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Responsible Research and Innovation and Its Implications for China

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Abstract

Responsible research and innovation (RRI) represents a new evolving approach to governing research and innovation that takes into account potential impacts on the environment and society. Most published studies on RRI focus on the social benefits of research and innovation through examining RRI's definitions and approaches for its implementation. In contrast, the present study addresses the influence of RRI on economic growth, and discusses the situations in which RRI will benefit economies. Our study finds that for its implementation to be successful, RRI needs to meet certain conditions, and that its implementation is not always beneficial to economic growth. To achieve a better result from RRI as part of an innovation policy, each country should balance the push and pull power of RRI to make sure that it becomes a building block rather than a stumbling block for innovation, economic growth and social welfare. To assure that RRI can be successfully implemented, China needs to strengthen and improve the participation mechanisms for stakeholders in major scientific and technological innovative activities.

Key words: China's innovation policy, economic growth, responsible research and innovation

JEL codes: C5, O4, O32, O38

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1. Introduction

The story of the development of modern science and technology since the beginning of the 20th century demonstrates that it does not necessarily bring happiness to society when there is no proper assessments and public scrutiny for scientific and technological innovations (Von Schomberg, 2013). Moreover, the negative consequences of modern science and technology are often unpredictable and unintended (Owen et al., 2012). Against this background, a new developmental agenda of responsible research and innovation (RRI) has been raised by high income economies, which provides an operational route for sustainable development (Yan et al., 2014).

The concept of RRI has achieved "particular visibility and traction in an EU, and specifically European Commission policy context" since 2011 (Owen et al., 2012, p. 751). Although it is a new evolving concept, there is no consensus on the definition of "responsible research and innovation," and approaches to how RRI should be implemented differ. For instance, the "Science with and for Society" (SwafS) program developed one of the most influential concepts of RRI in Europe (Schroeder, 2015) define RRI as "an inclusive approach to research and innovation, to ensure that societal actors work together during the whole research and innovation process" (SwafS, 2013). Stilgoe et al. (2013) put forward the well-known four dimensions of responsible innovation, which are anticipation, reflection, inclusion and responsiveness. The basic idea of the Stilgoe framework is to predict the direct and indirect effects of innovation and to reflect on the innovative subject's own motivation, behavior and other assumptions. At the same time, to deal with the issues arising during the innovation process, it calls for more actors to be involved in the innovation process. Although there are differences among the explanations of RRI, they have similar elements, and all emphasize the importance of stakeholders' participation during the research and innovation process, and that the outcomes of research and innovation should be able to benefit society. Furthermore, scholars argue that RRI is a comprehensive approach to achieve a better alignment of research and innovation with societal needs; that is, RRI can steer the innovation process towards societally beneficial objectives (Von Schomberg, 2013).

China is currently at a critical stage to build a "moderately prosperous society," and efforts are being directed to deepen reforms. The role of science and technology in economic and social development has never been so important for China's economy. How China can benefit from innovation while reducing potential risks and costs is a major concern for China's innovation policy. RRI is an emerging framework that may be helpful in addressing some of the challenges and risks faced during the research and innovation process.

Current studies on RRI mainly concentrate on high income economies. Less focus has been given to emerging economies, such as China. The published literature on RRI in China centers on the introduction of the RRI framework. Yu (2013) discussed responsible innovation at the "3TU-5TU International Conference of Ethics of Science and Technology" held in 2012 in China. Yu (2013) indicates that responsible innovation, a contemporary issue combining technological ethics with management, should be given more attention in China. Yan et al. (2014) use case studies to provide an interpretation of responsible innovation, and review the historical background, origin and connotations of RRI. They point out that the main purpose of responsible innovation is to combine the enterprises of social responsibility closely with technological innovation practices, and to evaluate effectively all aspects influencing technological innovation from the perspective of ethics to ensure the sustainability and social acceptability of the result from the new technological

innovations. Guo (2014) argues that big data technology has made great progress, but there are still uncertain risks in the technology innovation process. As a new methodology designed to test ethical issues in the field of technology innovation, RRI provides a method of guidance for technologically innovative designs represented by big data. Thus, Guo argues that responsible innovation has great significance for the innovation and application of big data technology in China. Liu (2015), undertaking a comprehensive analysis of the research status and development tendency of RRI, finds that responsible innovation is both an innovative idea and a practice, with the goal of respect for and the protection of human rights as well as the improvement of social benefits characterized by full responsibility being undertaken by innovation community. He further points out that the RRI may play a significant role in developing theories of innovation and ethics, and in implementing innovation-driven strategies. Zhao (2011) and Mei et al. (2014) systematically analyze and discuss RRI from the perspective of ethics. In contrast, examination of RRI from the perspective of economics, especially through the innovation theoretical models, is rare, and the present paper will make a contribution in this aspect.

There is always a trade-off between successful innovation and effective innovation. This is an important concern for both high income economies and emerging economies like China. Because they all seek to boost potential growth, and have all emphasized the role of innovation policy after the international financial crisis, they all pay special attention to the potential outcomes of research and innovation. Therefore, in the present paper, we build a theoretical model to illustrate the influence of RRI on economic growth, and discuss in what situation RRI will benefit economies around the world.

The question of how useful the RRI concept could be in China is difficult answer, as the RRI framework has been developed with high income countries in mind. This is an important question to consider in relation to China's national-level innovation policy.

The rest of the paper is organized as follows. Section II discusses the theoretical model depicting the role of RRI in economic growth. Section III analyzes the innovation policy options to consider whether the RRI approach is of benefit to China. Section IV concludes.

2. Theoretical Motivation and the Responsible Research and Innovation Model

This paper establishes three types of models to illustrate the effects of RRI on economic growth. The theoretical framework in each model includes two parameters: the probability of the successful innovation and the efficiency of the innovation. These two parameters are set differently in three models.

2.1 Benchmark Model

Our benchmark model follows a simplified version of the Aghion–Howitt model (Aghion and Howitt, 1992) on the economics of innovation, which considers the modeling of traditional innovation into the economic growth framework, in which one innovative firm takes the lead in the innovation process.[2]Because our research focus is on the economic consequences of RRI, it is appropriate to use a growth model with innovation included in the benchmark model. In this benchmark model, the innovation, once it succeeds, will not trigger any social costs or risks. The firm and the whole economy will benefit from the innovation. There is no RRI in the benchmark model but we will add the RRI process in the extended version of the model. In the model setting, two major parameters have been considered: the probability of successful innovation λ ($0 < \lambda < 1$)

[2] This simplified version can be obtained in Bénassy-Quéré et al. (2010).

and the efficiency of the innovation γ (γ > 1). The former presumes that a firm has a certain chance to fail during the R&D process; thus, λ is a number between 0 and 1. The higher the λ, the easier it is for the firm to succeed. The latter measures how effective the innovation is once it has succeeded and how it will boost the potential growth of the economy. Because the firm and the whole economy will benefit from the innovation process, the outcome of this innovation for economic growth will always be better than the growth without innovation. Thus, γ is always greater than 1.

To incorporate the innovation process into a growth model, we first need to set up the production function. Following the simplified Aghion–Howitt model (1992), labor (L) is the only factor in the model and working hours can be allocated either to goods production or to research and innovation. We assume them to be X0 and R0 in the benchmark model. Thus, the production function is $Y_0 = AX_0^{\alpha}$, where A > 0 and 0 < *a* < 1. Y_0 is the output, *A* is the productivity and *a* is the output elasticity of labor.

R_0 will not be included in the input of the production function; rather, it will be included in *A*. Once the research and innovation succeeds, the revised production function can be described as:

$$Y_0 = \gamma A X_0^{\alpha}, \tag{1}$$

where γ ($\gamma > 1$) is the efficiency of the innovation.

Based on these assumptions, we can obtain the profit of the firm once its research and innovation has been successful:

$$\pi_0 = \gamma A X_0^{\alpha} - \omega_0 X_0, \tag{2}$$

where ω_0 is the hourly real wage paid in the goods production process. With profit maximization, the optimum profit level with successful research and innovation will be:

$$\pi_0 = \frac{1-\alpha}{\alpha}\omega_0 X_0. \tag{3}$$

However, the research and innovation process will not always be successful; it has a probability of $1 - \lambda$ of failing. In that case, we assume that it brings no return. Thus, the expected profit from the research and innovation will be $\lambda \pi_0$. With a labor market equilibrium, this expected return should be equal to the real wage, ω_0. Then from Equation (3), we have the allocation of labor:

$$X_0 = \frac{1}{\lambda}\frac{\alpha}{1-\alpha},\ R_0 = L - \frac{1}{\lambda}\frac{\alpha}{1-\alpha}. \tag{4}$$

It is easy to observe that the higher the probability of success of innovation λ, the greater the effort that will be placed into research and innovation.

With this labor allocation decision, it is easy to derive the growth rate of the economy. Because there is no demographic change and no capital input, the growth rate will depend on the production enhancement from research and innovation, $\lambda R_0 (\gamma - 1)$. Thus, the growth rate resulting from the successful research and innovation of the benchmark economy will be:

$$g_0 = (\lambda L - \frac{\alpha}{1-\alpha})(\gamma - 1). \tag{5}$$

This shows the effectiveness of the traditional research and innovation process for economic growth. Along with the clearance of the labor market and the maximization of profit, the outcome of the research and innovation process is closely related to the probability of successful innovation λ and the efficiency of innovation γ. With higher levels of successful probability λ and higher efficiency γ, the growth of the whole economy will be higher.

The benchmark model in general considers the contribution of traditional research and innovation towards economic growth. However, certain research and innovations might not benefit society, or may even do harm. In this case, RRI is necessary. How does the RRI process influence economic growth? This is the question that our extended models will answer. Therefore, based on

the benchmark setting, we further introduce RRI into the model. To better illustrate RRI, we will consider two scenarios: without RRI (scenario 1) and with RRI (scenario 2). In scenario 1, the firm is trying to develop innovations that will not benefit the economy as in the benchmark model, but there is no RRI to monitor the process. In scenario 2, there is stakeholder involvement in the research and innovation process. Improper innovation will be terminated at the beginning and appropriate innovation will be enhanced during the whole research process. We will analyze both scenarios and their potential outcomes.

$$Y_1 = (\gamma - k)AX_1^{\alpha}. \tag{6}$$

Compared with the benchmark model, the enhancement of productivity in scenario 1 is lower due to its potential negative effect on the economy. In the same way, the profit obtained from the innovation will also turn out to be lower in scenario 1 once the innovation has become successful:

$$\pi_1 = (\gamma - k)AX_1^{\alpha} - \omega_1 X_1. \tag{7}$$

By maximizing profit, the optimum level of profit in scenario 1 can be expressed:

$$\pi_1 = \frac{1-\alpha}{\alpha}\omega_1 X_1. \tag{8}$$

Because the allocation of labor only depends on the probability of the successful research and innovation, there is no difference in labor allocation between scenario 1 and the benchmark model:

$$X_1 = \frac{1}{\lambda}\frac{\alpha}{1-\alpha},\ R_1 = L - \frac{1}{\lambda}\frac{\alpha}{1-\alpha}\ . \tag{9}$$

The growth rate of scenario 1 will depend on the probability of successful research and innovation, the labor allocation and the efficiency of the research and innovation:

λR_1 (γ – k – 1). Thus, the growth rate resulting from the successful research and innovation of scenario 1 will be:

$$g_1 = (\lambda L - \frac{\alpha}{1-\alpha})(\gamma - k - 1). \tag{10}$$

Therefore, the growth rate not only depends positively on the efficiency and the probability of the successful research and innovation in scenario 1, it also depends on the efficiency lost because of irresponsible research and innovation. The higher the loss k, the lower the growth rate g_1.

2.2 Scenario 2: Model with Responsible Research and Innovation

In scenario 2, the firm takes the approach of RRI. In this case, an improper innovation will not occur at an early stage while a proper innovation will be more beneficial with the full participation of different stakeholders. Thus, both λ and γ need to be adjusted. The probability of a successful innovation is assumed to be lower for l than in the benchmark model and scenario 1. The efficiency of the innovation is assumed to be higher for μ than in the former two models due to the adoption of the RRI policy. Therefore, we revised the probability of successful innovation as $\lambda - l$ ($0 < \lambda < 1$, $0 < l < \lambda$) and the efficiency of the innovation as $\gamma + \mu$ ($\gamma > 1$, $\mu > 0$). Thus, in scenario 2, the probability of successful innovation will be lower than in the case in the benchmark model and scenario 1, because the research and innovation will be monitored and terminated if necessary. Because of the efficiency enhancement stemming from the RRI process, the efficiency of the innovation in scenario 2 will be higher.

Similarly, as in the benchmark model and scenario 1, the working hours of labor (L) can be allocated either to goods production (X_2) or research and innovation (R_2). The pattern of the production function is the same as in the benchmark model and scenario 1: $Y_2 = AX_2^{\alpha}$, where $A > 0$, $0 < \alpha < 1$.

Research and innovation (R_2) together with the RRI process will enter the production function by enhancing productivity. Once RRI succeeds, we can obtain the revised production function:

$$Y_2 = (\gamma + \mu)AX_2^{\alpha}. \tag{11}$$

The profit of the firm, once its research and innovation has been successful, will be:

$$\pi_2 = (\gamma + \mu)AX_2^{\alpha} - \omega_2 X_2. \tag{12}$$

The profit is the highest among all three of the models that we have discussed and it turns out to be a benefit from RRI. The optimum profit level with successful responsible research and innovation can be expressed:

$$\pi_2 = \frac{1-\alpha}{\alpha}\omega_2 X_2. \tag{13}$$

The probability of the successful innovation is lowest among all of the cases. Given $\lambda - l$ as the firm's probability of successful innovation due to the RRI process, it is easy to obtain $1 - \lambda + l$ as the probability of failing in innovation. Once the firm fails in the innovation, it earns no return. Thus, the expected profit of the research and innovation will be $(\lambda - l)\ \pi_2$. With the labor market equilibrium, this expected profit should be equal to the real wage, ω_2. Then based on Equation (13) we obtain the allocation of labor:

$$X_2 = \frac{1}{\lambda - l}\frac{\alpha}{1-\alpha},\ R_2 = L - \frac{1}{\lambda - l}\frac{\alpha}{1-\alpha}. \tag{14}$$

Therefore, with RRI, the firm will devote less effort to research and innovation compared to the benchmark model and scenario 1.

With the labor allocation decision, we can derive the growth rate based on research and innovation in scenario 2. Again, the growth rate will depend on the efficiency of the innovation, which is highest, the probability of successful innovation, which is lowest, and the allocation of labor to innovation. The growth rate resulting from the successful research and innovation in scenario 2 with RRI will be:

$$g_2 = [(\lambda - l)L - \frac{\alpha}{1-\alpha}](\gamma + \mu - 1). \tag{15}$$

As for the growth rate in scenario 2, it is positively related to the original efficiency of successful innovation γ and the probability of λ. This is consistent with the benchmark model. Furthermore, the growth rate is positively related with the additional efficiency μ as a result of RRI. It is negatively related to the probability loss of successful research and innovation l due to RRI.

2.3 Comparison and Discussion

Table 2 summarizes the basic comparisons among the benchmark model, scenario 1 without RRI and scenario 2 with RRI. The first two columns summarize the two key parameters of the three models: the probability and the efficiency of successful research and innovation. The third column summarizes the growth rate of the three models. In this subsection we will discuss the growth rate difference as a result of the research and innovation process in the different scenarios.

Table 1 Model Comparison

	Probability	Efficiency	Growth rate
Benchmark model	λ	γ	$g_0 = (\lambda L - \frac{\alpha}{1-\alpha})(\gamma - 1)$
Scenario 1	λ	$\gamma - k$	$g_1 = (\lambda L - \frac{\alpha}{1-\alpha})(\gamma - k - 1)$
Scenario 2	$\lambda - l$	$\gamma + \mu$	$g_2 = [(\lambda - l)L - \frac{\alpha}{1-\alpha}](\gamma + \mu - 1)$

(1) The growth rate in scenario 1 (irresponsible research and innovation) is always lower than the growth rate of the benchmark model (i.e. $g_1 < g_0$).

It is easy to obtain that:

$$\frac{g_0}{g_1} = \frac{(\lambda L - \frac{\alpha}{1-\alpha})(\gamma - 1)}{(\lambda L - \frac{\alpha}{1-\alpha})(\gamma - k - 1)} = \frac{\gamma - 1}{\gamma - k - 1}. \quad (16)$$

Because $k > 0$, $\frac{g_0}{g_1} > 1$, thus, $g_1 < g_0$. The growth rate in scenario 1 is always lower than in the benchmark model because of the low efficiency coming from irresponsible research and innovation. Thus, irresponsible innovation will reduce the potential growth of the economy and result in less improvement to the whole society.

(2) The growth rate in scenario 2 (with RRI) is higher than the growth rate of the benchmark model when either condition is satisfied:(i) the efficiency enhancement μ is greater than a threshold μ^* ($\mu^* = \frac{l(\gamma-1)L}{(\lambda-l)L-\frac{\alpha}{1-\alpha}}$); (ii) the additional probability of failed innovation l is lower than a threshold l^* ($l^* = \frac{\mu(\lambda L - \frac{\alpha}{1-\alpha})}{\gamma+\mu-1}$).

It cannot be directly concluded from Table 1 whether the growth gained from RRI is greater than or lesser than in the benchmark model. In fact, this occurs only under certain conditions where the efficiency boost is high enough or the probability of failed innovation is low enough. To see this, assume that g_2 is greater than g_0. If $g_2 < g_0$:

$$\left[(\lambda - l)L - \frac{\alpha}{1-\alpha}\right](\gamma + \mu - 1) - \left(\lambda L - \frac{\alpha}{1-\alpha}\right)(\gamma - 1) > 0. \quad (17)$$

Reorganizing Equation (17), we obtain:

$$\left[\left(\lambda L - \frac{\alpha}{1-\alpha}\right) - lL\right][(\gamma - 1) + \mu] - \left(\lambda L - \frac{\alpha}{1-\alpha}\right)(\gamma - 1) > 0. \quad (18)$$

Hence:

$$\mu\lambda L - \mu\frac{\alpha}{1-\alpha} - lL\gamma + lL - lL\mu > 0. \quad (19)$$

It is easy to recognize Equation (19) as:

$$\mu > \frac{l(\gamma-1)L}{(\lambda-l)L-\frac{\alpha}{1-\alpha}}. \quad (20)$$

Denoting $\mu^* = \frac{l(\gamma-1)L}{(\lambda-l)L-\frac{\alpha}{1-\alpha}}$, the additional efficiency enhancement from the RRI process μ needs to be greater than a threshold μ^* to make sure that the growth gained from RRI is greater than the benchmark model and the model without RRI.

We can also rearrange l as:

$$l = \frac{\mu(\lambda L - \frac{\alpha}{1-\alpha})}{\gamma+\mu-1}. \quad (21)$$

Denoting $l^* = \frac{\mu(\lambda L - \frac{\alpha}{1-\alpha})}{\gamma+\mu-1}$, the additional probability of the failed innovation from the RRI process l needs to be less than the threshold l^* to make sure that the growth gained from RRI is greater than in the models that we have discussed above.

Based on the model comparison, this subsection provides a simple framework for selecting and evaluating a growth-friendly and socially-compatible RRI for policy-makers and all stakeholders thinking about incorporating RRI in the innovation process. There is both a push power and a pull power from RRI. The push power is that RRI benefits economic growth and enhances the efficiency of the innovation process. The pull power refers to that RRI might reduce the probability of successful innovation, causing a lower growth rate comparing with innovation without RRI. The push and pull powers must be balanced to make sure that RRI becomes a building block rather than a stumbling block for innovation, growth and social welfare. For China and other developing countries, it is especially important to pay attention to the role that RRI plays in enhancing growth efficiency.

2.4 Responsible Research and Innovation Matrix

How can we enhance the additional efficiency, μ, and reduce the probability of failure, l, in the RRI process? Von Schomberg (2013) provides an RRI matrix from both the product dimension and the process dimension (Table 2). The purpose of the matrix is to help stakeholders to design and implement RRI properly from five different perspectives: technology assessment and foresight, the application of the precautionary principle, normative/ethical principles to design the technology, innovation governance and stakeholder involvement, and public engagement. It also provides insights and principals when one country is trying to incorporate RRI into its innovation policy. Stakeholders or countries should bear in mind these issues when designing an RRI scheme. In addition, these issues have certain implications within the framework of our RRI models. Some of them have direct implications for enhancing efficiency (summarized as μ in Table 2) or influencing the probability of failure (summarized as l in Table 2).[3]

Table 2. Responsible Research and Innovation Matrix and Implications for Economic Growth

Product dimension	Process dimension	1. Technology assessment and foresight	2. Application of the precautionary principle	3. Normative/ ethical principles to design technology	4. Innovation governance and stakeholder involvement	5. Public engagement and public debate
1. Technology assessment and foresight		*X*	Development of procedures to cope with risks	Which design objectives to choose?	Stakeholder involvement in foresight and technology assessment	How to engage the public?
			μ	—	μ	—
2. Application of the precautionary principle		Identification of nature of risks	*X*	Choice and development of standards	Defining proportionality: How much precaution?	How safe is safe enough?

[3]However, this does not necessarily mean that it will reduce the probability of failure; rather, it might increase the probability of failure due to the design of the process.

	l		*l*	*l*	*l*
3. Normative/ethical principles to design technology	"Privacy" and "safety" by design	Setting of risk/ uncertainty thresholds	*X*	Which principles to choose?	Which technologies for which socially desirable goals?
	—	*l*		—	*μ*
4. Innovation governance and stakeholder involvement	Defining scope and methodology for technology assessment/ foresight by stakeholders	Defining the precautionary approaches by stakeholders	Translating normative principles in technological design	*X*	How can innovation be geared towards socially desirable objectives
	μ	*l*	*μ*		*μ*
5. Public engagement and public debate	Defining/ choice of methodology for public engagement	Setting of acceptable standards	Setting of social desirability of RRI outcome	Stakeholders roles in achieving socially desirable outcomes	*X*
	—	*l*	*l*	*M*	

Sources: Von Schomberg (2013) and authors' judgment.

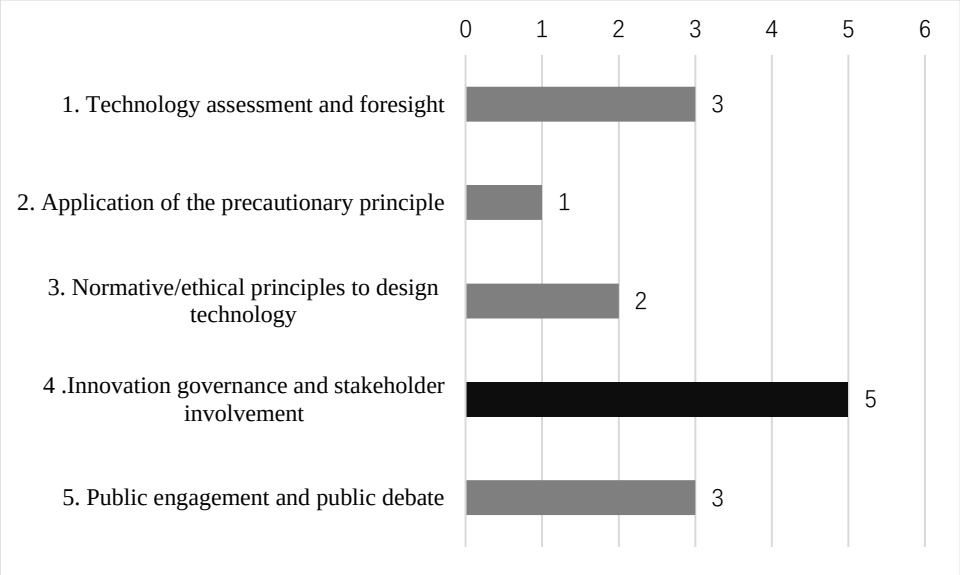
Notes: μ is the additional efficiency and l represents the influence of the responsible research and innovation process on the probability of failure. — denotes that this question has no direct relationship with efficiency or probability of failure.

In Table 2, the purpose of technology assessment and foresight is to predict the possible consequences for the consumers and societies of certain research and innovation to reach societal desirable outcomes. The application of the precautionary principle is in accordance with European Union's law, especially in the field of product authorization procedures. The cautious attitude towards genetically modified organisms is an example of this principle. Normative/ethical principles in design technology emphasize the social–ethical reflexivity in the research process. These principles call for social/ethnical experts' participation in developing emerging technologies. Innovation governance should be emphasized with stakeholder involvement as the core of the governance framework. Stakeholders from different fields should be brought together to reflect the voices from industry, research and society for a more responsible innovation process. Public engagement and public debate allows for feedback from the public to policy-makers to close knowledge gaps and to form an effective innovation cycle.

Because the major concern of this paper is to think about the implications of RRI on China and other developing countries, we have paid special attention to the role that RRI plays in enhancing growth efficiency. Based on Table 2, we summarized the growth enhancing role for the five perspectives of the RRI matrix to obtain the growth enhancing dashboard for the RRI matrix. When one issue under these perspectives is considered to be growth enhancing, this perspective receives

one point (Figure 1). The fourth perspective, innovation governance and stakeholder involvement, scores highest among the five perspectives, which reflects its important role in promoting economic growth during the RRI process. Thus, based on the dashboard, developing countries like China should consider innovation governance and stakeholder involvement as a priority when applying the RRI process, while technology assessment and foresight and public engagement and debate are also worth considering.

Figure 1. Growth Enhancing Dashboard for Responsible Research and Innovation Matrix



3. Responsible Research and Innovation and Improvements for China's Innovation Policy

Knowledge and innovation are increasingly becoming key drivers of growth in high income economies and emerging market economies. Thus, a number of countries will inevitably focus on RRI's impact on their economic outcome when assessing RRI. As mentioned earlier, the successful implementation of RRI requires that certain conditions be met. To be more specific, one must focus on realizing the push power of RRI and properly avoiding the pull power of RRI. It can be argued that the models in Section II reveal the major difficulties that may be encountered when RRI is implemented around the world.

The implementation of RRI relies primarily on the practices of each country. However, it is clear that the level of economic development and the regulatory capacity of countries are different, which directly affects the role of RRI. Therefore, the policy-makers of each country need to identify the potential impact of RRI in their own national context, as well as the main constraints in developing their own responsible innovation policies and ways of alleviating such constraints. This section will first discuss China's innovation policies in the framework of the RRI matrix. Then, based on the matrix and dashboard above, some suggestions to improve China's innovation policies will be provided.

3.1 Responsible Research and Innovation 's Matrix and China's Innovation Policies

In the case of China, since its reform and opening up in the late 1970s, the focus of the government on science and technology innovation has gradually transformed from simply attaching great importance to economic development, to paying equal attention to economic development and social development. To some extent, key elements in the RRI matrix are reflected in China's

innovation policies. This subsection will review how China's innovation policies meet the five major perspectives in the RRI matrix.

The first perspective is technology assessment and foresight. It requires investigation and predictions for the research and innovations to reach societal desirable outcomes. One way to evaluate this criterion is to look at the funding requirements for certain research. In China, the Natural Science Foundation of China (NSFC) is an important public funding organization affiliated with the State Council that is in charge of the National Natural Science Fund. The NSFC emphasizes societal desirability as a funder requirement. The NSFC provides not only general intellectual support for social and economic development, but also direct scientific solutions to the strategic importance encountered during the course of social and economic development. For instance, the Major Program of the NSFC is intended to solve major scientific problems emerging from either scientific or socioeconomic development and to provide scientific support for the optimization and upgrading of industrial structures and the development of strategic emerging industries (Engelhard et al., 2014).

The second perspective is the application of the precautionary principle. The third perspective is the normative/ethical principles towards design technology. In practice, they are usually combined. Based on the dashboard of RRI, these two perspectives are the least growth enhancing; thus, we put them together for the analysis of China. With regards to the precautionary principle, China is cautious towards new technology and its application. For example, China established the National Nanotechnology Standardization Technology Committee in May 2005 and set up the Nanotechnology Health, Safety and Environment Standardization Working Group. This working group focuses on ethical acceptability. It is responsible for the standardization of work on the medical and biological effects of nanotechnology, and the impact of nano materials and products on personal safety and environmental safety in the process of production as well as in relation to packaging and transportation. With respect to synthetic biology, the Report of the Twelfth Five-year Plan of Standardization Development developed by the National Standardization Management Committee pointed out that the government should strengthen the development of standards in biological agriculture, bio-manufacturing, marine biology and biomedical engineering areas, and promote the healthy development of the biotechnology industry. This shows that the Chinese Government has a cautious attitude towards synthetic biology.

The fourth perspective is innovation governance and stakeholder involvement. A major purpose of innovation governance for one country in the framework of RRI is to make the innovation and its outcome more sustainable. Chinese science and technology innovation policy also highlights sustainability. The issues of resources and the environment have been development bottlenecks since the commencement of China's reform and opening up, and these are also the focus of Chinese science and technology innovation policy. In 1994, the Chinese Government published a White Paper on China's Population, Environment and Development in the 21st Century, which marked the beginning of sustainable development process in China. At present, sustainable development is a basic national policy in China, which aims to achieve development for more people sustainably. To realize the target of building an environmentally-sustainable society, a number of regulations and policy documents have been delivered in recent years. For instance, Opinions of the State Council on Strengthening the Key Tasks of Environmental Protection, issued in 2011 by the State Council of China, stresses the need for transformation of the former development strategy to protect the environment during the process of development. In addition, reform and innovation are considered

to be the driving forces by the government to realize sustainable development in China today.

The last perspective is public engagement and public debate. China's innovation policies emphasize the need for policy-makers to concern the demands of the public in formulating policy. Among the key challenges currently facing Chinese society are unbalanced development between rural and urban areas, a shortage of basic public services, the enlargement of the income gap, and the existence of poverty-stricken populations in rural areas. To confront these challenges, the Proposal for the Formulation of the 13th Five-year Plan for National Economic and Social Development set forth the general goal of completing the building of a moderately prosperous society in all respects, and it highlighted five approaches to realize this goal: innovative development, coordinated development, green development, open development and shared development. These approaches to tackle the above challenges align with the societal desirability criterion of RRI as interpreted in Europe. Science and technology innovation policy in China emphasizes that only when scientific and technological achievements are combined with national needs, peoples' demands, market demands, …, can innovation value be truly achieved and innovation-driven development be realized (Xi, 2014).

3.2 Improvements for China's Innovation Policy

The above discussion shows that China's current innovation policy has similar goals to RRI. It provides the basis for introducing RRI into China's innovation policy. However, if we examine China's innovation policy in relation to the analysis of the above models, it can be argued that China needs to strengthen and improve the participation mechanism of stakeholders in major scientific and technological innovations (referring to the fourth perspective) to ensure that RRI can be successfully implemented. This would not only result in additional economic efficiency through RRI, but would also avoid unnecessary failure due to the RRI process. An OECD study using innovation surveys from 21 countries shows that firms receiving public support for innovation invest 40–70 percent more than those that do not. In addition, higher levels of firm investment in innovation lead to higher innovation sales and productivity (OECD, 2010). Furthermore, modern technology innovation models underline the knowledge flow in the innovation network composed of various stakeholders, and believe that technology innovation is the result of each stakeholder's interaction in the innovation network, and the coordination, competition and the cooperation level among stakeholders determines the performance of enterprises in relation to technology innovation (Sheng, 2009). In addition, modern technology innovations emphasize the concept of including stakeholders in innovation policy research and design are an inherent requirement of the innovation policy, which promotes social fairness and justice, protects socially vulnerable groups, and guides the formation of innovation networks and other social functions (Chen et al., 2014).

However, reflecting on stakeholder participation in technology assessments during the scientific and technological innovation process over the past 20 years, it is worth noting that when promoting stakeholder participation in major scientific and technological innovation evaluation, China inevitably faces the following three difficulties. The first is finding "qualified" participants (having both the willingness and the ability to participate), especially relating to issues that have higher technical requirements. The second is that the participants are likely to focus on specific issues. The third is the increased cost of R&D, popularization and application of technology (Lu and Zhao, 2014).

China is currently in a period of economic and social transition, and stakeholder participation

in technology assessment during the scientific and technological innovation process is still relatively scarce. Furthermore, the analysis of the above theoretical models indicates that an innovation outcome measured using economic growth will be less beneficial if RRI is excessively emphasized without explicit guidance.

Currently in China, the focus in science and technology innovation policy is to facilitate stakeholders' participation and collaboration in innovative activities, to promote the accumulation and development of social capital of innovations (Chen et al., 2014). Article 27 of *Several Opinions of the CPC Central Committee and the State Council on Deepening the Reform of Systems and Mechanisms to Accelerate the Implementation of Innovation-driven Development Strategies* issued by *the CPC Central Committee and the State Council* in 2015 states that the government will conduct a survey and create an evaluation system for its innovation policy, to better understand the opinions of businesses and the public, and to track the implementation of policies. The government should also improve and adjust policies in a timely manner. Although it requires to consider from the views of businesses and the public during implementation, China's innovation policy needs further improvements. RRI strengthens the stakeholders' participation "during the whole research and innovation process" (SwafS, 2013), and recommends including "stakeholders that are involved in the processes of research and innovation at an early stage" (van den Hoven et al., 2013, p. 3). Therefore, there is great potential for China to improve stakeholder participation through its science and technology innovation policies. At this stage, it could be argued that the relevant government departments should select a number of major scientific and technological innovation fields as pilots to research the mechanism of stakeholder participation. After a period of testing and analysis, the policy-makers could adjust policy in accordance with the resulting practice, and then gradually promote the new approach across the country.

4. Conclusion

Innovation is an important force to promote the development of a country. The emerging agenda of RRI will be conducive to addressing the growing demands for green growth and a more inclusive society. Moreover, in terms of the pressing social and global challenges facing human society today, including those relating to health, food security and the environment, the RRI agenda could become a global framework for analyzing and solving these issues. However, when RRI is implemented around the world, it needs to rely on individual country's practices. In this case, developing countries should pay attention to RRI, especially its economic consequences. Since growth is still the major target for developing countries, they should bear this in mind while applying RRI. Therefore, this paper explores the influence of RRI on growth and uses theoretical models to discuss in what situations RRI will benefit economies around the world. The findings illustrate that the successful implementation of RRI needs certain conditions to be met, which are not always beneficial to economic growth. There is both a push power and a pull power from RRI. The push power is that RRI benefits economic growth and enhances the efficiency of the innovation process. The pull power is that within the RRI process, the innovations that might harm society and will be terminated or revised, making the probability of successful innovation lower than the innovation process without RRI. To achieve a better result from RRI as part of an innovation policy, each country should balance the push and pull power of RRI to make sure that it becomes a building block rather than a stumbling block for innovation, growth and social welfare.

The findings here should be helpful for countries making policy choices in association with the

new RRI agenda, especially in terms of helping countries to address how they will face challenges if economic growth fails to be affected by RRI. One could adjust national innovation policies from five perspectives as showed in the growth enhancing dashboard for the RRI matrix.

With respect to its current innovation policy, China needs to improve the participation mechanism of stakeholders in major scientific and technological innovation fields to ensure that RRI benefits economic growth and enhances the efficiency of the innovation process without improperly reducing the probability of successful innovation.

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