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Scientists' Ethical Obligations and Social Responsibility for Nanotechnology Research

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Abstract Scientists' sense of social responsibility is particularly relevant for emerging technologies. Since a regulatory vacuum can sometimes occur in the early stages of these technologies, individual scientists' social responsibility might be one of the most significant checks on the risks and negative consequences of this scientific research. In this article, we analyze data from a 2011 mail survey of leading U.S. nanoscientists to explore their perceptions the regarding social and ethical responsibilities for their nanotechnology research. Our analyses show that leading U.S. nanoscientists express a moderate level of social responsibility about their research. Yet, they have a strong sense of ethical obligation to protect laboratory workers (in both universities and industry) from unhealthy exposure to nanomaterials. We also find that there are significant differences in scientists' sense of social and ethical responsibility depending on their demographic characteristics, job affiliation, attention to media content, risk perceptions and benefit perceptions. We conclude with some implications for future research.

Keywords Social responsibility · Scientist perceptions · Research ethics · Nanotechnology

Introduction

At the 2013 American Association for the Advancement of Science (AAAS) Annual meeting in Boston, Mark S. Frankel, the director of the Scientific Responsibility,

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Human Rights, and Law Program at AAAS, argued that scientists should think deeply about their social responsibilities and ethical obligations for their research results. According to Frankel, scientists have professional or "internal" responsibilities for their scientific research, which means complying with "standards agreed upon by the scientific community" (Frankel 2013, Spring). In addition, Frankel argued that scientists have external, social responsibilities "toward the larger community" because scientific research is often funded by public money (Frankel 2013, Spring). This is a recent example of a call for scientists' social responsibility; yet, there have been concerns about the social responsibility of science throughout the late modern era (Brunner and Ascher 1992).

The purpose of this article is to give an updated view of how the leading U.S. nano-scientists think about their social responsibility and ethical obligations for their research. Scientists' sense of social responsibility could be particularly relevant for emerging technologies because regulation for these technologies often lags behind technological developments. Since there can be a regulatory vacuum in the early stages of emerging technologies, individual scientists' social responsibility might be one of the most important checks on the risks and negative consequences of the scientific research. In previous cases, when regulatory frameworks have been slow to develop scientists have acted on a sense of ethical obligation to take responsibility for their research without a law requiring them to do so (Frankel 1994; Lynch and Kline 2000). In line with these studies, Alvin Weinberg, a well-known nuclear physicist famously remarked,

> Of all the traits which qualify a scientist for citizenship in the republic of science, I would put a sense of responsibility as a scientist at the very top. A scientist can be brilliant, imaginative, clever with his hands, profound, broad, narrow – but he is not much as a scientist unless he is responsible (Weinberg 1978, p. 1).

There are two characteristics of the policy process that have contributed to the relatively slow development of regulations in the area of emerging technologies. First, the system of checks and balances on which the U.S. policy-making process is designed ensures that policy change is often incremental and slow moving (Lindblom 1959). As James Madison famously stated, "Ambition must be made to counteract ambition" (1788). This principle of the separation of powers in the U.S. Constitution has played an important role in preventing the concentration of power in one governmental branch. In short, it provides for a system of checks and balances (Sharp 1935). These checks and balances often yield a policy process that results in policy change that is incremental rather than comprehensive (Lindblom 1959). Since this governmental system of checks and balances can result in a more decentralized and democratic system, this is often a desirable characteristic of the policy process (Woodhouse and Collingridge 1993). However, an incremental and slow process of policy-making provides a challenge in the case of emerging technologies because the science tends to move forward quickly while regulations lag behind.

Second, a lack of scientific consensus about the full range of risks and benefits of nanotechnology (Kahan et al. 2007) can hinder the rapid development of new regulations to deal with the technology. Regulatory agencies, such as the U.S. Environmental Protection Agency (EPA) and the U.S. Food and Drug Administration (FDA), continue to rely on frequent and detailed conversations with leading nano-scientists to develop policies to protect the public from any risks associated with the technology (Corley et al. 2009; Roco and Bainbridge 2003). Thus, scientists' perceptions about the risks, benefits and social responsibility of nanotechnology research are especially relevant for emerging technologies.

Of course, Frankel's calls for social responsibility by scientists are not the only ones that are drifting through the academic community. This sentiment is represented in many normative calls that academic scholars have made for a sense of social responsibility among scientists. In the next section, we will briefly highlight some of the most relevant normative arguments by scholars, governments, and professional organizations.

Scientists' Social Responsibility: Normative Arguments

Within social science fields, several scholars have called for an increase in scientists' social responsibility and ethical obligations for their research (Guston and Sarewitz 2002; Jasanoff 2010; Krogsgaard-Larsen et al. 2011; Mansour 2009). At the same time, natural and physical scientists have argued for social responsibility within their fields of study (Nordgren 2001; Eggleson 2013). As one example, Kathleen Eggleson, a scientist at the University of Notre Dame, argues that "thought about dual-use, and action when appropriate, is inherent to socially responsible practice of nanobiomedical science" (Eggleson 2013). To further reinforce her beliefs, Dr. Eggleson founded the Nano Impacts Intellectual Community at Notre Dame. This program involves a monthly meeting that draws together campus researchers, leaders from the local area, visiting scholars, and authors from outside the university to discuss the ethics and impact of nanotechnology development.

In addition to individual social scientists and natural scientists, professional organizations and groups have also called for scientific social responsibility. For example, the AAAS Committee on Scientific Freedom and Responsibility notes that "scientific responsibilities arise as a result of the scientist's special knowledge, and from the insight emerging from that knowledge" (Lippincott 1975, p. 417). This same committee concluded that "the issues of scientific freedom and responsibility are basically inseparable" (Lippincott 1975, p. 417).

More recently, the National Academy of Sciences published a guide for responsible conduct in research, titled "On Being a Scientist." In accordance with previous editions published in 1989 and 1995, this document provides an overview of standards for responsibility in research. It points out how scientific results greatly influence society because policy makers and voters rely on science when making decisions, thus "researchers have an obligation to act in ways that serve the public" (COSEPUP 2009, p. 2). In addition, the National Science Advisory Board on Biosecurity (NSABB) has acknowledged the dual-use potential of science; they have argued that "individuals involved in any stage of life sciences research have an ethical obligation to avoid or minimize the risks and harm that could result from malevolent use of research outcomes" (NSABB 2012, p. 9).

Not only do scientists increasingly consider social and ethical responsibilities during their research, scholars also have argued that these concepts should be a core part of training and education for scientists and engineers (Pimple 2002; Zandvoort et al. 2013; Børsen et al. 2013). Yet, in traditional departments, scientists are often encouraged to pursue their work with a goal of advancing science as quickly as possible, while shying away from dealing with the non-science aspects of their research (such as politics, ethics or social responsibility) (Evers 2001). In fact, scientists have often been treated as trusted experts because their research was believed to be based solely on the scientific method (and separated from societal viewpoints). According to this traditional worldview, scientists' main task is to test theories and advance scientific knowledge, while the application of this knowledge (as well as the management of risks) is left for industry, policy makers or politicians (Evers 2001).

Many professional and governmental organizations are challenging this traditional worldview by arguing that scientific disciplines should change the way scientists are trained to better address issues of social responsibility (Bird 1994, 1999; Colby and Sullivan 2008). For example, in 1999, the World Conference on Science issued a "Declaration on Science and the Use of Scientific Knowledge" that proposed the inclusion of science ethics in scientific curricula. The declaration stated that ethics and scientific responsibility are integral parts of scientists' work and, therefore, they should be a primary part of the education and training of all scientists (UNESCO 2000).

Although the border between policy neutrality and policy advocacy may not always be clear (Lackey 2007), recent theories of science policy regard scientists as individuals with heuristics and biases rather than neutral or objective informants who are free from making judgements of value (Weber and Schell Word 2001; Weible et al. 2009; Ravetz 1990; Collingridge and Reeve 1986). For example, within the public policy literature, the concept of an Advocacy Coalition Framework (ACF) emphasizes the role of scientists in the policy making process (Sabatier 1998; Sabatier and Jenkins-Smith 1993, 1999). Furthermore, the ACF assumes that political actors (including scientists) are subject to cognitive biases or belief systems (Henry 2009). Similarly, Weible (2007) argues that there is a growing recognition that public policy controversies are often driven by value differences instead of technical deficiencies.

Cultural theorists argue that the social values and worldviews of an individual play an important role in perceptions and behaviors (Leiserowitz 2006; Dake 1991; Wildavsky and Dake 1990). More specifically, people with different values may react in divergent ways to the same information. Also, they may assess the dangers (or benefits) of technology in different ways (Kahan et al. 2007; Siegrist et al. 2007). While many existing studies focus on the role of lay person values, a recent survey of nano-scientists and engineers has shown that value predispositions affect scientists' opinions about technology as well (Ho et al. 2011). This study suggests that both scientific experts and lay people use heuristic deliberations when forming opinions about nanotechnology; however, experts tend to rely relatively less on values than the public (Ho et al. 2011). If individual scientists hold different worldviews or value predispositions, they might perceive their social and ethical obligations differently (even if they have the same scientific information).

Hypotheses

In this study, we used eight survey questions to capture scientists' sense of ethical obligation and social responsibility for their research. In Table 1 below, we outline these eight statements and their associated descriptive statistics.

While several of these statements are designed to measure scientists' sense of social and ethical responsibilities about their general research, three of the eight statements are focused specifically on issues of responsibility for nano-worker safety. This focus is important because one of the most urgent ethical issues surrounding nanotechnology is related to the potential health and environmental risks of nanoparticles (Schummer 2004). Furthermore, a significant aspect of nanotechnology regulations involves protecting workers from unhealthy exposure to nanomaterials (Poland et al. 2008). Even though the Occupational Safety and Health Act of 1970 (OSHA) requires employers to provide working conditions that are free of known dangers, there are few regulations in place to protect manufacturing and laboratory workers from nanomaterials. While the National Institute for Occupational Safety and Health (NIOSH) has taken the lead on providing research results and best practices for nano-worker safety issues, they do not issue formal regulations.

Table 1 Nano-scientist perceptions regarding ethical obligations and social responsibility (N = 444)

	Mean	SD
1 = strongly disagree; 5 = strongly agree		
Ethics variables—laboratory safety		
(1) "Directors of university-based laboratories have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials"	4.67	0.72
(2) "Directors of industry-based laboratories have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials"	4.72	0.69
(3) "Federal funding agencies (such as the National Science Foundation) should require that funded nanotech laboratories implement internal guidelines to protect lab workers from unhealthy exposure to nanomaterials"	4.07	1.17
Ethics variables—balancing ethics and academic freedom		
(4) "The authorities should formally oblige scientists to respect ethical standards"	3.80	1.15
(5) "Scientists should be free to carry out the research they wish, provided they respect ethical standards"	4.24	1.09
Social responsibility variables		
(6) "Scientists are responsible for the misuse of their discoveries by other people"	1.85	1.07
(7) "A discovery is in itself neither good nor bad, it is only the way the discovery is used which matters"	4.18	1.07
(8) "As members of society, scientists share responsibility for any use or misuse of their discoveries"	3.11	1.35

In the absence of formal regulations to protect workers from nanomaterials, one of the most important limits on unhealthy exposure might be a supervisor's ethical obligation to ensure that laboratory and manufacturing workers are taking safety precautions against the potential risks of nanomaterial exposure. Additionally, employers and workers may expect scientists and authoritative organizations to help interpret hazard and risk data; yet, this expectation might require that scientists go beyond the standard boundaries of their daily research (Schulte and Salamanca-Buentello 2007). Based on the existing literature, we have developed several hypotheses related to scientists' perceptions about social and ethical responsibilities for their research. We will discuss these below.

Demographic Variables

Previous research has demonstrated that factors such as gender, career status, and political ideology are related to how scientists view (and form commitments to) society (Besley and Nisbet 2013). In this section, we will highlight some of these existing studies and use them to develop our hypotheses.

Gender

Previous studies on human behavior and gender roles have concluded that females tend to be more interdependent, cooperative, and have a stronger "ethic of care," while males tend to be more independent and competitive (Chodorow 1974; Gilligan 1977). Given these previous studies, we expect that female scientists will have a stronger responsibility for the social implications of nanotechnology. Our first hypothesis is listed below.

Hypothesis 1 Female nano-scientists have a stronger sense of social and ethical responsibility for their nanotechnology research than male nano-scientists.

Career Affiliation

Although the distinction between academic science and industrial science is less dramatic than it was decades ago, there are still resource and time delays for academic discoveries to make their way into commercial products and practical applications (Rotblat 1999). Therefore, we speculate that university researchers might be less likely than industrial researchers to translate their research outcomes into practical applications; and this could be correlated with a weaker sense of social responsibility for research than scientists working in other environments (such as industry). This existing research informed the development of our second hypothesis which is listed below.

Hypothesis 2 Nano-scientists working in academia have a weaker sense of social and ethical responsibility for the implications of their nanotechnology research than their peers in non-academic environments.

Political Ideology

We also explored the relationship between scientists' political ideology and their sense of social and ethical responsibility for their research. In the U.S., citizens maintain a broad range of social perceptions about citizenship rights and responsibilities. Previous research has demonstrated that there is a partisan polarization among the public for a number of social and moral issues (Coffe and Bolzendahl 2011; Dalton 2009). Additional studies have confirmed considerable (and growing) gaps between partisan groups on these issues (Evans 2003; Graham et al. 2009). At the same time, research has demonstrated that Democrats might put more value on social duties and political participation (such as voting in elections, paying taxes, serving in the military, and obeying the law) than Republicans, while Independents often have weaker citizenship norms and put less value on political duties in comparison to both Democrats and Republicans (Dalton 2008, 2009). Additionally, some scholars have concluded that Democrats are more supportive of social welfare and government social policies, while Republicans are less supportive of government intervention across areas of social policy (Coffe and Bolzendahl 2011). Although most of the research on social and ethical values across partisan lines is focused on the public more broadly (and not specifically focused on scientists), previous research has demonstrated that scientists do reference their political ideology when making policy decisions about nanotechnology (Corley et al. 2009). Taken together, these existing studies inform our third hypothesis. As an aside, since our sample only contains a small proportion of scientists who identify as Republicans (see Table 2), we have combined Republicans and Independents together in our hypothesis and analysis.

Hypothesis 3 Nano-scientists who identify as Democrats have a stronger sense of social and ethical responsibilities about their research than their peers who identify as either Republicans or Independents.

Media Attention

Some scholars have argued that access to media information about the risks and benefits of technologies is a key component of political engagement for an informed public (Nelkin 1989). The media environment has changed dramatically over the past decade, with the internet becoming a primary source for news about science and technology. Yet, traditional media outlets can also be influential news sources for lay people (NSB 2012). The mass media can play a significant role in risk communication about emerging technologies, with experts (such as policy makers, regulators and, public officials) often relying on the media as both a source of information and an indicator of public opinion (Nelkin 1989; Nisbet and Scheufele 2009; Ho et al. 2011).

Previous studies have shown that media attention variables are significantly related to both public and scientist perceptions about policy decisions and technological risks/benefits (Cacciatore et al. 2011). Anderson and Slade (2013) found that newspaper use was positively related to risk perceptions about

Table 2 Descriptive statistics (N = 444)

	Mean values (SD)
Demographic variables	
Respondents' age	46.07 (12.02)
Percent male[a]	82.53
Percent White	63.51
Percent Asian	31.76
Political party affiliation[b]	
Percent Republican	6.31
Percent Democrat	45.27
Percent Independent	45.05
Percent with no response	3.37
Career variables	
Ph.D. year[c]	1993.67 (12.98)
Percent in university-based positions[d]	74.15
Disciplinary variables	
Percent in Biology	11.49
Percent in Chemistry	30.63
Percent in Math and Engineering	13.74
Percent in Material Sciences	13.96
Percent in Medicine	3.15
Percent in Physics	16.44
Percent in other disciplines	3.38
Percent with no disciplinary response	7.21
Risk and benefit perceptions	
1 = strongly disagree; 5 = strongly agree	
"Nanotechnology is risky for society"	2.42 (1.21)
"Nanotechnology is useful for society"	4.77 (0.60)
At what level should nanotechnology regulation be implemented?[e]	
Percent choosing local or state level	10.14
Percent choosing national level	55.18
Percent choosing international level	31.76
Percent with no response	2.92

[a] "What is your gender?" (1 = female; 0 = male)

[b] "In politics today, do you consider yourself a Republican, Democrat, or Independent?" (1 = Republican, 2 = Democrat, and 3 = Independent)

[c] "In what year did you complete your Ph.D.?"

[d] "Which of the following describes your current position?" (1 = non tenure-track university-based position; 2 = tenure-track university-based position; 3 = industry-based position; 4 = other)

[e] "At what level should nanotechnology regulation be implemented?" (1 = local level, 2 = state level, 3 = national level, and 4 = international level)

nanotechnology, while internet use was negatively related to risk perceptions. Another study concluded that people who pay attention to science news media are more supportive of federal funding for nanotechnology than their peers (Ho et al. 2011).

Even though the existing studies in this area utilize slightly different variables than we have in our survey data, we can use these previous studies to inform our hypothesis development about the relationship between scientists' media attention and their sense of social responsibility. Our hypotheses for these variables are listed below.

Hypothesis 4a Nano-scientists who pay more attention to the media coverage of science and technology issues have a stronger sense of social and ethical responsibility for their research than their peers who pay less attention to the media.

Hypothesis 4b Nano-scientists who pay more attention to the media coverage of the social or ethical implications of emerging technologies issues have a stronger sense of social and ethical responsibility for their research than their peers who pay less attention to the media.

Risk and Benefit Perception

Previous research has demonstrated that risk and benefit perceptions about nanotechnology are significantly related to perceptions about the regulation of the technology (Satterfield et al. 2009). In particular, several studies have demonstrated this relationship for both the general public (Satterfield et al. 2009; Scheufele and Lewenstein 2005; Cacciatore et al. 2011; Anderson et al. 2014) and nano-scientists (Corley et al. 2009, 2013).

These relationships between risk/benefit perceptions and policy perceptions are applicable to other technology areas as well. For example, Leiserowitz (2006) contends that the public's risk perceptions are significantly related to the political, economic and social actions they take to address policy issues. In addition, public support or opposition to climate policy (including regulations) is greatly influenced by an individual's risk perceptions about global climate change (Leiserowitz 2006). In a related fashion, a study on the public acceptance of nuclear power concludes that the public's risk perceptions about nuclear energy are strongly associated with lack of support for the construction of new nuclear power plants (Peters and Slovic 1996).

In sum, multiple existing studies have demonstrated that risk/benefit perceptions are significant for developing perceptions about policy actions for emerging technologies. Even though the variables are somewhat different in these earlier studies, we have extended this relationship to also include issues of social responsibility for our hypotheses. Therefore, we hypothesize that risk and benefit perceptions will be related to scientists' sense of social responsibility. This leads to our fifth hypothesis below.

Hypothesis 5a Nano-scientists with higher risk perceptions about nanotechnology will have a stronger sense of social and ethical responsibility for their research than their peers with lower risk perceptions.

Hypothesis 5b Nano-scientists with higher benefit perceptions about nanotechnology will have a weaker sense of social and ethical responsibility for their research than their peers with lower benefit perceptions.

Level of Governmental Regulations

Previous research has shown that scientists' support for nanotechnology regulations at different levels of government (local, national, and international) is related to the role that they see for the technology in society (Kim et al. 2012). In a 2007 survey of leading U.S. nanoscientists, Kim et al. (2012) found that supporters of national and international nanotechnology regulations were more likely to argue that scientists and the government should play a significant role in nanotechnology policy development. On the other hand, respondents who supported local regulations for nanotechnology were more likely to think that public opinion should play a significant role in nanotechnology policy development. Clearly, these earlier studies did not explore social responsibility; rather, they explored the relationship between the regulatory level and the role of different policy players in regulation development. However, we speculate that support for different levels of nanotechnology regulation might also be correlated with social responsibility in our dataset. Since we could not find existing literature in this area, this part of our analysis is more exploratory. As a result, we did not create a formal hypothesis around this concept. Yet, we do expect that there will be a relationship between nano-scientists' support for regulations at the local/national/international levels and their sense of social responsibility for their research. We will explore this relationship in the "Results" section.

Data Collection

The analyses presented here were drawn from a mail survey of leading U.S. nanoscientists. The survey was conducted between June and September 2011. It was administered by the University of Wisconsin Survey Center in four waves following Dillman's Tailored Design Method (Dillman et al. 2009). The sampling design was based on identifying the authors for the most highly cited nanotechnology publications that were indexed in the ISI Web of Knowledge database in 2008 and 2009. In order to rigorously establish which publications were actually within the multidisciplinary field of nanotechnology, we drew on work by another group in the Center for Nanotechnology in Society at Arizona State University (CNS-ASU) that has refined the definition of nanotechnology using specific bibliometric terms (Porter et al. 2008).

In order to develop the final sample for the 2011 scientist survey, Porter and colleagues delivered to our team a database of 189,014 nanotechnology publications from the ISI Web of Knowledge that were published in 2008 and 2009. We cleaned these records to remove any duplicate names, non-U.S.-affiliated scientists, graduate students, and authors who were cited fewer than 39 times in the 2 year period 2008–2009. This filtering process was used to ensure that the survey sample focused on the most highly cited, most active, U.S.-affiliated scientists within the nanotechnology field. The final filtering process produced 1405 names with complete addresses, and this yielded 444 completed questionnaires. The response rate for the survey was 31.6 % (AAPOR RR-3: 31.6 %) (AAPOR 2008).

As Table 2 illustrates, 82.5 % of the respondents were male. The mean age for respondents was about 46 years old and the mean year for receiving a doctoral degree was 1994. In terms of ethnicity, 63.5 % of the scientists identified themselves as White, 31.8 % were Asian, 2 % were Hispanic, and 0.5 % were African American. As for political ideology, about 45 % of the respondents identified as Democrats, 45 % as Independents, and about 6 % as Republicans. When asked about their current job position, 74 % of the respondents reported that they had a university-based research position and 44 % of the scientists were tenured.

Results

Now, we turn to a discussion of our analysis and results. As we mentioned earlier, previous research has demonstrated that factors such as gender, career status and political ideology can influence how scientists view the social aspects of their research. To test our hypotheses, we conducted a series of statistical analyses including comparison of means tests, correlation analyses and regression analyses.

Table 3 includes a series of *t* tests that we conducted for each of the eight statements that captured scientists' sense of social and ethical obligations for their research. Our first hypothesis was that female nano-scientists would have a stronger sense of social and ethical responsibility for their research than male scientists. This hypothesis was confirmed for one variable, the statement on scientists' perceptions about mandatory guidelines from federal funding agencies that fund nanotech laboratories. That is, compared to their male counterparts, female nano-scientists were more likely to believe that federal funding agencies should require funded nanotech laboratories to implement internal guidelines that protect lab workers from unhealthy exposure to nanomaterials. One caveat associated with gender differences in this data set is the fact that about 82.5 % of the respondents in our survey were male. Therefore, future research with a sample stratified across gender will be important for further investigating this gender gap in social responsibility perceptions.

Our second hypothesis was focused on the relationship between respondents' career affiliation (e.g., scientists in academia vs. scientists in non-academic work environments) and their sense of social and ethical responsibilities. Our tests for this hypothesis yielded mixed results. Specifically, we did not find significant differences in responses between academic and non-academic scientists for four of the eight statements that measured nano-scientists' sense of social responsibility. Yet, our hypothesis was confirmed for half of the statements. In particular, university-based scientists were less likely than other scientists to say that directors of university-based and industry laboratories have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials. Similarly, scientists in academia were less likely to say that federal funding agencies should require funded nanotech labs to implement internal guidelines for protecting lab workers from nanomaterials. Not surprisingly, the scientists in academia were also more likely to say that scientists should be free to carry out the research that they wish if they respect ethical standards.

Our third hypothesis focused on the relationship between scientists' political ideology and their sense of social and ethical responsibility. We predicted that nano-scientists who identified as Democrats would have a stronger sense of social and ethical responsibilities about their research than their peers who identified as either

Table 3 Comparisons of means for social responsibility variables across demographic and work variables

	Gender (mean)		Career affiliation (mean)		Nanotech regs[a] (mean)	
	Male	Female	Academia	Others	Local or state	Natl. or intl.
1 = strongly disagree; 5 = strongly agree						
Ethics variables—laboratory safety						
(1) "Directors of university-based laboratories have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials"	4.66	4.70	4.63**	4.81**	4.60	4.68
(2) "Directors of industry-based laboratories have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials"	4.73	4.66	4.68*	4.82*	4.69	4.72
(3) "Federal funding agencies (such as the National Science Foundation) should require that funded nanotech laboratories implement internal guidelines to protect lab workers from unhealthy exposure to nanomaterials"	3.99**	4.45**	3.95**	4.53**	3.77	4.10
Ethics variables—balancing ethics and academic freedom						
(4) "The authorities should formally oblige scientists to respect ethical standards"	3.78	3.88	3.79	3.88	3.41*	3.84*
(5) "Scientists should be free to carry out the research they wish, provided they respect ethical standards"	4.27	4.09	4.32*	4.06*	4.16	4.25
Social responsibility variables						
(6) "Scientists are responsible for the misuse of their discoveries by other people"	1.89	1.67	1.79	2.00	1.50**	1.89**
(7) "A discovery is in itself neither good nor bad, it is only the way the discovery is used which matters"	4.16	4.25	4.18	4.19	4.48*	4.14*
(8) "As members of society, scientists share responsibility for any use or misuse of their discoveries"	3.16	2.96	3.03	3.31	2.86	3.14

* $p < 0.05$; ** $p < 0.01$

[a] "At what level should nanotechnology regulation be implemented?" (1 = local level, 2 = state level, 3 = national level, and 4 = international level)

Republicans or Independents. However, our results do not confirm this hypothesis. In short, scientists' sense of social and ethical responsibility was not significantly different for Democrat respondents and Independents/Republicans. To further investigate whether Democrats have different perceptions in terms of scientists' sense of social responsibility, we compared our two largest groups of respondents (Democrats vs. Independents).[1] This analysis reveals that scientists who identify as Democrats (M = 4.080; SD = 1.159) were less likely (t value = −1.980; p value = 0.048) to agree with the statement that scientific discovery is value neutral than their peer Independents (M = 4.290; SD = 0.959). These results indicate that when compared to Independents, Democrats are more likely to believe scientific discovery itself can be value-laden rather than objective. This is consistent with our hypothesis.

We also explored the relationship between scientists' views about governmental involvement in nanotechnology regulations and their sense of social responsibility. We expected that scientists who support national or international regulations for nanotechnology would have a stronger sense of social responsibility.

Table 3 demonstrates that scientists who support nanotechnology regulations at the local or state level government have a weaker sense of social and ethical responsibility for their research than their peers across three different variables. In comparison to the supporters of national or international level regulations, supporters of local or state level regulations were less likely to believe that scientists are responsible for the use of their research by others. In addition, the local and state regulation supporters were less likely to argue that authorities should formally oblige scientists to respect ethical standards. There is one caveat about this analysis that we want to highlight here. As our descriptive statistics demonstrate, only about 10 % of the scientists supported nanotechnology regulations at the local or state level. On the other hand, about 57 % of the scientists supported national regulations and 33 % supported international regulations for nanotechnology. Given the small sample size for the supporters of local or state level regulations, it will be important to further explore this relationship in future research.

Unlike the nominal independent variables (Gender, Political Ideology, and Level of Governmental Regulations) presented in the previous sections, our variables that measured scientists' attention to media coverage and perceptions on nanotechnology are ordinal. Most of these variables are Likert scale variables with a range from 1 = strongly disagree to 5 = strongly agree. Therefore, to test hypotheses 5 and 6, we conducted a series of correlation analyses on these variables. Correlation analysis explores whether there is a relationship between two sets of variables (Agresti and Agresti 1970). Given our variable type, we adopted Goodman and Kruskal's gamma for our correlation analysis. This measure is most commonly used for measuring the strength of the relationship between two ordinal variables (Goodman and Kruskal 1979; Freeman 1965; Göb et al. 2007).

Our fourth hypothesis was focused on scientists' attention to media coverage in two areas: (a) science and technology and (b) the social or ethical implications of emerging technologies. As Table 4 illustrates, media attention in both of these areas was associated with scientists' perceptions that federal funding agencies should

[1] As previously stated, our sample contains only a small proportion of Republicans.

Table 4 Goodman and Kruskal's gamma: media attention, risk/benefit perceptions and social responsibility

	Attention to media coverage		Nanotechnology perceptions	
	Science and technology[a]	Social/ethical implications of technology[b]	"Nano is useful for society"	"Nano is risky for society"
1 = strongly disagree; 5 = strongly agree				
Ethics variables—laboratory safety				
(1) "Directors of university-based laboratories have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials"	0.115	0.154	0.146	0.121
(2) "Directors of industry-based laboratories have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials"	0.127	0.026	0.233	0.109
(3) "Federal funding agencies (such as the National Science Foundation) should require that funded nanotech laboratories implement internal guidelines to protect lab workers from unhealthy exposure to nanomaterials"	0.197**	0.207**	−0.077	0.161**
Ethics variables—balancing ethics and academic freedom				
(4) "The authorities should formally oblige scientists to respect ethical standards"	0.102	0.118*	0.071	0.109
(5) "Scientists should be free to carry out the research they wish, provided they respect ethical standards"	0.005	−0.078	0.248*	−0.154**
Social responsibility variables				
(6) "Scientists are responsible for the misuse of their discoveries by other people"	−0.078	0.121	−0.232*	0.178**
(7) "A discovery is in itself neither good nor bad, it is only the way the discovery is used which matters."	0.070	−0.002	0.127	0.033
(8) "As members of society, scientists share responsibility for any use or misuse of their discoveries"	−0.082	0.063	−0.085	0.187**

* $p < 0.05$; ** $p < 0.01$

[a] "In general, how much attention do you pay to the media coverage focused on science and technology?" (1 = none; 2 = very little; 3 = some; 4 = quite a bit; 5 = a lot)

[b] "In general, how much attention do you pay to the media coverage focused on social or ethical implications of emerging technologies?" (1 = none; 2 = very little; 3 = some; 4 = quite a bit; 5 = a lot)

require internal laboratory guidelines to protect nanotechnology lab workers. However, we did not find a significant relationship between scientists' media attention to these two topics and their opinions on ethical obligations for the directors of university and industry nanotech labs. Yet, scientists who paid more attention to social/ethical media coverage were more likely to argue that authorities should oblige scientists to respect ethical standards.

The values from Table 4 indicate that our results for this hypothesis test were mixed. Scientists' media attention was correlated with a stronger sense of social and ethical responsibility in some cases, but not all cases. Therefore, we decided to test this hypothesis by including some control variables in our analysis. We did this by running a series of OLS regression models (shown in Table 5).

For our regression analysis, we first explored whether we could combine any of the social responsibility and ethics statements into a summative index that could be used as a dependent variable for our model. After a reliability analysis of all combinations of the eight social responsibility and ethics statements listed in Table 4, we found that only one combination of the eight statements yielded a Cronbach's alpha above 0.70. In this case, statements 1 and 2 from Table 4 yielded a Cronbach's alpha value of 0.932. Therefore, these two statements were combined into a summative index. This index serves as the dependent variable for Model 1 in Table 5. Since creating an index from additional statements did not yield sufficiently high Cronbach's alpha values, we ran six additional OLS models using statements 3–8 as dependent variables. In Table 5, we list only the models that yielded a significant F test (at the 0.05 level).[2]

Table 5 indicates that when we control for gender, age and academic position, attention to media is correlated with laboratory ethics variables, as well as scientists' perceptions about the misuse of their research. In particular, as scientists pay more attention to science and technology media, they are more likely to support ethical obligations for protecting laboratory workers (Model 1).

Similarly, as scientists pay more attention to the social and ethical implications of emerging technologies, they are more likely to say that "scientists are responsible for the misuse of their discoveries by other people" (Model 4). On the other hand, we found an unexpected result in Model 4. Contrary to our hypothesis, scientists who pay more attention to science and technology media were less likely to say that "scientists are responsible for the misuse of their discoveries by other people."

In sum, our analysis in Table 5 supports our Hypothesis 4a when laboratory ethics variables served as the dependent variable (i.e., Models 1 and 2). In addition, our results support Hypothesis 4b for the case of one social responsibility variable (i.e., Model 4).

Our fifth hypothesis was focused on the relationship between scientists' nanotechnology perceptions and their sense of social responsibility. As demonstrated in Table 4, we found that scientists' risk perceptions were positively correlated with their social and ethical responsibilities in four cases. In particular, scientists with higher risk perceptions were more likely to believe that federal

[2] Statements number 5 and 7 in Table 4 did not yield a significant F test for the OLS regression model. Therefore, they are not included as models in Table 5.

Table 5 OLS regression analysis for social responsibility variables

	Standardized coefficients				
	Model 1: DV = ethics index[a]	Model 2: DV = ethics funding[b]	Model 3: DV = authorities oblige[c]	Model 4: DV = responsible misuse[d]	Model 5: DV = share responsibility[e]
Demographic variable and values					
Male (1 = male; 0 = female)	0.014	−0.119*	−0.032	0.090	0.073
Age	−0.042	0.029	0.108*	0.061	0.011
Career variables					
Academic position (1 = yes; 0 = no)	−0.088	−0.200**	−0.049	−0.096	−0.098
Attention to media coverage, by topic					
Science and technology[f]	0.119*	0.194**	0.070	−0.148*	−0.072
Social and ethical implications of technology[g]	−0.003	0.042	0.032	0.185**	0.090
Nanotech perceptions					
Benefit perceptions[h]	0.071	−0.048	0.011	−0.065	−0.053
Risk perceptions[i]	0.124*	0.133**	0.171**	0.113*	0.164**
Model R-square (%)	4.6*	12.2**	4.7*	7.2**	5.6**

* $p < 0.05$; ** $p < 0.01$

[a] Summative index of two below statements about ethical obligations and laboratory workers (Cronbach's alpha = 0.932). (a) "Directors of university-based laboratories have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials" (1 = strongly disagree; 5 = strongly agree). (b) "Directors of industry-based laboratories have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials" (1 = strongly disagree; 5 = strongly agree)

[b] "Federal funding agencies (such as the National Science Foundation) should require that funded nanotech laboratories implement internal guidelines to protect lab workers from unhealthy exposure to nanomaterials" (1 = strongly disagree; 5 = strongly agree)

[c] "The authorities should formally oblige scientists to respect ethical standards" (1 = strongly disagree; 5 = strongly agree)

[d] "Scientists are responsible for the misuse of their discoveries by other people" (1 = strongly disagree; 5 = strongly agree)

[e] "As members of society, scientists share responsibility for any use or misuse of their discoveries" (1 = strongly disagree; 5 = strongly agree)

[f] "In general, how much attention do you pay to the media coverage focused on science and technology?" (1 = none; 2 = very little; 3 = some; 4 = quite a bit; 5 = a lot)

[g] "In general, how much attention do you pay to the media coverage focused on social or ethical implications of emerging technologies?" (1 = none; 2 = very little; 3 = some; 4 = quite a bit; 5 = a lot)

[h] "Nanotechnology is useful for society" (1 = strongly disagree; 5 = strongly agree)

[i] "Nanotechnology is risky for society" (1 = strongly disagree; 5 = strongly agree)

funding agencies should require funded labs to protect nano-workers. Also, respondents with higher risk perceptions were more likely to believe that scientists are responsible for any use or misuse of their research. At the same time, respondents with higher risk perceptions were less likely to believe that scientists should be free to carry out the research they wish.

We also found two significant relationships between scientists' benefit perceptions about nanotechnology and their sense of social responsibility. Respondents with higher benefit perceptions were more likely to believe that scientists should be free to carry out the research they wish—and they were less likely to state that scientists are responsible for the misuse of their discoveries by other people.

In Table 5, we present the results of our fifth hypothesis test, while controlling for gender, age and academic position. After including these control variables in our analyses, our results for the risk perceptions are similar to our results from Table 4. For all of our models in Table 5, risk perceptions were significantly (and positively) correlated with scientists' sense of ethics and social responsibility for their research. However, the inclusion of control variables in Table 5 yielded different results from Table 4 for benefit perceptions. In particular, when controlling for gender, age and academic position, we can conclude that scientists' benefit perceptions are not significantly correlated with their sense of ethics and social responsibility for their research.

Now that we have discussed the results of our hypotheses tests, we would like to briefly highlight some interesting relationships that we observed in Table 5 for our control variables. First, we find it noteworthy that male scientists and scientists in academic positions were less likely than their colleagues to support ethics requirements for federal funding of laboratories (Model 2). This reinforces the result for gender that we presented Table 3. Second, we found that age is related to scientists' perceptions about ethical oversight of their research (Model 3). In particular, older scientists were more likely than their younger colleagues to support authorities formally obliging scientists to respect ethical standards.

Before moving on to the conclusion section of our article, we would like to point out one caveat associated with the models in Table 5. While we believe that it is important to include the models in Table 5 in this article (to allow for the inclusion of control variables), we would like to note the low R squared values. Even though all of the models in Table 5 yielded significant F test results, the independent variables do not explain a large portion of the variance in our dependent variables. Therefore, we encourage some caution in the interpretation of the models in Table 5.

Discussion and Conclusion

Our data analysis included a focus on many different variables; yet, we believe there are five take-home messages from our results. Before delving into each of these messages, it is important to make one of our overarching assumptions of this research clear. Throughout this analysis, we have assumed that a strong sense of social responsibility on the part of scientists is desirable for both society and science. Scientific research can have a significant impact on the environment, the health of human beings, economic development, personal privacy, national security, and many other aspects of human life. While many fields of science and technology can be used for fruitful purposes, they can also be destructive (IAC 2012). Furthermore, when dealing with technologies that have high levels of scientific uncertainty, many stakeholders (e.g., the public, professional organizations, scholars and policy-makers) expect scientists and engineers to be accountable for their research and its impacts (Frankel 1994). As we mentioned at the beginning of this article, many professional organizations and scholars in a variety of fields have made normative arguments about how scientists should be concerned with the social aspects of their research. We want to make it clear that we use this same lens when we are interpreting our data results for these conclusions. Now we turn to the take home messages.

First, our results demonstrate that the leading U.S. nano-scientists demonstrate a moderate level of social responsibility about their research (Table 1). So how might we encourage more social responsibility on the part of scientists if we believe this is a desirable characteristic for society and science? We can address this question in part with our second point, which is that media attention is correlated with scientists' social responsibility levels in some cases. Our analyses reveal that when scientists pay more attention to science media coverage, they are likely to have higher levels of social and ethical responsibility. Our data do not allow us to determine a direction of causation for this correlation, but it seems clear that attention to media content is correlated with a stronger sense of responsibility. While this might seem intuitive, it demonstrates that encouraging scientists to pay more attention to media focused on the social and ethical implications of science can be linked with stronger social responsibility about their research. While scientists are often exposed to news about their own field (through research journals or conferences), their exposure to the societal implications of the research is sometimes limited. An increase in exposure to the social and ethical implications could occur through newsletters from professional organizations (for example, publishing additional columns on social and ethical obligations of the discipline). Also, conference organizers could increase the number of panels and discussions about the social and ethical implications of S&T at science and engineering disciplinary professional conferences.

Third, risk and benefit perceptions about nanotechnology are linked with scientists' sense of social responsibility. To the best of our knowledge, this empirical relationship has not been previously tested for the case of nanotechnology. As we expected, nano-scientists with higher risk perceptions about nanotechnology have a stronger sense of ethical obligation and social responsibility for their research than their peers. This result leads us to the following question that we cannot answer with the current data set: how might we encourage higher levels of social responsibility among scientists working in emerging technology fields while risks and benefits are still unclear? At the early stage of an emerging technology, if the risks are potentially high and unknown, will scientists feel sufficient social responsibility for those potential risks in the absence of regulations?

Fourth, we find that the scientists' opinions about the level of regulatory government are associated with their sense of social responsibility. Our hypothesis that nano-scientists who support nanotech regulation at higher governmental levels would have a stronger sense of social responsibility was only partially confirmed in Table 3. These results are in line with previous studies that concluded that nano-scientists who support regulation at a higher level of government are more conscious about their role in technology policy development (Kim et al. 2012).

Lastly, our results indicate that overwhelmingly the leading U.S. nano-scientists believe that lab directors (in both university and industry environments) have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials (Table 1). Yet, few U.S. universities have firm guidelines and regulations in place for their nanotech laboratories. In most cases, lab directors are left to individually figure out how to implement a "safe nanotechnology laboratory environment." Given how important laboratory worker protection is for the scientists in our sample, it seems that universities should be doing more to implement university-wide guidelines in this area. Also, the scientists in our sample supported linking federal research funding with mandatory internal laboratory guidelines that would protect lab workers from unhealthy exposure to nanomaterials. This is an area where the National Science Foundation and National Institutes of Health (among other federal agencies that fund nanotech research) could aid in nano-worker safety. Recent studies in science journals show that there have been growing concerns over the safety of nano-workers (Conti et al. 2008; Schmid and Riediker 2008; Balas et al. 2010; Schulte et al. 2014). While some guidelines for nanotech worker safety exist, researchers question whether they are sufficient (Kuzma and Besley 2008; Bowman and Gilligan 2010; Balbus et al. 2007). By tying federal nanotech research funding to explicit expectations about worker safety, federal agencies could help to limit unhealthy exposure of graduate students and technicians in nano-laboratories. Our data indicate that the leading nano-scientists in the U.S. would overwhelmingly support a policy move like this on the part of federal funding agencies.

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