}$)
Condition	$G \leq W + \frac{k}{1-\beta}$		$G > W + \frac{k}{1-\beta}$
P(fail,subm)	$1-\beta$	>	$(1-\beta)p = \frac{\beta k}{G-W-k}$
P(fail,subm,acc)	$\pi(1-\beta)$	>	$(1-\beta)p\pi = \frac{\pi\beta k}{G-W-k}$
P(fail,subm,acc,no check)	$\pi(1-\beta)$	>	$(1-\beta)p\pi(1-q) = \frac{\pi\beta k}{G-W-k}\frac{g}{B+g}$
P(fail,subm,acc,check)	0	<	$(1-\beta)p\pi q = \frac{\pi\beta k}{G-W-k}\frac{B}{B+g}$
P(success,subm,acc,check)	0	<	$\beta\pi q = \frac{\pi\beta B}{B+g}$

4.3 Types of Research

In order for the model to resemble the research process more closely, Lacetera and Zirulia introduce another stage to the game. A full representation of the new game can be found in figure 2 in the appendix. In the first stage the scientist can now choose to perform radical or incremental research. Radical research can lead to the discovery of major innovative findings. While incremental research can lead to only rather small advancements, it is more likely to be successful ($\beta_r \leq \beta_i$). Radical research yields a higher benefit ($B_r \geq B_i$) if permanently published, but is also more costly to perform ($c_r \geq c_i$) as well as to check ($k_r \geq k_i$). Also the other parameters can now differ, so that the relation of the probabilities as stated in table 1 might change. One could expect that there is more fraud in radical research, for example due to the high sunk cost if the project fails and the higher benefit. To find out whether this notion proves true, the extended game has to be solved. The equilibria identified before are now subgame-perfect equilibria and the equilibria of the whole game can be found by backward induction. A chooses the type of research that gives the highest expected payoff. In a pooling equilibrium, where A always submits and R never checks, the expected payoff is

$\beta[\pi(B-c)+(1-\pi)(-c)]+(1-\beta)[\pi(B-c)+(1-\pi)(-c)]$, which is $\pi B - c$. In a semi-separating equilibrium A submits when the research is successful, if the research project failed, A is indifferent between submitting and not submitting. Because not submitting gives A a net payoff of $-c$, submitting yields this as well. R checks with probability q. The expected payoff of A in a semi separating equilibrium can therefore be described by: $\beta[\pi(q(B-c)+(1-q)(B-c))+(1-\pi)(-c)]+(1-\beta)[p(-c)+(1-p)(-c)]$,which is $\pi\beta B - c$. Conditional on the parameter set and which expected payoff is higher, A will decide between radical and incremental research. The equilibria of this extended game are described by a four-tuple consisting of i) the chosen type of research ii) the chosen action of A if the project is successful iii) the chosen action if the project failed and iv) the chosen action of R.

Table 2: Equilibria of extended game (type of research)

Conditions for equilibrium of subgame	Conditions for type of research	Equilibrium	Subgame-perfect equilibrium
$G_r \le W_r + \frac{k_r}{1-\beta_r}$, $G_i \le W_i + \frac{k_i}{1-\beta_i}$	a) $\pi_r B_r - c_r > \pi_i B_i - c_i$ b) $\pi_r B_r - c_r \le \pi_i B_i - c_i$	a) (r; subm, subm; no check) b) (i; subm, subm; no check)	a) Pooling b) Pooling
$G_r \le W_r + \frac{k_r}{1-\beta_r}$, $G_i > W_i + \frac{k_i}{1-\beta_i}$	a) $\pi_r B_r - c_r > \pi_i \beta_i B_i - c_i$ b) $\pi_r B_r - c_r \le \pi_i \beta_i B_i - c_i$	a) (r; subm, subm; no check) b) (i; subm, subm with $p_i = \frac{\beta_i}{1-\beta_i}\frac{k_i}{G_i - W_i - k_i}$; check with $q_i = \frac{B_i}{B_i + g_i}$)	a) Pooling b) Semi-separating
$G_r > W_r + \frac{k_r}{1-\beta_r}$, $G_i \le W_i + \frac{k_i}{1-\beta_i}$	a) $\pi_r \beta_r B_r - c_r > \pi_i B_i - c_i$ b) $\pi_r \beta_r B_r - c_r \le \pi_i B_i - c_i$	a) (r; subm, subm with $p_r = \frac{\beta_r}{1-\beta_r}\frac{k_r}{G_r - W_r - k_r}$; check with $q_r = \frac{B_r}{B_r + g_r}$) b) (i; subm, subm; no check)	a) Semi-separating b) Pooling
$G_r > W_r + \frac{k_r}{1-\beta_r}$, $G_i > W_i + \frac{k_i}{1-\beta_i}$	a) $\pi_r \beta_r B_r - c_r > \pi_i \beta_i B_i - c_i$ b) $\pi_r \beta_r B_r - c_r \le \pi_i \beta_i B_i - c_i$	a) (r; subm, subm, subm with $p_r = \frac{\beta_r}{1-\beta_r}\frac{k_r}{G_r - W_r - k_r}$; check with $q_r = \frac{B_r}{B_r + g_r}$) b) (i; subm, subm with $p_i = \frac{\beta_i}{1-\beta_i}\frac{k_i}{G_i - W_i - k_i}$; check with $q_i = \frac{B_i}{B_i + g_i}$)	a) Semi-separating b) Semi-separating

In this game-theoretic model only one of the eight equilibria will be played. This is, however, not very useful for making statements about the real world. Lacetera and Zirulia now implicitly assume the case of a scientific community, where parameters differ from field to field, scientist to scientist, etc. It could be the case that, although in one parameter set that decides on the equilibria of the subgames, the choices of scientists on radical and incremental research might differ. For example, production costs and benefits from publications can differ among scientists even in the same field. It is therefore implicitly assumed that in the four parameter sets both types of research are conducted. The second and the third parameter set now constitute interesting cases. There it is possible that the observed cases of fraud are not representative of the overall amount of committed fraud. To be more precise, the type of research that is more likely to be fraudulent and the type of research that is more likely to be caught if fraudulent do not necessarily match.

In the second parameter set a pooling equilibrium for the radical research would be played and a semi-separating equilibrium for the incremental research. The probability that a published fraudulent paper gets caught is zero for radical research, because in a pooling equilibrium the reader does not check. The probability for published fraudulent incremental research to be revealed is $\frac{B_i}{B_i + g_i}$, which is above zero and therefore higher. So only fraud in incremental research will become public. The probability that a research project failed but is still submitted as a fraudulent paper, on the other hand, can be higher for radical research, if the inequality $(1 - \beta_r) > \frac{\beta_i k_i}{G_i - W_i - k_i}$ holds.[4] So it is possible that a lot more fraud is actually committed in radical research, while fraud is only detected in incremental research. This would greatly mislead policies aimed at reducing fraud. The possibility that more fraud exists in radical research might correspond to one's expectations. But this is only true for a certain set of values of parameters. For the third set it is just the other way around. There, incremental research is more likely to be fraudulent, while radical research is more often discerned as fraudulent. Therefore it is implausible that Lacetera and Zirulia extrapolate their findings for the third set of parameters and present them as results that are generally valid (Lacetera and Zirulia, 2011, p. 571-572). This could be considered as fraud in research on fraud, as it is definitely overselling of results. The interesting and surprising result, that the observed fraud can be misrepresentative in terms of types of research, though, holds true.

4.4 Types of Researchers

Lacetera and Zirulia further extended their model to account for the impact of the career of researchers. Two types are introduced, a high-reputation scientist, who is rather renowned

[4] The probability of acceptance is not included here, because it is uncertain, if the probability for radical research is higher. The literature concerning this is conflicting. Some highlight the pressure to publish interesting results (e.g. Zietman 2017), others describe the peer-review process as harmful to innovative ideas (e.g. Starbuck 2003).

and has already published a lot of papers, and a low-reputation scientist, who is either at the beginning of his/her career or is just not that highly esteemed by peers. He/she, therefore, has more to gain from an additional publication, so that the benefit for the low-reputation scientist, B^l, is higher than B^h, the high-reputation scientist's gain. The latter is, though, more likely to successfully produce new research ($\beta^h > \beta^l$), and has a higher chance of acceptance at the journal ($\pi^h > \pi^l$). But he/she also has more to lose in the case of detected fraud ($g^h > g^l$). The question now is, if these payoff variations have an impact on the equilibria of the game and on the probabilities of fraud production and detection.

Both scientists are assumed to choose the same type of research, radical or incremental. So, the parameters are the same with respect to the type of research and the subscripts can be left out. The equilibria are now decided by $W^h + \frac{k}{1-\beta^h}$ in relation to G^h and the relation of $W^l + \frac{k}{1-\beta^l}$ to G^l. Since $\beta^h > \beta^l$, $W^h + \frac{k}{1-\beta^h} > W^l + \frac{k}{1-\beta^l}$ is true for a lot of values of k and W, respectively. In that sense, the chances that the equilibrium is pooling is higher for the high-reputation scientist than for the low reputation scientist. Accordingly, a semi-separating equilibrium is more likely for the low-reputation scientist. Assuming that these will be played, then high-reputation scientists will never be caught committing fraud, because in a pooling equilibrium the reader does not check. In a semi-separating equilibrium the probability that a reader checks is positive and increases with higher benefits for A and decreases with higher punishments. Since B^l is high and g^l is low in relative terms, the probability that a low reputation scientist's work is revealed as fraud is even higher. However, the probability that a paper is fraudulent, published and not caught may be greater for high-reputation scientists and not their low-reputation peers, though they are the ones getting caught committing fraud. This is the case if $\pi^h(1-\beta^h) > \frac{\pi^l \beta^l k}{G^l - W^l - k} \frac{g^l}{B^l + g^l}$, which is likely since g, π and β are lower for low-reputation scientists and B is higher. Though $(1-\beta^h)$ is also low, the inequality holds true for a large set of values of G^l, W^l and k. Therefore, as for the type of research, a mismatch concerning observed fraud and actual fraud might also exist with regard to the type of researchers. This would be such that unknown scientists are more often caught publishing fraudulent papers, while esteemed and renowned scientists actually commit more fraud.

This finding is rather easy to imagine. Aspiring researchers might anticipate their work to be read more thoroughly and therefore refrain from misbehaving, while already successfully established scientists know they will not be scrutinized like that, because of their higher probability of success, the higher penalty and the lower benefit, and therefore can "afford" fraud. However, in theory this is only a likely possibility. Again, Lacetera and Zirulia could be accused of exaggerating, as they state this finding to be always true. But also again, the proposition that observed fraud can be misrepresentative, this time in terms of types of researchers, is confirmed.

4.5 Pressure to Publish

There exists a perception in the scientific community as well as in the part of the general public that concerns itself with science, that researchers are under high pressure to publish and that this is a reason why fraud is committed. Lacetera and Zirulia thus extend their model once more to depict the publication process even more closely and to find out what the effects of a pressure to publish are.

A pressure can be modeled by modifying the gains from publication for both the author and the reader. Since a publication is more important for the career of a scientist, the author is assumed to receive a higher benefit, B, if he/she publishes a paper. The reader, who can be a rivaling colleague, is therefore likely to experience a loss from the others' publications. The benefit from a publication, W is therefore reduced, if the pressure intensifies. For detecting fraud, though, the reader receives more than before and G increases. These three parameters have an impact on the game only in the semi-separating equilibrium. There, the higher G and the lower W both reduce $p = \frac{\beta}{1-\beta}\frac{k}{G-W-k}$, the probability that A submits, if the project failed, a therefore fraudulent paper. Consequently, the probability that a fraudulent paper is published at all as well as the probability that it stays unrevealed decreases. G and W also alter the parameter space in which the equilibria can take place in such a manner that the parameter space for the semi-separating equilibrium grows. A higher pressure to publish could therefore induce a move from a pooling to a semi-separating equilibrium.

A higher benefit for the author, B, increases, $q = \frac{B}{B+g}$ the probability with which R checks papers for fraud. The probability of undetected fraud thus decreases in a semi-separating equilibrium. If the altered parameters actually have effects on the probabilities, depends on the equilibrium played after the rise in pressure.

If the equilibrium is semi-separating before and after the increase, the probability of undiscovered fraud decreases, since authors submit less fraudulent research and readers check more. If the equilibrium, on the other hand, is pooling in both states, the probabilities do not change, because authors always submit and readers never check in this type of equilibrium. But, if the equilibrium moves from pooling to semi-separating due to the changes in G and W, the probability decreases from $\pi(1-\beta)$ to $(1-\beta)p\pi(1-q)$ for the existence of undetected fraud. This is due to the fact that now authors do not necessarily submit fraudulent work and readers sometimes check. In this simple analysis an increase in the pressure to publish would either have no effect or a positive one, where both authors and readers behave “better“. But if now the extension of distinguishing between two kinds of research is added, the results may change. Since all parameters can have different values for the respective types of research, the probabilities differ, too. Even if the type of subgame-perfect equilibrium does not change, an increase in B_r or B_i can lead to a different type of chosen research. In a pooling equilibrium then the probability of success of a project can alter the amount of fraudulent papers produced. Whereas in a semi-separating equilibrium both p and q might be higher or lower depending on the values of the parameters. A change in the type of subgame-perfect equilibrium then can also have both positive and negative effects.

All in all, a pressure to publish does not necessarily promote fraud, it can have the opposite effect as well, where it not only decreases the amount of produced but also the amount of overall permanently published fraud. Whether the persistent belief that the pressure is a culprit is justified is difficult to say, since the game only models possibilities. The claim that a pressure will always have a strictly negative influence, however, can be denied.

5. Including the Rest: A Scientific Community

Lacetera’s and Zirulia’s model has provided a lot of valuable insight so far. One of the main findings is that science is not necessarily self-correcting, because fraud always occurs in their equilibria and then again, if not revealed as faked incorrect results survive. The analysis also allows for the rejection of the belief that only radical research is fraudulent, both, radical and incremental research can be fraudulent. The interesting discovery is that there can be a mismatch between observed and committed fraud. This is also possible with regard to the type of researchers, low-reputation and high-reputation scientists. The belief that only low-reputation scientists commit fraud can be rejected, it is likely that they are just getting caught more often, while high-reputation scientists are actually producing most of the faked research. Another common misbelief revealed is the one that pressure always causes fraud, it can have fraud-deterring effects too, depending on parameters. So far so good, one thing that is missing from Lacetera’s and Zirulia’s examination is the size of the readership. Though sometimes implicitly assumed in order to make general statements, the potential effects within a group of readers have not been addressed. At this point Verbeck’s research fills a crucial gap as it provides a framework to analyze the interaction within the scientific community.

5.1 The Game

The publication process is modeled very similar to Lacetera and Zirulia. The structure of the game as depicted in figure 1 is the same, though there is one stage less, the editor is omitted. A full representation of the game can be found in figure 3 in the appendix. There are at least two readers and if one discovers fraud this is assumed to become common knowledge right away. Unlike Lacetera and Zirulia (and Kiri et al.), a reader that checks then detects fraud only with probability $\tau \in (0,1)$, the overall probability of fraud detection for a paper, $1-(1-\tau)^n$, then increases with the amount of checking readers. The payoffs are slightly modified. First of all the author does not incur a cost for conducting research. The benefits from a permanent publication for the author as well as the reader depend on the truthfulness of the paper. A receives benefit B for a truthful paper and benefit B' for a fraudulent paper, with $B \geq B' > 0$. This can be explained that in the case of a fraudulent publication the author only gets a benefit for his/her career, while in the case of a truthful publication the author furthermore gets a benefit from his/her intrinsic motivation to advance science. If a published paper, however, is revealed to be fraudulent, the author experiences a damage $g \in (0,+\infty)$. The reader in turn receives benefit $G \in (0,+\infty)$ for detecting fraud. Checking for fraud generates cost $k \in (0,+\infty)$. A non-fraudulent paper that is permanently published can positively or negatively affect a reader, depending on possible conflicts with the reader's own scientific career. This payoff is denoted by $W \in (-\infty,+\infty)$. If the permanently published paper is fraudulent the reader incurs a loss $W'(-\infty,0)$, because the reader might build up on the faked results, which is presumably a scientific cul-de-sac. Though both reader's payoffs can be negative, it holds that $W \geq W'$. So, since checking readers detect fraud only with a probability, the payoff to A and R in the case a fraudulent paper is submitted depends on the probability τ and on the amount of checking readers n. The expected payoff of A for submitting a fraudulent paper, that is checked with a reader's individual probability $q_i \in (0,1)$, is $E_A(subm\,|\,fail) = (1-(1-q_i\tau)^n)(-g) + (1-q_i\tau)^n B'$. A single reader's expected payoff from checking a paper depends on the other possibly checking readers and is $E_R(check) = \beta(W-k) + (1-\beta)[\tau(G-k) + (1-\tau)(1-q_i\tau)^{n-1}(W'-k)]$.

5.2 Equilibria

The game is solved for all perfect Bayesian equilibria, in which all readers check with the same probability.[5] Again, these can be separating, pooling or semi-separating, where the author and the readers can either play pure or mixed strategies. If there exists a separating equilibrium, it must be that in case of success the author submits and in the case of failure he/she does not, since submitting clearly dominates not submitting if the project is successful. After A's move the reader updates his/her beliefs such that submitting conveys the message that the project was successful. For each reader then not checking dominates che-

[5] If readers are allowed to differ in their individual checking probability, there exist many more equilibria, these are then such that they are asymmetric in regard to the strategies of the readers. Here only "symmetric" equilibria are examined.

cking. This gives A an incentive to deviate from the separating strategy in case of failure in order to receive B instead of nothing. Therefore, like in the model of Lacetera and Zirulia, no separating equilibrium exists.

But there could be a pooling equilibrium where exactly that happens, that the author always submits and the readers do not check. Not checking dominates checking if the expected payoff from checking is not higher than the expected payoff from not checking, so $\beta W + (1-\beta)W' \geq \beta(W-k) + (1-\beta)[(\tau(G-k) + (1-\tau)^n(W'-k)]$, which can be transformed into $G \leq W' + \frac{k}{(1-\beta)\tau}$. Because A does not have an incentive to deviate from submitting, since this is the best possible outcome for him/her, this pooling equilibrium exists in the form (subm, subm; no check), which indicates A's action when the project succeeded, when the project failed, and the readers' action, respectively.

Since there are several readers as opposed to one, they might employ mixed strategies in order to make each other indifferent. Therefore, a pooling equilibrium in which readers check with some probability can exist. Again, it has to be such that the author always submits. The reader then chooses the individual checking probability $q_i \in (0,1)$ to make other readers indifferent between checking and not checking. Equating the expected payoffs yields $\beta(W-k) + (1-\beta)[\tau(G-k) + (1-\tau)(1-q_i\tau)^{n-1}(W'-k)] = \beta W + (1-\beta)(1-q_i\tau)^{n-1}W'$ which can be solved for $q_i = (1 - \sqrt[n-1]{\frac{1}{W'}(G - \frac{k}{(1-\beta)\tau})})\frac{1}{\tau}$. From q_i being higher than zero, it follows that $G > W' + \frac{k}{(1-\beta)\tau}$.[6] For the equilibrium to hold, also A's strategy has to yield the highest expected payoff, so for submitting fraud to be a rational action it must hold that $(1-(1-q_i\tau)^n)(-g) + (1-q_i\tau)^n B' \geq 0$. Inserting checking probability q_i yields the condition $G \leq W'(\frac{g}{B'+g})^{\frac{n-1}{n}} + \frac{k}{(1-\beta)\tau}$. The players' strategies are rational actions so that no one has an incentive to deviate and a second pooling equilibrium exists in the form (subm, subm; check with $q_i = (1 - \sqrt[n-1]{\frac{1}{W'}(G - \frac{k}{(1-\beta)\tau})})\frac{1}{\tau}$).

The last possible equilibrium is a semi-separating one in which both the author and the readers employ mixed strategies. It has to be such that if the project is successful, the author always submits, and if it failed the author randomizes over submit and not submit. Conversely the readers randomize over checking and not checking and choose individual checking probability $q_i \in (0,1)$. The author is indifferent between submitting and not submitting if $(1-(1-q_i\tau)^n)(-g) + (1-q_i\tau)^n B' = 0$ which can be solved for $q_i = (1 - \sqrt[n]{\frac{g}{B'+g}})\frac{1}{\tau}$.

Because dependent on the success of research, A chooses different actions, in the case of a

[6] The condition that q has to be smaller than 1 is still valid, but the subsequent condition for G is not binding and therefore not mentioned here.

successful research project A chooses the pure strategy submit, and in case the research project failed A chooses to randomize with $p \in (0,1)$. Consequently, the readers are not able to update their beliefs perfectly. R's belief that a published paper is based on successful research is $\mu(success|pub) = \frac{\beta}{\beta + p(1-\beta)}$ and $\mu(fail|pub) = \frac{p(1-\beta)}{\beta + p(1-\beta)}$ for failed research, in which case the paper is fraudulent. R's expected payoff from checking is $E_R(check, pub) = \frac{\beta}{\beta + p(1-\beta)}(W-k) + \frac{p(1-\beta)}{\beta + p(1-\beta)}[\tau G + (1-\tau)(1-q_i\tau)^{n-1}(W'-k)]$, $E_R(nocheck, pub)$ follows analogously. Equating the two, since A has to make the readers indifferent between checking and not checking, substituting $(1-q_i\tau)$ with $(\frac{g}{B'+g})^{\frac{1}{n}}$ and solving for p yields $p = \frac{\beta}{1-\beta}\frac{k}{\tau(G - W'(\frac{g}{B'+g})^{\frac{n-1}{n}}) - k}$, the probability that A will submit if the project failed. From p being smaller than one, the following condition can be derived: $G > W'(\frac{g}{B'+g})^{\frac{n-1}{n}} + \frac{k}{(1-\beta)\tau}$. [7] There exists a semi-separating equilibrium of the form (subm, subm with p; check with q_i). This equilibrium resembles an inspection game as it shares typical features such as the influence of the payoffs of one player on the strategy of the other player and vice versa. Probabilities for the occurrence and detection of fraud are presented in table 3.

Table 3: Probabilities of occurrence and detection of fraud (game scientific community)

	Pooling I (subm, subm; no check)	Pooling II (subm, subm; check with $q_i = (1 - \sqrt[n-1]{\frac{1}{W'}(G - \frac{k}{(1-\beta)\tau})})\frac{1}{\tau})$	Semi-separating (subm, subm with $p = \frac{\beta}{1-\beta}\frac{k}{\tau(G - W'(\frac{g}{B'+g})^{\frac{n-1}{n}}) - k}$; check with $q_i = (1 - \sqrt[n]{\frac{g}{B'+g}})\frac{1}{\tau})$
Condition	$G \leq W' + \frac{k}{(1-\beta)\tau}$	$W' + \frac{k}{(1-\beta)\tau} < G \leq W'(\frac{g}{B'+g})^{\frac{n-1}{n}} + \frac{k}{(1-\beta)\tau}$	$W'(\frac{g}{B'+g})^{\frac{n-1}{n}} + \frac{k}{(1-\beta)\tau} < G$
P(fail,subm)	$1-\beta$	$1-\beta$	$(1-\beta)p$
P(fail,subm, not caught)	$1-\beta$	$(1-\beta)(1-q_i\tau)^n$	$(1-\beta)p(1-q_i\tau)^n$
P(fail,subm, caught)	0	$(1-\beta)(1-(1-q_i\tau)^n)$	$(1-\beta)p(1-(1-q_i\tau)^n)$
P(success, subm,caught)	0	$\beta(1-(1-q_i\tau)^n)$	$\beta p(1-(1-q_i\tau)^n)$

[7] G also has to be higher than 0, but the inequation stated above constitutes the binding condition. The conditions derived from the definition area of q do not affect the parameter sets for the other equilibria and are therefore not mentioned here.

If the benefit G from detecting fraud is not high enough in comparison to the loss from an undetected fraudulent publication W' and the checking cost k, the readers never check. Then, the first Pooling equilibrium is played, where failed research projects are always published as fraudulent papers and are never revealed. If, however, the incentive for a reader to engage in costly verification activities is strong enough, the reader's strategy turns into a probability. A reader takes into account the probability of the other readers to check and to successfully find flaws. And because every reader would prefer a fraudulent paper to be detected but not incur the costs to reach that, the readers choose their checking probability to make the others indifferent.

If furthermore g, the disutility the author experiences for getting caught committing fraud, is high enough compared to the benefit from a permanently published fraudulent paper B', the author sometimes chooses not to fake a result and refrain from submitting it. In this case, the semi-separating equilibrium is played, which is from a normative point of view the preferred one, because the least possible fraud is published here and the probability that it will be detected is the highest of all equilibria. An interesting aspect is that the author incorporates into his/her decision, the probability that a reader will check his/her publication. The semi-separating equilibrium therefore differs from the other equilibria such that it is not a typical inspection game, where the own strategy is only based the other player's payoff and not on the own. Basically, a reader takes into account the other readers when making the decision about checking a paper or not, and since the author chooses p as to make a reader indifferent, his/her submission probability is also influenced by the behavior of the readers.

5.3 Effects of Multiple Readers

The interesting question now is, whether the size of the readership has an impact on the production and the detection of fraudulent papers. Since the overall probability of fraud detection increases with the amount of checking readers, it is reasonable to assume that more readers would lead to a higher probability of overall fraud detection. This belief, however, ignores the fact that discovering fraud constitutes a positive externality for the scientific community. The costly activity of checking therefore has features of a public good and readers might be tempted to free-ride on the other's work. This idea was already raised but not tested by Lacetera and Zirulia. Fortunately it was picked up by Verbeck who examined the effects of an increase in the amount of readers. If there even are effects depends on the type of equilibrium.

In the first pooling equilibrium an additional reader neither changes the behavior of the author nor that of the readers, since all play pure strategies which remain best responses. This proposition can be demonstrated with the help of the equivalent equilibrium identified by Lacetera and Zirulia, where only one reader is modeled. If in the presence of one reader as well as n readers an equilibrium exists, it will very much exist for $n+1$ readers as well.

In the second pooling equilibrium the amount of readers can have an impact, because readers play mixed strategies. Here the problem of free-riding might emerge. The probability that a fraudulent paper gets caught is $1-(1-q_i\tau)^n$. This probability decreases in n if $1-(1-[(1-(\frac{1}{W'}(G-\frac{k}{(1-\beta)\tau}))^{\frac{1}{n-1}})\frac{1}{\tau}]\tau)^n > 1-(1-[(1-(\frac{1}{W'}(G-\frac{k}{(1-\beta)\tau}))^{\frac{1}{n}})\frac{1}{\tau}]\tau)^{n+1}$ which can be transformed into $(\frac{1}{W'}(G-\frac{k}{(1-\beta)\tau}))^{\frac{n}{n-1}} < (\frac{1}{W'}(G-\frac{k}{(1-\beta)\tau}))^{\frac{n+1}{n}}$. Because both sides of the equation are probabilities, the base of both sides has to be between zero and one. So the inequality is equivalent to $\frac{n}{n-1} < \frac{n+1}{n}$, which can be transformed into $n^2-1<n^2$, which is true. Therefore, probability that a fraudulent paper is revealed as such is smaller for $n+1$ readers. The presence of more possibly checking readers apparently crowds out the readers' own incentives to check and free-riding takes place. All in all, in the second pooling equilibrium an increase in the number of readers does not change the amount of committed fraud but rather increases the amount of undetected fraud.

In the semi-separating equilibrium both the author and the readers play mixed strategies, so both the amount of committed fraud as well as the amount of detected fraud might change. The probability that a fraudulent paper is submitted rises with an additional reader if $(1-\beta)\frac{\beta}{1-\beta}\frac{k}{\tau(G-W'(\frac{g}{B'+g})^{\frac{n-1}{n}})-k} < (1-\beta)\frac{\beta}{1-\beta}\frac{k}{\tau(G-W'(\frac{g}{B'+g})^{\frac{n}{n+1}})-k}$. This can be transformed into $(\frac{g}{B'+g})^{\frac{n-1}{n}} > (\frac{g}{B'+g})^{\frac{n}{n+1}}$. With the same reasoning as before it follows that $n^2-1<n^2$, which is true. The production of fraud therefore increases with the amount of readers. The probability that fraud is discovered does not change as can be proved by $1-(1-[(1-(\frac{g}{B'+g})^{\frac{1}{n}})\frac{1}{\tau}]\tau)^n = 1-(1-[(1-(\frac{g}{B'+g})^{\frac{1}{n+1}})\frac{1}{\tau}]\tau)^{n+1}$, so again free-riding occurs to some extent, because the overall probability of detection increases in the number of readers. All in all, when the amount of readers rises in a semi-separating equilibrium, the amount of permanently published fraudulent articles rises too, since the probability that these are being published is higher and the probability that they are being caught stays the same.

The number of readers moreover influences the parameter spaces for which the different equilibria are played. The parameter set for the second pooling equilibrium expands at the expense of the semi-separating equilibrium. The probability that a fraudulent paper is published is higher in the pooling equilibrium since all papers are submitted independent of their truthfulness. The amount of fraud therefore further increases.

Altogether one can say that the amount of produced fraud as well as the amount of undetected fraud either stays the same or increases if the number of readers rises. The belief that more readers are definitely “better“ for the quality of scientific publications is incorrect. Their negative effects however could be offset by different values of the parameters that might change with an increasing amount of readers.[8]

Verbeck additionally acknowledges the importance of priority in science. The model is extended by making the benefit from detecting fraud conditional on the number of readers that detect the fraud. Following a reduction in the expected benefit for readers, the amount of undetected fraud can increase or remain the same. Not only does the parameter space for the semi-separating equilibrium decrease to the benefit of the second pooling equilibrium where the probability that a fraudulent article is published is higher, but also the individual checking probability decreases in this equilibrium. In the semi-separating equilibrium the probability to submit a fraudulent article increases and the checking probability remains the same, so that the amount of produced as well as undetected fraud increases.

In this setting of $n \geq 2$ readers the possibility of free-riding and increased competition arises among the readers, which can both increase the amount of permanently published fraudulent research. This setting, as compared to the setting with only one reader developed by Lacetera and Zirulia, is more conducive to the survival of faked results.

Another matter that arises when looking at more than one reader is the heterogeneity concerning opinions in the scientific community. In a further extension to account for the characteristics of the scientific community, Verbeck modifies the payoff of one reader, who is assumed to support different scientific theories than the author and therefore is more skeptical with regard to the author’s publications. Due to a higher benefit from fraud detection G, lower checking costs k or a lower benefit from a permanently published paper W', this reader has a higher incentive to check and will check a publication even if no one else does. As a result, the overall amount of fraudulently published papers decreases and the probability that fraud is detected increases. A higher diversity in opinions among scientists is beneficial to the production of scientific knowledge.

6. What about Time?

The analysis so far did not take into account that time could be an important factor in the publication game. Scientists usually are scientists for a long time and therefore produce numerous publications. When deciding whether to thoroughly check a colleague’s publication one might take into consideration the colleague’s future decision about checking an own publication. Kiri et al. (2015) tested the interesting idea that researchers might play according to

[8] Especially B’ and G are expected to possibly increase with the amount of readers (Verbeck 2018 and Kiri et al. 2015).

a grim-trigger strategy, where they do not play check up until one checks, from which on they will only check, thus reaching the equilibrium. This equilibrium consists of pure strategies and was obtained by Kiri et al. in an extension of their model, where the benefit from checking a sound publication was increased. They found that for two scientists, who switch their roles from author to reader every round, a grim-trigger strategy can be a subgame-perfect equilibrium, if the discount factor is high enough. The discount factor can understood as being related to the interaction frequency of the two scientists, which implies that collusion is more likely when the same scientists read each other's papers on a rather regular basis. This requires that both scientists are working in the same, rather small field. Whether this is a realistic depiction of the scientific community, is difficult to verify. From my point of view it sounds rather abstract that researchers would conspire to deliberately overlook possible fraud and thereby increase the volume of undetected fraud.

7. Increasing the Penalty: Reasonable Policy Proposal or Common Misbelief?

Since increasing the penalty for scientific misconduct is one of the most commonly proposed remedies, I want to briefly examine this notion. In the model of Lacetera and Zirulia the punishment for committing fraud $g \in (0, +\infty)$ is only relevant in case the semi-separating equilibrium is played. There it decreases the probability of the reader to check, which in turn increases the amount of fraud going undetected. These results are the same ones Tsebelis (1989) proposed for inspection games in general, just applied to scientific misconduct. Though the results are straightforward, they are not entirely satisfying as it is simply very hard to imagine that a higher penalty would really not affect a scientist's decision on whether or not to commit fraud. As mentioned in section 2 there have been measures taken to punish scientists who have committed fraud, even to the extent of imprisonment. So, this belief that punishing the criminals more severely is always better, is apparently quite convincing.

In order to further investigate this question, one can take a look at whether the results obtained by Lacetera and Zirulia also hold when multiple readers are present, as in the model of Verbeck. There the penalty also affects the parameter spaces for which the different equilibria exist. A higher g actually increases the set of parameters for the semi-separating equilibrium and decreases the set for the second pooling equilibrium. This first result is already rather contradictory to the effects inspection games propose. The penalty increases so that the author does not always submit a failed research project as a fraudulent paper. Moreover are both types of players actions affected by g. The probability that a reader checks decreases, as in the model of Lacetera and Zirulia. His/her incentives are crowded out by the higher penalty. The probability to submit in case of a failed project, however, also decreases in g, therefore countervailing the effects of a lower q_i. The model of Verbeck, therefore, exhibits some proof for the intuition that a higher penalty deters scientists from committing fraud, even in a dynamic game with mixed strategies.

8. Discussion

The problem of theoretic research about the publication process is its restricted ability to perfectly represent reality. In my choice of modeled aspects to investigate, I tried to consider only the most realistic depictions of the scientific community. Still, the models of Lacetera and Zirulia as well as Verbeck leave room for discussion.

One of the most disputable points concerns how scientific misbehavior itself is treated in the models. Both assume that failed research has to be faked to be published and only rather severe misconduct can take place. To me it is not clear why failed research projects cannot be published. If a failed project equals a negative result, that should be a valuable result, since the hypothesis cannot be proven to be true. But also an inconclusive result could be interesting. I suspect the notion that because journals tend to publish fascinating results in order to attract a wider readership, they are therefore biased towards publishing positive results. That would mean that a negative result is considered a failed project and would not be accepted by the editor. The severity of this bias is being examined (e.g. Stanley 2005, Zietman 2017). The modeling of misconduct as only rather severe misconduct naturally simplifies the analysis since the case that a successful project is wrongfully improved can be eliminated. However, also positive findings could be altered in order to have a higher chance of acception.

Furthermore, the production costs of a scientific paper can be approached differently. If one views the conduction of the research project and the writing of the paper as two separate steps, the author would incur less cost if he/she decides not to submit the research, because then the writing of the paper is not necessary. This would change the model(s) as it would make not submitting a more attractive action.[9] The production of a fraudulent paper then could be seen as even more costly. In this context also the different levels of effort associated with different costs as in the model of Gall and Maniadis (2018) could be considered.

Additional to the assumptions about the author, the reader is as well subject for debate. The reader can engage in costly checking, which consists not only of activities to find the fraud but also the publication of these results. Checking an article can thus be viewed as a whole new research project. The decision of the reader about whether to check an article could therefore be considered as a new game where the reader compares the expected benefits, which in the former game would be G, with the expected costs, k. In the literature there

[9] In the model of Lacetera and Zirulia the cost of a research project could be left out, in the model of Verbeck an additional cost could be added in the case of submission.

exists a distinction between „new“ research and replicative research, which is essentially checking, and the decision problem scientists face (Hamermesh 2007, Ioannidis 2012). Extending the checking action of a reader to depict the decision between writing a paper on own new research or someone else’s work is a worthwhile idea. The decision process of witnesses of fraud, such as the author’s colleagues, coauthors, supervisors, etc, could also be worth analyzing, especially since these face lower costs to reveal the fraud, but on the other hand could have more to loose from exposing an acquaintance.

One of the major differences between the model of Lacetera and Zirulia and the model of Verbeck is that in the latter, checking readers detect fraud only with a probability. Since checking is a rather costly endeavor as already reviewed, one could expect the investigator to be successful, otherwise checking would not be a worthwhile action. Especially since the models only deal with severe misconduct, the flaws in the paper should be rather striking when, for example, replicating the experiment. In this point, Lacetera and Zirulia’s assumption seems more realistic to me, as the question if fraud is found essentially comes down to whether the suspected paper is investigated or not. Perhaps it would make more sense in the model of Verbeck if readers were allowed to invest different levels of effort to find fraud, with different associated detection probabilities, or the definition of misconduct was expanded to include milder misbehavior, which could be more difficult to detect. Otherwise it is not completely apparent why the readers should detect fraud with a certain probability, which is fixed for all of them.

One major point of issue, as already brought up in section 5.2 and section 7, are the features of inspection games. As examined by Tsebelis (1989), in a basic inspection game the actors play mixed strategies which are influenced only by the payoffs of the other player and not the own. It is not only unrealistic that a person even takes all the other players’ payoffs into account, but it is even more unrealistic that they would not take into account the own payoffs. A behavioral economics approach could be very useful here. The semi-separating equilibrium in the model of Lacetera and Zirulia is essentially an inspection game. Therefore, when increasing the pressure to publish and modifying the payoffs, as long as types of research are not distinguished, the payoffs of one player only influence the strategy of the other player. In the model of Verbeck, however, this would have different effects. Since the submitting probability of the author is affected by the checking probability of the reader, both the readers’ as well as the author’s payoffs determine the author’s strategy. And in the second pooling equilibrium the reader’s checking probability depends on the reader’s own payoffs. In contrast to the model of Lacetera and Zirulia, in Verbeck’s model the effects of a change in parameters would have the intuitively expected effects. This is even more straightforward in the case of an increased penalty, where the probability to submit a fraudulent paper actually decreases. One could say that Verbeck’s model, as it comes closer to reality by assuming multiple readers, manages to avoid the problems of inspection games having rather difficult implications.

Of the several chosen parameter definitions that could be questioned, the payoff of the reader is the most interesting to discuss. Verbeck attempts to link the preference of a reader about a publication to the diversity of opinion in the scientific community. He suggests readers only like results that fit well into existing research, because then they are complementary to own prior work and when they do not fit well into existing research they might substitute own prior or future publications. But one might also take the view that both results that fit well into existing research as well as results that do not can be complementary or substitutional to own prior or future research. One could even go further and claim that the rivals of the same opinion are a bigger problem than opponents who favor a conflicting theory, because the rivals could be faster at publishing a result that another researcher obtained, too. Additional to the benefit from a permanently published paper, it is also possible to discuss the loss a reader incurs from a fraudulent paper. It is comprehensible that a faked result might lead scientists to engage in unpromising lines of research, but I would suggest to exclude this from the one-shot game. First of all, if a reader follows the line of research from a fraudulent publication this could make him/her discover the fraud, which otherwise would not have happened since the reader decided not to check the paper, this would constitute a benefit for the reader. Maybe the harmful effects are predominant, but they do not come into existence immediately. At a later point in time, when the reader takes the role of the author in the publication game, he/she might have higher gains from publication, since he/she had a loss in the past from engaging in an unpromising line of research that was sparked by a fraudulent publication. So it could make sense to displace the negative effects from reading a fraudulent paper in the next game. As for the other mentioned argument that one prefers not to be cheated on, what you do not know, does not hurt you. The payoff for the reader from a fraudulent publication should therefore be considered not be strictly negatively modeled.

9. Conclusion

The objective of this thesis was to identify the forces that shape scientists' decisions about committing fraud and checking for fraud, and to understand their interaction. In order to do so, I analyzed the aspects modeled by Lacetera and Zirulia and Verbeck that seem to depict the actual publication process as realistically as possible. After analyzing theoretical models, I of course cannot say how which factor exactly impacts the scientist's decision, but some rather surprising statements can be made about how factors do not influence the publication process.

The analysis done by Lacetera and Zirulia provides a well-suited framework to determine main effects. First of all, fraud occurs in all two equilibria with positive probability. Only if the benefits compared to the cost are high enough, the reader will sometimes check, and the author will not always commit fraud if possible. As a result, science is not necessarily self-correcting. This is the first of several common misbeliefs Lacetera and Zirulia successfully debunk. Another possible belief that can be rejected is that only radical research is fraudulent, in fact, both radical and incremental research can be faked. The interesting result is that the type of research that is more likely to be fraudulent does not have to the same as the type of research that is more likely to be caught. Observed fraud can therefore be misrepresentative. Additionally to the type of research, observed fraud can also be misrepresentative with respect to the type of researcher. It is likely that unknown scientists are more often caught publishing fraudulent papers, while esteemed scientists actually are the ones committing more fraud. The possible belief that only low-reputation scientists commit fraud can therefore be rejected.

Lacetera and Zirulia were furthermore able to reject the belief that a pressure to publish is always bad, i.e. conducive to fraud. However, the effects are different when one takes into account the whole scientific community. Whether these are strictly positive depends on the relative changes in the payoffs as well as on the other parameters. The effects of increasing the penalty for fraud, which is one of the most commonly proposed remedies, behave rather analogously to the one from a higher pressure to publish. Lacetera and Zirulia as well as Tsebelis found it to be a bad idea, as it would only reduce the checking probability. In Verbeck's model the effects are different, here a higher punishment deters some scientists from misbehaving, thereby showing proof for the intuitive impacts. The important result, though, is that the publication game may not be as similar to an inspection game as one thought. This would have great implications for the development of policies aimed at reducing scientific fraud.

Including a whole scientific community has even more interesting effects. Though fraud still occurs in all resulting equilibria with positive probability, it can now be worth it for readers to check a publication even if the author always submits failed research projects as fraudulent papers. The interesting effect at work here is the characteristic of the checking activity to constitute a public good for the scientific community. Readers may be tempted to free-ride on the others costly checking. This is why an increase in audience size weakly increases the amount of undetected fraud. The belief that more readers are definitely “better“ for the quality of scientific publications can thus be rejected. Applying the so-called priority principle, i.e. increasing the reward for the first successful inspector at the expense of the following, further increases the problem of provision of the public good. Another aspect Verbeck models is the heterogeneity of preferences among the scientist. If scientists are allowed to differ in their opinions then this can have positive effects on the detection probability. Here Verbeck's notion of ideological diversity deterring fraud proves to be true.

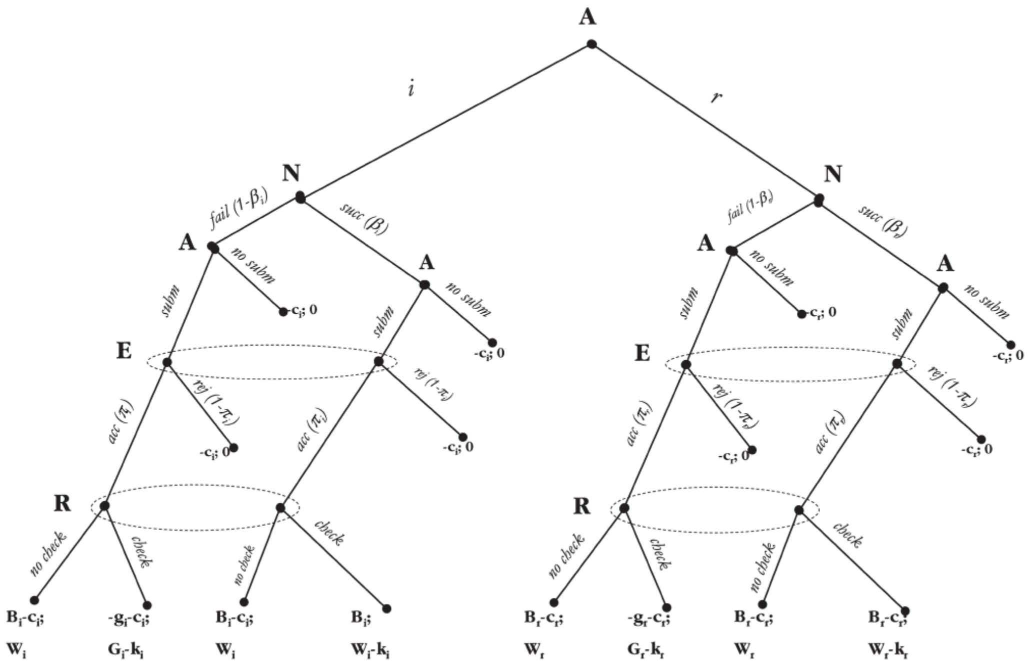
The possibility that researchers collude and do not check each others work is an interesting idea to analyze, though, the theory has rather strong limits when it comes to applicability. Kiri et al. found that in a repeated game collusion can be an optimal strategy.

From my point of view, the result that observed fraud can be misrepresentative of overall fraud is an especially important one, since measures taken against scientific fraud are based mainly on observed fraud. Observed fraud therefore influences the eye of the (scientific) public, which could change so that the type of research that is more likely to be found to be fraudulent is socially less appreciated. Lower benefits from publishing this type of research would then deter scientists from engaging in this type. If radical research would be the one that is more often found to be fraudulent, while in fact most fraudulent research is actually incremental research, this could have severe social consequences when noticeably less scientist perform radical research.

Appendix

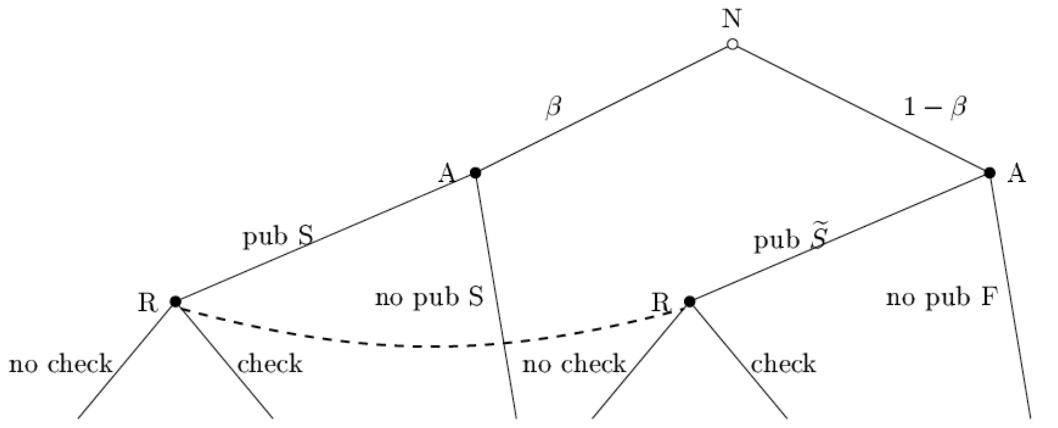
- Figure 2: Game tree for the publication game with different types of research

Please note that the payoff the author receives in the case of a checked publication of successful incremental research is denoted incorrectly here, it has to be $(B_i - c_i)$.



Source: Lacetera and Zirulia (2011)

- Figure 3: Game tree fur the publication game with a scientific community under the simplifying assumption of $n = 1$ reader



$$\begin{pmatrix} B \\ W \end{pmatrix} \quad \begin{pmatrix} B \\ W-k \end{pmatrix} \quad \begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{pmatrix} B' \\ W' \end{pmatrix} \begin{pmatrix} \tau \cdot (-g) + (1-\tau) \cdot B' \\ \tau \cdot G + (1-\tau) \cdot W' - k \end{pmatrix} \quad \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

Source: Verbeck (2018)

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Declaration in lieu of oath

By signing this declaration I confirm that I have completed the present thesis/essay independently, without help from others and without using resources other than indicated and named. All phrases that are taken directly or indirectly from other sources (incl. electronic resources), quoted verbatim or paraphrased are indicated accordingly. I am aware that any violation of this declaration will result in the work being graded as ‘failed’ (1 grade point according to § 16 (2) and 28 respectively of "Allgemeine Bestimmungen“).

Marburg, 29.03.2018