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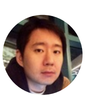

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The Current Status and Future Direction of Nanotechnology Regulations: A View from Nano-scientists

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Abstract

This article presents an up-to-date view of leading U.S. nanoscientists' perceptions about the regulation of nanotechnology. Our analysis draws from the results of a 2011 mail survey with 444 of the most prolific nanoscientists in the United States to explore their perceptions about existing nanotech policies, the development of new nanotech policies, and mandatory policies about the implementation of safe lab practices for federally funded nanoresearch. In addition to exploring the scientists' perceptions about these pressing policy issues, we also test relationships between their perceptions about regulation and control variables such as gender, disciplinary affiliation, and political ideology. Last, the results of the 2011 data collection are compared with a similar mail survey that was conducted in 2007 with leading U.S. nanoscientists to explore any changes over the four-year time period in scientists' perceptions about nanotechnology policy making, and governmental involvement in nanotechnology research.

KEY WORDS: governance, high-tech, nanotechnology, national governance

Introduction

Commercial products in the United States regularly contain nanoscale materials, but many Americans still do not know what nanotechnology means. According to the U.S. Environmental Protection Agency (EPA), nanotechnology is "the understanding and control of matter at dimensions of approximately one to 100 nanometers" (U.S. Environmental Protection Agency, 2011). One of the characteristics of nanomaterials that make them especially challenging for the regulatory environment is that particles at this small scale can behave in fundamentally different ways than larger-sized particles of the same material. As the EPA points out, these "differences often enable nanoscale materials to be used in new and valuable ways," yet these differences also mean that nanomaterials could present environmental, health, and safety risks that might not be present with larger particles of the same chemical substance (U.S. Environmental Protection Agency, 2011).

Given the fast pace of technological innovation in the area of nanotechnology—along with the policy challenges associated with particles that behave differently based on size—the regulation of nanomaterials has become an increasingly urgent topic for the policy-making community. This urgency was particularly clear on June

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9, 2011 when the White House issued a formal memo to the heads of all U.S. executive departments and agencies about the regulation of nanotechnology (Holdren, Sunstein, & Siddiqui, 2011). The memo was titled "Policy Principles for the U.S. Decision-Making Concerning Regulation and Oversight of Applications of Nanotechnology and Nanomaterials" and it outlined how U.S. agencies should move forward with regulating nanotechnology by recommending "generally applicable principles relevant to promoting a balanced, science-based approach to regulating nanomaterials and other applications of nanotechnology in a manner that protects human health, safety, and the environment without prejudging new technologies or creating unnecessary barriers to trade or hampering innovation." The memo was written to federal agencies that have regulatory responsibilities for nanotechnology, particularly the EPA, the U.S. Food and Drug Administration (FDA), and the Occupational Safety and Health Administration (OSHA). In this communication, the White House outlined the importance of scientific insights and opinion in the development of regulations for nanotechnology; specifically, the memo states that "risk-based approaches reflect awareness that regulation should be grounded in the best available science and able to evolve as scientific insights mature and the body of evidence grows and evolves." This call from the White House for a science-based approach to the regulation of nanotechnology implies that the leading U.S. scientists working in the field of nanotechnology will have explicit involvement in the present and future development of policies for nanotechnology research and commercial products. But what do these scientists think about nanotechnology regulation—and what is the current policy environment for the regulation of nanomaterials in the United States? These questions are the focus of this article.

Current Regulatory Environment for Nanotechnology

Between FY 2006 and FY 2012, the U.S. government increased funding of environmental, health, and safety dimensions of nanotechnology from $37.7 million to $123.5 million (Holdren et al., 2011). At the same time that we have seen this large increase in nanoresearch funding in environment, health, and safety (EHS) areas, we have also seen a difficult and slow nanotech regulatory process for federal agencies. The three main federal agencies in the U.S. that have taken on the task of developing nanotechnology regulations are the EPA, the FDA, and OSHA; in addition, the National Institute of Occupations Safety and Health (NIOSH) has served a strong role in nanotechnology research and guideline development for workers exposed to nano-materials (Marchant, Sylvester, & Abbott, 2007).

According to a recent report from the EPA's Office of the Inspector General, the EPA has the statutory authority to regulate nanomaterials in a few different ways (U.S. Environmental Protection Agency Office of the Inspector General, 2011). First, the EPA can regulate nanoscale materials while they are being manufactured, formulated, and distributed commercially through the Toxic Substances Control Act (TSCA). The EPA can also regulate nanoscale materials that are present in pesticides through the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Last, the EPA has the statutory authority to regulate nanoscale materials that are released into the environment through existing regulations, such as the

Clean Water Act, the Clean Air Act, the Comprehensive Environmental Response, Compensation and Liability Act, or Resource Conservation and Recovery Act.

Despite this somewhat broad statutory authority, over the past decade the EPA has regulated nanomaterials largely under the TSCA. Many nanomaterials can be classified as "chemical substances" under TSCA, but the key issue for regulation is whether there is a "new" chemical substance introduced when particles at the nanoscale are used in manufacturing. In the past under TSCA, a nanoscale version of an existing chemical might not be considered new if the larger particles of the chemical substance were not regulated as a new substance. In these cases, the nanoscale version of the substance might have slipped through the regulatory framework without being regulated by the EPA.

To ensure that future nanomaterials are more comprehensively covered under TSCA, however, the EPA has recently pursued a regulatory "four-pronged approach," which includes premanufacture notifications, a significant new use rule (SNUR), an information gathering rule, and a test rule (U.S. Environmental Protection Agency, 2012). Many of the EPA's regulatory changes include transitioning from a preference for voluntary reporting programs for nanomaterials to more explicit, mandatory reporting requirements. For example, in 2010 the EPA submitted a proposed rule under TSCA Section 8(a) to the Office of Management and Budget that would require that any chemical substance between 1 and 100 nanometers in size would be considered "new" and, therefore, subject to the SNUR of TSCA (U.S. Environmental Protection Agency Office of the Inspector General, 2011). This means that manufacturers of nanoscale products would have to inform the EPA about their plans at least 90 days in advance of any manufacturing. This new regulatory push by the EPA could help to resolve some of the loopholes for the regulation of nanoscale materials that have occurred under TSCA in the past.

Additionally, on June 17, 2011 the EPA issued a Federal Register notice proposing a new policy under the FIFRA to ensure that new pesticides containing nanoscale materials would be registered with the agency. This is another example of the EPA attempting to make new reporting rules mandatory instead of voluntary. This push for mandatory reporting requirements follows the agency's 2008 voluntary program (titled "Nanoscale Materials Stewardship Program"—NMSP), which was not highly successful at getting nano-industries to report their use of nanomaterials. The EPA's voluntary reporting program was ended in December 2009 due to a lack of success that was highlighted in an interim report on the program (U.S. Environmental Protection Agency, 2009). The EPA found through the NMSP that few manufacturers will voluntarily share information about their manufacturing use of nanomaterials with federal agencies.

Despite the EPA's recent efforts to "beef up" TSCA and FIFRA for nanotechnology, both external and internal stakeholders have recognized that the EPA has not been especially effective when it comes to regulating nanomaterials up to this point. On December 29, 2011 the Office of the Inspector General at the EPA issued a report that concluded the "EPA does not currently have sufficient information or processes to effectively manage the human health and environmental risks of nanomaterials" (U.S. Environmental Protection Agency Office of the Inspector General, 2011). The report further outlined that despite having "statutory authority to regulate nanomaterials," the EPA does not have the appropriate "environmental and human health exposure and toxicological data" to effectively regulate research and products in the area of nanotechnology. Clearly one of the next steps for the EPA is to consult more regularly with nanoscientists and nanomanufacturers to gather data for the science-based approach to policy making that has been outlined by the White House in President Obama's June 2011 memo.

So if the EPA has not effectively regulated nanomaterials yet, what about the FDA? As we mentioned earlier, the FDA also has responsibility for regulating nanomaterials; however, the FDA regulates products and not technologies. Therefore, the FDA regulates nanotechnology on a product by product basis—and different categories of products (e.g., drugs versus cosmetics) can have varying levels of regulatory oversight. For example, drugs receive more rigorous oversight from the FDA than dietary supplements do, regardless of the presence of nanomaterials in either category. Concerns about the FDA's categories for products—and specifically the discrepancies in levels of regulation across categories—have increased over time among the public and scientists. In December 2011, the Institute for Agriculture and Trade Policy led a coalition of nonprofit consumer safety and environmental groups in a lawsuit against the FDA over nanotechnology regulation. The consumer safety and environmental groups argued that the FDA has not sufficiently regulated the use of nanoscale materials in some consumer products (such as cosmetics, dietary supplements, and sunscreens) (Food Safety Magazine, 2012; Gunderson, 2011).

Concerns about the FDA's regulation of nanomaterials are not new; in 2006 a report that was commissioned by the Woodrow Wilson Center's Project on Emerging Nanotechnologies argued that the FDA was not ready to respond to the regulatory pressures that nanomaterials introduced, largely because of the agency's increased regulatory responsibilities over time and their lack of adequate funding from Congress (Taylor, 2006). In the report, Taylor also discusses how the FDA is challenged by gaps in its legal authority when it comes to nanotechnology—especially in the areas of supplements and cosmetics (some of the same areas of concern that are discussed in the recent 2011 lawsuit).

In addition to the EPA and FDA, the OSHA also deals with nanotechnology regulation and standards, but largely as they relate to workplace safety and health. Historically, OSHA has highlighted the existing standards that might be applicable for the case of worker exposure to nanomaterials; yet OSHA has not implemented many policy changes to address the specific issues associated with nanotechnology. The existing standards that they have highlighted include recording and reporting occupational injuries and illness, personal protective equipment (general requirements), eye and face protection, respiratory protection, hand protection, sanitation, and hazard communication, among others (Occupational Safety and Health Administration, 2012).

Similarly to OSHA, NIOSH focuses on research and guideline development for safety and health issues for workers that are exposed to nanoscale materials. Also, the agency has established several committees and produced multiple reports outlining some of the risks for workers that are exposed to nanomaterials. Even though NIOSH does not have formal rule-making authority for nanoregulations, they do offer interim guidelines for best practices that should be used for workers that could be exposed to nanomaterials. For example, in 2009 NIOSH published a report titled "Approaches to Safe Nanotechnology: Managing the Health and Safety Concerns Associated with Engineering Nanoparticles" that provided an overview of knowledge about nanoparticle toxicity, exposure assessments, engineering controls, and personal protective equipment for dealing with nanomaterials (National Institute for Occupational Safety and Health, 2009).

Despite the recent efforts by multiple federal agencies to address issues of nanotechnology regulation, the current state of nanoregulations is sparse and patchy. Given this policy environment—and the White House's call for a more "science-based" approach to the regulation of nanomaterials—federal agencies will increasingly rely on the professional perceptions and data generated by leading nanoscientists on the risks, benefits and regulation of the technology. To explore how these scientists are thinking about regulation of the technology, we now turn to some recent data-collection efforts with leading U.S. nanoscientists.

Scientists' Views on Nanotechnology Regulation: An Updated View

As federal agencies move forward with nanotechnology regulation, it will be important to both identify the application areas that have the highest priority for new regulations, and to take a more granular look at the different types of regulations that could be adopted (e.g., distinctions between regulating academic nanotech research and commercial nanotech research). One aspect of developing policy for emerging technologies is to draw on the perceptions and opinions of the experts in the field about risks, benefits, and regulations. These experts are often the scientists "on the ground"; the people who are dealing with nanomaterials daily. And these scientists are the most likely group to have educated and informed opinions about the future needs for nanotech regulations, as well as the current state of existing regulations across application areas. Previous research supports this inclusion of scientists in the policy-making process. As Bosso (2010) points out, experts have regularly influenced the discourse on regulation in the case of technology policy development. Scientists are often considered leading authorities in policy debates with their strong levels of societal trust and their contribution in the discussion of controversies over technologies (Besley & Nisbet, 2013; Scheufele et al., 2007).

Regulation of Nanotechnology

Within the literature there is some tension about whether existing nanotechnology regulations are sufficient or not. On the one hand, environmental groups and activists have strongly argued for stricter regulations of nanotech—and many industry watchers agree that additional regulations are needed (Marchant & Sylvester, 2006). Scholars have also pointed out that the potential risks of the environment, health, and safety issues surrounding nanotechnology require revised regulatory frameworks—even if they are not entirely new (Choi, Ramachandran, & Kandlikar, 2009; Maynard & Rejeski, 2009). Other scholars, however, have argued that regulatory change is not needed for nanotech because emerging technologies and their risks are not significantly different from existing concerns (Jacobstein, 2006)—or that the creation of new regulations requires large amounts of time and financial resources without guaranteeing additional levels of effectiveness and protection (Mandel, 2009). In this article, we explore this tension about existing and future nanotech regulations by using the results of a 2011 survey with leading U.S. nanoscientists to provide an updated view of their normative perceptions about the levels of commercial and academic nanotech research that should be regulated, as well as their descriptive perceptions about the current state of nanotech regulations in the United States. We explore the drivers of these normative and descriptive regulation variables by including them as dependent variables in three hierarchical ordinary least squares (OLS) regression models with a series of independent and control variables that we discuss below.

Independent and Control Variables

In our models, we include a series of demographic and career variables as control variables. Previous studies have shown that women tend to perceive more risks than men for a variety of technologies (Finucane, Slovic, Mertz, Flynn, & Satterfield, 2000; Flynn, Slovic, & Mertz, 1994)—and women are more likely to show concern about the health and safety implications of any given level of technological risk (Davidson & Freudenburg, 1996; Greenberg & Schneider, 1995). These results lead to our first hypothesis.

> Hypothesis 1a: Female nanoscientists are more likely to believe that commercial and academic nanotechnology research should be regulated.

> Hypothesis 1b: Female nanoscientists are less likely than male scientists to think that current regulations are adequate.

Previous research has demonstrated that both political ideology and discipline are significantly related to regulation perceptions for scientists (Corley, Scheufele, & Hu, 2009). Therefore, in addition to gender variables, we also include age, political ideology, and disciplinary field as control variables in our models.

As many scholars have outlined, mass media can also play an important role in framing public debate and shaping public opinion about emerging technologies (Anderson, Scheufele, Brossard, & Corley, 2012; Ho, Brossard, & Scheufele, 2008; Ho, Scheufele, & Corley, 2010, 2011; Nisbet et al., 2002; Pidgeon, Harthorn, & Satterfield, 2011; Scheufele & Lewenstein, 2005). Scientists are often somewhat critical of formal media coverage, especially if they believe news coverage conveys biased or sensationalistic information to the public (Besley & Nisbet, 2013; Blok, Jensen, & Kaltoft, 2008; Corley, Kim, & Scheufele, 2011; Schuler, 2004). Yet recent research demonstrates that scientists increasingly rely on informal media outlets, such as blogging, to contribute to the framing of scientific controversies (Nisbet & Mooney, 2007; Nisbet & Scheufele, 2009). In the case of nanotechnology, previous studies have demonstrated that media attention variables can be important control variables to include in models of regulation/policy perceptions for scientists (Cacciatore, Scheufele, & Corley, 2011). To control for media attention, we include both informal and formal media attention variables in the models. Based on previous research, we expect the following relationship between these variables and regulation perceptions.

> Hypothesis 2a: Scientists' attention to scientific content in both formal and informal media outlets is positively correlated with support for the regulation of academic and commercial nanotechnology research.

> Hypothesis 2b: Scientists' attention to scientific content in both formal and informal media outlets is negatively correlated with their belief that existing regulations are adequate.

Risk and benefit perceptions are another category of variables that can impact scientists' regulation perceptions. Understanding trends in risk and benefit perceptions of nanomaterials is critically important for regulators because research has shown that risk perceptions can induce or restrain policies (Satterfield, Kandlikar, Beaudrie, Conti, & Herr Harthorn, 2009). For example, public support or opposition to climate policies (including taxes and regulations) are significantly influenced by the public's risk perceptions about climate change (Leiserowitz, 2006). In another area of high scientific uncertainty, researchers found that the acceptance of gene technology was linked with perceived benefits and risks of the technology (Siegrist, 2000). Similarly, recent research on genetically modified foods illustrated that there is a relationship between risk perceptions and trust in government regulation (Poortinga & Pidgeon, 2005). Yet not all studies that focus on the relationship between risk perceptions and support for regulation have found positive relationships between these variables, especially when trust in regulators is factored into the equation. For example, some scholars have found a negative relationship between perceived risk and trust in government actions for technologies (Cvetkovich, 1999; Flynn et al., 1994).

Recent research on risk and benefit perceptions for scientists, however, has demonstrated that scientists' risk perceptions about emerging technologies impact their regulation perceptions while benefit perceptions do not impact regulation perceptions (Besley, Kramer, & Priest, 2008; Corley et al., 2009). In addition, most of this research has concluded that as risk perceptions about emerging technologies increase, support for the regulation of those technologies also increases. These studies form the foundation for our third hypothesis, which is listed below.

> Hypothesis 3a: Scientists' risk perceptions are positively correlated with their support for the regulation of academic and commercial nanotechnology research.

> Hypothesis 3b: Scientists' risk perceptions are negatively correlated with the belief that existing regulations are adequate.

Previous studies have also demonstrated that scientists' perceptions about the role of science in society can impact the way they think about the regulation of emerging technologies (Besley & Nisbet, 2013; Corley et al., 2009). These "societal allocation of risk" and "scientific freedom/responsibility" variables explore the trade-offs between advancing science and protecting the public from risks. Silva and Jenkins-Smith (2007) have argued that it is important to include these control variables when modeling scientists' regulation perceptions about a technology. In order to capture a measure of these tensions between science and society for the scientists, we have included a series of "societal allocation of risk" and "scientific freedom/responsibility" statements as independent variables in our models. We build upon previous studies in this area to develop our fourth hypothesis.

Hypothesis 4a: Scientists who value the advancement of science over protecting the public are less likely to support the regulation of academic and commercial nanotechnology research.

Hypothesis 4b: Scientists who value the advancement of science over protecting the public are more likely to think that existing regulations are adequate.

Even though there has been limited attention to the ethical aspect of nanotechnology research (Bowman & Hodge, 2006), some of the most urgent ethical issues surrounding nanotechnology research are related to the protection of human health and the environment within the workplace (National Institute for Occupational Safety and Health, 2009; Poland et al., 2008). For example, worker protection (in both academic and industry lab settings) remains a key issue for any emerging technology, and many of the regulatory challenges posed by nanomaterials are no exception. Therefore, we also explore scientists' sense of laboratory/research ethics for nanotech to see if these variables are related to support for the regulation of nanotechnology. To our knowledge, this area of laboratory/research ethics has not been included in the previous research that has focused on scientists' regulation perceptions about emerging technologies. Therefore, we were not able to develop literature-based hypotheses for this relationship. We speculate, however, that as scientists' sense of ethical obligation about nanotech increases, they will be more supportive of providing a limit on that research with nanoregulations. This leads to our fifth hypothesis.

Hypothesis 5a: Scientists who perceive stronger ethical obligations for nanotech researchers are more likely to support the regulation of academic and commercial nanotechnology research.

Hypothesis 5b: Scientists who perceive stronger ethical obligations for nanotech researchers are less likely to think that existing regulations are adequate.

Now that we have outlined the hypotheses that we test with our models, we will turn to a brief discussion of our data collection efforts and then present the results of our analyses.

Data Collection

The data used in this article are drawn from a nationally representative study of leading U.S. nanoscientists. The survey was conducted by mail between June and September 2011, and it was administered by the University of Wisconsin Survey Center in four waves following Dillman's Tailored Design Method (Dillman, Smyth, & Christian, 2008). The final response rate for the survey was 31.6% (AAPOR RR-3: 31.6%) (AAPOR, 2008). 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. For a more detailed description of this group's refinement process for nanotechnology search terms, see the article by Porter, Youtie, Shapira, and Schoeneck (2008) that outlines and explains their process.

Table 1. Mean Responses for Demographic Variables (N = 444)

	Mean	Standard Deviation
Demographic and values variables		
Percent male	82.529	N/A
Respondents' age	46.071	12.016
Percent Republican	6.306	N/A
Percent Democrat	45.270	N/A
Percent Independent	45.045	N/A
Political ideology[a] (1 = very conservative; 5 = very liberal)	3.475	0.820
Religiosity[b] (1 = No guidance at all; 10 = A great deal of guidance)	3.232	2.783
Type of employment		
Percent in non-tenure-track university-based position	15.700	N/A
Percent in tenure-track/tenured university-based position	58.454	N/A
Percent working in industry	6.522	N/A
Percent in none of the above three work categories	19.324	N/A
Career variables		
Year of PhD	1,993.674	12.980
Percent of respondents with tenure at a university	43.961	N/A
General discipline of doctoral degree		
Percent biology	12.379	N/A
Percent chemistry	33.010	N/A
Percent mathematics and engineering	14.806	N/A
Percent materials science	15.049	N/A
Percent medicine	3.398	N/A
Percent physics	17.718	N/A
Percent other fields	3.641	N/A

[a]"In general, would you describe your political views as . . ." (1 = very conservative; 2 = conservative; 3 = moderate; 4 = liberal; 5 = very liberal).
[b]"How much guidance does religion play in your everyday life? Use a ten-point scale where '1' means no guidance at all and '10' means a great deal of guidance."

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 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 less than 39 times in the two-year period of 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 1,405 names with complete addresses, and this yielded 444 completed questionnaires.

As Table 1 illustrates, 82.5% of all the respondents were male, 44% had tenured academic positions, and 6.5% worked in industry. The average age for the respondents was about 46 years and the average year for the receipt of a doctoral degree was 1994. We also observed some disciplinary diversity among the respondents. The largest percent of respondents were in the field of chemistry (33%), followed by physics (17.7%), material science (15%), mathematics and engineering (14.8%), and biology (12.4%). There was also some diversity in political ideology with about 45% of the respondents being registered Democrats, about 45% being Independents, and about 6% being registered Republicans.

Table 2. Leading U.S. Scientists' Perceptions about Nanoregulations (2007 and 2011)

	2007 (N=363)		2011 (N=444)	
	Mean	SD	Mean	SD
Normative regulation statement (1 = strongly disagree; 5 = strongly agree)				
"Academic nanotechnology research should be regulated."**	2.117	1.222	**2.616**	**1.309**
"Commercial nanotechnology research should be regulated."**	2.958	1.335	**3.434**	**1.305**
Descriptive regulation statement (1 = current regulations sufficient; 5 = need new regulations)				
"Thinking about applications of nanotechnology in each of the following areas, please indicate to which degree you think current regulations are sufficient or we need new regulations in order to address the new realities created by nanotechnology."				
Machines and computers	2.333	1.242	2.388	1.261
Environment and energy*	**3.081**	**1.309**	2.841	1.275
Military and defense	3.018	1.330	2.851	1.333
Surveillance and privacy**	**3.285**	**1.360**	2.869	1.406
Other consumer products	2.898	1.133	3.005	1.186
Cosmetics	3.030	1.327	3.043	1.359
Medicine	3.208	1.287	3.153	1.325
Biological engineering/human enhancement	3.432	1.286	3.354	1.319
Synthetic biology	N/A	N/A	3.162	1.309

Notes.
The results are for the comparison of two cross-sectional data collections (2007 and 2011) with nationally representative samples of leading U.S. nano-scientists; these are not panel data comparisons over time.
Significant differences across the two cross-sectional data collections (2007 and 2011) are represented as *$p < 0.05$ and **$p < 0.01$, and the higher values are bolded.

Results

Before delving into the details of our hierarchical OLS regression analysis, we will present some summary statistics for the dependent and independent variables that we use in our models. In Table 2, we highlight the summary statistics for our dependent variables: the normative and descriptive statements about nano-regulation. In our data collection, we distinguished between these two types of regulation statements so we could take a granular look at any differences between how scientists think nanomaterials should be regulated (our two normative regulation statements) and how they actually are regulated now (our nine descriptive regulation statements).

The results in Table 2 demonstrate that in our 2011 data collection, scientists were more likely to say that commercial nanotech research should be regulated (Mean = 3.434; SD = 1.305) than academic nanotech research (Mean = 2.616; SD = 1.309). This is not completely surprising given that the majority of the respondents for this survey worked at universities—and, therefore, run many of the most productive academic nanotech research laboratories in the country. It is noteworthy, however, that there is a difference in the way that the leading nano-scientists think that academic and commercial nanotechnology should be regulated. This is a distinction that might be important for federal agencies as they make policy changes for nanotechnology in the future. This distinction might also mean that federal agencies (such as the EPA, FDA, and OSHA) should communicate with academic funding agencies (like the National Science Foundation and the National Institutes of Health) about coordinating regulation and standards development for nanotechnology research. So far, this type of coordination and communication between federal regulatory and funding agencies has not been visible in the policy environment for nanotech research.

In addition to reporting the 2011 regulation perceptions for the nanoscientists, we also wanted to compare this updated view with our 2007 data collection with leading U.S. nanoscientists. While the comparisons of the 2007 and 2011 data collections are not panel data comparisons, we did use a similar sampling design for the two national-level, cross-sectional scientist surveys. The full details of the 2007 scientist survey have been reported in earlier articles (Corley et al., 2009, 2011; Ho et al., 2011; Kim, Corley, & Scheufele, 2012; Youtie, Carley, Shapira, Corley, & Scheufele, 2011) so we only provide a brief snapshot here. The 2007 scientist survey was focused on collecting data from 363 leading U.S. nanotechnology scientists and engineers. The survey was conducted by mail between May and June 2007, and it was administered by the University of Wisconsin Survey Center following Dillman's Tailored Design Method (Dillman et al., 2008). The final response rate for the 2007 nanoscientist survey was 39.5% (AAPOR RR-3: 39.5%). As with the 2011 survey, the 2007 sampling design was also based on identifying the most highly cited authors in the nanotechnology field using records provided by Porter et al. (2008).

The results of the normative regulation statements for both 2007 and 2011 are presented in Table 2. Even though we do not have panel data comparisons for 2007 and 2011, we did conduct some basic independent samples *t*-tests across the two cross-sectional samples to explore any differences in mean regulation perceptions among the two groups. One notable result is that respondents in 2011 seem to have a stronger sense of urgency about the regulation of both academic and commercial nanotechnology research than the respondents in 2007. We speculate that this increase in the urgency about the way we should regulate nanotech research is driven partly by the continuing lack of a comprehensive regulatory framework for nanotechnology that we discussed at the beginning of this article.

We also included some descriptive regulation statements in our survey to capture how sufficient the leading U.S. nanoscientists think nanoregulations actually are right now. Since this is a descriptive question, we asked the scientists to report their perceptions about the adequacy of existing nanoregulations in nine general application areas: bioengineering, cosmetics, environment and energy, machines and computers, medicine, military and defense, surveillance and privacy, synthetic biology, and other consumer products. In Table 2, we have organized the mean responses for these categories in increasing order (i.e., displaying stronger need for new regulations as you go down the list) for the 2011 mean values. The results for the 2011 survey illustrate that the application areas where the nanoscientists are more likely to think that existing regulations are sufficient are: machines/computers, environment/energy, and military/defense. The application areas where the nanoscientists were more likely to think that existing regulations are not sufficient include: synthetic biology, bioengineering, medicine, and cosmetics.

When we compare the results of the 2007 survey with the 2011 survey results, we do not see many significant differences for the descriptive regulation statements. The only two application areas with significantly different means across years are

Table 3. Scientists' Perceptions about Laboratory Ethics and the Role of Science in Society (N = 444)

	Mean	Standard Deviation
Laboratory/research ethics statements (1 = strongly disagree; 5 = strongly agree)		
"Directors of university-based laboratories have an ethical obligation to protect their workers from unhealthy exposure to nano-materials."	4.674	0.718
"Directors of industry-based laboratories have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials."	4.717	0.693
"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."	4.071	1.172
Laboratory/research ethics index (Cronbach's alpha = 0.700)	13.459	2.108
Summative index composed of three statements listed above		
Scientific freedom and responsibility statements (1 = strongly disagree; 5 = strongly agree)		
"As members of society, scientists share responsibility for any use or misuse of their discoveries."	3.112	1.352
"The authorities should formally oblige scientists to respect ethical standards."	3.798	1.155
"Scientists should be free to carry out the research they wish, provided they respect ethical standards."	4.239	1.086
Societal allocation of risk statements (1 = strongly disagree; 5 = strongly agree)		
"Advancing nanotechnology quickly is more important than protecting society from the unknown risks."	2.604	1.268
"Public opinion is more important than the scientists' opinions when making decisions about scientific research."	1.747	0.925
"Regulating nanotechnology will significantly slow down scientific progress."	3.203	1.156

environment/energy and surveillance/privacy. In the 2011 data collection, the nanoscientists were more likely than the 2007 respondents to say that these two application areas had adequate existing regulations. We speculate that the one reason why we do not see many significant differences between the responses of the 2007 nanoscientists and the 2011 nanoscientists is again because there have not been major adoptions of new regulations for nanotechnology within that time frame.[1] The areas of bioengineering, medicine, and cosmetics continue to be application areas where leading nanoscientists see an urgent need for new nanotechnology regulations.

As we mentioned previously, there are some sections of the 2011 survey that were not included in earlier data collections. One of these new areas includes a focus on measuring scientists' perceptions about laboratory/research ethics. We included this new focal area in the 2011 survey because the protection of nanotechnology workers in both university-based and industry-based lab environments continues to be a key issue for OSHA and NIOSH. Workers in labs may be exposed to high concentrations of nanomaterials on a daily basis; yet many of the practices that are adopted in the lab to protect workers are voluntary and, therefore, up to the lab directors or the employees themselves. In our survey we explored scientists' views on the ethical obligation of lab directors for protecting workers from risks associated with lab exposure to nanomaterials. In Table 3 we report the summary statistics for statements related to both laboratory/research ethics and the role of science in society.

We included three statements about laboratory/research ethics in our questionnaire. The first statement captured scientists' perceptions about the ethical obligations of lab directors for university-based nanotech labs. The second statement captured scientists' perceptions about the ethical obligations of directors for industry-based nanotech labs. And the third statement is focused on scientists' perceptions about linking federal funding of nanotech research with formal, mandatory guidelines for worker protection.

Our survey results demonstrate that the respondents thought that lab directors in both university and industry settings have a strong ethical obligation to protect their workers from unhealthy exposure to nanomaterials (Mean = 4.674; SD = 0.718 and Mean = 4.717; SD = 0.693, respectively). Many of the respondents also thought that federal funding of nanotech research should be linked to formal guidelines that would protect workers from exposure to nanomaterials, although there was more variance for this question (Mean = 4.071; SD = 1.172). Taken together, the responses to the laboratory/research ethics statements illustrate that the scientists had a strong sense of ethical obligation for worker safety issues within nanotechnology research laboratories. To include this ethical obligation for protecting workers as an independent variable in our OLS hierarchical regression model, we created a summative "laboratory/research ethics" index from the above three statements (minimum value = 3; maximum value = 15; Mean = 13.459; SD = 2.108, Crobach's alpha = 0.700).

In addition to the laboratory/research ethics questions, we also captured the scientists' perceptions about scientific freedom and responsibility. Specifically, we asked the scientists about their own responsibility in any misuse of their research, their perceptions about authorities obliging them to respect ethical standards in their work, and their freedom to carry out any research that they wish. While the mean responses indicated a somewhat neutral position on scientists' responsibility for misuse of their research (Mean = 3.112; SD = 1.352), the scientists were in favor of having a high degree of academic and scientific freedom in their research (Mean = 4.239; SD = 1.086).

We also asked the scientists a series of three statements that captured their perceptions about the societal allocation of risk—in other words, the tension between protecting the public from risks and advancing science at the expense of public health or safety. The first statement focused on the trade-off between advancing science quickly and protecting the public from risks, while the second statement measured whether public opinion or scientists' opinions are more important for scientific decision making. The third statement captured perceptions about whether regulation would slow down scientific progress.

While, on average, the scientists somewhat disagreed with the statement that advancing nanotechnology quickly is more important than protecting the public from the risks of the technology (Mean = 2.604; SD = 1.268), they more strongly disagreed that public opinion is more important than scientists' opinions for scientific decision making (Mean = 1.747; SD = 0.925). The mean responses to the statement about nanoregulations slowing down scientific progress were relatively neutral (Mean = 3.203; SD = 1.156). We included these three "societal allocation of risk" statements in our hierarchical OLS regression model, which is presented in Table 4.

Hierarchical OLS Regression Models

To analyze the relationship between scientists' nanoregulation perceptions and demographic variables, media variables, risk/benefit perceptions, societal allocation

Table 4. OLS Regression Models for Normative and Descriptive Regulation Perceptions (Final Standardized Beta Coefficients)

	Normative Model 1: Commercial Regulation[a]	Normative Model 2: Academic Regulation[b]	Descriptive Model 3: Adequacy of Current Regs[c]
Block 1: demographics and career variables			
Age	−0.076	−0.078	−0.029
Male[d]	−0.013	−0.070	−.103*
Political ideology[e]	0.042	0.049	0.041
Disciplinary fields (biology is reference)			
Chemistry	−.130*	−.131*	−0.133
Math and engineering	−0.103	−.123*	0.014
Materials sciences	−0.042	−0.049	−0.015
Medicine	−0.012	−0.037	−0.039
Physics	−0.095	−0.032	−0.069
Other disciplines	−0.065	−0.037	−0.023
Incremental R^2—block 1	**.061****	**.072****	**.067***
Block 2: media attention/engagement			
Attention to science and technology[f]	−0.070	−0.074	−0.016
Attention to social/ethical implications[g]	0.065	0.042	0.106
Write a science blog[h]	0.024	−0.065	0.065
Read a science blog[i]	.109*	.124*	0.038
Incremental R^2—block 2	**.026***	**.032***	**.051****
Block 3: risk and benefit perceptions			
Nano-risk perception index[j]	.273**	.182**	.209**
Nano-benefit perception index[k]	0.052	0.035	−0.049
Incremental R^2—block 3	**.080****	**.052****	**.074****
Block 4: scientific freedom and responsibility			
Scientists share research responsibility[l]	−.140**	−.113*	0.054
Scientist free to conduct any research[m]	0.032	−.094*	0.074
Authorities should oblige[n]	.109*	.173**	0.077
Incremental R^2—block 4	**.031****	**.063****	**.031****
Block 5: societal allocation of risk			
Advancing nano is important[o]	−0.066	−0.068	−.158**
Regulation slows science progress[p]	−0.090	−.190**	−.154**
Public opinion more important[q]	0.037	.182**	0.039
Incremental R^2—block 5	**.029****	**.099****	**.087****
Block 6: ethical obligations			
Laboratory/research ethics index[r]	.174**	.165**	.198**
Incremental R^2—block 6	**.025****	**.022****	**.031****
Final R-squared for model	**.251****	**.339****	**.340****

Significance level: *p < .05, **p < .01.

[a]"Commercial nanotechnology research should be regulated." (1 = strongly disagree; 5 = strongly agree)

[b]"Academic nanotechnology research should be regulated." (1 = strongly disagree; 5 = strongly agree)

[c]Summative index (Cronbach's alpha = 0.930) of the following statement for nine application areas listed below: "Thinking about applications of nanotechnology in each of the following areas, please indicate to which degree you think current regulations are sufficient or we need new regulations in order to address the new realities created by nanotechnology": (1 = current regulations are sufficient; 5 = we need new regulations)
(1) cosmetics, (2) military and defense, (3) medicine, (4) biological engineering/human enhancement, (5) environment and energy, (6) machines and computers, (7) surveillance and privacy, (8) synthetic biology, and (9) other consumer products.

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

[e]"In general, would you describe your political views as . . ." (1 = very conservative; 2 = conservative; 3 = moderate; 4 = liberal; 5 = very liberal)

[f]"In general, how much attention do you pay to 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 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]"How often, if ever, do you write for a blog about science?" (1 = never; 2 = rarely; 3 occasionally; 4 = often)

[i]"How often, if ever, do you read a blog about science?" (1 = never; 2 = rarely; 3 occasionally; 4 = often)

[j]Summative index (Cronbach's alpha = 0.833) of the following statements. (1 = strongly disagree; 5 = strongly agree)

Table 4. Continued

(1) "Nanotech may lead to the loss of personal privacy"
(2) "Nanotech may lead to an arms race between the U.S. and other countries"
(3) "Nanotech may lead to new human health problems"
(4) "Nanotech may be used by terrorists against the U.S."
(5) "Nanotech may cause a loss of more U.S. jobs"
(6) "Nanotech may lead to the uncontrollable spread of very tiny self-replicating robots"
(7) "Nanotech may lead to more pollution and environmental contamination"

[k]Summative index (Cronbach's alpha = 0.791) of the following statements. (1 = strongly disagree; 5 = strongly agree)

(1) "Nanotech may lead to new and better ways to treat and detect human diseases"
(2) "Nanotech may lead to new and better ways to clean up the environment"
(3) "Nanotech may give scientists the ability to improve human physical and mental abilities"
(4) "Nanotech may help us develop increased national security and defensive capabilities"
(5) "Nanotech may lead to technologies that will help solve our energy problems"
(6) "Nanotech may revolutionize the computer industry"
(7) "Nanotech may lead to a new economic boom"

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

[m]"Scientists should be free to carry out the research they wish, provided they respect ethical standards." (1 = strongly disagree; 5 = strongly agree)

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

[o]"Advancing nanotechnology quickly is more important than protecting society from the unknown risks." (1 = strongly disagree; 5 = strongly agree)

[p]"Regulating nanotechnology will significantly slow down scientific progress." (1 = strongly disagree; 5 = strongly agree)

[q]"Public opinion is more important than the scientists' opinions when making decisions about scientific research." (1 = strongly disagree; 5 = strongly agree)

[r]Summative index (Cronbach's alpha = 0.700) of the following statements. (1 = strongly disagree; 5 = strongly agree)

(1) "Directors of university-based laboratories have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials."
(2) "Directors of industry-based laboratories have an ethical obligation to protect their workers from unhealthy exposure to nanomaterials."
(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."

of risk variables, and ethical perceptions, we ran three hierarchical OLS regression models with the two normative regulation statements and the one descriptive regulation statement as dependent variables.

The three dependent variables in our analysis (one for each model) represent scientists' normative perceptions about the regulation of commercial nanotech research (Model 1), scientists' normative perceptions about the regulation of academic nanotech research (Model 2), and scientists' descriptive perceptions about the sufficiency of existing regulations for nanotechnology (Model 3). As previously mentioned, in Table 2 we outlined the descriptive statistics for each of the dependent variables (including means and standard deviations).

The independent and control variables were the same for each of the three models—and we entered those variables into the models in six consecutive blocks. The first block was a set of demographic variables that included age, gender, political ideology, and disciplinary field. The second block included a series of four statements that measured media attention to science issues. The third block included a summative index for nanotechnology risk perceptions (Cronbach's alpha = 0.791; seven statements) and a summative index for nanotechnology benefit perceptions (Cronbach's alpha = 0.833; seven statements). The fourth block focused on "scientific freedom and responsibility" variables while the fifth block focused on "societal allocation of risk variables." The sixth, and final, block included our laboratory/research ethics index (which was previously explained in Table 3).

Model 1: Normative Perceptions about the Regulation of Commercial Nanotechnology Research

For Model 1, we used the following statement to represent the scientists' normative perceptions about nano-regulation of commercial research: "Commercial nanotechnology research should be regulated" (1 = strongly disagree; 5 = strongly agree). Our results demonstrate that the demographic and career variables in block 1 accounted for 6.1% of the variance in the scientists' normative perceptions about commercial nanoregulation. Scientists in the disciplinary area of chemistry were less likely to say that commercial nanotech research should be regulated than biologists (the reference group for disciplinary field). The media attention variables accounted for about 2.6% of the variance in the dependent variable. Even though attention to formal media outlets (focused on science and societal implications) was not significant, engagement with informal media outlets was significantly related to the scientists' perceptions about the regulation of commercial nanotechnology research. Scientists that regularly read a science blog were more likely than their non-blog-reading peers to say that commercial nanotech research should be regulated.

About 8.0% of the variance in the dependent variable for Model 1 was explained by risk and benefit perceptions. In agreement with previous studies, we found that risk perceptions had a positive and significant relationship with the scientists' perceptions about regulation, while benefit perceptions were not significantly related with the scientists' commercial nanotech regulation perceptions.

The "scientific freedom/responsibility" variables and the "societal allocation of risk" variables each explained about 3.0% of the variance in the dependent variable for Model 1. Scientists that felt somewhat responsible for any misuse of their research were less likely to support regulating commercial nanotechnology research. We speculate that since these respondents felt that scientists should be held responsible for the outcomes of their research, they expected to impose personal limits on themselves rather than leaving the constraints solely to external regulations. Surprisingly, the scientific freedom variable was not significant for the commercial regulation model. We speculate that the scientists viewed scientific freedom as something that is more relevant for academic research than for industry-based or commercial nanotech research. Additionally, the three "societal allocation of risk" variables were not significant for this model; it seems that the trade-offs between advancing science and protecting society from risks are less important to scientists than other factors when they make policy decisions about commercial nanotechnology research.

Lastly, the laboratory/research ethics index was significant and it explained about 2.5% of the variance in the scientists' normative perceptions about regulating commercial nanotech research. Scientists with a strong sense of ethical obligation to protect workers within a laboratory environment were more likely to say that commercial nanotech research should be regulated. The overall R^2 value for Model 1 was 0.251.

Model 2: Normative Perceptions about the Regulation of Academic Nanotechnology Research

We believe it is crucial to separate the scientists' normative perceptions about the regulation of academic nanotech research from their perceptions about the regulation of commercial nanotech research because previous research has demonstrated that the goal of marketing a product can push commercial research forward at the expense of public safety. As Macoubrie (2005, p. 4) highlights "past safety issues with specific products, ranging from drugs to genetically engineered crops, have led to a widespread perception that industry pushes products to market without adequate safety testing, makes too many errors affecting people's health, and puts its own motives ahead of consumer safety." We used the following statement to represent the scientists' normative perceptions about nanoregulation of academic research: "Academic nanotechnology research should be regulated" (1 = strongly disagree; 5 = strongly agree).

Our results demonstrate that the demographic and career variables in block 1 accounted for 7.2% of the variance in the scientists' normative perceptions about academic nanoregulation. Scientists in the disciplinary areas of both chemistry and math/engineering were less likely to say that academic nanotech research should be regulated than biologists (the reference group for disciplinary field). The media attention variables accounted for about 3.2% of the variance in the dependent variable for regulation of academic nanotech research. The results for the media attention block variables were the same as for Model 1; scientists who read a science blog regularly were more likely than their peers to say that academic nanoresearch should be regulated.

As with Model 1, the scientists' benefit perceptions were not significantly related to their perceptions about the regulation of academic nanotech research, but scientists with higher risk perceptions were more likely than their fellow scientists' to say that academic nanotech research should be regulated. About 5.2% of the variance in the dependent variable for Model 2 was explained by risk and benefit perceptions.

The "scientific freedom/responsibility" variables and the "societal allocation of risk" variables explained about 6.3% and 9.9%, respectively, of the variance in the dependent variable for Model 2. While the results for the scientific responsibility variables were the same as they were for Model 1, they did differ from Model 1 for the "scientific freedom" variable. The scientists with a strong sense of "scientific freedom" were less likely than their peers to say that academic nanoresearch should be regulated. Since this was not a significant variable for Model 1, it seems that this concept of "academic freedom" or "scientific freedom" only comes into play for the scientists when they consider regulating academic research (not commercial research). This is in line with our speculation above that the scientists viewed scientific freedom as a concept that is more important for academic research than for commercial research.

Lastly, the laboratory/research ethics index continued to be positively correlated with regulation perceptions for Model 2 (as it was for Model 1) and it explained about 2.2% of the variance in the scientists' normative perceptions about academic nanotech research. The overall R^2 value for Model 2 was 0.339.

Model 3: Descriptive Perceptions about the Adequacy of Existing Nanoregulations

For Model 3, our dependent variable was the summative index of nine descriptive statements that measured scientists' perceptions about the adequacy of current regulations in the following application areas: cosmetics, military and defense, medicine, biological engineering/human enhancement, environment and energy, machines and computers, surveillance and privacy, synthetic biology, and other consumer products (Cronbach's alpha = 0.930; 9 statements). In Table 2 we highlighted the summary statistics for this index, including the original survey question, minimum value, maximum value, mean value, and standard deviation.

Our results for Model 3 demonstrate that the demographic and career variables in block 1 accounted for about 6.7% of the variance in the scientists' descriptive perceptions about existing nanoregulations. Even though we found disciplinary differences for the normative regulation statements, we did not see any disciplinary differences for Model 3. We did, however, find significant differences across gender for the descriptive perceptions about nanoregulation. While male and female scientists tended to think similarly about how academic and commercial nanotech research should be regulated, female scientists were more likely than their male peers to think that existing nanotech regulations are not sufficient.

The media attention variables accounted for about 5.1% of the variance in the dependent variable for the adequacy of existing nanoregulations; however, none of the media attention variables were significant in block 2. While attention to informal media outlets (such as reading a science blog) seems to impact the way scientists think about the normative aspects of nanotech regulation (i.e., how regulation should function), their attention to these outlets does not seem to impact their descriptive perceptions about the adequacy of existing regulations. This is an interesting finding because it means that engagement in informal media outlets online impacts scientists' normative perceptions about the regulation of their fields; yet this type of media engagement does not change perceptions about existing regulations.

As with Models 1 and 2, the scientists' benefit perceptions were not significantly related to their perceptions about the adequacy of existing regulations, but scientists with higher risk perceptions were more likely than their peers to think that the current regulations for nanotech were inadequate. The risk and benefit perceptions block explained about 7.4% of the variance in Model 3.

The "scientific freedom/responsibility" variables and the "societal allocation of risk" variables explained about 3.1% and 8.7%, respectively, of the variance in the dependent variable for Model 3. Interestingly, the scientific freedom and responsibility variables were not significantly correlated to the scientists' descriptive perceptions about the adequacy of existing regulations. Since these variables were significant (to differing degrees) in Models 1 and 2, it seems that the concepts of scientific freedom and responsibility matter much more to the scientists when they make normative statements about regulating nanotech research (either in the academic or commercial environment) than when they think about whether existing regulations are adequate. On the other hand, statements that captured the scientists' perceptions about societal allocation of risk were significant for Model 3. In particular, as scientists were more likely to argue that advancing science is more important than protecting the public—or that regulation could slow down scientific progress—they were more likely to say that existing regulations were sufficient.

Finally, the laboratory/research ethics index continued to be positively correlated with regulation perceptions for Model 3 and it explained about 3.1% of the variance in the scientists' perceptions about the adequacy of existing nanotech regulations. The overall R^2 for Model 3 was about 0.340. In the next section, we discuss our results with a focus on our hypotheses and we conclude with some summary observations.

Discussion

The purpose of this article is to explore how leading U.S. scientists perceive the current policy environment for the regulation of nanomaterials, as well as how they think nanomaterials should be regulated in the United States in the future. To flesh out the regulation perceptions of the nanoscientists we tested a series of hypotheses. Our first hypothesis was that female nanoscientists would be more likely to support new nanotech regulations from both a normative and descriptive perspective. This hypothesis was based on previous research that has consistently shown significant differences in risk and regulation perceptions across gender (Corley et al., 2009; Davidson & Freudenburg, 1996; Finucane et al., 2000; Flynn et al., 1994; Greenberg & Schneider, 1995). This hypothesis was confirmed for our descriptive statement about the adequacy of existing nanoregulations; in other words, women were more likely to believe that existing nanoregulations were not sufficient. On the other hand, we did not see any gender differences in the normative perceptions that the nanoscientists had for the regulation of academic or commercial nanotech research.

Our second hypothesis was focused on attention to science content in media outlets. Although the public's media attention is positively associated with their support for nanotechnology (Cacciatore et al., 2011), studies have shown that scientists are generally more critical of formal media coverage (Besley & Nisbet, 2013; Blok et al., 2008; Schuler, 2004). We expected that as scientists paid more attention to science content and societal implications content online, they would be more likely to support the future regulation of academic and commercial nanoresearch and that they would be more likely to say that existing regulations were inadequate. As with hypothesis 1, our second hypothesis was only partly confirmed. Our results did show that scientists who paid attention to informal science media outlets online (e.g., reading a science blog regularly) were more likely to say that academic and commercial nanotech research should be regulated. The result is particularly interesting because current studies show that scientists are increasingly exposed to informal media such as blogs (Nisbet & Mooney, 2007; Nisbet & Scheufele, 2009). Yet the level of attention to science media online did not have a significant impact on the way scientists perceive the adequacy of existing nanoregulations.

We also expected that the nanoscientists' risk perceptions would be positively correlated with their current support (i.e., Model 3) and future support (i.e., Models 1 and 2) for higher levels of nanoregulation. Our third hypothesis was confirmed for all three models. Our fourth hypothesis was focused on the relationship between scientists' views of the role of science in society and their support for regulation. While scientists in general seem to underestimate public opinion (Besley & Nisbet, 2013; Michael & Brown, 2000; Moore & Stilgoe, 2009), we found that scientists who value public opinion in decision making about nanotechnology were more likely to say that academic nanotechnology should be regulated. In general, the societal allocation of risk variables was significantly related to the scientists' perceptions about how we should regulate academic nanoresearch, as well as their perceptions about the current state of nanoregulations in the United States; yet the societal allocation of risk variables were not significantly related to the scientists' perceptions about the regulation of commercial nanotech research. Our results indicate that trade-offs between science advancement and public safety are less important for scientists when they make decisions about commercial nanotech research.

Our final hypothesis was that scientists with a stronger sense of research/laboratory ethical obligations would be more likely than their peers to support nanoregulations in academic and commercial settings. We also expected that these scientists would be more likely to think that existing nanoregulations are not adequate. This hypothesis was confirmed for all three models indicating that scientists' sense of ethical obligations is strongly linked with their perceptions about regulations in their research fields.

We believe that there are several important summary points to take from this research. First, we found that nanoscientists draw on different heuristics when they make normative and descriptive decisions about nanotechnology regulation. We also concluded that scientists use different heuristics when they consider academic and commercial nanotechnology regulation. These results demonstrate that context matters quite a lot to scientists when they think about regulating nanotechnology. For example, when scientists make normative policy decisions about regulating commercial nanotechnology research, they draw on their experiences with informal media sources, risk perceptions, sense of ethical obligations, views on scientific responsibility, and disciplinary background. When scientists make similar policy decisions about regulating academic nanotechnology research, they draw on their experiences with informal media sources, risk perceptions, sense of ethical obligations, views on scientific freedom, views on the trade-offs between scientific advancement and protecting society, the role of public opinion, and disciplinary background.

A second noteworthy finding is that scientists' attention to science blogs online can significantly impact the way that they think their field should be regulated (within both academic and commercial environments). This result has implications for agencies that regulate nanotechnology and hope to involve scientists in policy development. These agencies might consider engaging scientists in longer-term discussions online about the future of the nanotech field—as well as normative questions about regulation—before asking them for policy advice.

A third implication is that scientists draw heavily on their sense of professional ethics to make decisions about current and future regulation of nanotechnology. In previous data collection efforts, we have not seen an explicit focus on scientists' ethical views of their work and how those view might relate to their policy decisions. This research has shown that this is a relationship that is significant across a variety of different regulatory contexts for nanotech.

Lastly, we can conclude from our data analysis that the leading U.S. nanoscientists believe that the application areas in which current regulations are the weakest include: bioengineering/human enhancement, medicine, synthetic biology, and cosmetics. This finding is particularly relevant for federal agencies as they continue to move forward with a more comprehensive policy framework for nanotechnology. Instead of focusing policy development resources on application areas that might have stronger existing regulations (such as machines and computers), these federal agencies could make the weaker application areas a top priority.

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Note

1. Note that synthetic biology was not included as an application area in the 2007 survey so no results are reported for that column.

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