Firms' Perceptions of Health and Environmental Hazards and Regulations: Evidence from a Survey of U.S. Nanotechnology Companies

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This study tests the hypothesis that firms are able and willing to assess and reduce health and environmental risks. US nanotechnology executives' survey results indicate that companies involved in research collaboration with universities show greater confidence in their ability to assess such risk and greater awareness that lack of safety standards could compromise future growth. Gender also makes a difference in attitudes. Management reveals conflicting views about responsibility for health and environmental R&D and the government's role. The best governmental strategy may be to support universities' safety research and to rely on such institutions for the diffusion of acquired knowledge.

INTRODUCTION

Job safety risks and health hazards have been the object of economic analysis in the context of the theory of compensating wage differentials. The discussion has focused both on the validity of the assumptions on which the theory is based and on the empirical testing of its main prediction, i.e., that workers employed in more dangerous jobs would command higher wages. Within this context, economic studies have also discussed the value of government occupational safety regulations. However, very little empirical analysis exists regarding employers' attitudes toward occupational hazards: their understanding of such hazards; their willingness to control them; and their views toward governmental health, safety, and environmental regulations. This study tries to cast light on some of these topics by analyzing firms' opinions about risk, safety, and the government's role in the context of potential, but still largely unknown, health hazards, i.e., the workplace risks associated with nanotechnologies.

Nanotechnology has been described as the biggest technological change introduced in production processes since the industrial revolution. Despite the lack of full agreement about its definition (Hodge at al., 2007), nanotechnology is often meant to describe "the art and science of manipulating matter at the nanoscale (down to 1/100,000 the width of a human hair) to create new and unique materials and products" (Woodrow Wilson International Center for Scholars, 2011a). The value of the nanotechnology market is predicted to reach 1 trillion dollars by 2015 (Berger, 2007), and the inventory of nanotechnology consumer products (in areas ranging from health care to food to IT products) increased by 521% between 2006 and 2011, going from 212 to 1317 available products (Woodrow Wilson International Center for Scholars, 2011b). This dramatic growth is happening despite continuous concern about the environmental and health impacts of nanoparticles and nanomaterials. In fact, compared to larger materials, nanomaterials are not only dramatically smaller but can also exhibit new properties, including toxicological behaviors that are only partially understood. Because of these novel properties and their ability to enter the body and reach almost any organ and be retained much longer once in the body,

nanomaterials present greater potential risks for workers employed in the manufacturing of nanoproducts and in the manipulation of nanomaterials for the production of other goods[1] (Grégoire, 2009, Handy and Shaw, 2007, Savolainen et al. 2010, Springston, 2008). However, there is still no consensus regarding the limits of occupational exposure to nanomaterials (Murashov et al., 2009). This raises big challenges for the establishment of government regulations. On one hand governments want to foster R&D in these new technologies with great potential for leading to new products and economic growth; on the other hand, governments need to respond to concerns that such new activities may imply great societal risk leading to potential negative health effects that could only manifest in humans long after exposures. Therefore, the difficulty of assessing the hazards of these new materials and new industrial processes has led most governments to formulate only recommendations with no specific legislation on nanotechnologies (Ponce Del Castillo, 2009)[2]. This leaves firms to rely mainly on self-regulation. We know very little, however, about how employers actually behave when facing unknown workplace risks. The goal of this study, therefore, is to cast some light on firms' attitudes toward both safety concerns and regulations. It does so by making use of data extracted from a survey of US nanotechnology executives that was administered in 2006 and first described by Hock at al. (2006).

BACKGROUND

Health and safety hazards are job attributes that can produce substantial costs for firms: higher wages to attract workers, workers' compensation costs, higher quit rates and corresponding adjustment costs. Economic theory has explored the role played by occupational risk in the context of the hedonic theory of compensating differentials. In this context, the theory predicts that firms will invest in safety up to the point where the value of the marginal benefits associated with such investment is greater than or equal to the marginal costs of developing safer work environments (Viscusi, 1979). This theory also predicts that in a competitive labor market workers who are more risk-averse will match with safer firms that pay lower wages, and vice versa (Rosen, 1974). The empirical literature on this topic has focused on testing whether or not firms indeed pay compensating wage differentials. Much less work has been done (Viscusi and O'Connor, 1984) on assessing the value of the main critique to this theory: that compensating wage differentials presume that workers are aware of the risks they face in different jobs, while in reality, most employees do not have such knowledge or have incomplete information. This criticism is likely to be even stronger in the context of occupational health hazards that are not fully known and the potential consequences of which may manifest themselves only after several years. This debate, however, seems to be completely silent about another implicit assumption of the hedonic wage theory: that employers themselves are aware of risk, know how to reduce it, and know the costs of doing so. It is because of such presumed employer awareness that these models often capture firms' choices with isoprofit curves describing the tradeoffs between various combinations of risk and wage levels. However, to the best of my knowledge, no economic empirical study has tried to explore the extent, and the determinants, of firms' knowledge about occupational hazards.

It is important to understand firms' attitudes because both management and environmental health literatures have stressed the key role played by management outlook in affecting workplace safety. Management's high *risk awareness*, together with high safety commitment, a strong belief that accidents can be prevented, and high safety priorities are attitudes that have been found to be important predictors of firms' behaviors and responses to hazards (Rundmo and Hale, 2003). When these responses result in management commitment to prevention and willingness to commit resources for the development of safety management systems, firms gain by safer employee behaviors (Fernandez-Muñiz et al., 2007), better prevention and management of disabilities (Amick III et al., 2000), and a reduction in workers' compensation costs (Butler and Park, 2005).

The development of risk awareness is clearly very problematic when firms manufacture or make use of technologies and materials, such as nanotechnologies and nanoproducts, the hazards of which are still under scientific investigation. Furthermore, when dealing with something "new", stakeholders (including managers) may be more optimistic. Indeed this has been found to be the case with nanotechnology

(Throne-Holst and Stø, 2008, Conti et al., 2008, Hock et al., 2006). Managers' evaluation and responses may also be affected by competing goals: "while R&D is likely to be led by scientist-managers with a 'push the edge of the envelope' orientation, product market and commercialization choices are likely to be made by functional managers with a 'be first to market and gain competitive advantage' (first mover) orientation" (Lee and Jose, 2008, p.119). The result is that mangers may be tempted to "export" the responsability: to transfer onto others (workers, scientists, governmental agencies) the task of assessing the hazards of the production process (Nuñez, 2009, Spielholz at al., 2008, and Throne-Holst and Stø, 2008).

This situation creates a challenge for government regulation. Again, under the theoretical framework of hedonic wage theory, government regulation may be undesirable because it penalizes those workers who do not place a high value on job safety. However, the situation is different when the risk is unknown. Government is challenged to find a regulatory approach that does not penalize promising emerging businesses but, at the same time, minimizes the risk of repeating past mistakes made by some countries due to delays in acknowledging health hazards associated with other substances. Indeed, history has already shown us the very high cost of ignoring early findings and warnings about the health and environmental risk associated with some material (such as asbestos where several decades passed between the first recorded evidence about its serious negative health effects and the first set of regulations) (European Environmental Agency, 2001). At the same time, the unique ability of nanotechnology to change not only the size, but also the known properties of materials, challenges our ability to "borrow" rules from existing regulations (Lee and Jose, 2008, Ponce Del Castillo, 2009). Therefore opinions range from those of supporters of the application of the precautionary principle (Throne-Holst and Stø, 2008), to those of the proponents of hybrid regulations -where responsibility for regulation is shared by businesses and researchers on one side, and the state on the other (Levi-Faur and Comanesher, 2007) - to those of the proponents of self-regulation. But even in the case of self-regulation it is suggested that because of pressures posed by competing goals, firms should develop internal ethical standards, invest in risk research, monitor early warning signals, and explore collaborative solutions with other stakeholders (Lee and Jose, 2008). In this paper I try to explore the extent to which managers may be ready to acknowledge risk and to engage in some of these responses described by Lee and Jose (2008).

EMPIRICAL ANALYSIS

The Data

This study makes use of information collected through a telephone survey of nanotechnology company executives in the US. The survey was conducted in 2006 by the University of Massachusetts Lowell Center for Economic and Civic Opinion and by Small Times Magazine, a publication considered one of the leading sources of information for businesses involved with nanotechnology and microelectronics. The survey was administered among subscribers of the magazine and had a response rate of 33 % corresponding to a total number of 407 respondents. Although such a response rate could be considered to be low, it is perfectly consistent with the typical response rate found across studies that surveyed executives or organizational representatives (Baruch and Holtom, 2008; Cycycota and Harrison, 2006).

The majority of respondents were male (88%) and identified themselves as senior executive managers (60%). Only 9% had an occupational title suggesting a technical background (such as scientist, engineer, or research manager). They represented mainly small sized companies (employing less than 100 employees) (79%), and those with estimated sales of less than $10 million (70%). Companies were quite evenly distributed across the different regions of the USA, but differed in the type of engagement with nanotechnology: 47% were already engaged and 13% planned to be engaged in the manufacturing of nanotechnology material; 88% were engaged in manufacturing products incorporating nanotechnologies; 77% dealt with the design or manufacture of equipment to manipulate nanoscale materials (**Table 1**).

TABLE 1
PERCENTAGES OF EXECUTIVES' ANSWERS TO SELECTED QUESTIONS

Manufacturing Sector			**Job Title**	
Engaged in the manufacture of *nanotechnology materials*	47%		Senior Executive Management	60%
Engaged in the manufacture of *products incorporating nanotechnology*	88%		Executive Management	20%
Engaged in the *design or manufacture of equipment or instrumentation* that manipulates, measures or produces nanoscale materials	77%		Business Management	11%
			Technical Management	9%
Business Strategy			**Gender**	
Internal R&D main source of nanotech. expertise	77%		Male	88%
Utilize facilities *at local university*	58%		Female	12%
Barriers to Growth (very or somewhat significant)			**Region of Country**	
Lack of knowledgeable work force	24%		Northeast	25%
Lack of financing	45%		South	29%
Intellectual property issues	46%		Midwest	17%
Lack of cooperation with universities and other research organizations	28%		West	29%
Lack of available prototype facilities	43%			
Lack of public acceptance of nanotechnology	30%			
Lack of nanotech safety standards	36%			
Estimate of sales of nanotechnology products three years from now			**Number of Employees**	
Less than $10 Million	38%		1 - 20	25%
$10 Million to $100 Million	48%		21 - 100	54%
$100 Million+	15%		101+	21%

Source: Hock et al. (2006)

A first descriptive analysis of this data conducted by Hock et al. (2006) on behalf of Small Times Magazine and the Center for Economic and Civic Opinion at the University of Massachusetts Lowell highlighted that these executives were deeply convinced of the very important role that nanotechnology was going to play in the US economy and were very optimistic about the growth perspectives of their companies (while 70% of executives reported estimated sales below $10 million for the following year, 86% estimated sales below $100 million in the following three years). That original study also reported that 65% of respondents acknowledged that the risk associated with nanotechnologies was unknown; that 97% felt that the government had to play a major role in addressing potential health and environmental risks; and that 58% of these firms were utilizing, or planning to utilize, facilities at local universities.

This study builds on this original set of findings to further examine executives' perceptions about environmental and safety risks as well as their expectations with regard to government's role.

Regression Analysis

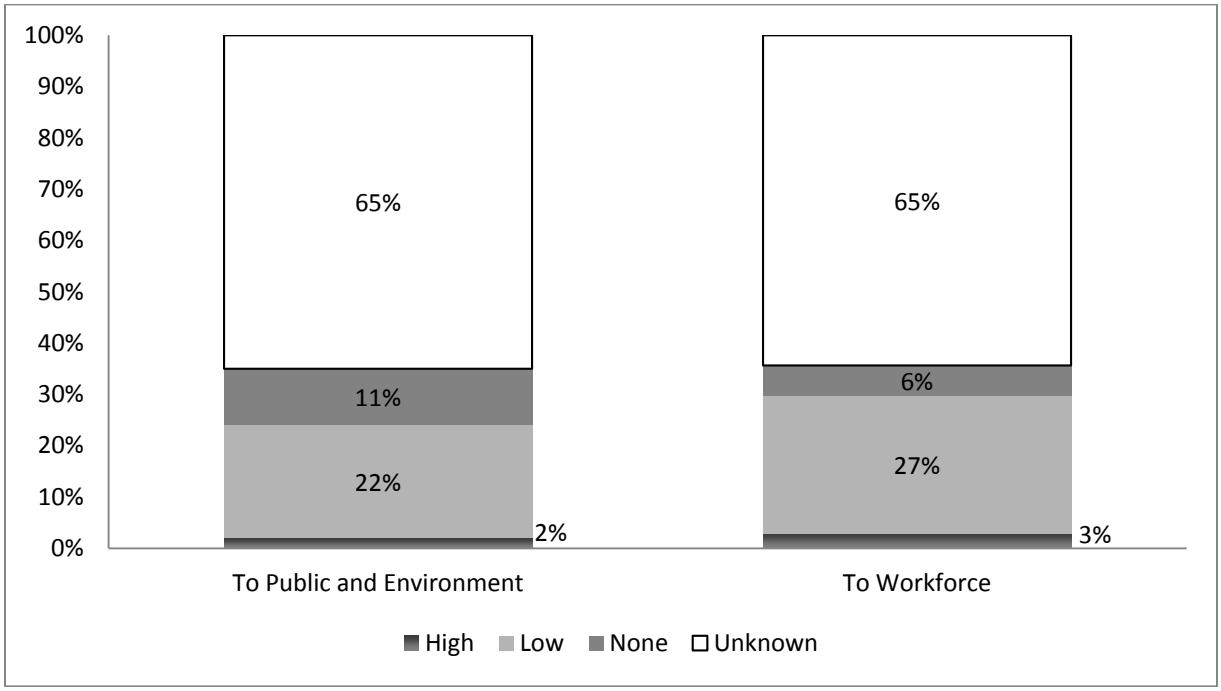
The econometric estimates explore whether there are any specific management or firm characteristics that predict executives' perceptions about hazards and regulations. I considered four main sets of regressors: variables capturing individuals' characteristics (gender) and firms' demographic characteristics (location, number of employees, and whether managers predicted growth in their company's sales of nanotechnology products or equipment over the next three years); variables describing the type of manufacturing activity and nanotechnology (whether firms manufactured nanotechnology materials, products incorporating nanotechnology materials, equipment or instruments to manipulate nanoscale materials, and, more specifically, whether they were manufacturing or using nanotubes); variables capturing potential exposure to scientific information (whether the internal R&D was the main source of nanotechnology expertise and/or whether the firms collaborated with universities); and variables describing reported barriers to growth (lack of a knowledgeable labor force and lack of financing). All these regressors are included as potential predictors of different outcomes in the different Logit estimates presented in **Table 2.**

Perception of Unknown Risks

I first studied firms' ability to evaluate the hazards associated with the production processes they are implementing or developing. 65%[3] of interviewed executives stated that the risks associated with exposure to nanoparticles were unknown, both in terms of risks for the public and the environment and for the workforce (**Figure 1**). Columns 1 and 2 of Table 2 presents Logit estimates of the role played by different factors in affecting perception of unknown risk (versus a clear assessment of high/low risk or no risk) for the public/environment and the workforce. It shows that, in terms of the type of manufacturing processes, only executives employed in companies dealing with the manufacturing of equipment to manipulate nanoscale material were significantly more likely to report that the risk to the public was unknown. To the extent that these companies' activities implied the manipulation of nanomaterials, this finding could be related to the results of previous studies that found that the perceived risk of nanoproducts often increases the closer the application of nanotechnologies gets to our bodies and skin (Throne-Holst and Stø, 2008). Surprisingly, the regressions also suggest that the lack of clear opinion about hazards does not seem to differ for those firms that are manufacturing or using nanotubes, despite the fact that carbon nanotubes are the nanotechnology products that so far have raised the greatest concerns in terms of toxicity (Donaldson et al., 2006, Grégoire, 2009). Compared to very small firms (with less than 21 employees), medium and large firms were found to be more likely to report that the risk to the public associated with the new technology was unknown, a result consistent with previous studies (Lindberg and Quinn, 2007). The likelihood of believing in a still unknown hazard associated with nanotechnology was significantly inversely related to two additional factors. First, firms involved in research collaboration with universities felt clearly less uncertain and therefore better able to assess the risk associated with the exposure to nanomaterials. Second, a higher assertiveness about the existence or non-existence of risk was also true for male respondents. Female executives were found to be especially concerned about the unknown risks that the new technologies may pose to the workforce (table 2, column 2). These are interesting results. On the one hand, they confirm what was found by Throne-Holst and Stø (2008): most stakeholders, including businesses, rely on the scientific community and individual researchers for assessment of the risks of nanotechnology. On the other hand, these results give us interesting insights about which factors may affect employer attitudes toward workplace risks. In this case, the results show that gender may produce significant differences in risk perception. Indeed, previous studies have already shown that males exhibit higher acceptance and perceive less risk and higher potential benefits from science and technology (Satterfield, Mertz, and Slovic, 2004). Behavioral research and feminist studies have provided a variety of arguments to explain women's different responses to risk: women's greater experience of vulnerability and lower status; women's more limited access to and use of

technologies; and women's greater tendency to empathize. These are just some of the factors that could explain this difference in answers between male and female executives. (Herr Harthorn et al., 2009).

FIGURE 1
HOW MUCH RISK IS THERE?



Note: Calculations based on data from Hock et al. (2006)

Lack of Safety as a Barrier to Growth

The survey data also allows us to study executives' attitudes toward risk from another perspective: whether they perceive the lack of nanotechnology safety standards as a barrier to growth for their business. Thirty-six percent of individuals interviewed reported such a lack of standards to be a significant obstacle to the growth of their business[4]. Table 2, column 3, highlights once again the key role played by collaboration with universities: companies that share research facilities with universities were much more concerned about the obstacles created by lack of safety standards (possibly because they were more informed, as suggested by the previous regression results). At the same time, such perceived obstacles also seem to be predicted by executives' concerns about the lack of a knowledgeable labor force to employ in their nanotechnology companies. Indeed, despite the dramatic growth of manufacturing using nanotechnologies, there is still a very limited supply of individuals with skills in nanotechnology employed outside academia (Stephan et al., 2007). Furthermore, it is not unusual to find that employers put the responsibility for safety practices on employees, while workers blame management for the lack of involvement in safety promotion (Spielholz at al., 2008).

TABLE 2
LOGIT ESTIMATES (N=400)

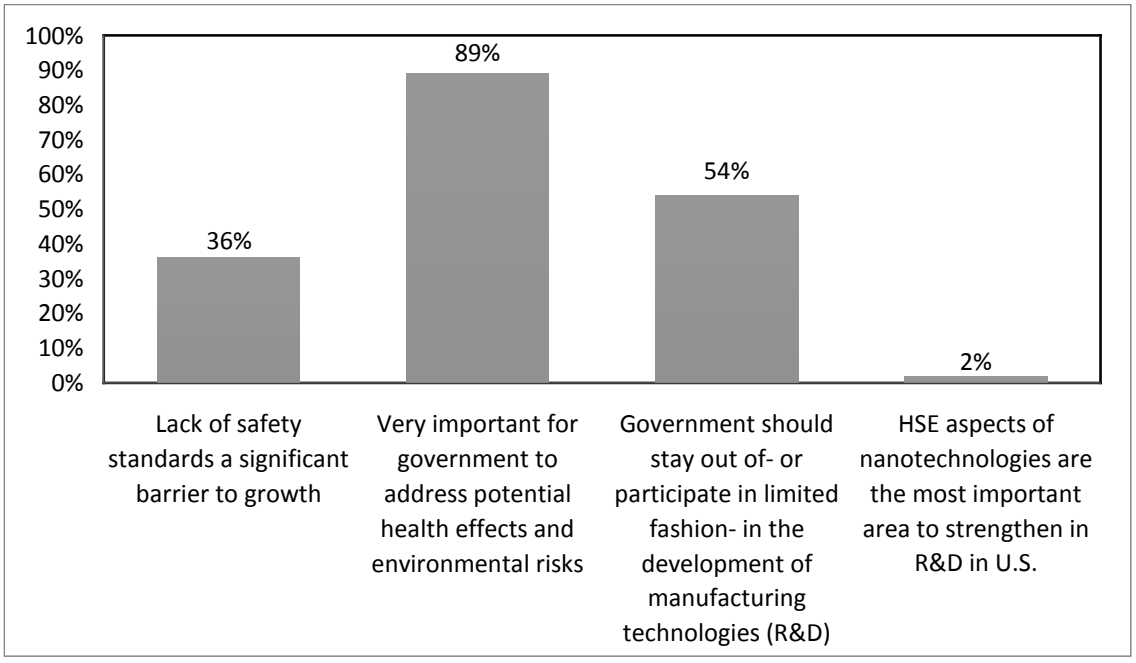
	Risk to Public or Environment Not Yet Known (1)		**Risk to Workforce Not Yet Known (2)**		**Lack of Safety Standard a Barrier To Growth (3)**		**Government Should Take the Lead (4)**	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
Manufacturing sector:								
Nano materials	-0.07	0.23	-0.14	0.23	-0.27	0.23	0.06	0.21
Products incorporating nano	-0.48	0.36	-0.51	0.36	-0.43	0.34	-0.21	0.32
Equipment manipulating nano	**0.49***	**0.28**	0.39	0.28	-0.08	0.28	0.09	0.27
Nanotubes	0.04	0.23	0.16	0.23	0.14	0.23	-0.03	0.21
University collaboration	**-0.61*****	**0.23**	**-0.70*****	**0.23**	**0.46****	**0.23**	-0.24	0.22
Internal R&D main source of expertise	0.21	0.26	0.37	0.26	-0.16	0.26	**0.52****	**0.25**
Barriers to growth: *Lack of*								
Knowledgeable Labor Force	0.05	0.27	0.16	0.27	**1.24*****	**0.27**	0.32	0.26
Financing	-0.43	0.33	-0.31	0.33	0.24	0.33	0.20	0.32
20<N. employees≤100 †	**0.44***	**0.26**	0.40	0.26	0.30	0.27	0.15	0.25
N. Employees>100 †	0.30	0.31	0.25	0.32	-0.14	0.33	-0.43	0.31
Sales Projected to Grow	0.21	0.23	0.11	0.23	-0.18	0.24	0.06	0.22
Male	**-0.60***	**0.35**	**-0.76****	**0.35**	0.12	0.33	0.14	0.31
Constant	**1.10****	**0.56**	**1.28****	**0.57**	-0.72	0.54	-0.64	0.52

Note: Stars track significance with * p<0.10, ** p<0.05, ***p<0.01. † The reference category is "Number of employees <=20".

Role of Government

Given managers' perceptions and attitudes toward potential environmental and safety hazards, it is interesting to analyze whom they perceive to be responsible for addressing such risks. At different points during the survey executives were asked to reflect on the role of government and on the need for government involvement in R&D. As already highlighted in the original survey report (Hock et al. 2006), almost all interviewed individuals (89%) answered that it was very important for the government to address health effects and environmental risks associated with nanotechnology, but only 45% replied that the government should take the lead in R&D and commercialization incentives in nanotechnologies (. Furthermore, despite the reported unknown risks and the implications for a company's future growth, only 2 % of the interviewed executives felt that the US should make it a priority to foster R&D in the area of health, safety, and environmental hazards (**Figure 2**). Column 4 of table 2 shows the estimation of a Logit model assessing which factors may be related to managers' belief that the government should take the lead in the development of nanotechnologies. I found that only those companies whose main source of nanotechnology expertise was internal R&D felt a significantly stronger need for governmental leadership.

FIGURE 2
NEED TO ADDRESS HEALTH, SAFETY, AND ENVIRONMENTAL RISKS



Note: Calculations based on data from Hock et al. (2006)

CONCLUSIONS

Despite the relevance of occupational hazards as determinants of labor market outcomes and firms' costs, very little research has been conducted to assess firms' ability to assess the occupational and environmental risks associated with their production processes. The recent development and rapid growth of specific new technologies (nanotechnologies) represent an opportunity to study how companies approach a potential, but still largely unknown, occupational risk.

In this study I analyzed data collected through a survey of US nanotechnology executives to assess both the determinants and the consistency of different answers managers gave to questions regarding risk, priorities, and responsibilities in addressing environmental, health, and safety concerns.

The results reinforce what had been found in previous studies (Throne-Holst and Stø, 2008): a general optimism toward these new technologies (34% predicted a growth in sales of at least 10% over the next three years, and 33% believed there was no or very low risk associated with the technologies), as well as an inclination to transfer onto the research community the responsibility of studying the unknown hazards of nanomaterials. In fact, companies that were involved in research collaboration with universities showed greater confidence in their ability to asses such risk and greater awareness that the lack of safety standards could compromise the future growth of their business. Concern about the lack of safety standards was also more likely among those managers who had also expressed concern about the lack of a knowledgeable labor force. This may suggest that concerns about hazards are more common among those executives who, more broadly, attach a higher value to knowledge. This same finding, however, could also be interpreted to suggest that in executives' opinions the management of safety is largely the responsibility of employees. An additional interesting finding indicates that female managers are much more cautious about their ability to clearly assess the risks associated with such new technologies. This confirms that indeed there may be a large affective component influencing people's responses to surveys about health, safety, and environmental risks (Loomes, 2006), and that individual empathy or personal experience with technology or with risk may affect managers' attitudes toward hazards.

The findings also reveal a somewhat conflicting management view regarding responsibility for health, safety, and environment R&D and the role of the government. On the one hand, the large majority of executives interviewed (89%) claimed that it is very important for the government to address environmental and occupational risks associated with nanotechnologies. At the same time, only 2% stated that R&D in nanotechnology risk should be a priority for the U.S. Furthermore, only 45% answered that the government should take the lead in R&D (an opinion mainly expressed by firms that relied primarily on internal R&D for nanotechnology expertise). These numbers raise the question of what role companies really want the government to play. They are consistent with what was recently found in a study by the National Center for Manufacturing Sciences (2010) where surveyed executives ranked both regulatory concerns and environmental, health, and safety concerns as being in the same tier among the top industry barriers to growth. Companies are clearly asking the government to address potential risks, but they want to keep control of the production process. The majority do not trust the government to be actively involved in shaping the future of the technologies they are using. Companies, however, are also unlikely to take on the responsibility of conducting research in the area of nanotechnology hazards, and they seem more likely to use information from the academic research community. Therefore, the best governmental strategy may be to support safety research through universities and to rely on such research institutions for the diffusion of the acquired knowledge. History has shown us the risk of ignoring early warning about the health and environmental risk of new technology and material. It has also shown us that regulatory decisions can be challenged because of government conflicting goals of promoting safety but also of growing new profitable industries (Hansen et al., 2008). This increases the responsibility of researchers and calls for academia to become much more extensively engaged in safety research and very proactive in the dissemination of research results to both the public and the business community.

ENDNOTES

1. Nanomaterials and nanoproducts also present serious unknown risks for consumers who usually do not know which products contain nanomaterials and what their risk could be. This paper does not address consumer risk, however.
2. In the US, the National Institute for Occupational Safety and Health (NIOSH) has issued interim guidelines for controlling workplace exposures and hazard surveillance (Department of Health and Human Services, 2009) and recommended exposure limits to nanotubes and nanofibers

(Department of Health and Human Services, 2010). NIOSH has no regulatory power, however, and the US agency responsible for regulations, the Occupational Safety and Health Administration (OSHA) has not been active in regulating nanotechnologies (Marchant et al., 2007).

3. This percentage is higher than what was found by other surveys of firms: 50% in Lindberg and Quinn (2007) and 15% in Conti et al. (2008)
4. The biggest reported obstacles were "lack of financing" (45%) and "intellectual property issues" (45%), a result consistent with what was recently found in a report by the National Center for Manufacturing Sciences (2010).

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