

A cross-national comparison of framing nanotechnology: focus on clustering frame elements

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Abstract

This study examined how nanotechnology is framed in news articles, and what the dominant frames are and their variations that exist across South Korea, Germany, Austria, and Japan between 2001 and 2015. To identify the frames, this study executed two-step cluster analysis comprising a combination of hierarchical clustering and k-means clustering. First, six frames as clusters were identified as follows: overview of nanotechnology, policy, economic benefits, environmental risks, research and development, and health risks. Second, it was found that positive descriptions of nanotechnology were overwhelmingly more frequent than negative descriptions were. Third, there were obvious differences among countries even though they showed similar media frame patterns. Fourth, the more research and development increased over time, the more economic benefits decreased. By clustering frame elements, this study overcame the methodological limitation of frame studies. The study also contributes to the literature comparing media content between cultures and science communication studies.

Keywords: *media frame, frame element, cluster, nanotechnology*

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프레임 성분의 군집화 연구: 나노기술에 대한 미디어 프레임의 국제비교를 중심으로

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국문요약

본 연구는 프레임 성분의 군집화를 적용한 새로운 미디어 프레임 추출방식으로 2001년부터 2015년까지 한국, 독일, 오스트리아, 일본의 나노기술 관련 언론보도를 비교분석했다. 이에 따라 나노기술 개요, 정책, 경제적 이익, 환경적 위험, 연구개발, 건강적 위험의 여섯 가지 미디어 프레임을 확인하였다. 나노기술의 긍정적 측면을 강조한 보도가 상대적으로 많다는 공통점에도 불구하고, 국가별로 분명한 차이가 나타났다. 한국 언론에서 위험지향 프레임이 유일하게 나타났다. 독일 언론은 경제적 이익, 오스트리아 언론은 나노기술의 소개와 정책을, 일본 언론은 연구개발을 다룬 미디어 프레임이 다른 국가의 언론보다 상대적으로 많았다. 시기별로 연구개발 프레임과 경제 이익 프레임은 상반되게 나타났다. 본 연구는 기존 미디어 프레임 추출의 한계를 극복하기 위해 프레임 성분의 조합이라는 방식을 제안하여 검증하였다. 또한 나노기술에 대한 국제 비교분석으로 과학 커뮤니케이션의 지평을 확대했다는 점에서 의미를 지닌다.

주제어: 미디어 프레임, 프레임 성분, 군집화, 나노기술

I. Introduction

Nanotechnology generates nanomaterial with a new molecular structure because it controls its characteristics at the nanometer level. It modifies or even creates all materials because it can control the basic properties of specific material. Such characteristics present significant benefits to society at large. However, nanotechnology has risks in addition to its potential benefits. Nanomaterials are extremely tiny and can accumulate in a body without biologically decomposing. Furthermore, they cause various toxicities and induce new environmental pollution. Due to this duality, nanotechnology has emerged as a socially important issue. Moreover, like nuclear power and genetically modified organisms, nanotechnology triggers conflicting discourse related to its social acceptance. However, the public does not sufficiently understand it because of its high-level speciality and complexity. Accordingly, its representation in the media drives public opinion and social acceptance.

Regarding the media representation of nanotechnology, this study established two main goals: One is identifying media frames of nanotechnology, while the other is verifying a new approach to determine the media frames. First, this study analyzed how nanotechnology's media frame emerged. Media studies focus on the process by which the public accepts nanotechnology. According to information-processing cognitive models, the public does not use all available information to decide on scientific issues, such as nanotechnology, that require significant cognitive effort for an in-depth understanding. Rather, the public relies on heuristic or cognitive shortcuts to form an opinion about a topic they know little or nothing about. More specifically, as the public has little direct experience with nanotechnology, news coverage provides a key heuristic in this regard (Nisbet and Lewenstein 2002; Popkin 1994).

In accordance with the heuristic/framing model, public attitudes and opinions on nanotechnology are influenced by how media represent it (Scheufele and Lewenstein 2005). Media function as the key heuristics for the public and have become the most important tool for understanding nanotechnology's social acceptance.

In the 2000s, many researchers investigated the media frames of nanotechnology. Their studies pointed out that media mainly described the scientific findings and economic benefits of nanotechnology and emphasized its positive aspects. Although diverse countries implement nanotechnology globally through a variety of initiatives and policies, existing studies have focused only on news coverage in Europe and North America. Those studies were merely restricted to one country or region speaking the same language. Moreover, a few studies have been conducted since 2010, when various countries' regulations drew attention to the discussion of nanotechnology's potential risks. Consequently, this study identified media frames of nanotechnology and compared differences by country and time period.

Second, this study examined a new approach to eliminate the methodological limits of media frame, largely discussing two aspects. The methodological issues on media frame were discussed largely in two aspects. One limit is reliability and validity because of unclear standards on extracting the media frame. Existing studies generally identified the frames by in-depth analyses of news articles and established a coding book consisting of frames. Then, coders using the coding book conducted an empirical content analysis to classify a media frame. However, many studies failed to suggest clear standards for determining the media frame because researchers defined such standards randomly. Furthermore, since researchers' recognition varies by the issues' complexity, the media frame categories and quantities identified in news articles also varied.

The other limit is that emerging frames are not easily identified. The unique frame of a researcher, i.e., the coder frame, is identified depending on the researcher's recognition of the issue in the content analysis. When the media frame is determined on a specific issue, it is difficult to identify other media frames because of the researcher's schema. Moreover, researchers have the tendency to stereotype articles into the frame category which they identify.

Consequently, this study adopted a new approach using frame elements to identify the frame and maximize the independence from researchers' influence. This facilitated identifying new frames based on the combination of frame elements. This approach can improve the in-depth understanding of existing measurements by defining frame elements. It can also eliminate the methodological ambiguity of existing studies to identify media frames by determining such frames empirically rather than subjectively. However, the approach is not standardized because it has only been applied to a few studies. Thus, this research applied such an approach to examine the complicated nanotechnology issue. In addition, this study examined the methodological efficiency of the new approach by analyzing news coverage in various countries over a long period.

II. Theoretical background

IIa. Media frames of nanotechnology

In the last decade, the media frames of nanotechnology have been investigated in many countries. Most studies have covered the United States, the United Kingdom, Canada (Anderson et al. 2005; Laing 2006; Lewenstein et al. 2005; Weaver et al. 2009), Germany (Donk et al. 2012; Kohring et al. 2011), Norway (Kjolberg 2009), Denmark (Schmidt Kjærgaard 2010), Slovenia (Groboljsek and Mali 2012), Poland (Lemańczyk 2012), Turkey (Kamanlığlu and Güzeloğlu 2010), and Italy (Arnaldi 2008). In East Asian countries including South Korea and Japan, some studies covered understanding nanotechnology and social acceptance (Lee 2007; Song and Cho 2013), but the studies of the media frame have not been reported yet.

The media frames on nanotechnology in existing studies are classified into the three following types: the scientific project frame, the benefit frame, and the risk/regulation frame. The scientific project frame includes themes on research and development, scientific discoveries, and national initiatives. It has shown up in news coverage most frequently. The benefits frame focuses on the economic and medical benefits generated by nanotechnology. The risk/regulation frame warns of the potential risk that may occur due to nanotechnology and emphasizes suggesting policies to overcome the risks. The scientific project frame and the benefits frame are frequently discussed along with "scientific advancement" and the risk/regulation frame along with "Pandora's box." The scientific project and benefits frames are closely related to science and technology policy, and the risk/regulation frame occurs along with social conflicts in many cases (Lemańczyk 2012; Lewenstein et al. 2005).

In addition to the above frames, researchers have observed other diverse frames, including the science fiction and popular culture frames (Anderson et al. 2005), the public accountability frame (Lewenstein et al. 2005), the ambivalence frame (Donk et al. 2012), the education frame (Schmidt Kjærgaard 2010), and the visionary/futuristic frame (Kamanlığlu and Güzeloğlu 2010). The benefit-oriented frames (e.g., scientific project frame, benefits frame) mainly

represent nanotechnology positively, while risk-oriented frames (e.g., risk/regulation frame) describe nanotechnology negatively. Positive nanotechnology news coverage is found more often than negative coverage is. The same tendency has been observed regardless of when and where the studies were executed.

Except for the studies Lewenstein et al. (2005) and Schmidt Kjærgaard (2010) conducted, most media frame studies on nanotechnology focused on the 2000s. This was because most countries substantially started their nanotechnology initiatives after 2001, when the United States started the National Nanotechnology Initiative (NNI), which reflected higher public and media nanotechnology interest. Accordingly, the media frames in the relevant periods emphasized the development and technological benefits of nanotechnology depending on national support. However, the situation gradually changed as the risks of nanotechnology were pointed out starting in the mid-2000s and regulation-emphasizing frames increased (Weaver et al. 2009).

As for the differences between countries where media frame studies on nanotechnology were conducted, US media had greater interest in nanotechnology's economic benefits, but European media focused relatively more on risks and regulations (Lemańczyk 2012). Nevertheless, since the frames emphasizing nanotechnology benefits accounted for the overwhelming ratio in all countries' media, the difference between America and Europe is insignificant (Laing 2006).

It should be noted that there are no studies on the media frames of nanotechnology in Asia, especially South Korea and Japan, which have top-level nanotechnology. Most studies have also concentrated on the late 2000s, when various initiatives were implemented. Thus, there is no study on the 2010s, when the public has experienced the efficiency of technology by having used the products applying nanotechnology. Moreover, there is insufficient data on the periods when a variety of regulations started to be discussed to address the concern about the side effects of nanotechnology. The current study identified the media frames of nanotechnology and investigated the differences in media frames by country and time.

Iib. Clustering frame elements

The essential element of frame studies is to evaluate and describe frames in news articles. However, many researchers have raised concerns about the reliability and validity of identifying media frames (Gandy 2001; Hertog and McLeod 2001; Tankard 2001). In particular, frames are abstract variables that are difficult to code and identify in content analysis. As a result, it is challenging to measure frames by neutralizing the influence of researchers. (Marher 2001; Van Gorp 2005).

Frame studies can be classified into four methodological approaches to inductively measure media frames; these are the hermeneutic, linguistic, manual holistic, and computer-assisted approaches. First, the hermeneutic approach targets small discourse samples of a particular issue. The frames are described in depth and not quantified. In this way, media frames can be identified in detail, but it is difficult to determine how they have been extracted from the material. As a result, the hermeneutic approach involves the risk that researchers could only find what they expect in the material (Tankard 2001). Downs points out the subjectivity inherent in this method, where "researchers bear the burden of supporting personally observed claims, and support is more experiential and contextually contingent than

empirical” (Downs 2002, 47).

Second, the linguistic approach identifies the frames by analyzing the text’s selection, arrangement, and structure of specific words and sentences. This method is similar to the hermeneutic approach but has a clear difference in that the researcher determines the linguistic factor that signifies the frame. For example, Pan and Kosicki (1993) measured frames by classifying them into syntax, script, theme, and rhetoric. However, the linguistic approach has limitations in that it is difficult to analyze large-scale text samples due to excessive complexity, as well as to extract standardized frames. In addition, there is not enough explanation of how the linguistic approach’s elements are combined to form a frame (Esser and D’Angelo 2003).

Third, the manual holistic approach consists of two stages. Media frames are extracted by conducting an in-depth analysis of news articles. A coding book is created from the media frames identified in this way, and quantitative content analysis is performed. Although this method has the advantage of allowing analysis of large test samples, it is not clear on what basis the frame is extracted. Since the extraction and coding of frames are affected by how the researcher perceives the issue, the frames can be viewed as the researcher’s frames, not media frames. In addition, once a researcher decides on a frame, it is not easy to find another frame because it is used to analyze the contents of the frame (Wirth 2001).

Fourth, the computer-assisted approach started in earnest when Miller (1997) presented a new quantitative process called frame mapping. This method finds a frame by analyzing specific words in the text. Thus, frame mapping can be explained as a way of finding a specific word that appears in a particular text and does not appear simultaneously in another text. The advantage of this method is the objectivity of frame extraction. Frames are not discovered by researchers but are computed by computer programs. However, this method limits frames to clusters of words. Therefore, the frame identified by the computer-assisted approach is closer to a story topic than a frame proper. Also, although words with a low frequency of occurrence have a pivotal role in text meaning, they are excluded from frame extraction (Carragee and Roefs 2004; Hertog and McLeod 2001). In this respect, the computer-assisted approach can ensure reliability, but it is difficult to secure validity using this method. Furthermore, there is an inherent limitation that computers do not understand the complexity, ambiguity, and diversity of language (Simon 2001).

Although all the mentioned approaches play an important role in measuring frames, they cannot be free from criticism of the methodological limitations of frame studies in terms of reliability and validity. It is unclear which elements should be presented to signify the frame (Semetko and Valenburg 2000). To address this limitation, an alternative measurement that improves reliability and validity has been presented. Kohring and his colleagues argued that some elements are grouped systematically in a specific way and formed by a pattern that is identified in the text (Donk et al. 2012; Kohring and Matthes 2002; Matthes and Kohring 2008). They call this pattern a frame. According to their assumption, “a frame consists of several frame elements, and each frame element consists of several content analytical variables” and “every frame is characterized by a specific pattern of variable[s]” that “signify single frame elements [...] grouped together by hierarchical cluster analysis” (Matthes and Kohring 2008, 264).

As patterns are formed by a combination of frame elements, the method described above posits that frames are not coded directly with a single variable but are combined with frame

elements. Therefore, a frame with several content analytical variables can achieve reliability and validity than a frame with a single variable can; this is because frames are not subjectively determined but empirically suggested by an inductive clustering method. This method has another advantage in that the coding frame is resistant to a coder's schemata or bias because a coder codes variables rather than frames (Matthes and Kohring, 2008).

III. Research Questions

This study examined how nanotechnology is framed in news articles, what the dominant frames are, and the variations in frames that exist across countries. It also looked at whether newspapers in South Korea, Germany, Austria, and Japan represent nanotechnology in different ways, and how media frames of nanotechnology changed from 2001 to 2015. The research questions (RQs) are as follows:

RQ1: Which media frames are presented dominantly in news articles on nanotechnology?

RQ2: Is the pattern of the presence of media frames associated with countries like South Korea, Germany, Austria, and Japan? If so, which variations of the presence of media frames are revealed across the countries?

RQ3: Does the presence of media frames change between 2001 and 2015? If so, which variations of the presence are revealed across countries over time?

IV. Methodology

IVa. Operationalization

This study aimed to identify media frames of nanotechnology through a combination of frame elements. Entman (1993) defined the four frame elements constituting a frame as follows: problem definition, causal attribution of responsibility, moral evaluation, and treatment recommendation. Matthes and Kohring (2008) suggested that "if these elements are understood as variables, each of them can have several categories in a content analysis" (264). In this study, frame elements are operationalized through the content analysis variable. Content analysis variables were identified in this study's pretest, which was conducted in South Korea, Germany, Austria, and Japan, as well as in previous studies on the media frames of nanotechnology.

At first, the problem definition element includes the main topic and actor categories, which define the bottom lines of news stories. The main topic is a central issue under investigation or a primary argument around which the other arguments revolve. This study derives several subtopics from previous research about nanotechnology and then identifies subtopics summarized to the main topic with the seven following variables: scientific research, medical service/health care, economy, development of semiconductors, policy, moral/ethics, and overview of nanotechnology. An actor refers to the person, group, or organization that is most often cited in the news article. This includes six variables, which are as follows: scientists, economic actors, political actors, media, non-governmental organizations (NGOs), and militaries.

Table 1. Operationalization of frame elements

Frame Element	Categories	Variables
Problem definition	Main Topic	scientific research, medical service/health care, economy, development of semiconductor, policy, moral/ethics, an of nanotechnology
	Actor	scientist, economic actor, political actor, media, NGOs, military
Causal attribution of responsibility	Benefit attribution	science, economy, politics, medicine
	Risk attribution	science, economy, politics, medicine
Moral evaluation	Benefits	research, economy, health, consumer, environment
	Risks	research, economy, health, consumer, environment
Treatment recommendation	Call for regulation	regulation policy/negative prospects
	Call for support	support policy/positive prospects

Second, the causal attribution of responsibility elements includes the categories of benefit attribution and risk attribution. These explain who is responsible for the benefits/risks. For instance, science as a risk attribution variable means that scientific actors can be blamed for the risks related to nanotechnology. Actor variables that occur in news articles are not responsible for benefits or risks, but the public can be an actor in news articles. Therefore, the benefits' attribution and risk attribution categories include only four variables each: science, economy, politics, and medicine.

Third, the moral evaluation element's operational definition is executed by the elements of assessment of the benefits and risks of nanotechnology. It discusses what topics have benefits or risks due to nanotechnology. For example, the economy as a benefits variable means "nanotechnology as a benefit for the economy." These categories include five variables: research, economy, health, consumers, and the environment.

Finally, the treatment recommendation element was operationalized by the promotion and regulation of nanotechnology categories, and the positive and negative outlook on nanotechnology. Thus, treatment recommendation includes two categories—call for regulation and call for support. Call for regulation generally highlights the risks of nanotechnology and proposes regulation. Meanwhile, call for support generally focuses on the positive perspective and supports governmental initiatives or policies. Call for regulation includes the variable "regulation policy/negative prospects," while call for support includes the variable "support policy/positive prospects."

IVb. Countries and newspapers

This study selected South Korea, Germany, Austria, and Japan as countries to focus on. South Korea and Japan in East Asia are included in the Confucian Asia cluster (Gupta et al. 2002). Conversely, Germany and Austria are included in the Germanic Europe cluster (Szabo et al. 2002). These four countries have adopted democracy and the capitalist system, and they are advanced countries with high-level nanotechnology and national-level investment in common.

However, South Korea and Japan on the one hand and Germany and Austria on the other have extremely different cultural backgrounds, which is why this study selected those countries. Comparing countries with different cultures may more specifically contribute to standardizing media frames. In addition, few studies have directly compared the differences between more than three countries. The comparison has generally been restricted mainly to English-speaking countries (Laing 2006). Indeed, most studies focused on analyzing the media in a single country or in countries speaking the same language. There are limits to comparing the differences between countries because extraction and identification of frames vary among studies.

Two newspapers issued in each country in its language were selected for the four countries as follows: South Korean daily newspapers Chosun Ilbo and Hankyoreh Sinmun, German daily newspapers Frankfurter Allgemeine Zeitung and Süddeutsche Zeitung, Austrian daily newspapers Standard and Presse, and Japanese daily newspapers Yomiuri Shimbun and Asahi Shimbun. The selected newspapers were recognized as quality newspapers with nationwide influence in each country. Moreover, they substantially covered the public discourse on technology. Therefore, they were frequently used in studies conducting content analysis on news articles related to emerging technologies (Donk et al. 2012; Hibino and Nagata 2006; Kim 2001; Shineha et al. 2008).

IVc. Data collection

For a comparative study between countries, this study selected individual news articles from 2001 to 2015 because the media's attention to nanotechnology increased rapidly after 2001 when the US announced NNI. News articles including the word "nano" were searched from the online archive of each newspaper and classified into articles of two types—paper and online versions. The news articles on paper were used only for the analysis. Thus, this study analyzed only the articles in which nanotechnology accounted for more than 50% of the news article or that contained a statement essentially focused on nanotechnology. The analysis excluded news articles published in special supplements, recommendations for events, and the local section, while editorials and columns and articles in each section, including politics, society, or science, were included in the analysis. Furthermore, news articles that were not related to nanotechnology but included the word "nano" were excluded (e.g., Apple iPod "Nano," Indian automotive manufacturer Tata's "Nano").

IVd. Coding

Four trained coders were selected. The two German and one Japanese coder were bilingual in their native languages and Korean. Meanwhile, the South Korean coder used only the Korean language. The two German coders analyzed German and Austrian newspapers, and the Japanese and South Korean coders analyzed their homeland's newspapers.

To measure intercoder reliability, the coders coded a random sample of 10% of the South Korean newspaper articles because they all understood the Korean language well. The intercoder reliability of all variables, using Krippendorff's alpha, exceeded .80, which is generally accepted in content analysis. This test revealed a reliability coefficient of .81 for the main topic, .83 for actor, .84 for benefit attribution, .84 for risk attribution, .80 for benefits, .81 for risks, .87 for call for regulation, and .82 for prospect.

IVe. Statistical methods

This study computed binary variables for every original variable. Only binary variables with a frequency higher than 5% were adopted for statistical reasons.

This study executed a two-step cluster analysis comprising the combination of hierarchical clustering and k-means clustering. The combination was suitable for determining the optimal number of clusters and processing a large amount of data. Since it is not easy to estimate the specific number of clusters related to nanotechnology due to the comparison between countries and expanded timespan, this study determined an automatic decision on the number of clusters.

This study used PASW Statistics 18 as a statistical program for descriptive statistics, analysis of variance (ANOVA), and cluster analysis.

V. Results

Va. Descriptions of the sample

A total of 1,362 articles were collected. South Korea (n = 482) showed the highest number of articles on nanotechnology, followed by Japan (n = 324), Germany (n = 323), and Austria (n = 233). Interest in semiconductors drove more articles on nanotechnology in South Korea than in the other countries.

The year with the most articles published was 2006 (n = 153), while that with the least published articles was 2014 (n = 35). There were many articles on nanotechnology in the mid-2000s, but the numbers rapidly decreased in the early 2010s.

South Korea and Japan showed the highest number of articles in 2007, while Germany and Austria published the most in 2006. The development of semiconductor manufacturing using nanotechnology and the earnest research commencement on carbon nanotubes and graphene resulted in the highest number of articles in South Korea and Japan. Germany and Austria had the most in 2006 because of the dispute over the efficiency of nutritional supplements launched by Neosino, the official sponsor of FC Bayern München, and the

“NanoCare Project” initiated by the German federal government, which investigated the effect of nanomaterials on health.

Table 2. Number of articles on nanotechnology

Country	Newspaper	Number of articles (%)
South Korea	Chosun Ilbo	282 (20.7%)
	Hankyoreh Sinmun	200 (14.7%)
Germany	Frankfurter Allgemeine Zeitung	197 (14.5%)
	Süddeutsche Zeitung	126 (9.3%)
Austria	Standard	101 (7.4%)
	Presse	132 (9.7%)
Japan	Yomiuri Shimbun	164 (12.0%)
	Asahi Shimbun	160 (11.7%)
Total		1,362 (100.0%)

Vb. Media frames of nanotechnology

A hierarchical cluster analysis was executed to determine the similarity between subjects using a distance measurement. Based on a dendrogram acquired from the cluster analysis, it was determined that six clusters were the most suitable. They were finally selected through a k-means cluster analysis. To verify the validity of the clusters, this study conducted ANOVA to identify the differences between clusters depending on the variables. According to the ANOVA results, all clusters showed a significant difference, $p < .05$.

The first frame, accounting for 8.2% of articles, was named “overview of nanotechnology.” The articles included in this frame focused on extensive description of and introduction to nanotechnology. Scientists (40.8%) were the most frequently observed among actors, followed by media (26.5%) and economic actors (21.4%). The call to support nanotechnology was found in 8.2% of articles, and the call for regulation was evident in merely 3.1%.

The second frame, accounting for 6.1% of the articles, was named “policy.” The articles included in this frame focused on emerging technology policy. Medical implementation (74.0%) was observed mostly in the articles, followed by the development of the semiconductor (21.9%), which was mainly found in South Korea and Japan. Political actors (86.3%) were the most dominant among actors. Politics (90.4%) and research (74.0%) emerged as highest in terms of the benefit attribution and the benefit, respectively, in the second frame. The call for support (95.9%) of nanotechnology was overwhelmingly high.

The third frame, accounting for 20.0% of the articles, was named “economic benefits.” The articles included in this frame focused on the economic effects nanotechnology was to bring. Economy (49.6%) was the most frequent topic in this frame, followed by the development of

semiconductors (21.4%). Similar to policy, development of semiconductors was observed mainly in South Korea and Japan. Economic actors (82.4%), including enterprises and entrepreneurs, were found to be overwhelmingly highest among actors mentioned. Science (68.9%) and economics (71.0%) were identified the most with benefit attribution and benefit, respectively, in the third frame. Economy accounted for 30.3% in benefit attribution and consumer for 20.2% in benefits. Call for support (10.9%) of nanotechnology was more evident than call for regulation (0.4%), but this did not account for the significant ratio of overall articles.

The fourth frame, accounting for 3.2% of the articles, was named “environmental risks.” This frame focused on the environmental risks or side effects caused by nanotechnology. All articles in this frame adopted scientific research as the topic. Scientists (52.6%) were identified most frequently among actors, followed by political actors and media, which accounted for 21.1% each. No articles showed benefit attribution or benefits in the fourth frame. However, science was identified as the risk attribution, and the corresponding risks were all about the environment. Call for regulation (65.8%) on nanotechnology was significantly high.

The fifth frame, accounting for 54.6% of the articles, was named “research and development.” This frame provided scientific-oriented news articles. The articles focused mainly on presenting the research process and results on nanotechnology without social context. Accordingly, the highest topic was scientific research (62.3%), followed by medical implementation (10.3%), policy (9.8%), and development of the semiconductor (9.1%). Scientists (89.5%) were overwhelmingly highest among actors. The benefit attribution and benefit with the highest percentages in this frame were science and research (each at 70.2%), followed by health (18.6%) and consumers (8.8%). While call for support for nanotechnology was identified, its ratio was negligible (3.7%).

The last frame, accounting for 7.9% of the articles, was named “health risks.” The frame focused on the medical side effects or health risks caused by nanotechnology. All articles in this frame adopted scientific research as the topic. Scientists (54.3%) showed the highest mentions among actors, followed by political actors (25.5%) and media (14.9%). Science was identified as the risk attribution in this frame. The corresponding risks were all about medicine and health. Call for regulation on nanotechnology accounted for 45.7%.

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The frames describing nanotechnology positively were overwhelmingly higher (80.7%) than those describing it negatively (11.1%). The positive or negative tone of news articles in each frame was determined based on causal attribution and moral judgment in frame elements.

“Economic benefits,” “research and development,” and “policy” were positively described among all frames. Science (68.9%) showed the highest benefit attribution in “economic benefits,” and economy (71.0%) accounted for the highest as the corresponding benefits. In other words, news articles included in each frame investigated the economic benefits of science and technology and covered such economic benefits positively.

Table 3. Media frames on nanotechnology

Frame Element	Categories	Selected Variables (frequency ≥ 5%)	Frame					
			1	2	3	4	5	6
Problem definition	Main topic	Scientific research	-	-	-	100.0	62.3	100.0
		Medical implementation	-	74.0	1.7	-	10.3	-
		Economy	-	-	49.6	-	-	-
		Development of semiconductor	-	21.9	21.4	-	9.1	-
		Policy	-	4.1	7.1	-	9.8	-
		Overview of Nanotechnology	74.5	-	-	-	-	-
	Actor	Scientist	40.8	4.1	8.4	52.6	89.5	54.3
		Economic actor	21.4	2.7	82.4	5.3	8.8	5.3
		Political actor	11.2	86.3	2.1	21.1	0.3	25.5
		Media	26.5	6.8	7.1	21.1	1.4	14.9
Causal attribution of responsibility	Benefit attribution	Science	-	6.8	68.9	2.6	100.0	1.1
		Economy	-	2.7	30.3	-	-	-
		Politics	-	90.4	0.8	-	-	-
	Risk attribution	Science	-	-	-	100.0	-	100.0
Moral Judgment	Benefits	Research	-	74.0	1.7	-	70.2	1.1
		Economic	-	21.9	71.0	2.6	2.5	-
		Health	-	4.1	7.1	-	18.6	-
		Consumer	-	-	20.2	-	8.8	-
	Risks	Health	-	-	-	-	-	100.0
		Environment	-	-	-	100.0	-	-
Treatment recommendation	Call for support/ regulation	Support	8.2	95.9	10.9	-	3.7	-
		Regulation	3.1	-	0.4	65.8	-	45.7
Total			8.2	6.1	20.0	3.2	54.6	7.9
			overview of nanotechnology	policy	economic benefits	environmental risks	R&D	health risks

The only benefit attribution in “research and development” was science. Research (70.2%) showed the highest result in the corresponding benefits. This indicated that the articles in a relevant frame positively described the development of nanotechnology mainly through research and development. Politics (90.4%) in “policy” had the overwhelmingly highest proportion among benefit attribution, and research (70.4%) showed the highest percentage among corresponding benefits. Considering that the medical implementation (74.0%) topic showed the highest ratio in “policy,” the articles included in the relevant frame positively described the research on the medical application of nanotechnology, mainly according to policy. However, “environmental risks” and “health risks” were covered negatively. Science was the only risk attribution in both frames, and the corresponding risks were the environment and health, respectively.

Vc. Framing differences across countries

Table 4. Media frames on nanotechnology in each country

Country	Newspapers	Frame					
		1	2	3	4	5	6
South Korea	Chosun Ilbo	8.0	6.0	13.7	.0	41.4	30.9
	Hankyoreh Sinmun	7.3	2.8	8.5	21.5	50.3	9.6
	∑	7.7	4.7	11.5	8.9	45.1	22.1
Germany	Frankfurter Allgemeine Zeitung	8.1	3.1	33.5	.0	55.3	.0
	Süddeutsche Zeitung	5.1	.0	33.3	.0	61.6	.0
	∑	6.9	1.9	33.5	.0	57.7	.0
Austria	Standard	11.0	11.0	29.3	.0	48.8	.0
	Presse	14.0	11.4	15.8	.0	58.8	.0
	∑	12.8	11.2	21.4	.0	54.6	.0
Japan	Yomiuri Shimbun	8.9	10.8	13.4	.0	66.9	.0
	Asahi Shimbun	5.3	5.9	25.7	.0	63.2	.0
	∑	7.1	8.4	19.4	.0	65.0	.0
Total		8.2	6.1	20.0	3.2	54.6	7.9

“Research and development” (45.1%) showed the highest proportion among articles on nanotechnology in South Korea, followed by “health risks” (22.1%), “economic benefits” (11.5%), “environmental risks” (8.9%), “overview of nanotechnology” (7.7%), and “policy” (4.7%). Furthermore, “research and development” (57.7%) showed the highest percentage in Germany, followed by “economic benefits” (33.5%), “overview of nanotechnology” (6.9%) and “policy” (1.9%). In Austria, “research and development” (54.6%) showed the highest percentage, followed by “economic benefits” (21.4%), “overview of nanotechnology” (12.8%), and “policy” (11.2%). In Japan, “research and development” (65.0%) showed the highest percentage, followed by “economic benefits” (19.4%), “policy” (8.4%), and “overview of nanotechnology” (7.1%).

Of the four countries selected for analysis, Germany showed the highest frame concentration. The ratio of the top two frames in accumulative percentages of media frames was 91.2% in German newspapers, which was relatively higher than Japan (84.4%), Austria (76.0%), and South Korea (67.2%).

Vd. Framing dynamics over time

While “overview of nanotechnology” was highest in 2001 (16.1%), it was lowest in 2012 (1.5%). This occurred because of the change in the roles of news articles in “overview of nanotechnology.” While this frame was found mainly in articles introducing nanotechnology in the 2000s, in the 2010s, it was accompanied with articles included in other frames.

“Policy” exhibited its highest percentage in 2009 (9.1%) and its lowest in 2003 (2.1%). This frame had a relatively more stable tendency than the other because all countries selected for analysis implemented a national-level initiative on nanotechnology, and news articles continuously reported on that initiative.

“Economic benefits” accounted for its highest percentage in 2003 (34.0%) and its lowest in 2010 (9.2%). While the frame exhibited dynamic change from its rapid rise until the mid-2000s, it kept a stable percentage of around 10% after 2010. This was because nanotechnology’s economic effects have been felt since the late 2000s.

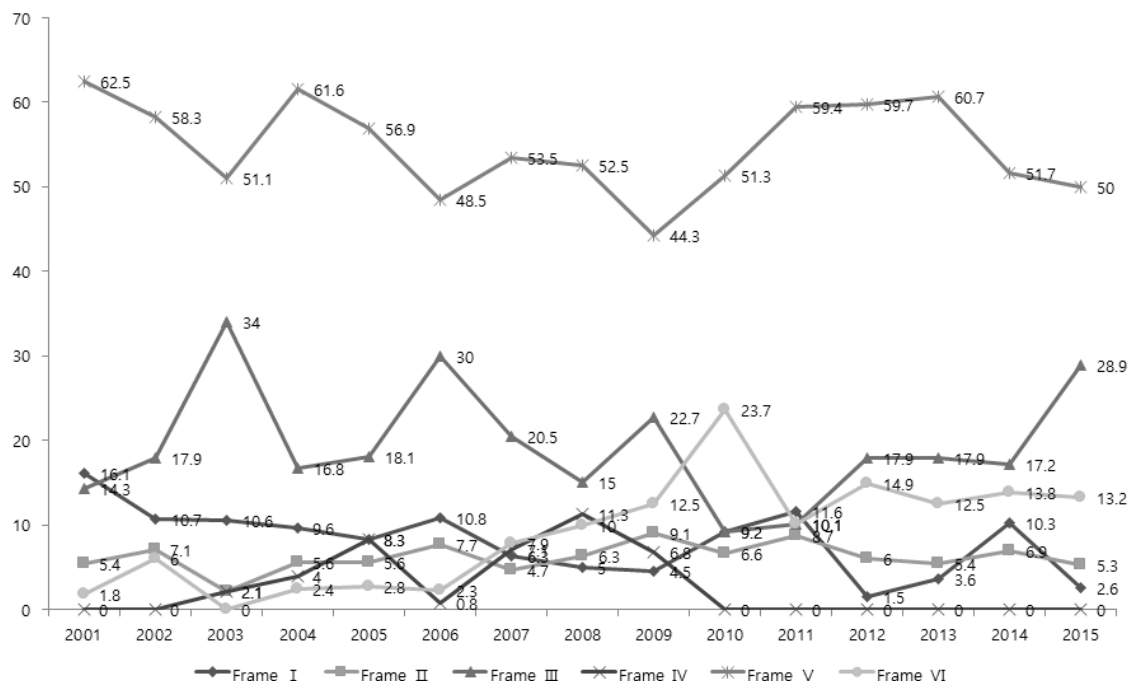
“Environmental risks” emerged temporarily from 2003 to 2009. It had its highest percentage in 2008 (11.3%) but experienced a sudden change from 2007 to 2009. It was observed only in Hankyoreh Sinmun from South Korea. Therefore, “environmental risks” have limits in describing the nanotechnology frame dynamics.

“Research and development” accounted for the highest percentage of all news articles, with its peak in 2001 (62.5%) and its lowest year in 2009 (44.3%). With the US national initiative in the early 2000s, each government began large-scale nanotechnology investment. Following this trend, newspapers also showed increasing interest in nanotechnology. While their interest later gradually decreased, it increased again as the achievements in nanotechnology arose in the 2010s. Since “research and development” was observed in the news articles covering successful nanotechnology research processes and developments, the dynamics of “research and development” most properly reflected newspapers’ nanotechnology interest.

“Health risks” as a frame was evident from 2007 on. It had its peak percentage in 2010 (23.7%). In spite of a sudden increase around 2010, it showed a stable tendency to stay at around 10% since then. Such change reflected the gradually increasing interest of newspapers

on nanotechnology's risks, as well as its benefits.

Figure 1. Frame dynamics on nanotechnology between 2001 and 2015



The following is the change of frame by the country during the relevant period. In South Korea, "Overview of Nanotechnology" showed its highest percentage in 2001 (22.2%), but it never appeared for several years. "Overview of Nanotechnology" accounted for a substantial percentage of the total articles in the early 2000s, but rapidly decreased since 2006 and didn't appear at all thereafter except for 2010, 2011, and 2014. "Policy" accounted for its highest percentage in 2002 (12.5%), but never appeared several times. Like "Overview of Nanotechnology," "Policy" frame appeared frequently in the early 2000s. However, with its rapid decline since the mid-2000s, this frame repeatedly appeared and disappeared.

While "Economic Benefits" showed its highest percentage in 2003 (34.5%), it didn't appear in 2001 and 2011. It had significant change around 2003, 2009, and 2013, but tended to stay stable from 2013 on. "Environmental Risks" had its highest percentage in 2008 (34.6%), but has not appeared since 2010. The frame percentage changed on a regular basis with 2005 and 2008 as its peak years.

"Research & Development" accounted for its highest percentage in 2001 (66.7%), and its lowest in 2008 (30.8%). It had been on a downturn but took an upturn from 2008 on. However, then it again showed a downturn since 2012. "Health Risks" showed its highest percentage in 2010 (41.9%) but did not appear in 2003. Despite its sudden rise several times, it was gradually taking an upturn as time went by. It was more frequently observed than the "Research & Development" frame in 2015.

In Germany, "Overview of Nanotechnology" had its highest percentage in 2010 (20.0%). However, it did not appear several times and has not appeared since 2011. "Policy" showed its

highest percentage in 2010 (10.0%). However, it failed to appear 10 times between 2001 and 2015. "Economic Benefits" accounted for its highest percentage in 2007 (53.3%) but did not appear in 2014. "Research & Development" showed its highest percentage in 2014 (100.0%), but its lowest in 2009 (41.7%). However, even with dramatic change in "Economic Benefits" and "Research & Development," those frames were the limited in explaining because there were only 6 articles in those relevant frames in German newspapers at that time.

In Austria, "Overview of Nanotechnology" showed its highest percentage in 2014 (50.0%) but did not appear several years. Since the number of frames in Austrian newspapers from 2010 was not sufficient, the change was relatively dramatic. "Policy" accounted for its highest percentage in 2005 (25.0%) but did not appear several years. In particular, the frame was rapidly decreasing from 2010 on. "Economic Benefits" had its highest percentage in 2015 (44.4%) but did not appear several years. "Research & Development" showed its highest percentage in 2011(100.0%), and its lowest in 2006(41.5%).

In Japan, "Overview of Nanotechnology" accounted for its highest percentage in 2001 (22.2%) but did not appear from 2008 to 2014. In 2015, the frame accounted for 11.1%. "Policy" had its highest percentage in 2011 (30.0%) and its lowest in 2007 (2.6%). The frame kept its percentage around 10% until 2007 and gradually increased since then. "Economic Benefits" had its highest percentage in 2013 (88.2%) and its lowest in 2015 (44.4%). While "Policy" and "Research & Development" accounted for a higher ratio than in other countries, the change of those frames was not significant.

VI. Discussion

This study identified six media frames on nanotechnology in newspapers in South Korea, Germany, Austria, and Japan. "Overview of nanotechnology" answered inquiries, including the following: "what is nanotechnology?" "what is the origin of the word "nano"?" "how tiny is a nanometer?" News articles on this topic supplemented articles on other frames because they were often published on the same page. In several news articles, the media explained nanotechnology to readers; for this reason, the media appeared as the actor in "overview of nanotechnology" relatively more than they did in the other frames.

"Policy" indicated that the public discourse on nanotechnology was formed in the political dimension. Political actors affected the use of nanotechnology in the medical field. This frame emerged in the overwhelming call for support of nanotechnology in "policy." Therefore, "policy" indicated the tendency related to nanotechnology in the sequence of "policy → R&D → health care/medical service."

"Economic benefits" discussed nanotechnology's practical and feasible benefits. This is one of the main frames specifying public discourse on nanotechnology. News articles included in "economic benefits" had lesser calls for support because they focused on the economic results that would be realized soon. Thus, this is compared to "policy" and its emphasis on politics as the benefit attribution. For "economic benefits," science and economy as benefit attribution and the economy as benefit were highlighted. Consequently, "policy" included a benefit-oriented tendency and a call for support in news articles on nanotechnology, while "economic benefits" showed only benefit-oriented tendencies. This indicated that business rather than political support was positioned as the core in relevant news articles because of

how efficiently nanotechnology was already verified in the economic sector.

Political actors and media had high percentages among various actors under “environmental risk,” which explained role sharing among actors because scientists investigated the negative effects of nanotechnology, the media warned society, and politicians tried to create policies to control it.

“Research and development” indicated that the public discourse on nanotechnology was still formed around technological development and scientific discovery. Emerging technologies and their efficiency rose as a social topic in their development phase. As they entered into the popularization and commercialization phases, their practical effects could be verified and public awareness of potential risks caused by those emerging technologies developed. While the technological benefits of nanotechnology presently have been realized—as it has entered into the popularization and commercialization phases—its risks are not yet scientifically verified. Accordingly, news articles on nanotechnology continue to focus on technological developments and corresponding benefits unless there is a definite risk that the public can perceive.

The “health risks” frame is similar to “environmental risks.” Specifically, both frames showed a higher ratio of the media as actor than the other frames did because the media’s roles in explaining the risks of nanotechnology well enough to be easily understood are reflected in both frames. Unlike the benefits of nanotechnology, its risks and side effects are not definitively determined. Accordingly, there are more opinions and judgments by the media compared with news articles on nanotechnology benefits. However, call for regulation on nanotechnology differed in both frames. While calls for regulation showed up in both frames, “environmental risks” showed relatively higher calls for regulation than “health risks.” The benefits and risks of nanotechnology to medicine and health are relatively well-known. Conversely, the risks of nanotechnology were mentioned more than benefits related to the environment. Thus, while nanotechnology use and its regulation are supported in terms of medicine and health, only regulation is supported respecting the environment.

This study also examined the differences in media frames by country and time. The most significant feature of media frames in South Korean newspapers is the appearance of the risk-oriented frame (“environmental risks” + “health risks”). This is based on the unique way South Korean newspapers deal with scientific issues. In South Korea, discussing scientific issues frequently shifts into political discourse and ultimately causes serious ideological conflicts. Such conflicts arise because of two scientific scandals that had enormous effects on South Korean society in the 2000s—manipulation of stem cell research and mad cow disease.

Both scandals definitely indicated that the public discourse in South Korea dramatically changed due to the media and public frenzy on scientific issues. While media frames in South Korean newspapers related to science and technology mainly focused on “scientific achievement,” “heroes,” or “economic benefits” before both scandals (Chung, 2004; Kim & Cho, 2005), “risks” and “social conflicts” appeared after them (Kim, 2011). In a study comparing media frames in newspapers in South Korea to those in the United Kingdom related to stem cells (Kim, 2011), the media frames in the United Kingdom passed through a process of “early concerns → British interest → medical progress.” However, the media frames in South Korea were changed, leading to the sequence of “bioethics → societal

irrationality/national success → social problems/legitimization” with the scandal of stem cell research manipulation. Consequently, the risk-oriented frame in South Korea was formed as news articles reflected a unique viewpoint that considered the uncertainty of emerging technology not by its scientific but by its political aspect.

Meanwhile, risk-oriented frame varied in South Korean newspapers. While "Health Risks" was strong in Chosun Ilbo, "Environmental Risks" was found relatively more often in Hankyoreh Sinmun. Both newspapers showed differences in the risk-oriented frame because while nanotechnology effects on medical and health care issues was discussed both as to its benefits and risks, nanotechnology discussion related to environmental issues mainly highlighted the risks. This was evident from the fact that "Economic Benefits" and "Policy" had relatively smaller percentages in the conservative Chosun Ilbo than in the liberal Hankyoreh Sinmun. And building on the aspect that the articles in "Policy" deal mainly with medical implementation, Chosun Ilbo focused on both positive and negative impacts of nanotechnology on the medicine field. However, Hankyoreh Sinmun emphasized the risks inherently caused by nanotechnology more than Chosun Ilbo by focusing on issues related to the environment.

The benefit-oriented frame was found relatively more often in Germany because this country has had no issues triggering the public to recognize the risks of nanotechnology up to now. The only negative issue regarding nanotechnology in German newspapers during the analysis period was the Neosino case, which was related to health supplements using nanotechnology. It did not point out nanotechnology risks, but it did damage public confidence in nanotechnology by raising doubts about its efficiency.

Another reason for the benefit-oriented frame predominance in Germany is the policy of the German federal government, which focuses on the benefits of nanotechnology. The German government has been concentrating on nanotechnology development and commercialization, which was evident in its announcing the "Action Plan Nanotechnology 2015." This plan indicated that Germany aims to maximize the benefits of nanotechnology. While the government supports research on risks, including the "NanoCare Project" investigating the effect of nanotechnology on health, German policies mainly reflect the expectation of economic consequences.

In Austria, the introduction to and policy on nanotechnology frames were relatively prominent. Both frames were frequently observed in the early development phase of nanotechnology. In this study, both frames were also identified often in the early 2000s, when nanotechnology initiatives were introduced in each country and nanotechnology projects were seriously started. Such a feature was identified as the policies of each country promoting nanotechnology potential were introduced in the media, gradually increasing the need to explain that emerging technology.

The "overview of nanotechnology" and "policy" frames were found relatively more often in Austria because the development of nanotechnology, and the formation of corresponding public discourse, emerged behind the other three countries. It is only since 2009 that the discourse on nanotechnology expanded from the science sector to society at large in Austria (Nentwich et al., 2014). This means that social discussion of nanotechnology had less of an effect on news articles in Austria than it did in other countries during the analysis period.

The unique result in Japanese newspapers was that "research and development" was found

more often than it was in other countries. A similar result was found in biotechnology frames, which drew attention as an emerging technology earlier than nanotechnology did (Hibino & Nagata, 2006; Shineha et al., 2008). The theme of biotechnology in Japanese newspapers changed from application to research, and the media frame related to research and development was positioned as the core consistently dominating news articles in Japan for 15 years.

Existing studies, and the present study as well, identified that scientific research and development and economic benefits were the main frames in nanotechnology news articles. This is because there is still no definite and direct risk caused by the technology that the public can clearly recognize, and nanotechnology still has no cultural stigma that specifies the negative aspects of merging technology like biotechnology does, where genetically modified crops are described as “Frankenstein food.”

Looking at the dynamics of the media frame, when “research and development” increased, “economic benefits” were generally reduced. The correlation between both frames running in opposite ways during the same period is based on the characteristics of nanotechnology. Since nanotechnology was still in the development phase, the recursive phases in the change of both frames could be understood in this context.

This study contributed to the literature comparing media content between cultures and media studies. The differences of media frame by countries reflected the cultural characteristics of each country. For example, the “Economic Benefits” frame was observed more frequently in a culture with stronger individualism. Germany had the strongest individualistic culture followed by Austria, Japan, and South Korea in that order (Hofstede 2001). Correspondingly, Germany showed the highest ratio of “Economic Benefits” followed by Austria, Japan and South Korea in that order. It indicated that the culture emphasizing competition and economic benefits resonated with the media frame related to economy.

While previous studies focused on the early development phase of nanotechnology, this research identified long-term tendencies by analyzing news articles for 15 years, including the 2010s, when the potential risks of nanotechnology were discussed in society. Moreover, unlike existing studies limited to comparisons on both sides of the Atlantic, this study expanded into regional and cultural comparisons that included German-speaking and Confucian culture. In addition, as comparing two countries is limited in terms of how this can inform generalizing results, the present study attempted to overcome this issue by studying four countries with different cultures. Regarding methodology, this study improved reliability and validity by clustering frame elements. To maximize the efficiency of the methodology, with the media frame as the cluster, it is necessary to select and examine the definitions of frames from a variety of researchers.

This study’s content analysis had limitations. Content analysis is effective for identifying a difference in issues, but it cannot determine causality because of its restricted inference ability. Diverse alternatives including interviews, surveys, or experiments will be combined for supplementing the limitation of content analysis whose causality cannot be easily identified.

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