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Study on Responsible Research and Innovation for Emerging Technology in Korea

- Barriers Analysis and Firms Implementation -

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Dedicated to my beloved family, professors, and KEIT

For their endless love, support, and sacrifices

Abstract

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This dissertation contains three essays on analyzing the social impacts of innovation on emerging technologies in Korea. Innovation studies on research and development in specific countries have conducted extensive debates over the decades. The essays in the dissertation investigate research questions, focusing on existing innovation policies through the responsible research and innovation (RRI) approach, a new framework for

analyzing innovation. Technologically advanced countries have recently highlighted RRI, which aims to increase the positive effects of innovations by intervening in the early stages of technological development. It is necessary to prepare for unexpected ripple effects that might occur as emerging technologies continue to develop.

The first essay consists of reviewing the literature to support social innovation in emerging technologies. In recent decades, the evolution and development of theories related to social innovation of emerging technologies in Europe have been investigated, and research questions and methodologies used in these studies have been summarized. In this study, I would like to provide answers to the research questions that need to be solved to introduce RRI: (1) what are the possible barriers to introducing RRI in Korea, and (2) whether firms that commercialize technology should introduce RRI.

Korea has a newly industrialized economy (NIE), making it important to examine the country's potential for RRI implementation, as RRI is still a controversial topic. Korea also lacks policy experience in regard to key RRI elements, which may present barriers to

RRI implementation in the future. Accordingly, the second essay of this study attempts to inform the adoption of RRI policies in Korea by using an analytical hierarchy process approach to identify and prioritize anticipated barriers to RRI implementation. Thirteen barriers were identified from the previous literature and categorized into five types: economic, implementation, policy and political, social, and technical. The analysis found economic and policy and political barriers to be the most significant categories of barriers. Specifically, increased innovation costs and a lack of economic incentives were the top two of the thirteen barriers. From these results, it can be inferred that Korea must provide proper financial support and clear policy directions for the successful implementation of RRI.

Simultaneously, with the recent rise of RRI initiatives in firms that commercialize innovation, experts have argued that in order for RRI to succeed, practical issues must be considered. Accordingly, the third essay explores RRI from the perspective of Korean emerging technology development firms. Although social benefits are expected from RRI, which aims to reduce the side effects of innovations for society, the implementation of RRI requires changing firms' existing rules and routines. Therefore, predicting benefits

and costs from the firm's perspective can shed light on the likelihood that RRI will succeed. In this study, through an expert survey, the relative weights of RRI-related benefit criteria (technological level, economic performance, and public contribution) and cost criteria (anticipation, reflexivity, inclusion, and responsiveness) were analyzed. On this basis, trends in priorities for RRI levels were evaluated from present and future perspectives. Unexpectedly, firms recognized that even if constraints such as RRI impose greater costs, they will eventually bring greater benefits. This finding implies that RRI-induced innovations can overcome obstacles, offset costs, and finally increase firms' competitiveness, and that firms are willing to do good for society through RRI. In the long term, a firm's ethical activities may eventually result in improved performance by its management. Therefore, it can be concluded that, even if RRI is enforced in a compulsory manner, it is highly likely that it can be well established and promoted even in firms that consider profit first.

Keywords: responsible research and innovation, analytical hierarchy process, emerging technology, barrier, regulation, ethics, corporate social responsibility

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Contents

List of Tables

List of Figures

Chapter 1. Overall introduction

1.1 Motivation and research background

A responsible research and innovation (RRI) has been successful in regard to effectively presenting the importance of responsible research to society (von Schomberg 2013). The European Union (EU) is strongly advocating for RRI as a part of Horizon 2020, a program for supporting research, and related academic research is being actively conducted (Chatfield, Iatridis, Stahl, & Paspallis, 2017; Guston et al., 2014).

RRI addresses technological innovation's effects on society and the environment and is a model developed through the participation of various actors, including the EU (Burget, Bardone, and Pedaste 2017; von Schomberg 2013). In the past, a person who has absolute power (e.g., the King) was responsible for inventing, possessing, and taking ownership of technology, allowing for control over technology (von Schomberg 2013). However, it has become difficult to control the effects of technological innovation as its subjects have diversified (von Schomberg 2013). In addition, the consequences of technological and scientific innovation have recently been more likely to pose risks to society as a result of their larger impacts and the lack of time that society has to cope with changes (Lowman, Trott, Hoecht, & Sellam, 2012). However, modern research and development (R&D) systems have faced difficulties, as they have often failed to focus on technological development while simultaneously considering its social and ethical

impacts (Stilgoe, Owen, & Macnaghten, 2013). In recognition of this, technologically advanced countries in Europe have recently started using the RRI approach to prepare for emerging technologies' social ripple effects (Burget et al., 2017).

Simultaneously, RRI is still developing in terms of both its conception and implementation. the conceptual basis of RRI is developing in different ways (Burget et al., 2017). There are two basic definitions of RRI: the definition of the European Commission and the definition of von Schomberg (2013, 63). The European Commission's definition emphasizes inclusiveness and participatory governance, and it presents RRI as an approach that provides a certain direction for research and innovation, not just a process, as exemplified by the following presentation of this approach: 'Responsible Research and Innovation (RRI) refers to the comprehensive approach of proceeding in research and innovation in ways that allow all stakeholders that are involved in the processes of research and innovation at an early stage (A) to obtain relevant knowledge on the consequences of the outcomes of their actions and on the range of options open to them and (B) to effectively evaluate both outcomes and options in terms of societal needs and moral values and (C) to use these considerations (under A and B) as functional requirements for design and development of new research, products and services (Burget et al., 2017).' von Schomberg's definition includes a comprehensive range of aspects and elements, including inclusiveness, participation, expectations, social satisfaction, and ethical acceptability, and is closely linked to the processes and values of European Union policies; as such, it is a commonly applied definition of RRI in the literature. This study follows the RRI definition suggested by von Schomberg (2013, 63): 'RRI is a transparent,

interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products.'

Evidence suggesting that RRI is more effective at an early stage in society's involvement in research and innovation processes as a way to control the impacts of technological innovation can be found from the 'dilemma of control' (also known as the Collingridge dilemma) (Genus & Stirling, 2018). This dilemma is explained as follows: 'attempting to control a technology is difficult…because during its early stages, when it can be controlled, not enough can be known about its harmful social consequences to warrant controlling its development; but by the time these consequences are apparent, control has become costly and slow' (Genus & Stirling, 2018). RRI includes the concept of establishing the right process at the right time to ensure that technological innovation has the right impact on society. However, as mentioned regarding the dilemma of control, controlling technological development in its early stages is difficult because the future direction of technology is unknown. Therefore, four dimensions of RRI were proposed by Stilgoe (2013) as a tool for predicting directions of technological development and measuring various types of participation and behaviors considering relationships with stakeholders. Recently, these four dimensions have been utilized in many RRI-related studies (Ceicyte & Petraite, 2018; Genus & Iskandarova, 2018; Paredes-Frigolett, 2016). Four dimensions are presented below (Asante, Owen, & Williamson, 2014; Stilgoe et al., 2013).

Anticipation: Anticipatory describes and analyses possible intended and unintended impacts that might arise, be these economic, social or otherwise. Supported by methodologies that include those of foresight, technology assessment and scenario development, these not only serve to articulate promissory narratives of expectation but also to explore other pathways to other impacts, prompting innovators to ask 'what if…' and 'what else might it do' questions. Tempered by the need for plausibility, such methods do not aim to predict, but are useful as a space to surface issues and explore possible impacts and implications that may otherwise remain uncovered and little discussed. They serve as a useful entry point for reflection on the purposes, promises and possible impacts of innovation. Background techniques include foresight, technology assessment, scenario.

Reflexivity: Reflexive reflects on underlying purposes, motivations and potential impacts, how benefits might be distributed, what is known (including those areas of regulation, ethical review or other forms of governance that may exist) and what is not known; associated uncertainties, risks, areas of ignorance, assumptions, questions and dilemmas. Background techniques include embedded social scientists and ethicists in laboratories, ethical technology assessment, codes of conduct.

Inclusion: Deliberative inclusion opens up visions, purposes, questions and dilemmas to broad, collective deliberation through processes of dialogue, engagement and debate, inviting and listening to wider perspectives from publics and diverse stakeholders. This allows the introduction of a broad range of perspectives to reframe issues and the

identification of areas of potential contestation. Background techniques include consensus conferences, citizens' juries and panels, lay membership of expert bodies, open innovation.

Responsiveness: Responsiveness uses this collective process of reflexivity to both set the direction and influence the subsequent trajectory and pace of innovation, through effective mechanisms of governance. This should be an iterative, inclusive and open process of adaptive learning, with dynamic capability. Background techniques include regulation, standards, niche management, stage-gates.

In technologically advanced countries, such as those in Europe, the importance of RRI is highlighted using the motto of being prepared for the risks of innovations resulting from emerging technologies (Burget et al., 2017; Chatfield et al., 2017; von Schomberg, 2013). RRI involves proactively anticipating possible risks from various stakeholders' participation in the early stages of innovation, and actively reflecting on how those risks will affect society (Genus & Stirling, 2018; Stilgoe et al., 2013). Because the EU is strongly promoting RRI as a core framework for Horizon 2020, RRI is developing in policy, academic, and even business settings (Chatfield, Iatridis, et al., 2017; Guston et al., 2014). Simultaneously, the conceptual basis of RRI is still a matter of lively discussion, and is evolving in different directions (Blok, V., & Lemmens, 2015; Burget et al., 2017; Nathan, 2015; Scholten & Blok, 2015; Stilgoe et al., 2013).

Unlike the EU, Asia lacks policy experience on key RRI elements, and given that it is expected that there will be barriers to overcome at various levels in regard to the practical

application of RRI (Burget et al., 2017). On the other hand, it has been argued that cross-national contexts play an important role in the application of RRI. Existing studies show that RRI effects differs across Europe depending on the specific country's (developed or less-developed) innovative environment (Lukovics, Flipse, Udvari, & Fisher, 2017). Therefore, before RRI can be effectively applied in each country, it is important to learn from Europe's experiences and to simultaneously recognize its unique context and identify its specific barriers to adoption.

In addition, it is argued that different technologies can have various side effects even within the same country, which indicates that countries need to tailor their RRI implementation strategies to cope with the unique side effects they may experience (van de Poel et al., 2017). The emerging technologies targeted for RRI are those that are likely to become dominant paradigms within 10 to 15 years (Berndt C Stahl, Eden, & Jirotka, 2013). Emerging technologies such as nanotechnologies, big data, alternative energy production, and genomics have a history of dispute (Scholten & Blok, 2015). In this way, emerging technologies can provide opportunities to address social challenges in terms of achieving sustainable and ethically acceptable results (Scholten & Van Der Duin, 2015). In order to select the technology to be analyzed, we investigated emerging technologies in the EU and Korea, and as a result, selected autonomous vehicles and biotechnology. The reviewed documents are presented in the text as shown in the table below. (1) EU: EC Horizon 2020 Societal Challenges Programme and RRI support programs/projects, (2) Korea: Government R&D investment plan, technology impact assessment technologies. The reviewed documents are summarized in Table 1.1. Accordingly, the present study

investigated the developmental status of autonomous vehicles (AV) and biotechnology (BT) in Korea and their ethical, legal, and social aspects as target emerging technologies. First, AV, which involves the intensive collection of advanced information and communications technology, is expected to lead to the greatest advancements in mobility yet seen in human society (KISTEP, 2018). Korea is developing AV technology with the goal of commercialization in 2030 (KISTEP, 2018). However, a concern with AV is that the technology will reduce human control and result in no one having responsibility for driving, and that paradoxically, increased connectivity between infrastructure combined with autonomous driving will pose socioeconomic threats (Cohen, Stilgoe, & Cavoli, 2018; Cui et al., 2019; Keeling, 2018; Sheehan et al., 2019; van de Poel et al., 2017). Meanwhile, BT is a technology that produces various high value-added products by utilizing the functions and information of living organisms, and Korea has shown a high export growth rate in BT of 11.5% per year, with recent exports of technology achieved through long-term R&D despite a small market and weak technology (MFDS, 2017; MOTIE, 2017a). However, concerns relating to BT include the fact that the combination of molecular biology, bioinformatics, and new device development entails the emergence of converging or destructive technologies, simultaneously posing a number of ethical, legal and social issues of concern to RRI (e.g. privacy protection, data confidentiality production, ownership of personal data, and prior consent issues) (Gartland & Gartland, 2018; Lecuona et al., 2017; Mitchell, Brown, & McRoberts, 2018; Thompson, 2018).

Table 1. 1. Emerging technologies studied in this research

Nation	Program/Project	Research	Emerging technology
EU	EC Horizon 2020 Societal Challenges	Owen, R. (2014)	Health (biotechnology), Integrated transport (automated Vehicle)
	Socio-Technical Integration Research (STIR)	Smolka, M. (2020)	Neuroscience (biotechnology)
		Flipse et al. (2013)	Biotechnology
		Flipse et al. (2018)	Automated Vehicle
	Engineering and Physical Science Research Council (EPSRC)	de Cock Buning et al. (2017)	Automated Vehicle
		Szollosy, M. (2017)	Robotics (automated Vehicle)
		Nulli et al. (2018)	IT (automated Vehicle)
		Taylor, K., & Woods, S. (2020)	Synthetic biology (biotechnology)
	Dutch Responsible Innovation (MVI)	De Hoop, E. et al. (2016)	Biofuels (biotechnology)
		Pols, A. J. K. et al. (2017)	Biofuels (biotechnology)
	ELSI	Kurihara (2011)	Biotechnology
		Gavrilovici (2004)	Biotechnology
		Shineha et al. (2018).	Biotechnology
		Bardill, J. (2014).	Biotechnology
		Meagher et al. (2016)	Biotechnology
	CTA	Moens et al. (2009)	ICT (automated Vehicle)
	ETC	Stahl et al. (2013)	ICT (automated Vehicle)
Korea	Government Investment Industry	(MOTIE, 2019)	Automated Vehicle, Biohealth (biotechnology)
	Government technology assessment	(KISTEP, 2014, 2015)	Automated Vehicle, Genetic scissors (biotechnology)

1.2 Research question and problem description

The following two considerations should be kept in mind in order to be introduced into the non-European region without RRI experience. The first consideration has a broader scope, considering the national context in which RRI is implemented. Research is being conducted on the implementation of RRI in contexts other than Europe, but there have been insufficient discussions about what factors should be considered as differentiators from Europe (Arnaldi et al., 2015; Dalziel et al., 2018; Davis & Laas, 2014; Lubberink, Blok, van Ophem, & Omta, 2019). It has been argued that cross-national context plays an important role in the application of RRI, which seems to be developing successfully because developed European countries are experienced in implementing policies relating to key RRI elements (Lukovics et al., 2017). For example, these countries have developed a variety of technology impact assessment methods, such as 'real-time technology assessment,' and they have gained experience with ethical reflexivity systems by evaluating the effects of certain ethical, legal, and social aspects (Guston & Sarewitz, 2002; Zwart, Landeweerd, & van Rooij, 2014). Furthermore, since the late 1970s, European countries have made concerted efforts to consider the opinions of the public and non-governmental organizations when making decisions related to science and technology (Landeweerd et al., 2015). These policy experiences are expected to have a positive impact on the use of RRI in the Europe context.

However, in the EU, researchers in developed countries expressed interest in the interaction between technology and society, while researchers in non-developed countries

expressed the need to concentrate on securing research funds and had a low understanding of the need to consider the social context of technological development (Lukovics et al., 2017). There were marked differences in perceptions. Thus, it is necessary to consider the innovation environment of each specific country to augment the effectiveness of RRI. In addition, it has been argued that technology level (high technology vs. low technology), culture, and material barriers to innovation are factors that affect attitudes toward RRI implementation and should be considered (de Hoop et al., 2016; Di Giulio, Groves, Monteiro, & Taddei, 2016; Hartley, McLeod, Clifford, Jewitt, & Ray, 2019).

The second consideration—with a narrow scope— is the preferred or feasible level of RRI. The benefits and costs of implementing RRI vary depending on the RRI target level (Paredes-Frigolett, 2016). Although research on the framework of RRI levels based on Stilgoe (2013) is ongoing (as will be described in detail in Section 3), it is understood the level of RRI preferred or considered acceptable will depend on its own capabilities, relationships with stakeholders, and similar factors (Gianni, R., & Goujon, 2014; Mei, L., & Chen, 2019; Paredes-Frigolett, 2016; Stilgoe et al., 2013). However, few studies have been conducted on the level of RRI preferred.

However, concerns regarding the side effects of RRI are more likely to be raised in technology-intensive countries where emerging technologies are actively being developed and promoted. Accordingly, Korea, which relies on industrial growth centered on exports of products and technologies, needs more preparation. Moreover, as mentioned above,

more in-depth and specific alternatives are required in these countries due to the lack of institutions, culture, and experience with discussing social issues. Accordingly, this paper intends to present a preliminary analysis conducted regarding the introduction of RRI using examples of emerging technologies in Korea.

Korea is a newly industrialized economy (NIE) and has a significant and important role in R&D. In addition, Korea's 2017 R&D intensity (i.e., the country's expenditure on R&D as a percentage of Gross Domestic Product) was 4.55%, which was the highest R&D intensity level in the world (Lee and Lim 2001; OECD 2019). Thus, it is as important to review Korea's RRI implementation as it is to explore RRI in technologically advanced countries. Nevertheless, the literature on social ripple effects in terms of the risks associated with emerging technologies is new and thus limited (Suh, 2019). As Korea lacks policy experience on key RRI elements, and given that RRI is still controversial in terms of both its conception and implementation, it is expected that there will be barriers to overcome at various levels in regard to the practical application of RRI (Burget et al., 2017). In addition, this study selected AVs and BTs, which have different characteristics and are the most representative emerging technologies in Korea and their ethical, legal, and social aspects as target emerging technologies.

The development of AVs is based on the convergence of various information and communications technologies (ICT) such as artificial intelligence/big data, high performance processing software (SW) and hardware (HW) platforms, and sensor systems. AVs are expected to make the largest advances in the mobility of human society

for various reasons, including a reduction in the number of traffic accidents(KISTEP, 2018). Korea is trying to develop AV technology with the goal of commercialization by 2030 (KISTEP, 2018). On the other hand, there is a concern that AV technology will reduce human control and lead to undesirable consequences (i.e., situations in which responsibility for an accident cannot be specifically assigned) (van de Poel et al., 2017). Paradoxically, the increased connectivity between infrastructures combined with autonomous driving can be a significant threat to the enormous socioeconomic benefits promised by AVs (Cui, Liew, Sabaliauskaite, & Zhou, 2019; Keeling, 2018; Sheehan, Murphy, Mullins, & Ryan, 2019).

In addition, BTs produce a variety of high value-added products using biological functions and information. Korea's BT industry has a small market size but a high yearly export growth rate of 11.5%. Despite Korea’s weak technical foundation, its BT companies have increased their long-term R&D investments, resulting in certain positive effects such as recent exports of technology (MFDS 2017; MOTIE 2017a). On the other hand, the combination of molecular biology, bioinformatics, and new device development factors may involve fusion or destructive technologies, which may simultaneously create various ethical, legal, and social issues of concern to RRI. For example, in the field of genome research, there are certain challenges that arise as a result of newly encountered problems, such as privacy protection, data confidentiality protection, ownership of intellectual property in personal data, and prior consent (K.M.A. Gartland and J.S. Gartland 2018; Lecuona et al. 2017)

Above all, before RRI can be effectively applied in Korea, it is important to learn from Europe's experiences and to simultaneously recognize Korea's unique context and identify its specific barriers to adoption. Because RRI research is new and has not yet been introduced to Korea, barriers to RRI adoption have yet to be fully understood. Therefore, in this dissertation, when considering the introduction of RRI to Korea, the first main task was considered to be the identification and ranking of possible obstacles. Although previous studies have identified the various obstacles that RRI must overcome, these barriers had not previously been weighted and/or ranked to indicate importance and relative impact. Therefore, this study focused on ranking such obstacles.

Recently, it has been argued that RRI should be applied in firms' R&D processes because it is primarily the role of firms to commercialize products and services that result from innovations in society (Lubberink, Blok, Ophem, & Omta, 2017). Recent RRI research has focused on firms that play a role in commercializing innovation, and on finding solutions to ethical concerns and responsibilities in the decision-making process of innovation within the firm (S. M. Flipse, Van Dam, Stragier, Oude Vrielink, & Van Der Sanden, 2015; Lukovics et al., 2017; Martinuzzi, Blok, Brem, Stahl, & Schönherr, 2018; Nathan, 2015). Thus, business objectives shift to optimizing economic, social, and environmental value in order to bring sustainable value for business and society (Scholten & Blok, 2015).

However, social involvement in innovation by private firms, as required by RRI, can be a novel challenge for private firms Although some firms do implement social

strategies, including those within the framework of corporate social responsibility (CSR) (van de Poel et al., 2017), voluntary CSR and social involvement are very different in nature from RRI, which may require changing the firm's existing rules and routines (Blok, V., & Lemmens, 2015; Gurzawska, Mäkinen, & Brey, 2017). Unlike CSR, RRI concerns the primary process of the firm, the so-called money-making machine (Blok, Scholten, & Long, 2018). This means that in addition to the various social benefits that are expected from RRI, losses (costs) for private firms can occur (Chatfield, Iatridis, et al., 2017).

These benefits and costs can vary greatly depending on the type of RRI (Paredes-Frigolett, 2016), which may reflect differences in the extent and intensity of implementation, and discussions are under way about the advantages and disadvantages of various approaches (Gianni, R., & Goujon, 2014; Mei, L., & Chen, 2019; Paredes-Frigolett, 2016; Paredes-Frigolett, Gomes, & Pereira, 2015).

In this context, a common argument of recent research is that industry adoption should take into account practical issues (Dalziel et al., 2018). However, despite the progress of research, it seems that the theoretical and empirical support for the following issues is also insufficient: (a) what is the motivation for the firm to accept RRI, (b) what the firm sees as the benefits and costs of RRI, and (c) the level of RRI that is appropriate for firms that reflect current, future and national contexts. Therefore, finding a solution to these issues was determined to be the second main task of this dissertation.

1.3 Research objectives and outline

The barriers to RRI adoption in Korea have not been fully understood, as RRI research is a novel field in Korea. Therefore, in this thesis, the first main task was to identify possible obstacles hindering the introduction of RRI to Korea. In addition, recent RRI studies have expressed an interest in RRI implementation in firms that commercialize technology. However, the reasons underlying the reported motivation for accepting RRI in firms that aim to pursue profit is not fully understood. Therefore, finding a solution to this conundrum was adopted as the second challenge.

To solve these problems, the two main objectives of this thesis are to analyze barriers from a policy perspective and cost/benefit tradeoffs from a firm perspective regarding RRI implementation in the context of Korea, more specifically with regard to innovations in emerging technologies. Thus, the thesis is divided into two parts: (1) an analysis of barriers (essay Ⅱ), and (2) an analysis of benefit perspectives and cost perspectives (essay Ⅲ).

The purpose of first part is to use a preliminary perspective to identify the factors that might impede the implementation of RRI in Korea. To this end, we first conducted an extensive literature review and consulted with experts to identify the various possible barriers to RRI adoption. As a result, we identified five barrier categories (economic, implementation, policy and politics, society, and technology) with a total of 13 barriers across these categories. Although previous studies have identified the various obstacles that RRI must overcome, these barriers had not previously been weighted and/or ranked

to indicate importance and relative impact. Therefore, this study focused on ranking such obstacles and then used the AHP method to weigh and prioritize the obstacles to offer advice for the Korean professionals who have a general understanding of the country's R&D systems and technologies.

The second, we analyze benefit perspectives and cost perspectives of RRI for emerging technologies in firms The specific process is described as follows. (a) the existing literature was reviewed to create a conceptual model suitable for the purposes of this study, and (b) the results were analyzed through expert recognition surveys. (c) Afterwards, the results of the analysis were compared with existing studies. More specifically, this study aimed to analyze the relative weights of decision criteria by identifying the benefit criteria, cost criteria, and RRI levels used when considering the implementation of RRI in firms, and then to investigate trends in priorities from current and future perspectives on the basis of an evaluation of the types of RRI.

Since the RRI concept is not universally proliferated in Korea, it is possible to predict the future impact of technology only by discussing specific technologies. Therefore, we selected autonomous vehicle (AV) and biotechnology (BT) developments as the target emerging technologies. The analytical hierarchy process (AHP) analysis method was used. AHP is a widely used tool for formulating and analyzing decision making processes and frameworks, and it is advantageous because it allows for pairwise comparisons to estimate the weight of certain criteria and to rank various alternatives (Saaty, 1990a, 2008).

- Chapter 2: Essay I -

Literature review on RRI to support social innovation in technology

Chapter 2. Literature review on RRI to support social innovation in technology

2.1 Development of theories related to social innovation

In the last 30 years, three types of science and technology governance have been developed in Europe, and through discussing these frameworks, I would like to discuss the background and necessity of RRI (see Table 2. 1) (Landeweerd et al., 2015). Science and technology development in the late 19th century was recognized as synonymous with social development. Subsequently, a technocratic style of governance (1970s–1980s), a social system in which technocrats (people with scientific knowledge and skills) manage the economic system, emerged. Then, as ethical issues stemmed from the negative effects of science and technology, ethical evaluations were institutionalized in examinations of scientific compliance, a typical example of which is the Ethical, Legal and Social Aspects (ELSA) framework. The third approach is institutionalized RRI with public participation, which began in the early 1980s in Europe as an approach for responding to public opinion and the opinions presented by NGOs. Although new technologies (e.g. nanotechnology, synthetic biology, human genomics) can solve international and social challenges such as climate change, energy security, economic crises, and global health problems, they should be approached using the concept of RRI because these innovations cause social concerns and diminish public trust.

Table 2. 1. European science and technology governance patterns in the last 30 years

Element	Technocratic	ELSA	RRI
Concept	Regulation of science and technology by technical bureaucrats with specialized knowledge	Assessment of ethical, legal and social implications for science and technology	Evaluation through public participation from the initial stage of technology development
Appearance	1919	Mid-1990s	2011
Target	Economics	Ethics	Economics, technical risk
Governance	Top-down	Bottom-up	Top-down and bottom-up
System	Regulating science and technology through law	Institutionalizing ethics in science and technology evaluation	Preventing risks associated with innovation through forecasting and citizen participation
Main actors	Experts, bureaucrats	Experts, bureaucrats and ethics experts	Experts, bureaucrats, ethics experts, sociologists, public

Technocracy is a social system in which a technical bureaucracy with scientific knowledge and skills manages the economic system—resulting in the mechanization and organization of society—and regulates science and technology through law (Landeweerd et al., 2015). Technical regulation consists of a double delegation process for technical risk assessment to scientists and technicians, who act as framers of governance procedures. Decisions about which scientific and technological frameworks must be implemented rely mainly on peer evaluations by independent experts. Within this framework, scientific and technological experts are seen as neutral, rational, and well-informed, whereas members of the public see these projects as irrational because of their lack of knowledge and lack of expertise or bias. The principal disadvantages of this framework are that (1) the legal framework of technocracy does not cope with the complexity of the innovation process, the increasing social impact of technological advances, and the rapid pace of change in technology, and (2) technocracy does not view science as an integral part of democracy, ethics, engineering, science, or policy-making.

By 1990, the existing philosophical, biological ethics, and technology assessment (TA) approach to science and technology was considered to be increasingly insufficient. James Watson, an American scientist who led the Human Genome Project (1990-2003), asked to review ethical, legal, and social implications (ELSI) when researching because he was concerned that genomic maps challenged traditional values. Later, in Europe, ELSA was introduced (ELSI 1990, ELSA 1994) (Zwart et al., 2014). In ELSA, ethics is institutionalized as a normative instrument, as R&D proposals are evaluated by the EU Ethics Expert Panel. Nonetheless, critics have pointed out that despite the demonstrable

rationality of the individualist approach to ethics. The problem is that scientists do not feel the need to follow ethics to act according to a collective ethics of “co-responsibility” (Zwart et al., 2014).

RRI is considered to have expanded innovation to strengthen accountability through stakeholder engagement (Blok, V., & Lemmens, 2015).

RRI = Regular innovation on ethical and social aspects + Stakeholder engagement.

New fields of research such as nanotechnology, synthetic biology, and human genomics have emerged over the past decade. These research fields are committed to addressing global and social challenges such as climate change, energy security, and economic crises through the development of sustainable biofuels and biomaterials, as well as the development of affordable medications. Some of these developments are considered positive, while others have resulted in social concerns and public distrust (Landeweerd et al., 2015). Therefore, RRI has emerged to integrate ethical and social aspects from the beginning of technology development so that developments in technology and science can be properly spread throughout society (Auer & Jarmai, 2018).

2.2 Theoretical discussion of RRI

2.2.1 Definition

There are two major definitions of RRI, as shown in Table 2. 2. The first, published by the EU, is referred to as administrative justice. The second was defined by scholars who have discussed the concept of RRI from an academic standpoint since the announcement made by the EU regarding RRI.

Table 2. 2. Key definitions of RRI within an EU and academic policy context (van Hove & Wickson, 2017)

Category	Research	Definition (property)
EU definitions	European Commission (2012)	RRI means that societal actors work together during the whole research and innovation process in order to better align both the process and its outcomes, with the values, needs and expectations of European society. RRI is an ambitious challenge for the creation of Research and Innovation policy driven by the needs of society and engaging all societal actors via inclusive participatory approaches. RRI is also described as having 6 keys: engagement, gender equality, science education, open access, ethics and governance

Category	Research	Definition (property)
	von Schomberg R (2013)	RRI is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)
Academic definitions	Owen R, Macnaghten P, Stilgoe J (2012)	Responsible innovation evokes a collective duty of care, first to rethink what we want from innovation and then how we can make its pathways responsive in the face of uncertainty. Acknowledging the power of innovation to shape our collective future, RRI challenges us, first and foremost, to ask what kind of future we want innovation to bring into the world
	Wickson F, Carew AL (2014)	Certain characteristics [of RRI] include: (1) A focus on addressing significant socio-ecological needs and challenges; (2) A commitment to actively engaging a range of stakeholders for the purpose of substantively better decision-making and mutual learning; (3) A dedicated attempt to anticipate potential problems, assess available alternatives and reflect on underlying values, assumptions and beliefs; and (4) A willingness among all participants to act and adapt according to these ideas

Category	Research	Definition (property)
	Ribeiro BE, Smith RDJ, Millar K (2017)	The concept of RRI appears to be an umbrella used to capture all aspects of the discourse concerning the question what can be done in order to ensure that science, research, technology and innovation have positive, socially acceptable and desirable outcomes

2.2.2 Four dimensions and tools for RRI

Stilgoe et al. (2013)) proposed four dimensions that delineate the directions that RRI pursues. Each dimension can be measured through various methodologies, and the characteristics for the most suitable tools are listed in Table 2. 3. Anticipation refers to predicting the predictable or unintended consequences of technological advancements. Unlike the personal and professional self-criticism used by scientists, responsibility makes reflexivity a public problem (Wynne, 2011). Reflexivity requires scientists to blur the line between their role responsibilities and broader moral responsibilities. Therefore, it requires openness and leadership within a culture of science and innovation. Inclusion denotes expanding the scope of technological innovation to include various stakeholders and the public. Responsiveness refers to an iterative and comprehensive learning process through which the various activities mentioned above are internalized.

Table 2. 3. RRI tools for implementation of the four dimensions

Dimension	Definition	Representative techniques and approaches	Factors affecting implementation	Research
Anticipation	A priori analysis that predicts and analyzes the expected or unintended impacts of technological developments and innovations	Foresight	Engaging with existing imaginaries	Martin, B. R. (2010)
		Technology assessment	Participation rather than prediction	Guston et al. (2002)
Reflexivity	Reviewing the fundamental objectives, motivations, potential impacts, and how benefits are distributed of technology development and innovation to meet regulatory and ethical standards	Embedded social scientists and ethicists in laboratories	Enlarging or redefining role responsibilities	Schuurbiers, D. (2011)
		Ethical technology assessment	Reflexive capacity among scientists and within institutions	Swierstra et al. (2009)
		Codes of conduct	Connections made between research practice and governance	von Schomberg (2013)

Dimension	Definition	Representative techniques and approaches	Factors affecting implementation	Research
Inclusion	A collective deliberation and discussion process through the inclusion of the public and various stakeholders to restructure possible problems and introduce a broad perspective.	Consensus conferences	Questionable legitimacy of deliberative exercises	Te Kulve et al. (2011)
		Citizens' juries and panels	Need for clarity about, purposes of and motivation for dialogue	Guston et al. (2002), Guston, D. H. (2014)
Responsive -ness	Inclusion of iterative and comprehensive learning processes and direction settings in an effort to internalize the process of prediction, reflection, and participatory deliberation into the innovation process.	Regulation	Science-policy culture	Strand et al. (2015), Watermeyer, R. (2010)
		Standards	Institutional structure	Voegtlin, C. et al. (2017)
		Niche management	Institutional cultures	Schot, J. et al. (2008)
		Stage-gates	Intellectual property regimes	Macnaghten, P., & Owen, R. (2011)

2.2.3 Levels of RRI implementation

Since firms are groups that constantly interact with society in the pursuit of profits, the implementation of RRI in firms is more complex than expected. In view of this complexity, some researchers have proposed implementing and developing RRI within a system. The characteristics of the four dimensions according to RRI implementation levels are summarized in Table 2. 4, combining Paredes-Frigolette, H. (2016, 2015), Chen et al. (2019), and Gianni, R., & Goujun, and P. (2014).

Table 2. 4. Research into levels of RRI implementation

Levels of institutional situations					Dimensions of responsible innovation			
Level	**Aware-ness**	**(1) Chen, J. (2019)**	**(2) Paredes (2016)**	**(3) Gianni (2014)**	**Inclusion**	**Anticipation**	**Reflexivity**	**Responsiveness**
Very high	Full aware-ness	Embed-dedness	Co-constructive model		(1) Core actors: public, other actors: innovators, policy-makers	(1) Whether innovation activities and influences comply with informal institutions, customs, traditions, norms and religions that have evolved from national and regional history	(1) Reflective activities are extended to the recognition of culture, customs, norms, and traditions of the country and region.	(1) National and regional level discussions related to mental values, social traditions, and culture.
					(2) Very high level of activity: private and public external stakeholders provide information overflowing with innovation	(2) Very high level of prediction: fundamental discussion of new prediction methods beyond current methods	(2) Very high reflection: fundamental discussion of new ways beyond current methods	(2) Very high reactivity
					(3) The public replaces the expert: the frame transitions so that the distinction between the expert and the public is no longer necessary			

Levels of institutional situations					Dimensions of responsible innovation			
Level	**Aware-ness**	**(1) Chen, J. (2019)**	**(2) Paredes (2016)**	**(3) Gianni (2014)**	**Inclusion**	**Anticipation**	**Reflexivity**	**Responsiveness**
High		Institu-tional environ-ment	Consultative model		(1) Core actors: policy-makers, other actors: innovators, public	(1) Whether innovative activities and influences comply with official game rules, including political, legal and bureaucratic systems	(1) Reflective activities follow national and regional political system principles, judicial and bureaucratic rules.	(1) Supervision, improvement, optimization, reform, innovation activities of political, judicial, and bureaucratic systems
					(2) High level of activity: External stakeholders provide innovation information.	(2) High prediction level: bottom-up governance	(2) High reflection level: institutional reflection	(2) High reactivity
					(3) Public and professional needs are the same, and the perception of risk is more important than expert knowledge. Experts have a knowledge base and the public is confronted with real risks, so both can contribute.			

Levels of institutional situations					Dimensions of responsible innovation			
Level	**Aware-ness**	**(1) Chen, J. (2019)**	**(2) Paredes (2016)**	**(3) Gianni (2014)**	**Inclusion**	**Anticipation**	**Reflexivity**	**Responsiveness**
Inter-med-iate	No Aware-ness	Gover-nance	Revised model	standard	(1) Key actors: innovators, policy-makers, and other actors: public	(1) Whether innovation activities and impacts comply with specific sector management and operational rules, such as technology contracts, commercialization agreements, etc.	(1) Promote governance by regulations through reflection and strictly follow organizational rules	(1) Governance methods and management plan reflect technology type, model, and innovation industry factors.
					(2) Expansion of stakeholders: participation in public sectors such as regulatory agencies	(2) Low forecast level: top-down governance, only internal innovators participate	(2) Low reflection level: self-reflection (code of conduct), minority outside	(2) Low reactivity: activities and responsibilities within the internal scope
					(3) Reinforcement of the regulatory process: education of the public about the uncertainty of risks has failed, leading to prejudices of risks and anxiety by the media Regulations have been strengthened to counter this risk			

Levels of institutional situations					Dimensions of responsible innovation			
Level	**Aware-ness**	**(1) Chen, J. (2019)**	**(2) Paredes (2016)**	**(3) Gianni (2014)**	**Inclusion**	**Anticipation**	**Reflexivity**	**Responsiveness**
					overestimate			
Low		Resource allocation and employ-ment	Standard model		Core actors: innovators, other actors: policy-makers	(1) Whether innovation activities and impacts are consistent with incentives for the price, participation of people, money, property, information, and other resources	(1) Focusing on rational resource allocation and effective utilization, and distribution of profits for participating	(1) Resource allocation and coordination of innovation activities and participation mechanisms
					(2) Low level of activity: only internal innovators without stakeholders	(2) Low prediction level: top-down governance	(2) Low reflection level: self-reflection (code of conduct)	(2) Low reactivity: responsible activities only within internal scope
					(3) Expert-oriented: Experts are objective and rational, and the masses are irrational. This is due to the lack of public knowledge and the environment that fosters pure expertise by separating facts from value judgments.			

2.2.4 Key elements of RRI

In early 2014, the European Commission formed a group of experts to monitor and assess the impact of RRI initiatives, and proposed eight indicators, as shown in Table 2. 5, to assess performance in relation to general and specific RRI objectives (Carbajo & Cabeza, 2018; Monsonís-Payá, García-Melón, & Lozano, 2017). A ranking of importance using AHP was proposed to compensate for the weaknesses of context-based indicators (Monsonís-Payá et al., 2017). However, they argued that these indicators cannot be provided to actors in the field of European research as a general list of priority indicators. Thus, state and local actors, universities and research institutes, civil society organizations, funding institutions, and other institutions should devise their own deliberation procedures to select and customize the proposed indicators and add their own indicators according to their specific goals and concerns.

Table 2. 5. Overview of definitions of key elements of RRI

Key elements	Description
Governance	Searching for acceptable and desirable futures, robust and adaptable to the unpredictable developments of research and innovation
Public engagement	Promoting all societal actors to work together in order to align outcomes, values, needs, and expectations
Science education	Enhancing the education process to better equip citizens with the necessary knowledge and skills
Gender equality	Always promoting, ensuring, and considering the gender dimension in the decision-making process
Ethics	Fostering research integrity and ethical acceptability of scientific and technological developments
Open access	Fostering accessibility and ownership of scientific information
Social justice	• Research and innovation, and social justice connections: the consideration of ethical issues and values in the design, development and implementation of new technologies • Social justice and research activities connections: participation of social groups in benefits arising from research
Sustainability	• R&I and sustainability connections: knowledge gap between the headline targets for inclusive and sustainable growth • Sustainability and research activities connections: monitoring of ecosystem services and their effect on human well-being

2.3 Regulation, CSR, and RRI comparison

2.3.1 Regulation perspective for RRI

From a technology innovation perspective, the regulatory framework plays an important role for firms because it not only dominates the direction of technology development, but also influences the ways in which research and innovation are managed. In addition, regulation can be regarded as one of the most effective factors for promoting the implementation of RRI (Auer & Jarmai, 2018). The following aspects of regulation are considered here: (1) RRI can be seen as a type of innovation, (2) we have to consider the structure and workflow of RRI, and (3) RRI targets emerging technology that has never been regulated before. Regarding the first point, it can be argued that regulation can promote or hinder innovation, and it has been argued that the relationship between RRI and regulation is the same as innovation (Auer & Jarmai, 2018). Therefore, the regulatory framework has important implications as a potential driver of RRI. Second, the regulatory approach is likely to take place through the implementation of RRI as a governmental policy that is promoted in a top-down manner. Third, the high uncertainty of emerging technologies poses a new challenge for regulatory policy. In the absence of sufficient scientific evidence for new technology risks, it is not easy to control risks using existing laws. In this regard, the existing literature presents three approaches: the regulatory law approach, the soft law approach, and the participatory governance approach, which are described below (Kim, 2013).

First, in the regulatory law approach, the first consideration in managing new technology risks is to consider whether new technologies can be managed through existing regulatory laws or whether new regulatory laws should be developed. The regulatory law approach is based on orders and controls, and can be divided into bans and restrictions on hazardous substances and mandatory registrations. Strong regulation involves high risk-prevention effect and has the advantage of ensuring the safety of products, but the possibility of reducing research and product development can amplify conflicts between stakeholders when the system is introduced.

Second, when there is no scientific evidence of risk and it is difficult to apply regulatory law, the government can induce autonomous safety management by firms or research institutes through a soft law approach. In the form of guidelines, guidelines, action plans and programs, there is no specific means of coercion, but this framework encourages self-regulation of their products. The advantage is that the acceptability of this approach for technology providers is high, while a disadvantage is that the participation responsiveness is low due to the lack of compulsory means; furthermore, the transparency and specificity of the policy may be insufficient.

Third, and more recently, participation governance has begun to be discussed to escape order and control. There are three reasons for this shift. First, in the absence of sufficient scientific evidence on the risks posed by new technologies, and where regulatory laws could not be applied, the alternatives were self-regulation through codes of conduct and participatory governance. Second, the success stories of biotechnology

such as ELSA have been brought to stakeholders' attention. Third, participation is active in Europe as well as in the United States. The advantages are that as the citizen surveillance function is strengthened, the acceptability of the relevant products increases, social conflict can be minimized, and the legitimacy of the policy increases. However, there are concerns that it is not certain whether to reflect the results of participatory governance in actual policy, or to slow down the speed of technology development to reach consensus.

Since RRI is a governmental policy that is promoted in a top-down manner, it is possible that a regulatory law approach will be taken. However, as countries around the world, including Europe and the United States, are pursuing multi-layered regulatory policies rather than relying on one specific method for the regulation of emerging technologies, RRI can follow this complex method.

2.3.2 Corporate social responsibility (CSR) perspectives on RRI

As RRI emerges in firms that commercialize innovation, it is necessary to examine CSR as a regulatory and corporate strategy as part of the external environment surrounding firms (Gurzawska et al., 2017). RRI and CSR are similar corporate strategies in that they pursue the development and growth of a firm through fostering a close relationship with society. In addition, RRI requires a more comprehensive view of the firm's business strategy and CSR activities (van de Poel et al., 2017). Therefore, I would like to examine the direction of RRI by analyzing the commonalities and differences between the two concepts.

CSR has a long history. In 1979, a study on the social contract of business (Caroll, 1979) led to the conceptualization of the social and economic role of a firm (Wallich and McGowan, 1970). Subsequently, the 1987 UN report "Our Common Future" argued for the importance of "sustainable development" policies. Since then, it has been further refined in the field of management through the Corporate Social Responsibility agenda (Blok et al., 2018). This study adopts the definition of CSR published by the European Commission (EC) in 2001 that views CSR as the responsibility of enterprises for their impact on society and, therefore, it should be firm-led (European Commisson, 2011).

For years, CSR has been firmly established in the business world, and more and more firms are committed to CSR. For example, the number of firms that have signed the 10 Global CSR principles of the United Nations Global Compact (currently large firms as

well as SMEs) is currently 9,733 (van de Poel et al., 2017). However, some criticisms of CSR have also been made, as some companies use CSR for symbolic or instrumental purposes rather than as practical elements. This critique can also be applied to RRI: “If RRI risks becoming a new label for business-as-usual, it also risks being used instrumentally, to smooth the path of innovation in society, and/or to achieve precommitted policies” (Owen et al.). So, as in CSR, the motivations behind RRI start (1) from just wanting to follow accepted practices, (2) to embedding various types of knowledge throughout the development or innovation process, and eventually (3) to solving social problems and needs collectively. This process can affect the accountability and goals of the firm's own activities and the results that the firm achieves.

The first difference between the two concepts relates to the product development and life cycle, as CSR usually focuses on later stages such as product manufacturing, use, and disposal. RRI instead emphasizes the early stages of R&D, innovation, and design (van de Poel et al., 2017). This is also important for firms because the results of innovation—that is, the impact and limitations on users and society as a whole—depend on decisions made in the early stages of the product life cycle. Changing products in the later stages of product development can increase development costs and delay innovation processes and ultimate market entry. Therefore, it is important to think about the problems that require the inclusion of social challenges and values in the initial product development stage. Products that better meet these challenges and values can be developed and are more successful socially, environmentally, and financially for businesses. Second, in terms of the implementation method, RRI is pursued as a top-down governmental policy, while

CSR focuses on a firm's own self-regulation. Third, regarding coverage, RRI is more specific, as it relates to the early stages of technology development and focuses on the social and ethical issues caused by new innovations being anticipated and integrated in the design process of innovations. In contrast, CSR focuses on whether business operations are principle-oriented, ethically sound at home and abroad, and reflect a genuine interest in the goals and needs of all legitimate stakeholders of the firm. Fourth, in terms of the relationships of these concepts with important tasks, RRI is directly related to the basic process of a firm, which has been referred to as a money-making machine (Blok et al., 2018). In contrast, CSR is often not part of the firm's main processes, and is instead related to the creation of shared values and the firm's social role.

Although RRI starts with technology development, it can ultimately affect the magnitude of a firm's profit generation; therefore, RRI is sometimes viewed as an extension of CSR. For this reason, future research should consider how to accept the corporate strategy aspect related to CSR.

2.4 Social Innovation Research Methodology

2.4.1 Quantitative analysis approach

Quantitative methodology related to social innovation is shown in Table 2.6. Within the CSR framework, quantitative analyses can be carried out using management data of companies accumulated over a long period of time, and related studies have been actively conducted. In contrast, there has only been one quantitative study related to RRI, which analyzed the concept of open innovation together with a case study (van Geenhuizen & Ye, 2014). The reason for this is that RRI is in the early stages of research, and relevant research has mainly focused on qualitative methodologies to explore the validity and necessity of RRI. Research on RRI for firms has also begun recently; as such, most studies have utilized qualitative methods, such as interviews, although the need for empirical studies is emerging. The concept of RSA is similar to RRI, and constructive technology assessment (CTA) also focuses on the qualitative analysis of case studies through interviews and surveys (see Table 2. 9).

Table 2. 6. Quantitative methodologies related to social innovation

Research	Objective	Research Field	Values, dimensions	Method
van Geenhuizen, M., &Ye, Q. (2014)	Conceptualization of responsible innovation and system changes in sustainability	RRI (vehicle technology)	Open knowledge networks	Regression analysis and case study
Li et al. (2019)	Examination of the role of internal motivations in the mechanism of CSR strategy	CSR	Internal motivation	Regression analysis (survey)
Zou et al. (2019)	Investigation to do CSR between firms tied by a corporate social network	CSR	Social network	Regression analysis (survey)
Kucharska et al. (2019)	Examination of the structure of relationships between firm culture, performance, CSR, and reputation	CSR	Sustainability	Regression analysis (database)
Story et al. (2015)	Investigation of whether employees attribute different motives to their organization's CSR efforts	CSR	Corporate performance	Regression analysis (survey)
Veríssimo et al. (2015)	Examination of the relationship between transformational leadership mediating integrity and CSR	CSR	Leadership	Regression analysis (survey)

2.4.2 Qualitative analysis approaches

An analysis of programs or projects that introduced RRI found that qualitative analysis methods such as case studies predominated, and the need for empirical analyses is emerging. Table 2.7 presents the five best-known examples: the Socio-Technical Integration Research (STIR) program, the Stratospheric Particle Injection for Climate Engineering (SPICE) project, the Engineering and Physical Science Research Council (EPSRC), and the Dutch Research Council (NWO)/Dutch Responsible Innovation (MVI) program. (Erik Fisher & Rip, 2013; Horst et al., 2015; R. Owen, 2014; Stilgoe et al., 2013).

Table 2. 7. Representative cases of RRI programs/projects in various countries

Division	**STIR program**	**SPICE project**	**EPSRC program**	**NWO/MVI program**
Country	USA	UK	UK	Netherlands
Feature	Midstream modulation (MM)	Stage-gate review	Risk register / public dialogue	RRI principles and promotion system
Adoption of RRI	Nanotechnology initiative for RRI	Evaluation of the four dimensions	Introduced RRI in October 2013	RRI introduced since 2009
Purpose	Embedded social, ethical interactions	Use of stage-gate to evaluate process	Introduced RRI into public research	Encouraging research for the ELSA
Technology	Nanotechnology	Geoengineering	Nanotechnology	Energy, etc.
Participation	Natural scientists, engineers, social scientists	RRI researchers, social scientists, civil society representatives, atmospheric scientists, aviation engineers	General citizens' opinions are reflected in the selection and evaluation processes	Researchers in the fields of science, humanities, social science

2.4.2.1 STIR (Socio-Technical Integration Research) program and midstream modulation

The STIR program seeks to improve the research and development process by fostering cooperation among natural scientists, engineers, and humanists and social scientists from an integrated perspective of social technology. (Erik Fisher & Rip, 2013; Seong Ji-eun, Song Wi-jin, Jang Young-bae, Park In-yong, Seo Se-wook, Jeong Byeong-girl, 2015). The purpose of STIR is to examine what is responsible innovation at the macro level of public policy, the micro level of laboratory research, and the intermediate level of the structure and implementation of the institutions that connect them. To this end, "midstream modulation (MM)" was introduced as part of the scientific research and technological innovation process. Humanities and social science researchers spend more than 12 weeks observing participation in a single laboratory, asking laboratory researchers questions whenever they make large or small decisions in the research process. These questions are called decision protocols and reflect the main concept of RRI. This is a kind of real-time technology impact assessment that provides an opportunity to control routine research activities in a way that conforms to social values by raising questions regarding laboratory practices, and it has brought about changes in the areas of responsibility in the scope of RRI. Table 2. 9 lists the related studies.

2.4.2.2 SPICE (Stratospheric Particle Injection for Climate Engineering)

The UK National Research Council launched SPICE, a climate change mitigation research project, as a stage-gate review system to assess possible political and ethical negative environmental impacts. (Seong Ji-eun, Song Wi-jin, Jang Young-bae, Park In-yong, Seo Se-wook, Jeong Byeong-girl, 2015; Stilgoe et al., 2013). This method is a mechanism to manage R&D in stages for the development of new products. SPICE was configured to include a set of responsible innovation criteria, as shown in Table 2. 8 (Stilgoe et al., 2013). The evaluation panel that determines the decision gates is made up of social scientists, civic group representatives, atmospheric scientists, and aviation engineers, including two RRI researchers. This example is meaningful in that it illustrates how core concepts of RRI, such as anticipation, reflection, and inclusion, can be applied to the governance of emerging technology that is controversial and highly uncertain.

Table 2. 8. Overview of stage-gate criteria and panel recommendations.

Criterion	Relevant RI dimensions
Risks identified, managed and deemed acceptable	Reflexivity
Compliant with relevant regulations	Reflexivity
Clear communication of the purpose of the project	Reflexivity, inclusion
Impacts described put in place to review these	Anticipation, reflexivity
Mechanisms identified to understand public and stakeholder views	Inclusion, reflexivity

2.4.2.3 EPSRC (Engineering and Physical Science Research Council)

In October 2013, the EPSRC, Britain's largest public research support organization, officially declared its acceptance of RRI as part of its research support policy. (Horst et al., 2015; Seong Ji-eun, Song Wi-jin, Jang Young-bae, Park In-yong, Seo Se-wook, Jeong Byeong-girl, 2015). In the review process, it will support research that incorporates reflection, anticipation, inclusion, and response factors. The EPSRC required applicants for research funds to submit a risk register. The risk register is an institutionalization of RRI reflections and predictions that 1) reveals social and ethical concerns that may result from the innovation process, 2) qualitatively evaluates the degree of risk and uncertainty that each impact will cause, and 3) lists the risk management manager. The risk registration form is evaluated by external judges, including sociologists, and is used as an important criterion for selection. Table 2. 9 lists the related studies.

2.4.2.4 NWO (Dutch Research Council)/ MVI (Dutch Responsible Innovation) program

In the Netherlands, MVI, an RRI program to support cooperation with the private sector, was launched (R. Owen, 2014; van der Molen, Ludwig, Consoli, & Zwart, 2019; Zwart et al., 2014). The MVI, which is operated by NWO, focuses on working towards socioeconomic goals through partnerships with industry and private firms. It is closely linked to the Dutch innovation policy of strengthening the top sector of the national economy through research and innovation. Innovation through RRI is expected to

strengthen the competitiveness of core industries in the Netherlands Table 2. 9 lists the related studies.

2.4.2.5 Constructive technology assessment (CTA)

In Europe, the constructive technology assessment (CTA), which emphasizes the practical aspects of technology impact assessment and seeks to foster more active involvement in technology development or policy implementation, has been developed. In the CTA, the interactions between various stakeholders such as technology developers, manufacturers using regulatory agencies, end users, and general citizens that take place during the ongoing technology development process are recognized as important. What distinguishes it from the existing technology impact assessment is that the CTA conceptualizes the process in which technology is developed or the process in which research is conducted as based on interactions between the researcher and stakeholders. In the development process, stakeholders' values and perspectives are mutually learned, and different perspectives are coordinated to form a consensus, based on which important decisions related to technology development can be made.

CTA involves the collaborative development of a product concept through an in-depth intervention in the technological development of a firm or research institute. For example, in the process of developing cement with reduced carbon dioxide emissions, a technology impact assessment was conducted by the Institute for Technology Assessment and Systems (ITAS), a German technology impact assessment research institute. In some cases, these initiatives have contributed to the development of "better technology" in

various aspects, such as economic feasibility, environmental protection, and industrial expansion (Grunwald, A. and Achternbosch, 2013). The first point to note here is that the role of the ITAS has expanded beyond just the evaluation of certain subjects to the selection of evaluation targets. Second, the purpose of the evaluation is to focus on "innovative technology development." This target is very different from that of the existing technology impact assessment framework, which has served as a means to support the political decisions of the National Assembly or the administration (Suh, 2019).

Table 2. 9. Qualitative methodology used in social innovation research

Program Project	Research	Objective	Research field (emerging technology)	Values, dimensions	Method
STIR	Fisher et al. (2015)	Responsiveness of research priority setting	Nanotechnology	Decision-making in policy initiative	Case study
STIR	Smolka, M. (2020)	Introducing generative critique to R(R)I as a practice	Neuroscience	Interdisciplinary collaborations	Case study
STIR	Flipse et al. (2013)	Exploring the use of MM to examine its appropriateness in industry	Biotechnology	Midstream modulation (MM)	Case study
STIR	Flipse et al. (2018)	Demonstrating methods of involvement of 'outsiders'	Automated vehicles	Constructive dialogue	Case study
STIR	Shelley-Egan et al. (2018)	Effects of RRI initiatives for R&I, policy, governance	Nanotechnology	Governance	Case study
EPSRC	de Cock Buning et al. (2017)	The legal problems caused by autonomous vehicles	Autonomous intelligent cars	Robotic ethics	Literature review
EPSRC	Szollosy, M. (2017)	Understanding of EPSRC Robotic Principles (2010)	Robotics	Robotic ethics	Literature review
EPSRC	Wilford, S. H. (2015)	Development of RRI guidelines required in the lab	Implementation of RRI	Participation	Case study

Program Project	Research	Objective	Research field (emerging technology)	Values, dimensions	Method
EPSRC	Nulli et al. (2018)	Understanding RRI through the AREA 4P framework	IT	Four dimensions	Literature review
EPSRC	Taylor, K., & Woods, S. (2020)	Understanding RRI through synthetic biologists	Synthetic biology	ELSI	Case study
NWO	De Hoop, E. et al. (2016)	Demonstrating barriers that make RI innovation difficult	Biofuels	Stakeholder involvement	Case study
NWO	Pols, A. J. K. et al. (2017)	Investigating irreversible social harms from an ethical perspective	Biofuels	Ethics	Case study
NWO	Van der Molen et al. (2019)	Exploring national dynamics contributed to the institutionalization of RRI	Science and policy	Public good inclusion	Case study
NWO	Garst et al. (2017)	Investigating firms' motivation for responsible outcomes	Food industry	Morality	Case study
NWO	Molen et al. (2018)	National case study on the implementation on RRI	Innovation policy context	Societal engagement	Case study
ELSI	Kurihara (2011)	Clarifying the ELSI of an exploratory human trial	Biotechnology	Ethics	Case study

Program Project	Research	Objective	Research field (emerging technology)	Values, dimensions	Method
ELSI	Gavrilovici (2004)	Description of ELSI as a synthesis of ethical debates	Biotechnology	Ethics	Case study
ELSI	Shineha et al. (2018)	Surveys for understanding the interests of stakeholders	Biotechnology	Stakeholder participation	Qualitative analysis
ELSI	Bardill, J. (2014)	Investigation about the ELSI of Native American DNA	Biotechnology	Ethics	Literature review
ELSI	Meagher et al. (2016)	Demonstrating deliberative public bioethics as a method of engagement	Biotechnology	Stakeholder participation	Case study
CTA	Moens et al. (2010)	Development a participatory approach on CTA for ICT	ICT	Anticipation	Case study
CTA	Franks et al. (2012)	Outlines the possibilities and rationale for incorporating CTA	Mineral technology	Responsiveness	Case study
CTA	de Boer et al. (2018)	Investigation of technological mediation approaches to CTA	Implementation of CTA	Inclusion	Case study
CTA	Versteeg et al. (2017)	Demonstration of an explorative study using CTA	Battery technology	Anticipation	Case study
CTA	Genus et al. (2006)	Presentation of a new perspective of CTA	Implementation of CTA	Reflexivity	Case study

2.5 Discussion and conclusion

The modern R&D system focuses on the economic benefits of technology and values the legal and institutional foundations and expert system for managing technology and science. However, environmental and ethical issues have been raised in relation to technology and science in society. In the process of resolving these issues, new attempts were made, such as the CTA focusing on the participatory viewpoint in the technology development process (mid-1980s) (Suh, 2019) and the ELSI framework focusing on ethical evaluation (mid-1990s). However, as attention finally came to be focused on the product and service stages that interface with society, RRI emerged as a framework insisting on the need for a more comprehensive perspective. RRI emphasizes the responsiveness of integrating anticipation (e.g., CTA), reflexivity (e.g., ELSI), and inclusion (e.g., public participation) that have been implemented individually into iterative learning systems. In addition, RRI implementation is considered to be more important in firms that commercialize technology. Meanwhile, RRI, which was announced in the EU in 2011, is still in its early stages. Discussions on implementation are underway in countries in Europe, and implementation in firms is also just beginning. Looking at the studies published so far, RRI-related research questions can be broadly divided into national policy-related and corporate-level research questions, as shown in Table 2.10.

First, the research questions related to policy from the national perspective are as follows (Blok, V., & Lemmens, 2015; Genus & Iskandarova, 2018; Karner et al., 2016;

Laird & Wynberg, 2016; Lukovics et al., 2017).

Q. To what extent, why, and how has responsible innovation achieved greater institutionalization?

Q. What are the dominant conceptions and concerns of responsible innovation research and practice?

Q. What perspectives or actors are marginalized in RI discourse, and why?

Q. What is RRI's impact assessment method considering the uncertainty of RRI and lack of experience?

Q. What challenges do policymakers face when developing a framework for RRI?

Q. How are RRI implementations different in countries in different contexts from the EU?

Q. What acts as a barrier to RRI implementation?

Next, the research questions related to the firm level are as follows:

Q. What are the motivations to integrate RRI in industry?

Q. What is the state of implementation of RRI in industry?

Q. What are responsible practices in innovation?

Q. Who are the stakeholders involved in RRI?

Q. Which factors have a bearing on RRI implementation in industry?

Q. How does RRI relate to adjacent discourses on responsibility of/in business?

Q. How should RRI implementation experience be accumulated in a firm?

Q. Which of these activities are beneficial for the implementation of responsible

innovation dimensions?

In this study, I would like to provide answers to the research questions that need to be solved to introduce RRI: (1) what are the possible barriers to introducing RRI in Korea, and (2) whether firms that commercialize technology should introduce RRI.

Table 2. 10. Research questions and major themes addressed in national and firm perspective

Level	Research	Research Questions	Themes
National	Genus, A., & Iskandarova, M. (2018)	To what extent, why and how has responsible innovation achieved greater institutionalization?	Major novelty and practical relevance of RRI Integration of existing approaches
National		What are the dominant conceptions and concerns of responsible innovation research and practice?	Explicit link between innovation and responsibility Extending the existing concept of responsibility to social responsibility
National		What perspectives or actors are marginalized in RI and why?	Wide range of actors who can reflect social background
National	Blok, V., & Lemmens, P. (2015)	What is RRI's impact assessment method considering the uncertainty of RRI and lack of experience?	RRI requires radical transformation of the innovation concept itself RRI applicability needs to be reviewed
National	Laird, S. A., & Wynberg, R. P. (2016)	What challenges do policymakers face when developing a framework for RRI?	Challenges in promoting socially beneficial research in some of the most technologically advanced industries
National	Lukovics, M., et al. (2017)	How are RRI implementations different in countries and regions in different contexts from the EU?	Practical implementation and use of RRI in less developed regions and countries
National	Karner, S., et al. (2016)	What acts as a barrier to RRI implementation?	Various barriers exist in the implementation of RRI, including a lack of trust among social stakeholders.

Level	Research	Research Questions	Themes
Firm	Chatfield et al. (2017) Chatfield et al (2017) Gurzawska et al. (2017)	What are the motivations to integrate RRI in industry?	Managing the ethical and societal risks of innovation Achieving better alignment with end user needs and resulting profits in better image Public recognition and consumer awareness, employee engagement Importance of instrumental motives (seeking profits, counter-acting regulatory pressure through voluntary self-regulation, or the desire to maintain legitimacy)
Firm	Stahl et al. (2017) Auer and Jarmai (2018)	What is the state of implementation of RRI in industry?	RRI maturity model for determining level of RRI implementation Companies are largely unaware of the RRI concept, but implement RRI practices at an operational level.
Firm	Van de Poel et al. (2017) Auer and Jarmai (2018)	What are responsible practices in innovation?	Measuring RRI through key performance indicators Anticipating innovation outcomes Including different stakeholders into innovation processes
Firm	Gurzawska et al. (2017)	Who are the stakeholders involved in RRI?	Internal stakeholders (employees, owners, firm representatives and managers) External stakeholders (suppliers, customers, CSOs, governments, creditors, shareholders)

Level	Research	Research Questions	Themes
Firm	Auer and Jarmai (2018) Chatfield et al (2017) Gurzawska et al. (2017)	Which factors have a bearing on RRI implementation in industry?	Regulatory framework, availability of financial resources, market-orientation, customer knowledge, organizational structure and knowledge among innovation partners Corporate culture, awareness of RRI, ethical codes of conduct
Firm	Lubberink et al. (2017) Dreyer et al. (2017) Stahl et al. (2017)	How does RRI relate to adjacent discourses on responsibility of/in business?	RRI governance principles Need for better alignment of RRI concepts, tools and methodologies with current industrial practices Distinction between responsible research and responsible innovation Purpose, process, and product aspects of responsibility
Firm	Blok & Lemmens (2015)	How should RRI implementation experience be accumulated in a firm?	RRI research focuses on policy perspective and academic R&D. Innovation takes place in an industrial environment.
Firm	Lubberink et al. (2017)	Which of these activities are beneficial for the implementation of responsible innovation dimensions?	Innovative activities and underlying mechanisms that facilitate the implementation of expectations, reflections, inclusion, deliberations, and responses in the business context

As a methodology for investigating research questions, Multiple-criteria decision-making (MCDM) is widely used in various decision-making problems and barrier analyses (Ghimire & Kim, 2018). If options for alternatives and a number of decision criteria are given, the preference ranking of alternatives can be derived (Mulliner, Malys, & Maliene, 2016). The three steps to applying MDCM are as follows (Ghimire & Kim, 2018): (1) identification of relevant decision criteria and alternatives, (2) measurement of the relative importance of the decision criteria and alternatives, and (3) derivation of estimates for evaluating the weights and rankings of the decision criteria and factors. Several types of MCDM methods exist. Below is a brief description of the weighted sum model (WSM), the weighting product model (WPM), and the analytical hierarchy process (AHP) (Kabir, Sadiq, & Tesfamariam, 2014).

WSM is one of the simplest and most commonly used MCDM methods, and it involves a process of adding reference values for each alternative and applying individual reference weights (Mulliner et al., 2016). If there are I alternatives and J criteria, the best alternative can be identified from the following equation (2.5.1) (Ghimire & Kim, 2018)

$$A_i = \sum_{j=1}^{j} a_{ij} w_j \qquad (2.5.1)$$

Where A_i is the score for each alternative, a_i is the weight of i-th alternative in terms of j -th criteria and w_i is the weight of j-th criteria. An alternative with the highest score is considered as the best alternative.

WPM is similar to WSM, and the main difference is that the mathematical process

utilizes multiplication instead of addition (Mulliner et al., 2016). The key feature is that all units of measurement are removed, enabling dimensionless analysis. Best alternative can be identified from the following equation (2.5.2) (Ghimire & Kim, 2018)

$$R\left({}^{A_k}/_{A_i}\right) = \prod_{j=1}^{j}\left({}^{a_{kj}}/_{a_{ij}}\right)^{w_j} \qquad (2.5.2)$$

Where is J is the total number of criteria and a_{kj} and a_{lj} is the value of k-th and l-th alternative in terms of j-th criteria. If the term $R(A_k/A_l)$ is greater than one, then it indicates that alternative A_k is more desirable than the alternative A_l.

AHP can also calculate preferences or importance weightings for criteria and alternatives. WSM uses actual values, whereas AHP is based on relative values. In addition, AHP is most commonly used because it enables estimation of the consistency index, which is important for ensuring that decisions are consistent and unbiased (Ghimire & Kim, 2018; Saaty, 1990a).

In this study, we use AHP to explore RRI, which is in an early stage of study, with most studies involving analyses of discourse or case studies. AHP was chosen as the analytical method because it can be used to solve complex problems by decomposing decision problems and creating hierarchical tree models, making it easier to identify barriers and problems in the early stages of RRI introduction. In this study, in order to pursue a preemptive study in preparation for the implementation of RRI in Korea, first, we analyze the RRI barriers in terms of policy. To this end, 13 barriers are derived, classified into 5 categories, and then weighted and ranked. Second, RRI benefits and

costs are analyzed from the firm's perspective. The RRI model design and evaluation criteria (benefit, cost, and RRI level) suitable for the study are identified, the relative weight of these evaluation criteria is evaluated, and the tendencies in RRI level preferences are analyzed from the present and future perspectives. Finally, based on the results of this analysis, policy and corporate aspects of the introduction of RRI in Korea are addressed.

The relationship between the two essays is as follows. Considering the introduction of RRI into Korea, the criteria at the policy (national) level, which summarize potential barriers on the basis of studies in the existing literature, are described on the left side of Table 2.11 below. Similarly, the costs that can occur upon the introduction of RRI to Korean firms are described on the right side of Table 2.11. The policy barriers are closely related to the cost criteria of the firms. The economic barriers are related to all four dimensions of RRI (anticipation, reflexivity, inclusion, and responsiveness). Implementation barriers are related to training and specialized personnel, organizational culture, and system establishment at firms. Policy and political barriers are related to self-reflection and institutional reflection of firms, which are soft regulation approaches. Social barriers are related to the formation and operation of external stakeholder networks of firms. Technical barriers are related to technological forecasting and technological exploration, as well as the certification of technology of firms.

Table 2.11 Relationship between RRI criteria from the national (policy) perspective and the firm perspective

National (policy) barrier	**Firm implementation criteria**	
	General-criteria (dimensions)	**Sub-criteria**
Economic barrier	Cost required to implement	Anticipation, reflexivity, inclusion, responsiveness
Implementation barrier	Responsiveness	Training and specialized personnel, organizational culture and system establishment
Policy and political barrier	Reflexivity	Self-reflection, institutional reflection; Soft regulation approach
Social barrier	Inclusion	External stakeholder network formation, external stakeholder network operation
Technical barrier	Anticipation	Technological forecasting and technological exploration, certification of technology

- Chapter 3: Essay II -

Identifying and ranking barriers to responsible research and innovation

: The case of emerging technologies in Korea

*This essay was submitted to Journal of Responsible Innovation and is now under revision. The title of the submitted paper is "Identifying and ranking barriers to responsible research and innovation: The case of emerging technologies in South Korea".

Chapter 3. Identifying and ranking barriers to responsible research and innovation: The case of emerging technologies in Korea

3.1 Introduction

A responsible research and innovation (RRI) approach has been recently developed to address technological innovation's effects on society and the environment. RRI is a model developed through the participation of various actors, including the European Union (EU) (Burget, Bardone, and Pedaste 2017; von Schomberg 2013). In the past, a person who has absolute power (e.g., the King) was responsible for inventing, possessing, and taking ownership of technology, allowing for control over technology (von Schomberg 2013). However, it has become difficult to control the effects of technological innovation as its subjects have diversified (von Schomberg 2013). In addition, the consequences of technological and scientific innovation have recently been more likely to pose risks to society as a result of their larger impacts and the lack of time that society has to cope with changes (Lowman et al., 2012). However, modern research and development (R&D) systems have faced difficulties, as they have often failed to focus on technological development while simultaneously considering its social and ethical impacts (Stilgoe et al., 2013). In recognition of this, technologically advanced countries in Europe have recently started using the RRI approach to prepare for emerging technologies' social ripple effects (Burget et al., 2017).

Korea is a newly industrialized economy (NIE) and has a significant and important role in R&D. In addition, Korea's 2017 R&D intensity (i.e., the country's expenditure on R&D as a percentage of Gross Domestic Product) was 4.55%, which was the highest R&D intensity level in the world (Lee and Lim 2001; OECD 2019). Thus, it is as important to review Korea's RRI implementation as it is to explore RRI in technologically advanced countries. Nevertheless, the literature on social ripple effects in terms of the risks associated with emerging technologies is new and thus limited (Suh, 2019). As Korea lacks policy experience on key RRI elements, and given that RRI is still controversial in terms of both its conception and implementation, it is expected that there will be barriers to overcome at various levels in regard to the practical application of RRI (Burget et al., 2017). On the other hand, it has been argued that cross-national contexts play an important role in the application of RRI. Existing studies show that RRI effects differs across Europe depending on the specific country's (developed or less-developed) innovative environment (Lukovics et al., 2017). Therefore, before RRI can be effectively applied in Korea, it is important to learn from Europe's experiences and to simultaneously recognize Korea's unique context and identify its specific barriers to adoption. This study determined that the introduction of RRI needs to take into account not only the policy aspects of creating and institutionalizing RRI policies, but also social acceptability, which reflects the concept of stakeholder partitioning that RRI values. Therefore, I wanted to look at Korea as a whole and to analyze experts when RRI was introduced. The participants in the survey were technical experts working in policy, academia, and companies. While research on enterprises has often been limited to more detailed management situations, this study examined fewer specific conditions, assuming that the

overall perception would be that Korea is still in the early stages of the introduction of RRI.

Therefore, this study aims to apply an analytical hierarchy process (AHP) to proactively and comprehensively identify the barriers to RRI adoption in Korea by targeting professionals who have a general understanding of Korea's R&D systems and technologies. AHP is a widely used tool for formulating and analyzing decision making processes and frameworks, and it is advantageous because it allows for pairwise comparisons to estimate the weight of certain criteria and to rank various alternatives (Saaty, 1990a, 2008). Although previous studies have identified the various obstacles that RRI must overcome, these barriers had not previously been weighted and/or ranked to indicate importance and relative impact. Therefore, this study focused on ranking such obstacles. We used an AHP approach to identify and prioritize the five categories and 13 barriers that are identified as obstacles to the implementation of RRI in Korea. Since the RRI concept is not universally proliferated in Korea, it is possible to predict the future impact of technology only by discussing specific technologies. Therefore, we selected autonomous vehicle (AV) and biotechnology (BT) developments as the target technologies, and the purpose of this study was to examine the effects of the characteristics of the emerging technologies on RRI adoption in Korea. AVs run the risk of system errors and responsibility disputes between operators in the event of an accident (Cui et al., 2019; Keeling, 2018; Sheehan et al., 2019; van de Poel et al., 2017), and BTs may lead to adverse effects and bioethical infringement risks (K.M.A. Gartland and J.S. Gartland 2018).

This paper is organized as follows. Section 2 includes a review of the RRI literature. Section 3 identifies and classifies the barriers to RRI adoption. Section 4 describes the AHP method used for the analysis. Section 5 includes the results and a discussion of the findings. Section 6 presents the conclusion, including the study's academic contributions, policy contributions, and limitations.

3.2 Literature review

The RRI approach has been successful in regard to effectively presenting the importance of responsible research to society (von Schomberg 2013). As part of Horizon 2020, which is the EU's program for supporting research, the EU is strongly advocating for RRI and related academic research is being actively conducted (Chatfield, Iatridis, et al., 2017; Guston et al., 2014). Simultaneously, the conceptual basis of RRI is developing in different ways (Burget et al., 2017). This study follows the RRI definition suggested by von Schomberg (2013, 63): 'RRI is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products.'

Though RRI has become important in recent policy research, previous studies have not fully investigated the application of RRI (Burget et al., 2017; Lubberink et al., 2017). Since the concept is new and impacted stakeholders have not had sufficient time to understand and prepare for its implications, it is expected that there will be various barriers in regard to the actual applications of RRI (Chatfield, Iatridis, et al., 2017), a likelihood identified by numerous researchers. First, as mentioned earlier, RRI's specific definitions and implementation methods are still under development (Burget et al., 2017; Carbajo & Cabeza, 2018; Chatfield, Iatridis, et al., 2017). Second, the potential benefits that might arise from RRI remain uncertain (Chatfield, Iatridis, et al., 2017; Genus & Iskandarova, 2018). Third, RRI claims to consider the social impact of technological

development results through the participation of social scientists or ethicists in the form of “laboratory engagement,” which can lead to traditional technologists' objections (de Hoop, Pols, and Romijin 2016; Owen et al. 2013). Fourth, the success of RRI varies depending on each country’s social, ethical, and environmental contexts (Davis & Laas, 2014; Lukovics et al., 2017). While there are several related RRI studies, such research is often limited to conceptual presentations and thus contains insufficient empirical evidence on the presence and magnitude of effects of these barriers. Therefore, it is necessary that numerous empirical studies on this topic be conducted in the future to address these gaps.

RRI’s inception was in technologically advanced European countries but it is gradually spreading to non-European countries (Arnaldi et al., 2015; Davis & Laas, 2014). RRI seems to be developing successfully because developed European countries are experienced in implementing policies on key RRI elements (Lukovics et al., 2017). For example, such countries have developed a variety of technology impact assessment methods, such as ‘real-time technology assessment,' and they have gained experience with ethical reflexivity systems by evaluating the effects of certain ethical, legal, and social aspects (ELSA) on science and technology research projects (Guston & Sarewitz, 2002; Zwart et al., 2014). Also, since the late 1970s, European countries have made a concerted effort to listen to public and non-government organization (NGO) opinions when making decisions related to science and technology (Landeweerd et al., 2015).

There are two distinct approaches in the existing research on Europe’s adoption of

RRI. The researchers who focus on science and technology in developed countries have tried to integrate RRI's interaction with society in their studies, whereas the researchers who examine non-advanced countries focus on securing research funds and lack a complete understanding of the need to consider social context in their research on technological development (Lukovics et al., 2017). It is important to consider a country's research and innovation environment as it can have a strong impact on the motivation to implement RRI. Korea can be considered to have an environment adverse to an RRI implementation. For example, Korea's technology impact assessment criticizes that the results are not used for R&D policymaking and that the citizen forum is too formal (Suh, 2019). Therefore, it is expected that Korea will face RRI implementation barriers different from those faced by advanced European countries.

It is argued that different technologies can have various side effects even within the same country, which indicates that countries need to tailor their RRI implementation strategies to cope with the unique side effects they may experience (van de Poel et al., 2017). RRI targets technologies that are likely to emerge if it is socially and economically feasible enough to do so in the next 10-15 years (Berndt C Stahl et al., 2013).

Accordingly, this study selected AVs and BTs, which have different characteristics and are the most representative emerging technologies in Korea. The development of AVs is based on the convergence of various information and communications technologies (ICT) such as artificial intelligence/big data, high performance processing software (SW) and hardware (HW) platforms, and sensor systems. AVs are expected to make the largest

advances in the mobility of human society for various reasons, including a reduction in the number of traffic accidents. Korea is trying to develop AV technology with the goal of commercialization by 2030 (KISTEP, 2018). On the other hand, there is a concern that AV technology will reduce human control and lead to undesirable consequences (i.e., situations in which responsibility for an accident cannot be specifically assigned) (van de Poel et al., 2017). Paradoxically, the increased connectivity between infrastructures combined with autonomous driving can be a significant threat to the enormous socioeconomic benefits promised by AVs (Cui et al., 2019; Keeling, 2018; Sheehan et al., 2019). In addition, BTs produce a variety of high value-added products using biological functions and information. Korea's BT industry has a small market size but a high yearly export growth rate of 11.5%. Despite Korea’s weak technical foundation, its BT companies have increased their long-term R&D investments, resulting in certain positive effects such as recent exports of technology (MFDS 2017; MOTIE 2017a). On the other hand, the combination of molecular biology, bioinformatics, and new device development factors may involve fusion or destructive technologies, which may simultaneously create various ethical, legal, and social issues of concern to RRI. For example, in the field of genome research, there are certain challenges that arise as a result of newly encountered problems, such as privacy protection, data confidentiality protection, ownership of intellectual property in personal data, and prior consent (K.M.A. Gartland and J.S. Gartland 2018; Lecuona et al. 2017).

3.3 Identification of RRI barriers

Because RRI research is new and has not yet been introduced to Korea, barriers to RRI adoption have yet to be fully understood. Figure 3. 1 displays and briefly describes the barriers that we derived from various literature reviews and expert interviews. In total, 14 people were interviewed in this study. The interviewed experts consisted of six social innovation experts (including sociologists), five public R&D planning experts, and three performance experts from public R&D. In addition, these experts were Ph.D. holders with 10-20 years of work experience in the field. As mentioned previously, there are 13 barriers grouped in five categories.

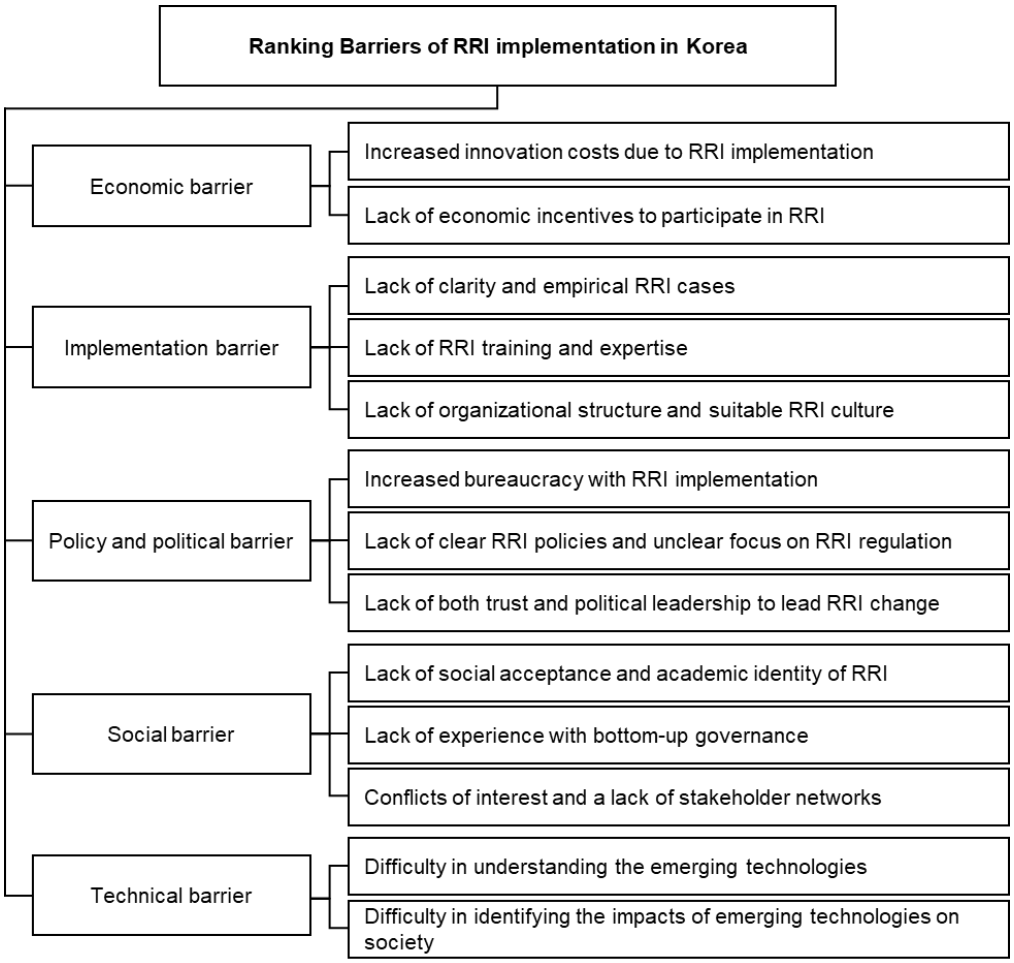

Figure 3. 1. RRI categories and barriers for identification and ranking in Korea.

3.3.1 Economic barriers

Economic factors can affect the RRI implementation. There are two economic barriers discussed below.

3.3.1.1 Increased innovation costs due to RRI implementation

RRI activities that involve various stakeholders incur additional costs and time. For example, anticipation of and reflexivity on the impact of technology, and interacting with stakeholders, both of which are important parts of RRI, can lead to additional costs. (Auer & Jarmai, 2018; Chatfield, Iatridis, et al., 2017; de Hoop et al., 2016; Genus & Stirling, 2018).

3.3.1.2 Lack of economic incentives to participate in RRI

Apart from the social demand for RRI, incentives driving RRI implementation are unclear (Chatfield et al. 2017; Dreyer et al. 2017; Gianni 2014; Gurzawska, Mäkinen, and Brey 2017; Lukovics et al. 2017).

3.3.2 Implementation barriers

A system that supports policy development is also important for the implementation of effective and efficient policies. Implementation barriers can occur when there are insufficient systems to support RRI adoption in society. Three implementation barriers are presented below.

3.3.2.1 Lack of clarity and empirical RRI cases

A lack of both clear RRI concepts and empirical examples can limit the specificity of RRI implementation in a variety of innovative environments (Burget et al., 2017; Carbajo & Cabeza, 2018; Chatfield, Iatridis, et al., 2017; Davis & Laas, 2014; de Hoop et al., 2016; Dreyer et al., 2017; Genus & Stirling, 2018; Gianni, 2014; Gurzawska et al., 2017; Monsonís-Payá et al., 2017; Paredes-Frigolett, 2016; Stilgoe et al., 2013).

3.3.2.2 Lack of RRI training and expertise

Learning and training are important so that impacted professionals can both understand the need and develop a motivation for RRI adoption. Training and expertise are also necessary for determining the appropriate RRI implementation methods. In addition, RRI implementation requires the presence of certain professionals who can address the training and expertise needs (Auer & Jarmai, 2018; Gianni, 2014; Heras & Ruiz-Mallén, 2017).

3.3.2.3 Lack of organizational structure and suitable RRI culture

Integrating RRI into organizations and systems can be time consuming and labor intensive because RRI implementation requires that the existing practices and procedures change (Auer & Jarmai, 2018; Chatfield, Iatridis, et al., 2017; van Geenhuizen & Ye, 2014).

3.3.3 Policy and political barriers

Governments establish various innovation policies, and each country's political environment can influence how such policies are developed and implemented. Three related barriers are presented below.

3.3.3.1 Increased bureaucracy with RRI implementation

The involvement of social scientists or ethicists in constraining the practices of existing laboratories may make non-social scientists feel as though the administrative and bureaucratic procedures are increasingly complex and restrictive (Forsberg, Shelley-Egan, Ladikas, & Owen, 2018; Gurzawska et al., 2017).

3.3.3.2 Lack of clear RRI policies and unclear focus on RRI regulation

RRI can be used in private companies' R&D strategies and in development of policies that support national R&D funding. However, the novelty of the RRI approach makes it unclear what form future policies and regulations will take (Auer & Jarmai, 2018; Genus & Iskandarova, 2018; Gianni, 2014; Landeweerd et al., 2015; Paredes-Frigolett, 2016).

3.3.3.3 Lack of trust and political leadership to lead RRI change

The RRI approach focuses on an improved integration of innovation in society through an increased responsiveness embedded in the system. This requires political

leadership to drive RRI, and associated societal confidence in the changes it will bring (Dreyer et al., 2017; Wahlster, Scahill, Lu, & Babar, 2015).

3.3.4 Social barriers

Society's acceptance of RRI is dependent on the scope of innovation extending to include diverse actors across society. Thus, a successful RRI implementation depends on the extent to which the societal members can understand and accept this. There are three related social barriers discussed below.

3.3.4.1 Lack of social acceptance and academic identity of RRI

A successful RRI implementation has to overcome society's existing routines, a capability which is far from certain (Davis & Laas, 2014; Genus & Iskandarova, 2018; Genus & Stirling, 2018; Landeweerd et al., 2015; Lukovics et al., 2017; Stilgoe et al., 2013).

3.3.4.2 Lack of experience with bottom-up governance

RRI emphasizes that the consequences of innovation may need to be discussed from social members' perspective. However, there is a lack of policy experience with this type of social discussion system (Burget et al., 2017; Genus & Iskandarova, 2018; Gianni, 2014; Gurzawska et al., 2017; Landeweerd et al., 2015; Stilgoe et al., 2013).

3.3.4.3 Conflicts of interest and a lack of stakeholder networks

In the absence of an effective network of experienced stakeholders involved in innovation, it may be difficult to find solutions when there is a conflict between the existing innovation approaches and RRI implementation (Auer & Jarmai, 2018; Carbajo & Cabeza, 2018; Chatfield, Iatridis, et al., 2017; Davis & Laas, 2014; de Hoop et al., 2016; Genus & Iskandarova, 2018; van Geenhuizen & Ye, 2014).

3.3.5 Technical barriers

It is difficult to predict the future ripple effects of an emerging technology due to the novelty of the technology itself. This can be an obstacle to RRI implementation in the following two ways.

3.3.5.1 Difficulty in understanding emerging technologies

Emerging technologies can be difficult to understand, as they deviate from the stereotypes and routines of existing technologies (Landeweerd et al., 2015). This is important because an understanding of the technology is necessary before its externalities can be identified and evaluated.

3.3.5.2 Difficulty in identifying the impacts of emerging technologies on society

By definition, emerging technologies are significantly different from existing ones, so it is difficult to predict how their unique methods and practices will impact society. Therefore, a barrier arises because it is difficult to know how to prepare for such impacts (Auer & Jarmai, 2018; Chatfield, Iatridis, et al., 2017; de Hoop et al., 2016; Genus & Iskandarova, 2018; Genus & Stirling, 2018).

3.4 Methodology

3.4.1 Analytical hierarchy process (AHP)

AHP is a useful way to solve complex decision-making problems. The problem to be solved can be broken down into several subproblems based on the criteria associated with the subproblem, and a hierarchical tree can be derived through this process. The AHP model has the advantage of making problems more intuitive and logical so that they are easier to understand (Saaty, 1990a, 2008; Vaidya & Kumar, 2006). Although previous studies have identified certain RRI barriers, they did not rank them or assign them weights (Chatfield, Iatridis, et al., 2017). Therefore, we focused on using the AHP method to rank the barriers to adoption. The highest level of this study's AHP model represents the goal of deriving the barriers to RRI implementation in Korea, and the other levels represent the categories and specific barriers. Table 3. 1 displays the four steps that are involved in this process (Ghimire & Kim, 2018; Luthra, Mangla, Xu, & Diabat, 2016).

Table 3. 1. Four stages involved in the AHP for identification and ranking of RRI barriers

Stage	Definition	Description
I	Structure the problem and model building	• Building a model by decomposing the obstacles predicted for RRI implementation into 13 barriers through 5 criteria
II	Collect data through pair-wise comparison and measurement	• Collect data based on a questionnaire on a 9-point scale • A pairwise comparison matrix is constructed by pairwise comparing factors in the immediate lower hierarchy that contribute to achieving the goals in the higher hierarchy
III	Calculate normalized priority weights of individual criteria	• Estimate the relative weights of the barriers using the eigenvalue method: $$\boldsymbol{Y} = \boldsymbol{A}\boldsymbol{w}, \boldsymbol{w} = (w_1, w_2, \cdots, w_n),$$ where $\boldsymbol{A}$ is a comparison matrix $(n \times n)$, n is the number of criteria, $\boldsymbol{w}$ is the eigenvector $(n \times 1)$ called as the priority vector • Calculate principal eigenvalue $\boldsymbol{\lambda}_{max}$ as follows: $$\boldsymbol{\lambda}_{max} = \frac{\boldsymbol{Y_1}/\boldsymbol{w_1} + \boldsymbol{Y_2}/\boldsymbol{w_2} + \cdots + \boldsymbol{Y_n}/\boldsymbol{w_n}}{\boldsymbol{n}},$$

Stage	Definition	Description
		• Calculate a consistency index (CI) as follows: $$CI = (\boldsymbol{\lambda}_{max} - n)/(n-1)$$ • Check the consistency of expert response by using consistency ratio (CR) as follows: $$CR = CI/RI,$$ Where RI is random index and if CR is less than 10%, the pairwise comparison matrix is considered to be consistent.
IV	Analyze the priority weights and deriving solutions	• Establishing relative priorities of decision-making by comparing weights obtained for each category and barrier

3.4.2 Data

Multi-criteria decision making (MCDM) methods, such as AHP, focus on expert knowledge rather than expert numbers (Hessami et al. 2012; Tummala, Chin, and Ho 1997). Existing AHP studies have relied on varying respondent numbers, from a sole respondent to many (Lee et al. 2012; Saaty 1990; Shin et al. 2009; Singh and Nachtnebel 2016). Additionally, studies with a large expert group included about 100 respondents to reflect opinions from various fields (Ghimire and Kim 2018; Lee et al. 2012; Shin et al. 2009; Singh and Nachtnebel 2016). Because RRI is a an approach to emerging technologies innovation, it should reflect not only industry, government, and academic opinions but also technological diversity. Therefore, we selected government, industry, and academic researchers. In this study, in order to overcome the limitations of the questionnaire for Korean experts with a low understanding of RRI, when sending the survey email, detailed information about RRI was also included to help participants understand the background and purpose of this study and to respond to the questionnaire. Then, after respondents became acquainted with the content of RRI, voluntary participation was confirmed, and only experts who agreed to participate in the survey proceeded to the survey stage. In order to ensure the objectivity and reliability of the respondents, only those with a Ph.D. or work experience of 10 years or more in the relevant field were eligible (47 Ph. D., 75 over 10 years experiences, 23 duplicate values), and all participants had expertise in either AV or BT. Finally, participation was limited to those with a high level of understanding of technology, as indicated by working in a technology development research institute or research department within a firm. We used 99 responses in the analysis, as we excluded responses that were either incomplete or had less than a 0.1 consistency ratio (Ghimire & Kim, 2018).Table 3. 2 presents information on the numbers of respondents per expertise area.

Table 3. 2. Total number of respondents' according to technical areas and their respective organization

Number of respondents		Autonomous vehicle	Biotechnology	Total
Government	Ministry of Industry etc.	12	11	23
Industry	Major company	8	5	13
	Midsize Business	6	6	12
	smaller business	11	14	25
Academia	University	6	6	12
	Research Institute	7	7	14
	Total	50	49	99

3.5 Results and discussion

3.5.1 Category hierarchy results

Table 3. 3 displays the results associated with the five barrier categories based on expert responses. The results indicate that economic barriers present the largest RRI obstacle (27.71%). As a newly industrialized economy, Korea had, and still has, a significant and important R&D role. On the other hand, due to its recent industrialization and the country's low rate of technical innovation, Korea's net commercialization profit rate is low due to its high dependence on components and overseas license payment fees. Therefore, RRI's introduction (as a new R&D innovation-related policy) is bound to be sensitive to Korea's economy.

The results indicate that the policy and political barrier category (24.90%) presents the second largest obstacle to RRI adoption. With the exception of certain large firms' research divisions and government-funded research institutes, Korea's firms remain vulnerable in regard to their abilities to develop their own technologies through R&D. Therefore, Korea's political climate has a relatively strong influence over its firms. In implementing RRI, the direction of government policy and the degree of regulation can have significant impacts on national research institutes and firms. Emerging AV parts makers and biotechnology companies — 65.4% of all companies have annual sales of less than 1 billion won — are financially weak and thus may be more sensitive to the direction of governmental policies (MOTIE, 2017b).

The results indicate that the implementation barrier (17.71%) presents the third most substantial obstacle to RRI adoption. In order for RRI to be applied at research sites in Korea, it is necessary to develop RRI policies that clearly indicate what the approach intends to accomplish or there may be confusion about the method and direction of RRI implementation. Therefore, the creation of common guidelines to follow can be helpful (Chatfield, Iatridis, et al., 2017). The results indicate that the technical (15.50%) and social (14.18%) barriers to adoption were ranked as fourth and fifth, respectively. The surveyed experts recognized that it is less important to prepare for emerging technologies' social ripple effects and to ensure that society would accept RRI than it is to address the economic barriers.

Table 3. 3. Category rankings for RRI implementation

Categories	Priority Weight	Priority Weight (%)	Rank
Economic barrier	0.277	27.71	1
Implementation barrier	0.177	17.71	3
Policy & political barrier	0.249	24.90	2
Social barrier	0.142	14.18	5
Technical barrier	0.155	15.50	4

* Note: CR = 0.001

3.5.2 Results within barrier categories

Table 3. 4 shows the results obtained by calculating and ranking the weights of the barriers to identify the degree of impact to RRI implementation in each category. The within category rankings suggest that certain barriers must be addressed first in order for RRI to be successfully implemented. Within the economic barrier, the increased innovation costs due to RRI implementation (16.46%) is the biggest obstacle to implementing RRI in Korea, followed by the lack of an economic incentive to participate in RRI (11.24%) (Table 3. 4). This shows that the experts perceive the increase in direct costs associated with RRI implementation to be more significant than the indirect incentives for adoption. Therefore, it is important to identify the direct costs involved and to suggest support measures for RRI implementation. Looking at the overall barrier ranking, the two barriers in the economic category accounted for the top two of the 13 barriers, meaning that the experts think recognized them as the largest barriers when introducing RRI to Korea.

Table 3. 4. Barrier rankings within economic category

Economic Barrier Category	Priority Weight	Priority Weight (%)	Rank
Increased innovation costs due to RRI implementation	0.165	16.46	1
Lack of economic incentive to participate in RRI	0.112	11.24	2

* Note: C.R. applies to three or more barriers

Within the implementation barrier, the results indicate that the largest obstacle is the lack of clarity/empirical RRI cases (7.13%), followed by the lack of organizational structure and culture that are suitable for RRI implementation (5.75%), and the lack of RRI training and expertise (4.82%) (Table 3. 5). Therefore, it would be helpful to provide specific RRI guidelines to address these barriers and to later develop appropriate organizational structure and training/education for RRI.

In the overall ranking of the 13 barriers, the three barriers in the implementation category are lack of clarity and empirical RRI cases (ranked sixth), lack of organizational structure and suitable RRI culture (ranked ninth), and lack of RRI training and expertise (ranked 11th). Lack of clarity and empirical RRI cases (7.13%, overall ranking 6) showed a similar importance to conflicts of interest and a lack of stakeholder networks (6.40%, overall ranking 7) within the social category. In addition, lack of organizational structure and suitable RRI culture (5.75%, overall ranking 9) showed almost the same importance as difficulty in understanding the emerging technologies (6.02%, overall ranking 8) within the technical category. Lack of RRI training and expertise (4.82%, overall ranking 11) showed similar importance to increased bureaucracy with RRI implementation (4.91%, overall ranking 10) within the policy & political category. Through this, it is possible to see the differences in importance recognized for individual barriers, which will be helpful in terms of the efficiency of policies to resolve barriers of similar importance when implementing RRI initiatives.

Table 3. 5. Barrier rankings within implementation category

Implementation Barrier Category	Priority Weight	Priority Weight (%)	Rank
Lack of clarity and empirical RRI cases	0.071	7.13	1
Lack of RRI training and expertise	0.048	4.82	3
Lack of organizational structure and suitable RRI culture	0.058	5.75	2

* Note: CR < 0.001

As displayed in Table 3. 6, the largest barrier within the policy/political category is lack of clear RRI policies/unclear focus on RRI regulation (10.13%). This is followed by a lack of political leadership/trust to lead RRI change (9.86%) and increased bureaucracy associated with RRI implementation (4.91%). The European Commission implemented RRI in a top-down manner, and thus it is expected that the state will implement RRI in Korea. Researchers are also in the process of expanding the conceptual interpretations of RRI. Therefore, it is important to provide a clearer scope in terms of RRI policy, including various viewpoints, and to support political leadership to lead the RRI implementation. In the overall ranking of the 13 barriers, the three barriers within the policy/political category are lack of clear RRI policies/unclear focus on RRI regulation (third place), lack of political leadership/trust to lead RRI change (fourth place), and increased bureaucracy associated with RRI implementation (10th place). The lack of clear

RRI policies/unclear focus on RRI regulation (10.13%, overall ranking 3) and lack of political leadership/trust to lead RRI change (9.86%, overall ranking 4) were similar to difficulty in identifying the impacts of emerging technologies. These barriers had almost the same importance as impacts on society (9.48%, overall ranking 5). The increased bureaucracy associated with RRI implementation (4.91%, overall ranking 10) showed similar importance to lack of RRI training and expertise (5.75%, overall ranking 11) within the implementation category.

Table 3. 6. Barrier rankings within policy & political category

Policy & political Barrier Category	Priority Weight	Priority Weight (%)	Rank
Increased bureaucracy with RRI implementation	0.049	4.91	3
Lack of clear RRI policies and unclear focus on RRI regulation	0.101	10.13	1
Lack of both trust and political leadership to lead RRI change	0.099	9.86	2

* Note: CR < 0.001

Table 3. 7 displays the social barrier results. Within this category, the largest barrier is conflicts of interest/lack of stakeholder networks (6.40%). This is followed by RRI's lack of social acceptance/academic identity (3.9%) and the country's lack of experience with bottom-up governance (3.9%). RRI aims to introduce a social discussion system into the technology development process. Therefore, exchanging information and communicating with various stakeholders is important for successful RRI implementation. Stakeholders include government, firm, and academic members involved in technology development (a narrow focus), as well as sociologists and citizens (a broad focus). When people who were previously unfamiliar with each other converse, this can have either positive effects or it can lead to dissension when there are conflicts of interest present. Korea lacks policy experience in these areas, which can lead to a substantial amount of trial and error with regard to RRI implementation.

In the overall ranking of the 13 barriers, the three barriers in the social category were conflicts of interest and a lack of stakeholder networks (seventh place), lack of social acceptance and academic identity of RRI (12th place), and lack of experience with bottom-up governance (13th place). Conflicts of interest and a lack of stakeholder networks (6.40%, overall ranking 7) showed similar importance to difficulty in understanding the emerging technologies (6.02%, overall ranking 8) within the technical category.

Table 3. 7. Barrier rankings within social category

Social Barrier Category	Priority Weight	Priority Weight (%)	Rank
Lack of social acceptance and academic identity of RRI	0.042	3.90	2
Lack of experience with bottom-up governance	0.039	3.90	2
Conflicts of interest and a lack of stakeholder networks	0.064	6.40	1

* Note: CR = 0.001

Table 3. 8 displays the results for the technology barrier category. Within this category, the most influential barrier to RRI implementation is difficulty in identifying the impact of emerging technologies on society (9.48%). This was followed by the difficulty in understanding emerging technologies (6.02%). Korea's current R&D system focuses only on technological development and its related economic effects without considering technology's social and ethical impacts; therefore, it is difficult to predict the future risks, or ripple effects, associated with emerging technologies.

Table 3. 8. Barrier rankings within technical category

Technical Barrier Category	Priority Weight	Priority Weight (%)	Rank
Difficulty in understanding the emerging technologies	0.060	6.02	2
Difficulty in identifying the impacts of emerging technologies on society	0.095	9.48	1

* Note: C.R. applies to three or more barriers

3.5.3 Overall ranking of results by technology type

Tables 2. 9 and 2. 10 present the overall results, as well as results from the individual AHP analyses for AVs and BTs. As shown in Table 3. 9, in terms of the five RRI barrier categories, results are consistent across AVs, BTs, and overall, with the economic and policy/political barriers being the two most important factors. Table 3. 10 shows the results for the 13 RRI barriers, which indicate that the findings for the AVs, BTs, and overall priorities are nearly identical. The five largest obstacles are the following: increasing innovation costs due to RRI implementation, lack of an economic incentive to participate in RRI, lack of clear RRI policies/unclear focus on RRI regulation, lack of political leadership/trust to lead RRI change, and difficulty in identifying the impacts of emerging technologies on society. As a result, the AV, BT, and overall results showed similar trends, with slight differences in the 5 RRI categories and 13 barriers.

Table 3. 9. Category rankings for RRI implementation by technology

Categories	Autonomous vehicle		Biotechnology		Overall	
	Priority weight	Rank	Priority weight	Rank	Priority weight	Rank
Economic barrier	0.301	1	0.253	1	0.277	1
Implementation barrier	0.156	3	0.200	3	0.177	3
Policy & political barrier	0.246	2	0.251	2	0.249	2
Social barrier	0.145	5	0.138	5	0.142	5
Technical barrier	0.152	4	0.158	4	0.155	4

* Note: CRs of all cases are less than 0.003

We calculated the overall weight and rank of the barriers with regard to the extent to which they interfere with RRI implementation by multiplying the weights of each category by the priority weights of the barriers. Table 3. 10 displays the overall ranking of all 13 barriers, which indicates that the five largest barriers are the following: increased innovation costs due to RRI implementation (16.46%), lack of an economic incentive to participate in RRI (11.24%), lack of clear RRI policies/unclear focus on RRI regulation (10.13%), lack of political leadership/trust to lead RRI change (9.86%), and difficulty in identifying the impact of emerging technology on society (9.48%). From these results, it can be inferred that Korea must provide proper financial support and clear policy direction in order for RRI to be successfully implemented in the country.

Table 3. 10. Overall barrier rankings for RRI implementation by technology

Overall barriers	Autonomous vehicle		Biotechnology		Overall	
	Priority weight	Rank	Priority weight	Rank	Priority weight	Rank
Increased innovation costs due to RRI implementation	0.178	1	0.151	1	0.165	1
Lack of economic incentive to participate in RRI	0.123	2	0.102	3	0.112	2
Lack of clear RRI policies and unclear focus on RRI regulation	0.091	4	0.111	2	0.101	3
Lack of both trust and political leadership to lead RRI change	0.103	3	0.093	5	0.099	4
Difficulty in identifying the impacts of emerging technologies on society	0.091	5	0.099	4	0.095	5
Lack of clarity and empirical RRI cases	0.066	7	0.076	6	0.071	6
Conflicts of interest and a lack of stakeholder networks	0.069	6	0.059	8	0.064	7
Difficulty in understanding the emerging technologies	0.061	8	0.059	9	0.060	8

Overall barriers	Autonomous vehicle		Biotechnology		Overall	
	Priority weight	Rank	Priority weight	Rank	Priority weight	Rank
Lack of organizational structure and suitable RRI culture	0.049	10	0.068	7	0.058	9
Increased bureaucracy with RRI implementation	0.051	9	0.046	11	0.049	10
Lack of RRI training and expertise	0.041	11	0.056	10	0.048	11
Lack of social acceptance and academic identity of RRI	0.039	12	0.039	13	0.039	12
Lack of experience with bottom-up governance	0.037	13	0.040	12	0.039	13

* Note: CRs of all cases are less than 0.005

3.6 Conclusion

As a newly industrialized economy, Korea is a country that has had a significant and important role in R&D in the past and maintains one today. Therefore, the country needs to prepare for emerging technologies' future social ripple effects. However, the debate on RRI implementation in Korea has just started and is thus limited. RRI recently emerged in technologically advanced European nations, and aims to increase the positive effects of innovation in the early stages of technological development. RRI remains controversial in terms of its concepts and practices, and Korea lacks in policy experience with regard to key RRI elements. Therefore, these problems may present a barrier to future successful RRI implementation in Korea.

The purpose of this study is to use a preliminary perspective to identify the factors that might impede the implementation of RRI in Korea. To this end, we first conducted an extensive literature review and consulted with experts to identify the various possible barriers to RRI adoption. As a result, we identified five barrier categories (economic, implementation, policy and politics, society, and technology) with a total of 13 barriers across these categories. Based on the existing literature on quantitative and qualitative methodologies for approaches to social innovation such as RRI (see 2.4 Social Innovation Research Methodology), CSR, which was introduced long ago and for which considerable amounts of data have been accumulated in companies, is a quantitative analysis research method. Research into CSR has been actively conducted. However, only one quantitative study on RRI has been carried out, which analyzed the open innovation

concept and a case study of RRI (see Table 3.6). Current research on RRI is qualitative, with a focus on the feasibility and necessity of introducing RRI in the early stages of research. For research on frameworks similar to RRI—ELSA and CTA (Constitutive Technology Impact Assessment)—case studies have been the main method of analysis. An investigation of the analytical methods used in the four representative programs/projects of the countries that introduced RRI (see Table 3.9) showed that qualitative analysis methods such as case studies were the most common, underscoring the need for empirical and quantitative studies in the future. Although previous studies have identified the various obstacles that RRI must overcome, these barriers had not previously been weighted and/or ranked to indicate importance and relative impact. Therefore, this study focused on ranking such obstacles and then used the AHP method to weigh and prioritize the obstacles to offer advice for the Korean professionals who have a general understanding of the country's R&D systems and technologies. The results indicate that the two most important barrier categories are the economic and policy/politics ones. More specifically, the two most important obstacles are the increased innovation costs due to RRI implementation and the lack of an economic incentive to participate in RRI. The government can consider operating a financial support plan by establishing an institutional foundation through the introduction of the RRI certification system and by providing incentives to firms that introduce and implement the RRI certification (Gurzawska et al., 2017).

This study provides one methodological and three theoretical contributions to the academic literature. First, this study demonstrates the applicability of RRI to newly

industrialized economies in non-European countries. The results obtained in our study demonstrate that technologically advanced countries and their national innovation environments are unique. Second, this study presents new empirical evidence by developing categorized barriers and setting weights for each barrier (based on the barriers identified in the existing literature). Third, the AV or BT technologies targeted for analysis have very different characteristics, and this analysis is meaningful in that it covers a very wide range of technologies. In terms of our methodological contribution, we demonstrate that it is possible to use the AHP method to identify and prioritize the expected RRI implementation barriers, as this approach allows researchers to intuitively and logically solve complex decision-making problems. In addition, this process provides us with a better understanding of the obstacles and their causes, and it allows us to identify more effective strategies in regard to responding to the barriers.

There are three policy contributions of this study. The first is that this study allows for discussions on how to overcome the identified barriers. Ranking the obstacles will also help Korea to overcome obstacles to RRI implementation. In addition, it suggests that it is most important to prepare alternatives to the economic and policy/political barriers, which have emerged as most impactful in our research. These results indicate that it is necessary to prepare the proper level of financial support and to clarify the policy direction in order to overcome the obstacles facing RRI implementation. In addition, it might be necessary to encourage active communication among the various stakeholders to gather differing perspectives in regard to overcoming the barriers to successfully implement RRI. Furthermore, sufficient preparedness efforts to anticipate potential

conflicts of interest between stakeholders can be useful in countries where R&D is important.

Second, we derive the characteristics of the emerging technologies from the RRI implementation examples in Korea. In the analysis results, there were no significant differences between the AV and BT detailed technologies in regard to the importance of the RRI obstacles. This finding could be important for promoting appropriate RRI policy. The selection and intensity of RRI policy implementation will differ based on characteristics of the technologies/industries (e.g., the calculated budgets will vary).

Third, we are able to predict the benefits of RRI in Korea. Implementing technological innovations that prevent emerging technologies from having negative effects is advantageous because it can strengthen the position of Korea to that of a technological power. In regard to future technology, the levels of risk and the magnitude of loss may be more difficult to predict; therefore, efforts to prepare for these potential issues can help the country's industrial policy.

This study has three limitations. First, because the analytical method used was based on expert perceptions, we were unable to estimate the quantitative figures needed to solve the obstacles. For example, it may be necessary to calculate certain arithmetic figures, such as estimating the costs involved with tackling the economic barriers, to implement RRI policies. We therefore recommend that further research be conducted to estimate these figures. Second, while our results can guide future research in other

countries/regions, this study focuses exclusively on Korea and thus cannot be generalized to other regions and contexts. Third, this study focused on only two emerging technologies, autonomous vehicles and biotechnology, and it is therefore necessary that future research explore additional emerging technologies such as robots, artificial intelligence, and renewable energy.

- Chapter 4: Essay III -

Why do firms implement responsible research and innovation?: The case of emerging technologies in Korea

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Chapter 4. Why do firms implement responsible research and innovation?: The case of emerging technologies in Korea

4.1 Introduction

In modern society, a problem of the existing system of technological innovation is a failure to consider the social impact of innovations due to its limited focus on technological development and economic performance (Lowman et al., 2012; Stilgoe et al., 2013; von Schomberg, 2013). As the risks posed by the results of emerging technologies have become particular concerns in recent years, the European Union has proposed responsible research and innovation (RRI) in the context of these research and innovation policies (Burget et al., 2017; von Schomberg, 2013). Recent RRI research has focused on firms that play a role in commercializing innovation, and on finding solutions to ethical concerns and responsibilities in the decision-making process of innovation within the firm (S. M. Flipse et al., 2015; Lukovics et al., 2017; Martinuzzi et al., 2018; Nathan, 2015).

However, social involvement in innovation by private firms, as required by RRI, can be a novel challenge for private firms (Auer & Jarmai, 2018; Ceicyte & Petraite, 2018; Timmermans, Yaghmaei, Stahl, & Brem, 2017). Although some firms do implement social strategies, including those within the framework of corporate social responsibility

(CSR) (van de Poel et al., 2017), voluntary CSR and social involvement are very different in nature from RRI, which may require changing the firm's existing rules and routines (Blok, V., & Lemmens, 2015; Gurzawska et al., 2017). This means that in addition to the various social benefits that are expected from RRI, losses (costs) for private firms can occur (Chatfield, Iatridis, et al., 2017). These benefits and costs can vary greatly depending on the type of RRI (Paredes-Frigolett, 2016), which may reflect differences in the extent and intensity of implementation, and discussions are under way about the advantages and disadvantages of various approaches (Gianni, R., & Goujon, 2014; Mei, L., & Chen, 2019; Paredes-Frigolett, 2016; Paredes-Frigolett et al., 2015).

In this context, a common argument of recent research is that industry adoption should take into account practical issues (Dalziel et al., 2018). (a) The question of what and how to implement RRI for business situations (Long & Blok, 2018; Lubberink et al., 2019), (b) the need to redefine the concept of responsibility and innovation in the business context (Martinuzzi et al., 2018), (c) problems with RRI and corporate profits (Blok et al., 2018), and (d) stakeholder engagement level and relationship establishment were raised as major practical issues (Blok, V., & Lemmens, 2015; Brand & Blok, 2019). However, despite the progress of research, it seems that the theoretical and empirical support for the following issues is also insufficient: (a) what is the motivation for the firm to accept RRI, (b) what the firm sees as the benefits and costs of RRI, and (c) the level of RRI that is appropriate for firms that reflect current, future and national contexts. To this end, (a) first, the existing literature was reviewed to create a conceptual model suitable for the purposes of this study, and (b) the results were analyzed through expert recognition surveys. (c)

Afterwards, the results of the analysis were compared with existing studies. More specifically, this study aimed to analyze the relative weights of decision criteria by identifying the benefit and cost criteria used when considering the implementation of RRI in firms, and then to investigate trends in priorities from current and future perspectives on the basis of an evaluation of the types of RRI. To this end, the analytical hierarchy process (AHP) analysis method was used among technical experts at firms.

This paper addresses these factors related to benefit perspectives and cost perspectives of RRI implementation in firms using example of emerging technology firms from Korea. Korea has rapidly grown into a newly industrialized economy (NIE). In 2017, Korea had the highest research and development (R&D) intensity in the world (2017, 4.55%) and the importance of R&D in Korea remains significant (K. Lee & Lim, 2001; OECD, 2019). Nevertheless, the social ramifications of technological innovation in Korea have only emerged as a topic of debate in recent years (Suh, 2019), and RRI is not widespread in Korea. Therefore, Korean researchers are beginning to consider the social impact of risks caused by emerging technologies, and this research agenda is expected to yield interesting results that are different from those reported in Europe (Burget et al., 2017; Lukovics et al., 2017). Firms specializing in autonomous vehicles (AV) and biotechnology (BT), which are both representative emerging technologies, were selected for this study, because of the wide range of technologies deployed in these fields.

This paper is structured as follows. Section 2 includes a review of the literature on RRI, emerging technology, and firm strategy. Section 3 discusses the conceptual model.

Section 4 describes the AHP method and data, Section 5 provides the results, and Section 6 concludes the paper with discussion and conclusion.

4.2 Literature review

4.2.1 RRI and emerging technology

In technologically advanced countries, such as those in Europe, the importance of RRI is highlighted using the motto of being prepared for the risks of innovations resulting from emerging technologies (Burget et al., 2017; Chatfield et al., 2017; von Schomberg, 2013). RRI involves proactively anticipating possible risks from various stakeholders' participation in the early stages of innovation, and actively reflecting on how those risks will affect society (Genus & Stirling, 2018; Stilgoe et al., 2013). Because the EU is strongly promoting RRI as a core framework for Horizon 2020, RRI is developing in policy, academic, and even business settings (Chatfield, Iatridis, et al., 2017; Guston et al., 2014). Simultaneously, the conceptual basis of RRI is still a matter of lively discussion, and is evolving in different directions (Blok, V., & Lemmens, 2015; Burget et al., 2017; Nathan, 2015; Scholten & Blok, 2015; Stilgoe et al., 2013).

The emerging technologies targeted for RRI are those that are likely to become dominant paradigms within 10 to 15 years (Berndt C Stahl et al., 2013). Emerging technologies such as nanotechnologies, big data, alternative energy production, and genomics have a history of dispute (Scholten & Blok, 2015). Mertens (2018) notes that there are three general characteristics of RRI for emerging technologies. First, emerging technologies require technology assessment because of their ultimate novelty and unpredictability. Second, an early assessment is necessary to impact the innovation

trajectory. Third, unknown factors need to be anticipated to prepare for unpredictable events (Mertens, 2018). In this way, emerging technologies can provide opportunities to address social challenges in terms of achieving sustainable and ethically acceptable results (Scholten & Van Der Duin, 2015).

Even within a single country, different technologies may have different side effects, so the corresponding RRI strategies should be tailored accordingly (van de Poel et al., 2017). Accordingly, the present study investigated the developmental status of autonomous vehicles (AV) and biotechnology (BT) in Korea and their ethical, legal, and social aspects as target emerging technologies. First, AV, which involves the intensive collection of advanced information and communications technology, is expected to lead to the greatest advancements in mobility yet seen in human society (KISTEP, 2018). Korea is developing AV technology with the goal of commercialization in 2030 (KISTEP, 2018). However, a concern with AV is that the technology will reduce human control and result in no one having responsibility for driving, and that paradoxically, increased connectivity between infrastructure combined with autonomous driving will pose socioeconomic threats (Cohen, Stilgoe, & Cavoli, 2018; Cui et al., 2019; Keeling, 2018; Sheehan et al., 2019; van de Poel et al., 2017).

Meanwhile, BT is a technology that produces various high value-added products by utilizing the functions and information of living organisms, and Korea has shown a high export growth rate in BT of 11.5% per year, with recent exports of technology achieved through long-term R&D despite a small market and weak technology (MFDS, 2017;

MOTIE, 2017a). However, concerns relating to BT include the fact that the combination of molecular biology, bioinformatics, and new device development entails the emergence of converging or destructive technologies, simultaneously posing a number of ethical, legal and social issues of concern to RRI (e.g. privacy protection, data confidentiality production, ownership of personal data, and prior consent issues) (Gartland & Gartland, 2018; Lecuona et al., 2017; Mitchell, Brown, & McRoberts, 2018; Thompson, 2018).

4.2.2 RRI in business and in global context

Recently, it has been argued that RRI should be applied in firms' R&D processes because it is primarily the role of firms to commercialize products and services that result from innovations in society (Lubberink et al., 2017). Thus, business objectives shift to optimizing economic, social, and environmental value in order to bring sustainable value for business and society (Scholten & Blok, 2015). However, social interventions in the technological development process required by RRI can be a novel challenge for private firms, and firms need to approach RRI implementation at a strategic level (Auer & Jarmai, 2018). Of course, some firms implement social strategies, including corporate social responsibility (CSR) (Campbell, 2007), and both CSR and RRI have commonalities in terms of pursuing firm development and growth through ties with society (Chatfield, Iatridis, et al., 2017; van de Poel et al., 2017). However, unlike CSR, RRI concerns the primary process of the firm, the so-called money-making machine (Blok et al., 2018).

Thus, a key aspect of RRI is that it may require changes in a firm's existing rules and routines (Blok, V., & Lemmens, 2015; Gurzawska et al., 2017; van de Poel et al., 2017), potentially incurring costs (Auer & Jarmai, 2018; Blok, V., & Lemmens, 2015; Chatfield, Iatridis, et al., 2017; Gurzawska et al., 2017). In this context, recent research on RRI in firms has argued that several practical issues hinder the adoption of RRI in industry (Dalziel et al., 2018). Some issues are: First, it is still unknown how to implement RRI in the business context. In other words, stakeholders at firms need to figure out what RRI means and how to characterize it (Long & Blok, 2018; Lubberink et al., 2019). Second, it

is necessary to expand discussions such as redefining the conceptual basis for applying RRI in the business context (Martinuzzi et al., 2018). Third, if there is a clear and predictable return on investment, RRI partially motivates firms to make decisions, but if not, how can RRI be introduced? (Blok et al., 2018). Fourth, there is a problem in establishing at which level stakeholders should be included in RRI implementation (Blok, V., & Lemmens, 2015; Brand & Blok, 2019).

Furthermore, it is thought that research into establishing an appropriate level of RRI implementation is also necessary, for which two considerations should be kept in mind. The first consideration—with a narrow scope— is the preferred or feasible level of RRI for a firm. The benefits and costs of implementing RRI for a firm vary depending on the RRI target level (Paredes-Frigolett, 2016). Although research on the framework of RRI levels based on Stilgoe (2013) is ongoing (as will be described in detail in Section 3), it is understood the level of RRI preferred or considered acceptable by a firm will depend on its own capabilities, relationships with stakeholders, and similar factors (Gianni, R., & Goujon, 2014; Mei, L., & Chen, 2019; Paredes-Frigolett, 2016; Stilgoe et al., 2013). However, few studies have been conducted on the level of RRI preferred by firms.

The second consideration has a broader scope, considering the national context in which RRI is implemented. Research is being conducted on the implementation of RRI in contexts other than Europe, but there have been insufficient discussions about what factors should be considered as differentiators from Europe (Arnaldi et al., 2015; Dalziel et al., 2018; Davis & Laas, 2014; Lubberink et al., 2019). It has been argued that cross-

national context plays an important role in the application of RRI, which seems to be developing successfully because developed European countries are experienced in implementing policies relating to key RRI elements (Lukovics et al., 2017). For example, these countries have developed a variety of technology impact assessment methods, such as ‘real-time technology assessment,’ and they have gained experience with ethical reflexivity systems by evaluating the effects of certain ethical, legal, and social aspects (Guston & Sarewitz, 2002; Zwart et al., 2014). Furthermore, since the late 1970s, European countries have made concerted efforts to consider the opinions of the public and non-governmental organizations when making decisions related to science and technology (Landeweerd et al., 2015). This policy experience is expected to have a positive impact on the use of RRI in the business context. However, in the EU, researchers in developed countries expressed interest in the interaction between technology and society, while researchers in non-developed countries expressed the need to concentrate on securing research funds and had a low understanding of the need to consider the social context of technological development (Lukovics et al., 2017). There were marked differences in perceptions. Thus, it is necessary to consider the innovation environment of each specific country to augment the effectiveness of RRI. In addition, it has been argued that technology level (high technology vs. low technology), culture, and material barriers to innovation are factors that affect attitudes toward RRI implementation and should be considered (de Hoop et al., 2016; Di Giulio et al., 2016; Hartley et al., 2019).

As such, research on RRI in business context has been conducted in various ways and through various approaches to RRI’s directivity, but until now, research has focused on

conceptual design and a few case studies, and theoretical and empirical studies are insufficient. However, considering that it is time to address these issues, this study attempted to explain the principles of the mechanism by which RRI works in firms through existing research, using the following theoretical framework. First, will RRI regulations help firms? It has been claimed that the regulatory nature of social interventions such as RRI can stimulate firms' innovation (Auer & Jarmai, 2018). Porter (1995) takes the environmental sector as an example, as stringent regulation triggers greater innovation, and induced innovation responds to regulations while improving the affected product itself and related processes. Thereby, it is possible to identify "innovation offsets" that exceed the cost of compliance, thus increasing industrial competitiveness (Porter & Van Der Linde, 1995). Second, how does firms' willingness to do good for society provides advantages to firms? The argument has been made that ethical principles resulting from RRI can also impose costs on businesses (Chatfield, Iatridis, et al., 2017; Schumacher & Wasieleski, 2013). However, it has been claimed that RRI-driven efforts to integrate ethics into the R&D process will lead to further innovation by promoting firms' attempts to solve social and environmental problems (Baucus, Norton, Baucus, & Human, 2008; Chatfield, Iatridis, et al., 2017). In addition, Schumacher (2013) and Farjoun (2010) insist that if a firm institutionalizes ethical principles from a long-term perspective, ethics and innovation can be compatible and complementary, thereby enabling the firm to survive long-term (Farjoun, 2010; Schumacher & Wasieleski, 2013). The above two claims provide insights into the motivations for firms to adopt RRI and how it will affect firms in the business context.

4.3 Benefit perspectives and cost perspectives to the firm for RRI implementation

4.3.1 Conceptual model at the firm level

To extend and develop the concept of RRI, framework development and application research is being conducted to consider RRI-related matters in an integrated way in order to measure RRI in business. Based on the framework of Stilgoe (2013), these studies discuss the advantages and limitations of applying that theoretical framework to RRI implementation in firms (Demers-Payette, Lehoux, & Daudelin, 2016; Foley, Bernstein, & Wiek, 2016; Long & Blok, 2018; Long, Blok, Dorrestijn, & Macnaghten, 2020). In this study, a conceptual model, as shown in Fig 4. 1, was developed on the basis of the theoretical model created by Paredes-Frigolett (2016) and Paredes-Frigolett, et al. (2015) using the dimensions of RRI. The model assumes that a firm will adopt one of the four RRI implementation levels, and includes the notion that raising the level will lead to higher expenditures, but on the other hand, a benefit can be obtained by doing so. In addition, this study shows that the RRI level preferred by the firm after the introduction of RRI may vary from the present point of time to the future, and there is a certain period of time until benefits occur through the implementation of RRI according to the selected level. Therefore, this study presents analysis results for the present and the future in 10 years. The arrow in Figure 4.1 represents this passage of time, and does not imply a causal analysis, which is not within the scope of this study.

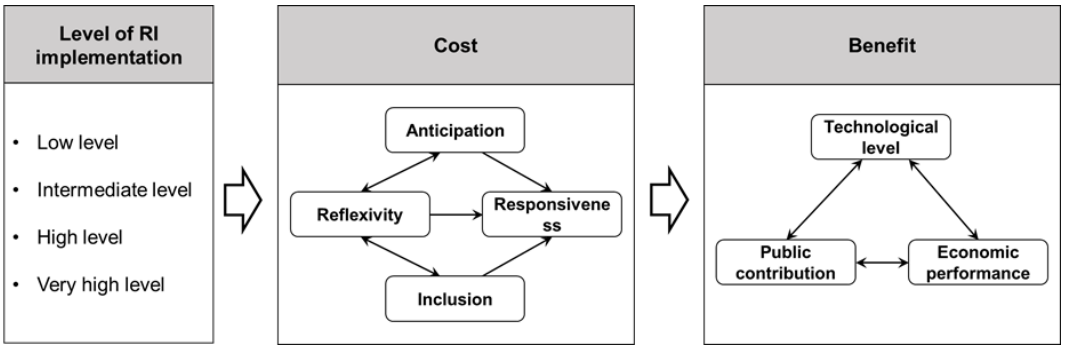

Figure 4. 1. A conceptual model of RRI implementation at firms

4.3.2 Benefit perspectives

The implementation of RRI could result in a number of benefits that the entity did not anticipate (Xavier, P., Daphne, C., & Victor, 2014). The benefits that can be obtained through RRI in a firm are classified into three general criteria and six sub-criteria, as presented below.

4.3.2.1 Technological level

Predicting the direction of technological developments through RRI and discussions with various stakeholders greatly enhances the firm's technology in two ways.

Technological excellence (TE): By inferring the direction of technological developments and evaluating the impact of technology on society, it is possible to achieve a superior quality of products compared to competitors by securing excellent technology with low risk (Ceicyte & Petraite, 2018; Chang, 2011; Chatfield, Iatridis, et al., 2017).

Social acceptability of technology (SAT): The involvement of various stakeholders through RRI can help to better match products and services to user needs, which can ultimately yield economic benefits (Ceicyte & Petraite, 2018; Chatfield, Iatridis, et al., 2017; van de Poel et al., 2017).

4.3.2.2 Economic performance

When firms consider social responsibility, they can find more efficient ways of doing business and develop new types of products that positively impact their success and profitability.

Profitability (PT): Firms that implement RRI can increase their market share to meet current or future market demands and achieve long-term economic success (Auer & Jarmai, 2018; Ceicyte & Petraite, 2018; Chang, 2011; Chatfield, Iatridis, et al., 2017; Gurzawska et al., 2017).

Firm competitiveness (FP): The implementation of RRI will enable a firm to meet the needs and expectations of its stakeholders, which will lead to a better corporate image and a variety of external collaborations that will increase the long-term viability of the firm (Auer & Jarmai, 2018; Blok, V., & Lemmens, 2015; Ceicyte & Petraite, 2018; Chang, 2011; Chatfield, Iatridis, et al., 2017; Gurzawska et al., 2017; Silva, Lehoux, & Hagemeister, 2018).

4.3.2.3 Public contributions

The sense that a firm can do social good while profiting can be divided into two main concepts.

Social contribution (SC): Implementing RRI enables firms not only to make economic profits, but also to help address social benefits, sustainability, and social challenges (Auer & Jarmai, 2018; Ceicyte & Petraite, 2018; Chatfield, Iatridis, et al., 2017; van de Poel et al., 2017).

Ethics (ET): Firms can implement ethical management and ensure legal compliance through RRI, and their ethical position can provide a unique way to differentiate themselves from the competition (Ceicyte & Petraite, 2018; Chatfield, Iatridis, et al., 2017; Chen & Chang, 2013).

4.3.3 Cost perspectives

RRI implementation activities incur a variety of costs for firms. In this section, the costs of a firm's RRI activities are divided into four general criteria and eight sub-criteria, as presented below.

4.3.3.1 Anticipation

Two categories of costs are useful when estimating the ripple effects of emerging technologies developed by firms.

Technological forecasting and technological exploration (TF): This refers to the cost of predicting and exploring the impact of technological developments and innovation to predict the side effects of innovation and reduce uncertainty (Chatfield, Iatridis, et al., 2017; Paredes-Frigolett, 2016).

Certification of technology (CT): This category refers to the cost of certification and standardization (e.g., policies and procedures, guideline development, and specific RRI standards to predict long-term results), such as long-term risk assessment procedures in a firm (Gurzawska et al., 2017; Paredes-Frigolett, 2016).

4.3.3.2 Reflexivity

There are two categories of costs for reviewing compliance with ethical standards in a firm's innovation process.

Self-reflection (SR): This is the cost of personal considerations about whether the fundamental purpose, motivation, and potential impacts of innovation, as well as the distribution of profits, meet ethical standards (Chatfield, Iatridis, et al., 2017; Gianni, R., & Goujon, 2014).

Institutional reflection (IR): This category refers to the cost of considerations at the institutional level (e.g., organizations and society) about whether the fundamental purpose, motivation, and potential impacts of innovation, as well as the distribution of profits, meet ethical standards (Chatfield, Iatridis, et al., 2017; Gianni, R., & Goujon, 2014; Paredes-Frigolett, 2016).

4.3.3.3 Inclusion

There are two categories of costs for communicating with external stakeholders in a firm's innovation process.

External stakeholder network formation (ENF): This refers to the cost for a firm to establish a network with various external stakeholders (Chatfield, Iatridis, et al., 2017;

Gianni, R., & Goujon, 2014; Long & Blok, 2018; Lubberink et al., 2017; Paredes-Frigolett, 2016).

External stakeholder network operation (ENO): This is the cost for the firm to maintain the network formed by various external stakeholders (Chatfield, Iatridis, et al., 2017; Gianni, R., & Goujon, 2014; Long & Blok, 2018; Lubberink et al., 2017; Paredes-Frigolett, 2016).

4.3.3.4 Responsiveness

Responsiveness reflects the cost of integrating anticipation, reflexivity, and inclusion into a firm's innovation process. It is classified into two categories.

Training and specialized personnel (TS): This category refers to the cost of securing and training the necessary professionals to implement RRI activities. It promotes RRI and fosters responsibility for innovation in the long term (Auer & Jarmai, 2018; Chatfield, Iatridis, et al., 2017).

Organizational culture and system establishment (OS): This category accounts for the cost of RRI activities in building an entity's institutions in a way that embeds them in the innovation process (Asante, K., Owen, R., & Williamson, 2014; Ceicyte & Petraite, 2018; Chang, 2011; Chatfield, Iatridis, et al., 2017; Chen & Chang, 2013; Lubberink et al., 2017; Paredes-Frigolett, 2016; Schumacher & Wasieleski, 2013).

4.3.4 Alternatives: levels of RRI implementation

Firms choose an RRI implementation level based on their own capabilities, their relationships with stakeholders, and the degree of regulation, resulting in specific costs and benefits to the firm. The RRI levels are presented in Table 3. 1 based on a combination of three studies (Gianni, R., & Goujon, 2014; Mei, L., & Chen, 2019; Paredes-Frigolett, 2016). The RRI implementation levels are divided into four categories: low, intermediate, high, and very high. These alternatives are shown in Figure 4. 2 and Figure 4. 3.

Table 4. 1. Summary of alternatives: levels of RRI implementation in Korea.

RRI dimensions	**Levels of RRI implementation**			
	Low	**Intermediate**	**High**	**Very high**
Anticipation	Focusing on predicting the rewards individuals receive for innovation (Chen, 2019).	Focusing on predicting whether innovations that occur will succeed in compliance with relevant sector regulations (Chen, 2019).	Focusing on innovation to comply with formal institutions such as political, legal, and bureaucratic systems in the relevant country and regions	Focusing on innovation to comply with informal institutions such as customs, norms, traditions, and cultures of countries and

RRI dimensions	Levels of RRI implementation			
	Low	**Intermediate**	**High**	**Very high**
Reflexivity	Self-reflection based on individual compliance with ethical codes of conduct (Paredes, 2016).	Self-reflection such as compliance with an organizational code of ethics and compliance with relevant regulations (Paredes, 2016).	(Chen, 2019; Paredes, 2016).	regions (Chen, 2019; Paredes, 2016).
Inclusion	Including only the firm itself in the scope of activities (Chen, 2019; Gianni, 2014).	Slightly expanding the scope of activities by engaging with other firms and policy-makers (Chen, 2019; Gianni, 2014).	Inclusion of a few general citizens (stakeholders) in firms and policy-makers (Chen, 2019; Gianni, 2014).	Inclusion of citizens as key stakeholders (expanding to participatory democracy) (Chen, 2019; Gianni, 2014).

RRI dimensions	Levels of RRI implementation			
	Low	**Intermediate**	**High**	**Very high**
Responsiveness	Focusing on internal activities involved in innovation, such as the allocation of resources for innovation and distribution of accrued profits (Chen, 2019).	Expanding the responsiveness range of innovation activities to areas where internal and innovation will be applied (Chen, 2019).	Responsiveness extends to oversight, improvement, optimization and reform of political, legal, and bureaucratic systems (Chen, 2019).	Responsiveness extends to discussions related to spiritual values, social traditions, and culture (Chen, 2019).

4.4 Methodology

4.4.1 Analytical hierarchy process (AHP)

AHP is very useful for solving complex problems by decomposing decision problems into several sub-problems, creating hierarchical tree models, and deriving the weights of factors through pairwise comparisons between factors (Tummala et al., 1997). This methodology can be applied to identify qualitative and quantitative criteria, to review competing and conflicting goals, and to prioritize alternatives for appropriate decisions (Saaty, 1990a, 2008). In addition, cost-benefit analyses using AHP have been conducted in various ways by numerous researchers (Ramanujam & Saaty, 1981; Saaty, 1983, 1990b; Vaidya & Kumar, 2006). In this study, two AHP hierarchical models—the benefit hierarchy (Fig 3. 2) and the cost hierarchy (Fig 3. 3)—are presented to analyze the benefits and costs of RRI implementation in a firm. The model derives the priority of the alternatives that are ultimately placed at the bottom of the hierarchy, with the goal of choosing the best RRI implementation. For this purpose, the general criteria and sub-criteria for benefits and costs presented in Section 3 are used as weighting factors. This process is carried out in four stages, as detailed in Table 3. 2 (Luthra et al., 2016).

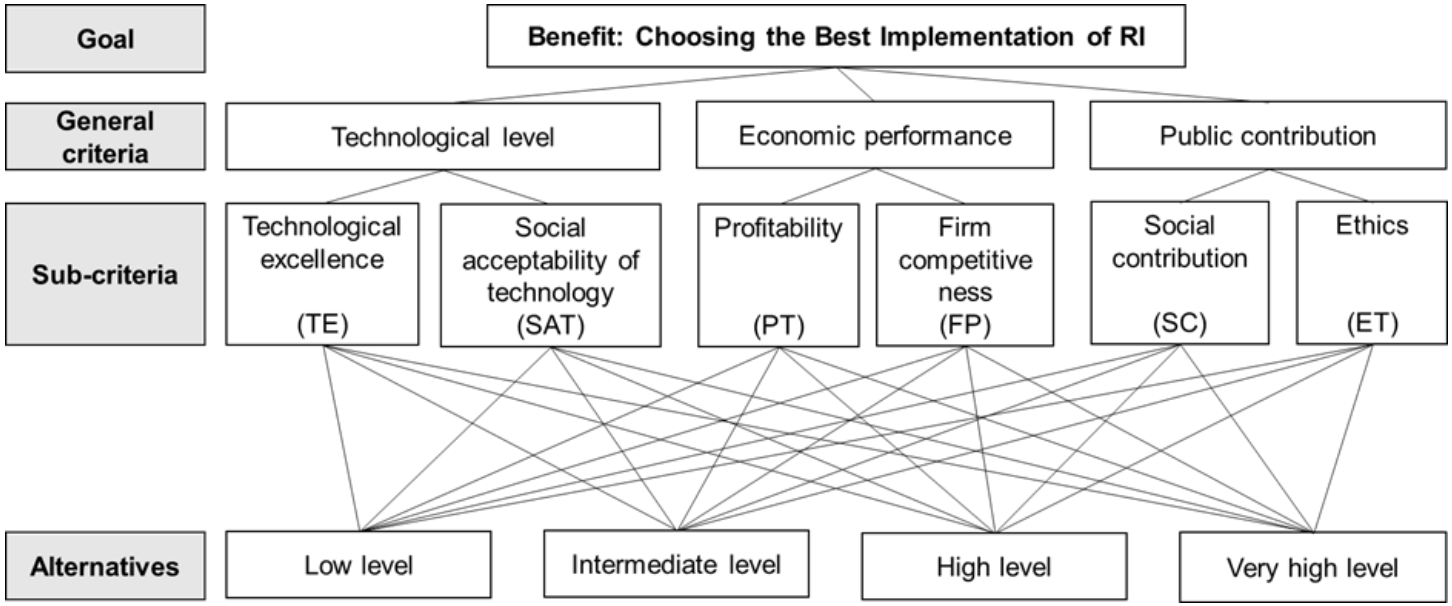

Figure 4. 2. Hierarchy of criteria and alternatives for the benefit perspectives of RRI

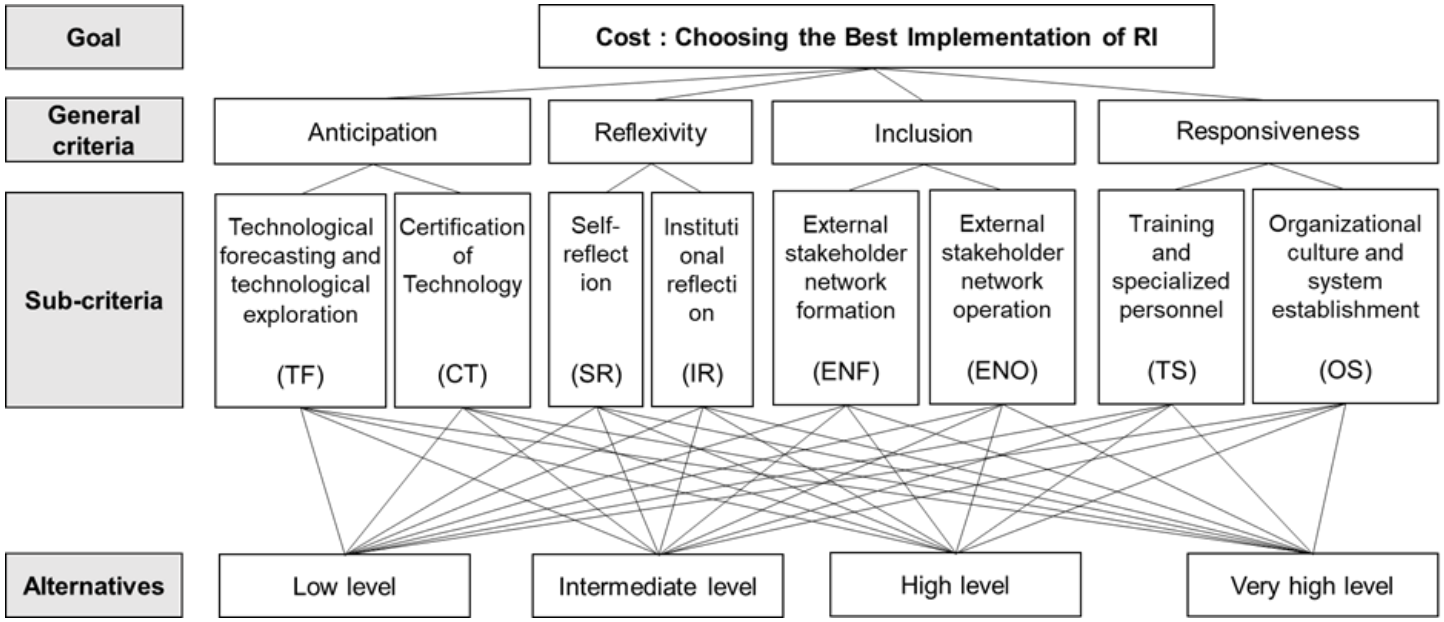

Figure 4. 3. Hierarchy of criteria and alternatives for the cost perspectives of RRI

Table 4. 2. Four stages involved in the AHP for choosing the best implementation of RRI

Stage	Definition	Description
I	Structuring hierarchical models	• The benefits and cost aspects of RRI implementation in a firm are identified and alternative RRI levels are configured to establish a decision hierarchy for each type of benefit and cost.
II	Measurement and data collection	• A pairwise comparison matrix is constructed by collecting data to determine the relative importance of general criteria, sub-criteria, and alternatives. This data indicates relative importance of two matched criteria on a nine-point scale by respondents and is entered the reciprocals together with n criteria or alternatives down the main diagonal.
III	Determination of normalized weights using the eigenvalue method	• The relative weights w_i (i = 1,⋯, n) of criteria or alternatives are estimated using the eigenvalue method as follows: $$AW = \lambda_{max} W,$$ where A is the pairwise comparison matrix (n x n) on each criterion or alternative, W is the priority vector (n x 1), also relative weights of each criterion or alternative, and λ_{max} is the largest eigenvalue of A which indicates relative importance of criteria or alternatives • Next, the degree of consistency is measured by the consistency

Stage	Definition	Description
		index (CI) as follows: $$CI = (\lambda_{max} - n)/(n-1)$$ • By using the result of CI, the consistency rate (CR) is obtained as follows: $$CR = CI/RI,$$ where RRI refers to a random index, and when CR is less than 0.1, the comparison matrix is considered to be consistent
IV	Ranking the alternatives of RRI using relative weights of criteria	• To find the priority vector (W), normalizing the comparison matrix (A) by dividing each entry by the sum of the column and take the overall row average • W is constructed for each layer (general criteria, sub-criteria, and alternatives) and finally produced three priority vectors. • Next, W is combined to obtain a comprehensive priority ranking of the alternatives being evaluated. • Doing the same procedures for the benefit (present, 10 Years in the future) and the cost (present, 10 Years in the future) and choosing the best implementation of RRI (alternatives)

4.4.2 Data

This study collected data through a survey of expert groups. In multi-criteria decision-making methods, such as AHP, knowledge is more important than the number of experts (Hessami, H. Z., Golsefid-Alavi, M., Shekaf, S. M., & Mavi, 2012; Tummala et al., 1997). In general, AHP does not require a fixed number of samples. It is possible to have from one respondent to about 100 (S. Lee et al., 2012; Saaty, 1990a; Shin et al., 2009; Singh & Nachtnebel, 2016). Saaty used a sample of about 25 respondents in a benefit and cost analysis (Saaty, 1983, 1988). In this study, in order to overcome the limitations of the questionnaire for Korean experts with a low understanding of RRI, when sending the survey email, detailed information about RRI was also included to help participants understand the background and purpose of this study and to respond to the questionnaire. Then, after respondents became acquainted with the content of RRI, voluntary participation was confirmed, and only experts who agreed to participate in the survey proceeded to the survey stage. In order to ensure the objectivity and reliability of the respondents, only those with a Ph.D. or work experience of 10 years or more in the relevant field were eligible (31 Ph. D., 50 over 10 years experiences, 13 duplicate values), and all participants had expertise in either AV or BT. Participation was limited to those with a high level of understanding of technology, as indicated by working in a technology development research institute or research department within a firm (distribution of respondent positions:12 cheif executive officers (CEOs), 15 executives, 5 mid-level executives, 36 research fellows). Finally, to reflect the diversity of companies in terms of size, the pool of respondents included experts working at large companies, medium-sized

companies, and small and medium-sized companies, with the goal of reflecting the reality of the distribution of Korean companies by size (large companies, 0.3%; medium-sized companies, 0.6%), and small and medium-sized companies, 99.1% as of 2018). In order to do so, the ratio of smaller businesses was approximately doubled. An examination of the proportional composition of responses in a previous study confirmed that the study focused on appropriate areas. Out of 99 surveys mailed, 77 were returned, and sixty-eight responses were used in the analysis, with the exclusion of those that were incomplete or had a consistency ratio less than 0.1 (9 survey is excluded). The response rate was 68.7%. Duration of surveys which includes time from sending the surveys and receiving responses were between July and September, 2019. Table 3. 3 shows the distribution of samples in terms of categories of respondents and Appendix C shows a summary of the survey that was sent to surveyed firms.

Table 4. 3. Total number of respondents according to technical areas and their respective organization

Firm size	Technology		Total
	Autonomous vehicle	Biotechnology	
Major company	12	5	17
Midsize business	10	7	17
Smaller business	16	18	34
Total	38	30	68

4.5 Results

4.5.1 Benefit perspectives and alternatives

The results of the analysis of the optimal alternatives for RRI implementation in Korean firms in terms of current benefits are shown in Table 3. 4. Among the three general criteria, economic performance (0.502) was most important for RRI implementation in Korean firms, followed by technical level (0.341) and public contribution (0.157). Of all six sub-criteria, the most important was profitability (PT) (0.266), followed by firm competitiveness (FP) (0.236) and technological excellence (TE) (0.229). Of the four alternatives, the highest priority was found for a high level of RRI (0.283), followed by a very high level (0.274), an intermediate level (0.259), and a low level (0.184). A high level and a very high level received similarly high scores, and were identified as the most preferred of the four alternatives in terms of current benefits. Within the high and very high levels of RRI implementation, profitability (PT) (0.070 and 0.071, respectively), firm competitiveness (FP) (0.068 and 0.065, respectively), and technological excellence (TE) (0.062 and 0.048, respectively) was important. The remaining sub-criteria were of low importance.

Table 4. 4. Relative weights of criteria and alternatives for the benefits of RRI at the present time.

Goal		Benefits: Present						Total
General-criteria		Technical level (0.341)		Economic performance (0.502)		Public contribution (0.157)		(1.000)
Sub-criteria		TE (0.229)	SAT (0.112)	PT (0.266)	FP (0.236)	SC (0.092)	ET (0.065)	(1.000)
Alter-natives	Low	0.053	0.019	0.053	0.039	0.012	0.008	0.184
	Intermediate	0.066	0.027	0.072	0.064	0.018	0.012	0.259
	High	0.062	0.033	0.07	0.068	0.03	0.02	0.283
	Very high	0.048	0.033	0.071	0.065	0.032	0.025	0.274

* Note: CRs of all cases are less than 0.008

* Note: technological excellence (TE), social acceptability of technology (SAT), profitability (PT), firm competitiveness (FP), social contribution (SC), ethics (ET)

Table 3. 5 shows the results of the analysis of the best alternative (levels of RRI implementation) in Korean firms in terms of future benefits (10 years in the future). Of the three general criteria, economic performance (0.401) had the largest impact on RRI implementation in Korean firms, followed by technical level (0.324) and public contribution (0.275). Of all six sub-criteria, the most important was firm competitiveness (FP) (0.219), followed by technological excellence (TE) (0.204) and profitability (PT) (0.182). Of the four alternatives, the highest priority was a very high level of RRI (0.302),

followed by a high level (0.296), an intermediate level (0.239), and a low level (0.163). A high level and a very high level were the most preferred of the four alternatives in terms of future benefits (10 years in the future). Within the high and very high levels of RRI implementation, firm competitiveness (FP) (0.062 and 0.064, respectively) was most important, followed by social contribution (SC) (0.054 and 0.064, respectively) and technological excellence (TE) (0.059 and 0.052, respectively). The remaining sub-criteria were of low importance.

Table 4. 5. Relative weights of criteria and alternatives for the benefits of RRI 10 years in the future.

Goal		Benefits: 10 Years in the future						Total
General-criteria		Technical level (0.324)		Economic performance (0.401)		Public contribution (0.275)		(1.000)
Sub-criteria		TE (0.204)	SAT (0.120)	PT (0.182)	FP (0.219)	SC (0.180)	ET (0.095)	(1.000)
Alter-natives	Low	0.039	0.017	0.032	0.038	0.025	0.012	0.163
	Intermediate	0.054	0.025	0.05	0.055	0.037	0.018	0.239
	High	0.059	0.04	0.052	0.062	0.054	0.029	0.296
	Very high	0.052	0.038	0.049	0.064	0.064	0.035	0.302

* Note: CRs of all cases are less than 0.007

* Note: technological excellence (TE), social acceptability of technology (SAT), profitability (PT), firm competitiveness (FP), social contribution (SC), ethics (ET)

4.5.2 Cost perspectives and alternatives

The results of analyzing the best alternatives for RRI implementation for Korean firms from the perspective of current costs are shown in Table 3. 6. Of the four general criteria, anticipation (0.367) had the greatest impact on RRI implementation in Korean firms, followed by responsiveness (0.275), reflexivity (0.193), and inclusion (0.165). Of all eight sub-criteria, the most important was technological forecasting and technological exploration (TF) (0.237), followed by training and specialized personnel (TS) (0.139) and organizational culture and system establishment (OS) (0.136). Of the four levels of RRI implementation, the highest priority was found for a high level of RRI implementation (0.288), followed by a very high level (0.274), an intermediate level (0.255), and a low level (0.183). The scores for a high level of RRI implementation and a very high level of RRI implementation were similarly high, with the largest current costs among the four alternatives. For a high level and a very high level of RRI implementation, technological forecasting and technological exploration (TF) (0.061 and 0.057, respectively), certification of technology (CT) (0.040 and 0.036, respectively), training and specialized personnel (TS) (0.042 and 0.040, respectively), and organizational culture and system establishment (OS) (0.038 and 0.039, respectively) were important. The remaining sub-criteria were of low importance.

Table 4. 6. Relative weights of criteria and alternatives for the costs of RRI at the present time.

Goal		Costs: Present								Total
General-criteria		Anticipation (0.367)		Reflexivity (0.193)		Inclusion (0.165)		Responsiveness (0.275)		(1.000)
Sub-criteria		TF (0.237)	CT (0.130)	SR (0.089)	IR (0.104)	ENF (0.095)	ENO (0.070)	TS (0.139)	OS (0.136)	(1.000)
Alter-natives	Low	0.055	0.022	0.02	0.014	0.016	0.01	0.024	0.022	0.183
	Intermediate	0.064	0.032	0.024	0.023	0.024	0.018	0.033	0.037	0.255
	High	0.061	0.04	0.023	0.034	0.029	0.021	0.042	0.038	0.288
	Very high	0.057	0.036	0.022	0.033	0.026	0.021	0.04	0.039	0.274

* Note: CRs of all cases are less than 0.009

* Note: technological forecasting and technological exploration (TF), certification of technology (CT), self-reflection (SR), institutional reflection (IR), external stakeholder network formation (ENF), external stakeholder network operation (ENO), training and specialized personnel (TS), organizational culture and system establishment (OS)

Table 3. 7 shows the analysis of the best alternatives for RRI implementation in the future (10 years in the future) in terms of cost. Of the four general criteria, responsiveness (0.294) had the greatest impact on RRI implementation in Korean firms, followed by anticipation (0.292), inclusion (0.211), and reflexivity (0.203). Of all eight sub-criteria, the most important was technological forecasting and technological exploration (TF) (0.182), followed by organizational culture and system establishment (OS) (0.175), institutional reflection (IR) (0.124), and external stakeholder network operation (ENO). Of the four levels of RRI implementation, the highest priority was a very high level of RRI implementation (0.297), followed by a high level (0.293), an intermediate level (0.246), and a low level (0.164). A high level of RRI implementation and a very high level of RRI implementation received similarly high scores, with the highest future costs expected among the four alternatives. For a high level and a very high level of RRI implementation, organizational culture and system establishment (OS) (0.049 and 0.059), technological forecasting and technological exploration (TF) (0.051 and 0.050), institutional reflection (IR) (0.039 and 0.043), and external stakeholder network operation (ENO) (0.038 and 0.036) were identified as sub-criteria of high importance. The rest were of low importance.

Table 4. 7. Relative weights of criteria and alternatives for cost of RRI at the future in 10 years.

Goal		Costs: 10 Years in the future								Total
General-criteria		Anticipation (0.292)		Reflexivity (0.203)		Inclusion (0.211)		Responsiveness (0.294)		(1.000)
Sub-criteria		TF (0.182)	CT (0.110)	SR (0.079)	IR (0.124)	ENF (0.092)	ENO (0.119)	TS (0.118)	OS (0.176)	(1.000)
Alter-natives	Low	0.034	0.017	0.017	0.017	0.015	0.017	0.022	0.025	0.164
	Intermediate	0.047	0.026	0.022	0.025	0.024	0.028	0.031	0.043	0.246
	High	0.051	0.035	0.021	0.039	0.027	0.038	0.033	0.049	0.293
	Very high	0.05	0.032	0.019	0.043	0.0256	0.036	0.032	0.059	0.2966

* Note: CRs of all cases are less than 0.01

* Note: technological forecasting and technological exploration (TF), certification of technology (CT), self-reflection (SR), institutional reflection (IR), external stakeholder network formation (ENF), external stakeholder network operation (ENO), training and specialized personnel (TS), organizational culture and system establishment (OS)

4.5.3 Benefit perspectives, cost perspectives, and alternatives by technologies

As shown in Table 4. 8, experts from AV firms preferred a high or very high level of RRI at the present, and they preferred a high or very high level of RRI in the future. This indicates that members of the firms' own organizations are willing to implement RRI. In terms of benefits, the highest preferences were shown for both high levels. This indicates that, as shown in Table 4.1, it is most preferred to implement RRI through formal institutions such as political, legal, and bureaucratic systems. In terms of costs, very high costs currently had the highest weight, but for the future, the highest weight was found for a high level of costs. As presented in Table 4.1, it is currently considered most expensive to implement RRI through informal institutions such as customs, norms, traditions, and cultures, which means very high levels of implementation, and in the future, the costs will include implementing RRI through formal institutions such as political, legal, and bureaucratic systems. This indicates that implementing RRI through those institutions would be the most expensive.

Experts from BT firms preferred a high or very high level of RRI at the present and a high or very high level in the future. This suggests that BT firms recognize the benefits of introducing RRI at the organizational and national level from a long-term perspective. In terms of benefits, the high level showed the highest preference in the present, and the very high level showed the highest preference in the future. At the moment, as indicated in Table 4.1, it is most preferred to implement RRI through formal institutions, such as political, legal, and bureaucratic systems. In the future, it was most preferred to

implement RRI through informal institutions such as customs, norms, traditions, and cultures. In terms of costs, the high level of costs currently had the highest preference, but for the future, the highest weight was found for the very high level. Table 4.1 indicates that currently, it is most expensive to implement RRI through formal institutions such as political, legal, and bureaucratic systems, while in the future, it will be most expensive to implement RRI through informal institutions such as customs, norms, traditions, and cultures, corresponding to very high levels of implementation.

This shows that Korean firms recognize that the benefits of RRI implementation increase as the level of RRI implementation increases. Both benefits and costs currently had the highest weight at the high level, and for the future, the highest weight was found for the very high level. This represents the current preference for implementing RRI through formal institutions such as political, legal, and bureaucratic systems. For the future, it was most preferred to implement RRI through informal institutions such as customs, norms, traditions, and cultures. This shows that Korean firms recognize that the benefits of RRI implementation increase as the level of RRI implementation increases. However, regarding benefits, experts from AV firms preferred a high level both for the present and future, but the experts from BT firms preferred a high level for the present and a very high level for the future. This may be due to the characteristics of the respective technologies. AV is a communication technology such as ICT applied to an existing machine-oriented vehicle, and it can be considered that the highest level of RRI implementation can be implemented within the present social system. In contrast, in BT, factors such as social contributions (e.g., ethics) can be important in terms of making BT human-friendly, and it can be inferred that experts from these firms recognize that the

greatest benefit can be obtained when operating at a very high level through informal institutions. More accurate interpretations should be made on the basis of studies involving more specific interviews in the future.

Table 4. 8. Results for levels of RRI implementation in terms of benefits and costs by technological sector.

Technologies	Alternatives	Present		Future in 10 years	
		Benefit	Cost	Benefit	Cost
Overall	Low level	0.184	0.183	0.163	0.164
	Intermediate level	0.259	0.255	0.240	0.245
	High level	0.283	0.289	0.296	0.293
	Very high level	0.274	0.274	0.302	0.297
Autonomous vehicle	Low level	0.173	0.178	0.146	0.149
	Intermediate level	0.265	0.263	0.247	0.256
	High level	0.284	0.277	0.305	0.304
	Very high level	0.278	0.282	0.302	0.291
Biotechnology	Low level	0.200	0.189	0.187	0.186
	Intermediate level	0.255	0.246	0.233	0.231
	High level	0.281	0.302	0.284	0.279
	Very high level	0.264	0.264	0.297	0.304

* Note: CRs of all cases are less than 0.017

4.6 Discussion and Conclusion

4.6.1 Discussion

As business objectives shift to optimizing economic, social, and environmental value to provide sustainable value to business and society, this study was conducted to analyze the motivations and factors for accepting RRI in firms (Scholten & Blok, 2015). Based on the existing literature on quantitative and qualitative methodologies for approaches to social innovation such as RRI (see 2.4 Social Innovation Research Methodology), CSR, which was introduced long ago and for which considerable amounts of data have been accumulated in companies, is a quantitative analysis research method. Research into CSR has been actively conducted. However, only one quantitative study on RRI has been carried out, which analyzed the open innovation concept and a case study of RRI (see Table 3.6). Current research on RRI is qualitative, with a focus on the feasibility and necessity of introducing RRI in the early stages of research. For research on frameworks similar to RRI—ELSA and CTA (Constitutive Technology Impact Assessment)—case studies have been the main method of analysis. An investigation of the analytical methods used in the four representative programs/projects of the countries that introduced RRI (see Table 4.9) showed that qualitative analysis methods such as case studies were the most common, underscoring the need for empirical and quantitative studies in the future. Although previous studies have reviewed various factors that should be considered when implementing RRI programs at the enterprise level, these factors have not been weighted or ranked to indicate their importance and relative impact. Therefore, in order to analyze

firms' motivations for adopting RRI, the importance of criteria in terms of RRI's benefits and costs from the perspective of the firm was first analyzed and then derived importance and priority using the AHP method.

Profitability (PT) and firm competitiveness (FP), as economic performance criteria, and technological excellence (TE) as a technical level criterion were important factors at the present, but in the future the importance of social contribution (SC) as a public contribution criterion increased, while firm competitiveness (FP) as an economic performance criterion and technological excellence (TE) as a technical level criterion remained important. Preferences for RRI implementation level also showed the same trend. At the present, the preference was for a high level of RRI implementation, with RRI being established within a formal institutional system (see Table 3. 1, high levels of RRI implementation) and having high benefits to firms in terms of profitability (PT) and firm competitiveness (FP) as economic performance criteria and technological excellence (TE) as a technical level criterion. In contrast, in the future, the preference was for a very high level of RRI implementation, extending to informal institutions (see Table 3. 1, very high levels of RRI implementation), and high benefits were anticipated for firms in terms of firm competitiveness (FP) as an economic performance criterion, technological excellence (TE) as a technical level criterion, and social contribution (SC) as a public contribution criterion. For the future, the experts determined that higher levels of RRI implementation would lead to greater benefits for their firms. Emerging technology is an area of high uncertainty, where firms have not yet completed their profit-making bases, but their RRI preferences are strong for both high and very high levels of implementation.

In cases of NIEs (e.g., Korea), the R & D intensity was high, which had positive results in terms of interactions with society, as in developed countries in Europe (Lukovics et al., 2017). Furthermore, the importance of public SC is expected to become more important for Korean firms in the future. This is in line with the finding from RRI research that focusing on trust with stakeholders led to increased revenue as an advantage (Dalziel et al., 2018). This means that Korean firms are willing to engage in RRI by embracing their interests in areas where technology interacts with society, similarly to researchers in developed countries with high technological levels (Arnaldi et al., 2015; Hartley et al., 2019).

From the cost perspective, technological forecasting and technological exploration (TF) and certification of technology (CT) as anticipation criteria and training and specialized personnel (TS) and organizational culture and system establishment (OS) as responsiveness criteria were important at present, but for the future, institutional reflection (IR) as a reflexivity criterion and external stakeholder network operation (ENO) as an inclusion criterion became important, in addition to technological forecasting and technological exploration (TF) as an anticipation criterion and organizational culture and system establishment (OS) as a responsiveness criterion. In other words, the importance of all general criteria was projected to become even. In both the present and the future, technological forecasting and technological exploration (TF) as an anticipation criterion was rated as the most important, which means that well-controlled emerging technologies can provide opportunities to solve societal challenges (Mertens, 2018; Scholten & Van Der Duin, 2015). At present, the importance of external

stakeholder network formation (ENF) and external stakeholder network operation (ENO) as inclusion criteria was not high, but in the future, the importance of external stakeholder network operation (ENO) at high and very high levels of RRI increased. This indicates that the utilization of the network and inclusion of stakeholders is important for RRI to be well implemented (Brand & Blok, 2019). The preferences for RRI implementation levels confirmed the above trends. At the present time, the highest priority was found for a high level of RRI, with firms expecting high costs in technological forecasting and technological exploration (TF) and certification of technology (CT) as anticipation criteria and training and specialized personnel (TS) and organizational culture and system establishment (OS) as responsiveness criteria. Instead, for the future, the highest priority was identified for a very high level of RRI implementation, with high costs anticipated in institutional reflection (IR) as a reflexivity criterion and external stakeholder network operation (ENO) as an inclusion criterion, as well as technological forecasting and technological exploration (TF) as an anticipation criterion and organizational culture and system establishment (OS) as a responsiveness criterion. Experts at the firms determined that higher levels of RRI implementation in the future would lead to higher costs.

Overall, the results showed that economic performance and technical level were important criteria for evaluating the benefits of RRI, while anticipation and responsiveness were important criteria for costs. However, differences were found between the present and the future. Also, taken together, the experts indicated that RRI implementation would cause firms to receive additional benefits, but also force them to pay additional costs. They also thought that there would be more benefits for the business

in a decade than at the present. In terms of costs, in the short term, the focus was on certain factors, but in the future, all RRI factors were distributed evenly. This indicates that firms are aware of how to distribute cost factors over the short and long term. These results imply that if sufficient preparation time is given for regulatory components within a firm, such as those involved in RRI, the corresponding principles can be internalized and become beneficial for the firm. The ability to share costs also shows that firms recognize how to mitigate the consumption of internal resources through appropriate controls. Firms recognized that even if constraints such as RRI impose greater costs, they will eventually bring greater benefits.

The results of this study consistent with that RRI promotes firms' ability to retain a competitive advantage, increasing its potential in terms of the profits of a firm or industry (Dalziel et al., 2018; Lees & Lees, 2018); therefore, firms implementing RRI overcome the challenges of RRI by securing a competitive advantage, even if there is no clear and predictable return on investment (Long & Blok, 2018). Ultimately, this finding indicates that the innovation induced by RRI overcomes obstacles, offsets costs, and then eventually increases firms' competitiveness (Porter & Van Der Linde, 1995). Next, this finding aligns with previous claims that firms are willing to do good to society through RRI (Chatfield, Iatridis, et al., 2017; Schumacher & Wasieleski, 2013). In the long term, a firm's RRI-driven ethical activities may eventually result in improved performance by its management (Farjoun, 2010; Schumacher & Wasieleski, 2013). Therefore, it can be concluded that, unlike voluntary CSR, even if RRI is enforced in a compulsory manner, it is highly likely that it can be well established and promoted even in firms that consider

profit first (Auer & Jarmai, 2018).

Based on these results, the motivations of firms to adopt the aspects of RRI evaluated in this study can be summarized as follows. Social interventions in the technology development process required by RRI can be a novel challenge for private firms. However, if firms prepare to approach RRI implementation at a strategic level (Auer & Jarmai, 2018), RRI will bring more benefits for firms through competitive advantage and ethical principles that are institutionalized by innovation (Farjoun, 2010; Lees & Lees, 2018; Porter & Van Der Linde, 1995; Schumacher & Wasieleski, 2013).

4.6.2 Implications and limitations

RRI views intervention in the early stages of technology development as especially important to prepare for offsetting the unintentional negative social effects of emerging technologies and thereby optimizing their benefits (Mitchell et al., 2018). Through RRI, firms perform technological forecasting and technological exploration (TF) and certification of technology (CT) activities in terms of anticipation and self-reflection (SR), and institutional reflection (IR) activities in terms of reflexivity. Firms engage in activities of external stakeholder network formation (ENF) and external stakeholder network operation (ENO) in terms of inclusion. Firms can also conduct training and specialized personnel (TS), organizational culture, and system establishment (OS) initiatives in terms of responsiveness. However, the compulsory nature of these interventions, which involve regulations, results in cost consumption for enterprises. If there are social benefits, the government pushes for them, but resistance to corporate policies can arise. However, it has been argued that the costs of introducing regulations such as RRI create offsetting efforts and bring about new innovations, which in turn provide benefits (Porter, M. E., 1995).

As a result, companies need to recognize regulations as a competitive opportunity. However, real-world companies are often not aware of this because they are not prepared to implement their innovation strategies (Ceicyte, J., & Petrite, M, 2018). Currently, data on RRI policies have not been gathered at the enterprise level, making it difficult to use quantitative methodologies. Thus, the AHP method based on expert awareness can help solve problems by utilizing a systematic hierarchy model. In this context, I suggest that

the results of this study, derived using the AHP, can help reduce the burden of introducing RRI policies, which companies perceive to be regulations, and provide an opportunity to accept RRI.

More specifically, the strategic utilization potential of RRI for firms at the firm or industry level is as follows. First, codes of conduct in AV are an important issue. The advantage of AV technology is that it can reduce accidents caused by human negligence. However, accidents that occur while driving an AV may impact pedestrians who are walking, or AV may choose to sacrifice the driver to protect pedestrians. At this time, I think it is necessary to make moral decisions that reflect a large number of interests. However, participants in a recent study approved of an AV that sacrificed the driver for greater benefit and wanted others to buy it, but they showed a contradictory tendency to want to ride in an AV that protected the driver at all costs. This duality may impede AV commercialization, regardless of the technological advancement of AV. In these situations, self-reflection (SR) and institutional reflection (IR), which examine how technology can interact with consumers in the real world, can help companies locate their products in the marketplace. These can become important issues that require social consensus. Therefore, it is necessary to develop a predictive scenario in the event of an AV incident and a response program in the event of an accident through external stakeholder network formation (ENF) and external stakeholder network operation (ENO), with stakeholders including the public (who can become customers). Companies can gain customer trust and a good reputation, and may have the distinction of their end products being chosen by consumers. Companies that have not gone through such a process might not be selected

by customers even if the performance of their AV vehicles is excellent (Bonnefon, et al. 2016). In Korea, in an interview with a researcher working at a car manufacturer, the firm was not familiar with the specific concept of RRI, but in preparation for the AV era, the vehicles were mandatorily equipped with a black box that is not a legally required product. Since automobile laws and regulations vary from country to country, or even from one state to another, automobile companies make and sell products that are produced as permitted by laws and regulations. Therefore, providing a non-mandatory black box in advance can be seen as a proof of responsibility for vehicle safety. Furthermore, the automaker sought to protect both drivers and pedestrians by preemptively installing black boxes. In addition, although these were not AV vehicles, their vehicles were equipped with a technology that prevents the door from opening when a driver is coming from behind when the driver tries to get out, or an alarm that goes off when a child is left in the back seat for safety. Korean automakers have been making preemptive efforts to address the risks of future AV, and all of these technologies are related to self-reflection (SR) and institutional reflection (IR) in terms of reflexivity and external stakeholder network formation (ENF) and external stakeholder network operation (ENO) in terms of inclusion, which is related to the formation of a social consensus.

Second, as an example from BT, the dairy industry in New Zealand has been in a recession recently, and the RRI aspect of customer relations has been improved through the improvement of eco-friendly images through external stakeholder network formation (ENF) and external stakeholder network operation (ENO). By emphasizing these aspects,

firms have secured competitiveness (FP) in terms of RRI benefits such as improvement in product premiums (Lees, N., & Lees, I., 2018).

Third, the results of a case study from the financial sector suggest that the stage gating review method is an appropriate mechanism to systematically implement RRI in enterprises when developing new products (PD) (Asante, K., Owen, R., & Williamson, G., 2014). In addition, in the introduction and implementation of RRI in start-up companies, a study of the "design and testing of tool" approach, called responsible management of innovation (RMoI), allows the elements of anticipation, reflexivity, inclusion, and responsiveness to be considered as part of firm-internal processes; this was expected to help firms implement RRI in practice (Long, TB, et al., 2020).

Based on the need and potential for RRI adoption, the results from this study will help the private sector to innovate responsibly and provide a broader framework of corporate behavior in which end users work closely together to ensure that end products are desirable. In this study, it is expected that RRI will act as a regulatory framework for enterprises, and will also serve as an opportunity to promote innovation for enterprises. From this point of view, I suggest that this research contributes to the elimination of uncertainty caused by RRI adoption (Mitchell, P. D., 2018).

This study also makes several academic contributions. Regarding its theoretical contributions, first, if RRI is implemented in a firm, will the firm adopt it voluntarily? If so, the reason for this is unknown. This study provides some small clues regarding this

question. Second, it is noteworthy that this study confirmed the applicability of RRI in a non-European country and presented empirical evidence to support its conclusions. This is meaningful in light of verifying the feasibility of RRI in countries where the RRI concept is not widespread. Third, the AV or BT targeted for analysis has very different characteristics and is meaningful in that it covers a very wide range of technologies. Next, there is a contribution to the firms. Technology-driven firms can quickly introduce RRI and hedge the risks of emerging technologies, giving them a opportunity to solidify their position. Since the risks of technology in the future can be unpredictable and cause higher-than-expected losses, hedging the risk of developing technology using RRI can be a good strategy for firms.

The policy contribution of this study lies in its discussion of how firms in Korea could facilitate the implementation of RRI. According to the results, in the long run, firms are willing to comply with RRI regulations if they provide corresponding benefits. These results show that firms are willing to respond to the side effects of emerging technologies. Therefore, the RRI implementation policy for a firm needs to present how it is beneficial for the firm (Lees & Lees, 2018). Nonetheless, like other studies, this study has limitations. First, this study did not produce the quantitative figures necessary for RRI implementation in industry, and further research is needed to analyze specific mechanisms broken down by firm size, technology level, and other factors. Second, this study was limited to Korea in Asia. This paper can serve as a guide for the study of RRI in other countries and regions. However, it is recommended to use the results of research that is tailored to the specific context of each country.

Chapter 5. Overall conclusion

5.1 Summary and contributions

The modern R&D system focuses on the economic benefits of technology and values the legal and institutional foundations and expert system for managing technology and science. However, environmental and ethical issues have been raised in relation to technology and science in society. In the process of resolving these issues, new attempts were made, such as the CTA focusing on the participatory viewpoint in the technology development process (mid-1980s) (Suh, 2019) and the ELSI framework focusing on ethical evaluation (mid-1990s). However, as attention finally came to be focused on the product and service stages that interface with society, RRI emerged as a framework insisting on the need for a more comprehensive perspective. RRI emphasizes the responsiveness of integrating anticipation (e.g., CTA), reflexivity (e.g., ELSI), and inclusion (e.g., public participation) that have been implemented individually into iterative learning systems. In addition, RRI implementation is considered to be more important in firms that commercialize technology. Meanwhile, RRI, which was announced in the EU in 2011, is still in its early stages. Discussions on implementation are underway in countries in Europe, and implementation in firms is also just beginning.

Korea has played a significant and important role in R&D in the past and maintains one today. Therefore, Korea needs to prepare for the social ripple effects of emerging

technologies. However, the debate on RRI implementation in Korea has just started and is therefore limited. RRI is a framework that recently emerged in technologically advanced European nations, with the goal of increasing the positive effects of innovation in the early stages of technological development. RRI remains controversial in terms of its concepts and practices, and Korea lacks policy experience with regard to key RRI elements. Therefore, this dissertation consists of three essays, which analyze the social impacts of innovation on emerging technologies in Korea from the perspective of RRI.

The first essay consists of reviewing the literature to support social innovation in emerging technologies. In recent decades, the evolution and development of theories related to social innovation of emerging technologies in Europe have been investigated, and research questions and methodologies used in these studies have been summarized. In this study, I would like to provide answers to the research questions that need to be solved to introduce RRI: (1) what are the possible barriers to introducing RRI in Korea, and (2) whether firms that commercialize technology should introduce RRI.

Korea has a newly industrialized economy (NIE), making it important to examine the country's potential for RRI implementation, as RRI is still a controversial topic. Korea also lacks policy experience in regard to key RRI elements, which may present barriers to RRI implementation in the future. Accordingly, the second essay of this study attempts to inform the adoption of RRI policies in Korea by using an analytical hierarchy process approach to identify and prioritize anticipated barriers to RRI implementation. To this end, we first conducted an extensive literature review and consulted with experts to identify

the various possible barriers to RRI adoption. As a result, we identified five barrier categories (economic, implementation, policy and politics, society, and technology) with a total of 13 barriers across these categories. Although previous studies have identified the various obstacles that RRI must overcome, these barriers had not previously been weighted and/or ranked to indicate importance and relative impact. Therefore, this study focused on ranking such obstacles and then used the AHP method to weigh and prioritize the obstacles to offer advice for the Korean professionals who have a general understanding of the country's R&D systems and technologies. The results indicate that the two most important barrier categories are the economic and policy/politics ones. More specifically, the two most important obstacles are the increased innovation costs due to RRI implementation and the lack of an economic incentive to participate in RRI. From these results, the government can consider operating a financial support plan by establishing an institutional foundation through the introduction of the RRI certification system and by providing incentives to firms that introduce and implement the RRI certification (Gurzawska et al., 2017).

Simultaneously, with the recent rise of RRI initiatives in firms that commercialize innovation, experts have argued that in order for RRI to succeed, practical issues must be considered. Accordingly, the third essay explores RRI from the perspective of Korean emerging technology development firms. Although social benefits are expected from RRI, which aims to reduce the side effects of innovations for society, the implementation of RRI requires changing firms' existing rules and routines. Therefore, predicting benefits and costs from the firm's perspective can shed light on the likelihood that RRI will

succeed. In this study, through an expert survey, the relative weights of RRI-related benefit criteria (technological level, economic performance, and public contribution) and cost criteria (anticipation, reflexivity, inclusion, and responsiveness) were analyzed. On this basis, trends in priorities for RRI levels were evaluated from present and future perspectives. Unexpectedly, firms recognized that even if constraints such as RRI impose greater costs, they will eventually bring greater benefits. This finding implies that RRI-induced innovations can overcome obstacles, offset costs, and finally increase firms' competitiveness, and that firms are willing to do good for society through RRI. In the long term, a firm's ethical activities may eventually result in improved performance by its management. Therefore, it can be concluded that, even if RRI is enforced in a compulsory manner, it is highly likely that it can be well established and promoted even in firms that consider profit first.

The results of this third essay consistent with that RRI promotes firms' ability to retain a competitive advantage, increasing its potential in terms of the profits of a firm or industry (Dalziel et al., 2018; Lees & Lees, 2018); therefore, firms implementing RRI overcome the challenges of RRI by securing a competitive advantage, even if there is no clear and predictable return on investment (Long & Blok, 2018). Ultimately, this finding indicates that the innovation induced by RRI overcomes obstacles, offsets costs, and then eventually increases firms' competitiveness (Porter & Van Der Linde, 1995). Next, this finding aligns with previous claims that firms are willing to do good to society through RRI (Chatfield, Iatridis, et al., 2017; Schumacher & Wasieleski, 2013). In the long term, a firm's RRI-driven ethical activities may eventually result in improved performance by its

management (Farjoun, 2010; Schumacher & Wasieleski, 2013). Therefore, it can be concluded that, unlike voluntary CSR, even if RRI is enforced in a compulsory manner, it is highly likely that it can be well established and promoted even in firms that consider profit first (Auer & Jarmai, 2018). Based on these results, the motivations of firms to adopt the aspects of RRI evaluated in this study can be summarized as follows. Social interventions in the technology development process required by RRI can be a novel challenge for private firms. However, if firms prepare to approach RRI implementation at a strategic level (Auer & Jarmai, 2018), RRI will bring more benefits for firms through competitive advantage and ethical principles that are institutionalized by innovation (Farjoun, 2010; Lees & Lees, 2018; Porter & Van Der Linde, 1995; Schumacher & Wasieleski, 2013).

This study provides three academic contributions to the scholarly literature. First, this study demonstrates the applicability of RRI to non-European NIE countries. The results obtained through our study demonstrate that technologically advanced countries and their national innovation environments are unique.

Second, it is noteworthy that this study confirmed the applicability of RRI in a non-European country and presented empirical evidence to support its conclusions. This is meaningful in light of verifying the feasibility of RRI in countries where the RRI concept is not widespread. This study presents new empirical evidence by developing categorized barriers and setting weights for each barrier (based on the barriers identified in the existing literature). In addition, if RRI is implemented in a firm, will the firm adopt it

voluntarily? If so, the reason for this is unknown. This study provides some small clues regarding this question.

Third, the AV or BT targeted for analysis has very different characteristics and is meaningful in that it covers a very wide range of technologies.

This study also makes one managerial implication and several policy contributions. There is a management implication. Technology-driven firms can quickly introduce RRI and hedge the risks of emerging technologies, giving them an opportunity to solidify their position. Since the risks of technology in the future can be unpredictable and cause higher-than-expected losses, hedging the risk of developing technology using RRI can be a good strategy for firms.

The first policy contribution is that this study sets the stage for discussions on how to overcome the identified barriers. Ranking the obstacles to RRI implementation will also help Korea to overcome those obstacles. In addition, this study suggests that it is especially important to prepare alternatives to economic and policy/political barriers, which emerged as the most impactful barriers in our research. These results underscore the necessity of preparing the proper level of financial support and clarifying policy directions in order to overcome the obstacles facing RRI implementation. In addition, it might be necessary to encourage active communication among various stakeholders to gather differing perspectives regarding how to overcome the barriers to the successful implementation of RRI. Furthermore, making sufficient efforts to anticipate and prepare

for potential conflicts of interest between stakeholders can be useful in countries where R&D is important.

Second, according to the results, in the long run, firms are willing to comply with RRI regulations if they provide corresponding benefits. These results show that firms are willing to respond to the side effects of emerging technologies. These findings provide valuable cross-cultural context regarding perceptions of RRI and shed light on how stakeholders balanced various ethical considerations regarding RRI.

Third, we derive the characteristics of emerging technologies from examples of RRI implementation in Korea. In the results of our analysis, there were no significant differences between the investigated technologies (AV and BT) with regard to the importance of RRI obstacles. This finding could be important for promoting appropriate RRI policies. The selection and intensity of RRI policy implementation will differ based on characteristics of the technologies/industries (e.g., the calculated budgets will vary).

Fourth, we are able to predict the benefits of RRI in Korea. Implementing technological innovations that prevent emerging technologies from having negative effects is advantageous because it can strengthen the position of Korea to that of a technological power. In regard to future technology, the levels of risk and the magnitude of losses may be difficult to predict; therefore, efforts to prepare for these potential issues can help the country's industrial policy.

5.2 Limitations and future research

Nonetheless, like other studies, this study has limitations, five of which are addressed below.

First, this study is a preemptive study conducted under the assumption that RRI is introduced to Korea as a novel framework, and it is the first such study to be attempted in Korea. Therefore, it is meaningful in that it analyzed barriers and drivers in existing studies (e.g., through qualitative research methods such as interviews), identified them as criteria, and investigated their importance at the national and firm levels through the AHP. However, we could not analyze certain issues, such as which parts of national-level barriers firms considered to be the most important. Furthermore, it will be necessary to analyze the policy demands of firms based on the research results. Such analyses will help R&D to bring synergies to policies and business sites more organically when RRI is introduced in Korea. Meanwhile, additional analysis should reflect the characteristics of the legal and institutional management system for emerging technologies. Although the process of technology development in AV and BT targeted in this study may appear similar, the rigors of related laws and regulatory management differ significantly from the beginning of commercialization. In AV, after development, prototypes are produced and commercialized by firms themselves or through certification by an authorized certification body. In contrast, the processes involved in BT are exemplified by new drug development in the pharmaceutical industry; it is said that new drug development takes a period of 15 years and involves a cost of about 500 million dollars after going through a

process of preclinical trials, three stages of clinical trials, new drug approval, and new drug approval after patent application. This phenomenon arises because firms are forced to follow new drug licensing processes, and the strictness of these regulations acts as a barrier to entry. Therefore, firms in the biological industry may exhibit different characteristics from those in the automotive industry even when implementing RRI. However, in the results of RRI implementation analysis for firms, there was no significant difference between AV and BT. Based on the results of these analyses, firms may see that when implementing RRI regulations, they are more influenced by the regulations themselves than by the technical characteristics of emerging technology. This may be because RRI is still in the early stages of implementation, so there are no specific measures for firms to respond to. Therefore, in future analyses, more organic relationships between technical, regulatory, and corporate details should be examined.

Second, in the same vein as above, this study focused on investigating the wider perceptions related to the introduction of RRI. However, in programs that support RRI in Europe and the United States, it has been seen that the use of specific methodologies emphasizes the uniqueness of those programs. Therefore, if RRI-related projects are to be carried out in Korea, it is necessary to consider the use of specific methodologies suitable for the context of Korea, and the constructive technology impact assessment method might serve as a promising example.

Third, because the analytical method used was based on expert perceptions, we were unable to estimate the quantitative figures needed to circumvent the identified obstacles

and to implement in industry. For example, it may be necessary to calculate certain arithmetical figures, such as estimating the costs involved in tackling economic barriers, to implement RRI policies. We therefore recommend that further research be conducted to analyze specific mechanisms broken down by firm size, technological level, and other factors using quantitative figures.

Fourth, while our results can guide future research in other countries/regions, this study focuses exclusively on Korea. However, it is recommended to use the results of future research that is tailored to the specific context of each country.

Fifth, this study focused on only two emerging technologies—autonomous vehicles and biotechnology—and it is therefore necessary for future research to explore additional emerging technologies such as robots, artificial intelligence, and renewable energy.

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Appendix A: Methodology

In this appendix, the detailed calculation process of the AHP method used in this paper is described (Dweiri, Kumar, Khan, & Jain, 2016). Since essays II and III use the same methodology, herein we present the analysis from essay II as an example, which includes both criteria (essay II and III) and alternative (essay III) assessments.

In order to choose the best implementation of RRI in business context using AHP, four stages are developed as shown in Table 4. 2. Each criterion is ranked based on respondents' opinions using surveys. Respondents were asked to perform pair-wise comparison of the criteria based on the importance scale shown in Table A. 1.

Table A. 1. Importance scale of factors in pair-wise comparison.

Importance scale	Importance description
1	Equal importance of "I" and "j"
3	Weak importance of "I" over "j"
5	Strong importance of "I" over "j"
7	Demonstrated importance of "I" over "j"
9	Absolute importance of "I" over "j"

* Note: 2, 4, 6, and 8 are intermediate values

Then for each general criterion or sub-criterion as well as alternatives (the level of RRI) is identified in the level of hierarchy based on respondents' opinions shown in Fig 4. 2 and Fig 4. 3. In this study, we consider four levels of RRI for ranking and Table 4. 1 will provide information about levels of RRI. At first, general criteria for benefits in the present perspective were evaluated. Each pair of the comparison matrix evaluated by the respondent is integrated by geometric means to form a single pair comparison matrix, as shown in Table A. 2.

Table A. 2. Respondents opinions for pair-wise comparison for general criteria for benefits in the present.

	Technical level	Economic performance	Public contribution
Technical level	-	0.649	2.278
Economic performance	1/0.649	-	3.071
Public contribution	1/2.278	1/3.071	-

Table A. 2 is represented in matrix A and will be used to illustrate how AHP works.

$$A = \begin{bmatrix} 1 & 0.649 & 2.278 \\ 1/0.649 & 1 & 3.071 \\ 1/2.278 & 1/3.071 & 1 \end{bmatrix}$$

The sum of the columns in A = (2.979 1.975 6.350)

A normalized matrix N is obtained by dividing each element of the matrix A by the sum of the respective column.

$$N = \begin{bmatrix} 0.336 & 0.329 & 0.359 \\ 0.517 & 0.506 & 0.484 \\ 0.147 & 0.165 & 0.157 \end{bmatrix}$$

To find the weight of each criterion, a matrix W is obtained by calculating the average for each row of the matrix N.

$$W = \begin{bmatrix} w_1 = \dfrac{0.336 + 0.329 + 0.359}{3} = 0.341 \\ w_2 = \dfrac{0.517 + 0.506 + 0.484}{3} = 0.502 \\ w_3 = \dfrac{0.147 + 0.165 + 0.157}{3} = 0.157 \end{bmatrix} = \begin{bmatrix} 0.341 \\ 0.502 \\ 0.157 \end{bmatrix}$$

Notice that $\sum W_i = 1.000$.

As a result, the relative weights of general criteria "technical level 0.341", "economic performance 0.502", "public contribution 0.157" were described in the first row of Table 4. 4.

Pair-wise comparisons were also used to rank the sets of sub-criteria with respect to their associated main criterion. The four levels of RRI were also ranked based on the sub-criteria using the same methodology and the results are shown in Table 4. 4. The values for the alternatives are assigned for each criterion, then multiplied by the corresponding weights and finally summed to give a total score. This process is performed multiple times for each step if the layering model contains multiple layers. For example, if there are two steps, the total score is calculated by multiplying the weight for the general criteria, and then multiplying the weight for the sub-criteria once more (Kabir et al., 2014). In the same way as above, identification for the benefit (10 years in the future) and the cost (present, 10 years in the future) and choosing the best implementation of RRI (alternatives) are shown Table 4. 5, Table 4. 6, and Table 4. 7. The above mentioned results are based on the qualitative judgement of emerging technologies experts. Their judgments were also performed on the web-based I MAKE IT software (http://imakeit.kr).

Appendix B: Survey for essay II

☞ Start survey

Q1. The current assessment identifies the relative importance of the project's goal, “Ranking barriers of RRI implementation in Korea” Please select which criterion (standard) is relatively more important.

Criteria	importance ◀								Equal (1)									▶ importance	Criteria
	Extreme importance (9)	(8)	Demonstrated importance (7)	(6)	Essential or strong (5)	(4)	Moderate importance (3)	(2)		(2)	Moderate importance (3)	(4)	Essential or strong (5)	(6)	Demonstrated importance (7)	(8)	Extreme importance (9)		
Economic barrier																			Implemen-tation barrier
Economic barrier																			Policy & political barrier
Economic barrier																			Social barrier
Economic barrier																			Technical barrier
Implemen-tation barrier																			Policy & political barrier
Implemen-tation barrier																			Social barrier
Implemen-tation barrier																			Technical barrier
Policy & political barrier																			Social barrier
Policy & political barrier																			Technical barrier
Social barrier																			Technical barrier

Q2. From the “economic barrier” point of view, please select which criterion (standard) is relatively more important.

Criteria	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Criteria
Increased innovation costs due to RRI implementation																		Lack of economic incentives to participate in RRI

Q3. From the perspective of "implementation barrier,” which alternative do you think is more appropriate?

Criteria	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Criteria
Lack of clarity and empirical																		Lack of RRI training and

Criteria	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Criteria
RRI cases																		expertise
Lack of clarity and empirical RRI cases																		Lack of organizational structure and suitable RRI culture
Lack of RRI training and expertise																		Lack of organizational structure and suitable RRI culture

Q4. From the “policy & political barrier” point of view, please select which criterion (standard) is relatively more important.

Criteria	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Criteria
Increased bureaucracy with RRI implementation																		Lack of clear RRI policies and unclear focus on RRI regulation
Increased bureaucracy with RRI implementation																		Lack of trust and political leadership to lead RRI change
Lack of clear RRI policies and unclear focus on RRI regulation																		Lack of trust and political leadership to lead RRI change

Q5. From the perspective of "social barrier,” which alternative do you think is more appropriate?

Criteria	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Criteria
Lack of social acceptance and academic identity of RRI																		Lack of experience with bottom-up governance
Lack of social acceptance and academic identity of RRI																		Conflicts of interest and a lack of stakeholder networks
Lack of experience with bottom-up governance																		Conflicts of interest and a lack of stakeholder networks

Q6. From the “technical barrier” point of view, please select which criterion (standard) is relatively more important.

Criteria	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Criteria
Difficulty in understanding emerging technologies																		Difficulty in identifying the impacts of emerging technologies on society

Appendix C: Survey for essay III

☞ Start survey: □ Please evaluate these questions at the current point (short term)

◉ First, please answer the questions focusing on benefits.

Q1. The current assessment identifies the relative importance of the project's goal, “Determine how RRI will apply in the firm: Benefits.” Please select which criterion (standard) is relatively more important.

Criteria	importance ◀								Equal (1)		▶ importance							Criteria
	Extreme importance (9)	(8)	Demonstrated importance (7)	(6)	Essential or strong (5)	(4)	Moderate importance (3)	(2)		(2)	Moderate importance (3)	(4)	Essential or strong (5)	(6)	Demonstrated importance (7)	(8)	Extreme importance (9)	
Technological level																		Economic performance
Technological level																		Public contribution
Economic performance																		Public contribution

Q2. From the “technical level” point of view, please select which criterion (standard) is relatively more important.

Criteria	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Criteria
Technological excellence																		Social acceptability of technology

Q3. From the perspective of "technological excellence,” which alternative do you think is more appropriate?

Criteria	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Criteria
Low level																		Intermediate
Low level																		High
Low level																		Very high
Intermediate																		High
Intermediate																		Very high
High																		Very high

In the same way as above, respondents evaluate the last questions for the benefits in the present.

☞ Next, the following questions focus on costs.

Q11. The current assessment determines the relative importance of the project's goal, “Determine how RRI will apply to the firm: Cost.” Please select which criterion (standard) is relatively more important.

Criteria	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Criteria
Anticipation																		Reflexivity
Anticipation																		Inclusion
Anticipation																		Responsiveness
Reflexivity																		Inclusion
Reflexivity																		Responsiveness
Inclusion																		Responsiveness

Q12. From the perspective of “anticipation,” please select which item (baseline) is relatively more important.

Criteria	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Criteria
Technological forecasting and technological exploration																		Certification of technology

Q13. From the perspective of “technical forecasting and technology exploration,” which alternative do you think is more appropriate?

Criteria	(9)	(8)	(7)	(6)	(5)	(4)	(3)	(2)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Criteria
Low level																		Intermediate
Low level																		High
Low level																		Very high
Intermediate																		High
Intermediate																		Very high
High																		Very high

In the same way as above, respondents evaluate the last questions for the costs in the present.

☞ Start survey: Please evaluate at the time point of 10 years later (long term)

In the same way as above, respondents evaluate the last questions for the benefits and costs in the future.

Abstract (Korean)

본 논문은 신기술로 촉진된 혁신의 사회적 영향을 분석하는 세 개의 에세이로 구성되어 있다. 한 국가에서 연구개발과 혁신은 지난 수십 년간 광범위한 논쟁의 대상이 되어왔지만, 본 논문은 새로운 혁신 프레임워크인 책임있는 연구혁신(responsible research and innovation, RRI) 접근법을 통해 기존의 혁신 정책에서 고려하지 못한 주제들에 대하여 조사한다. RRI는 최근 유럽의 기술 선진국에서 부각되고 있는 개념으로 기술개발 초기단계의 개입을 통해 혁신의 긍정적인 효과를 높이는 것을 목표로 한다. 신기술이 발전하면서 발생할 수 있는 예상치 못한 파급효과에 대한 대비 차원이다.

첫 번째 에세이는 신기술의 사회적 혁신을 지원하기 위한 문헌검토로 구성된다. 최근 몇 십년 간 유럽에서 신기술의 사회적 혁신과 관련한 이론의 진화와 발전과정을 조사하고, 이들 연구에서 해결하고자 한 연구 질문과 적용 연구방법론을 정리하였다. 이를 통해 본 연구에서는 RRI 도입을 위해 해결해야하는 연구 질문인 한국에 RRI 도입 시 발생 가능한 장애요인은 무엇인가와 기술을 상용화하는 기업에서 RRI를 도입해야 하는가에 대한 답을 제시하고자 한다.

신기술 개발을 통해 최근 산업화된 경제 국가로 성장한 한국에서도 RRI의

이행을 검토하는 것은 중요한 문제일 수 있다. 그러나 아직 RRI는 개념과 실행방식에서 논란이 존재하고 있고, 또한 한국은 RRI 개념의 핵심 요소들에 대한 정책적 경험이 미흡하다. 따라서 RRI가 한국에 도입될 때 이러한 문제점들이 장애요인으로 작용할 수 있다. 이에 따라 본 연구의 두 번째 에세이는 선제적 관점에서 예상되는 장애요인을 식별하고 계층화 분석 방법을 사용하여 우선순위를 정함으로써 RRI의 도입 시 정책적 활용도를 높이고자 하였다. 기존 문헌 검토를 통해 13개의 장애요인이 확인되었으며 이는 경제, 이행, 정책 및 정치, 사회, 기술의 5개 유형으로 분류되었다. 분석결과는 가장 중요한 두 가지 장애요인 카테고리가 경제와 정책 및 정치라는 것을 보여준다. 세부 항목에서는, ‘RRI 이행으로 인한 혁신 비용 증가’와 ‘RRI에 참여할 경제적 인센티브 부족’ 이 1, 2위를 차지했다. 이러한 결과로부터, RRI의 성공적인 실행을 위해서는 적절한 재정적 지원과 명확한 정책방향의 제시가 필요하다는 것을 유추할 수 있었다.

한편 최근 전문가들은 RRI가 사회에서 잘 자리잡기 위해서는 혁신을 상용화하는 역할을 하는 기업에서의 이행이 필요할 뿐만 아니라, 이를 위한 실질적인 이슈를 고려해야 한다고 주장한다. 이에 따라, 세번째 에세이는 한국의 신기술 개발 기업의 관점에서 RRI를 탐구한다. 사회를 위한 혁신의 부작용을 줄이는 것을 목표로 하는 RRI로부터 사회적 이익이 기대되지만, 기업에서의 RRI 이행은 기업의 기존 규칙과 루틴을 바꾸어야 하는 문제이다.

따라서 기업 입장에서의 편익과 비용을 예측하는 것은 RRI가 성공할 가능성을 조명할 수 있는 중요한 주제일 수 있다. 본 연구에서는 전문가 조사를 통해 RRI 관련 편익 기준(기술 수준, 경제적 성과, 공공 기여)과 비용 기준(예측, 성찰, 참여, 대응)의 상대적 가중치를 분석하였다. 이를 바탕으로 현재와 미래 관점에서 RRI 4개 수준의 우선순위 변화추이를 평가하였다. 놀랍게도 기업들은 RRI와 같은 제약조건이 비용을 부과하지만 결국 더 큰 이익을 가져올 것이라고 인식했다. 또한, 현재보다 미래에서 RRI가 강화되는 수준에 대해 편익이 더 높아진다고 생각하였다. 연구결과는 기업은 RRI로 유도된 혁신으로 장애요인을 극복하여 비용을 상쇄하고 최종적으로 기업의 경쟁력을 높일 수 있으며, 기업들은 RRI를 통해 사회에 좋은 일을 할 의향이 있음을 시사한다. 장기적으로는 기업의 윤리적 활동이 기업의 성과를 향상시킬 수 있었다. 따라서 RRI가 정책적으로 시행되더라도 이익을 추구하는 기업에서도 잘 정착되고 촉진될 가능성이 높다는 것을 추론할 수 있었다.

주요어 : 책임있는 연구혁신, 계층화분석, 신기술, 장애요인, 기업, 비용/편익

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