Developing Gender Indicators in Science and Technology from National Innovation Systems (NIS) Perspective

Learning from Innovation Policy and Investigating Gender Policy Context

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Abstract

As a part of innovation studies, gendered innovations came into spotlight in science and technology as it not only improves equality among the people in S&T, but also ensures scientific excellence. However, there are many challenges in gender policy in science and technology. There is a lack of policy study and development, compared to S&T and innovation policy. Many studies in gendered innovations have been conducted, but limited systematic policy package has been developed. In the field of innovation research, measuring innovation and development of indicators have been significant issues. In this context, this research proposes a practical framework which could be used to develop indicators related to gendered innovations by using the concept of National Innovation Systems and categorizing the elements shaping gendered innovations in a system. In addition, this research derives indicators to reveal national capabilities of gendered innovations from the framework and suggests an indicator system, called Gendered Innovations Index (GII).

1. Introduction

In the field of innovation research, measuring innovation and development of indicators have been significant issues in that most innovation studies strive to find stylized facts and conclusions cannot be proven by generalization of a few case studies. Since innovation research aims to investigate the characteristics, structure, and dynamics of populations and natural systems as a whole, the data that illustrate the creation, diffusion, and utilization of knowledge need to be developed (Smith, 2000). On the policy side, it is imperative to measure innovation and develop indicators to understand systems where innovation arise in the view of policy, and policymakers can thus determine the leverage point that is needed to bolster innovation performance and competitiveness of the system. In this context, researchers and policymakers in the field of innovation have tried to develop practical innovation indicators. For example, OECD publishes Main Science and Technology Indicator (MSTI), which provide basic statistics of S&T investment and personnel, and Science, Technology and Industry (STI) Scoreboard, that produce innovation indicators in the context of global industry changes and

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innovation landscape. In addition, there have been a number of studies conducted to develop innovation indicators at the level of region and nation, and utilized to develop policies.

These efforts have led to indicator development on specific issues of innovation study. For example, the Community Innovation Survey (CIS) is firm-level innovation survey, which question firms on their innovation inputs, outputs and performance. CIS is a part of EU science and technology statistics and surveys are carried out every two years by EU member states and number of ESS member countries. This survey provides qualitative information about use of knowledge and its diffusion through technological collaboration, and thus maps the innovation landscape of a country from the firms' perspective. OECD patent database has been developed to illustrate linkage of knowledge among disciplines and trends in knowledge production. The database provides information on patents by country and technology fields (EPO, PCT, USPTO, Triadic Patent Families), patents by regions and selected technology fields (EPO, PCT), and indicators of international co-operation in patents. In the case of entrepreneurship study, basic statistics on entrepreneurship, such as Global Entrepreneurship Monitor (GEM), provide instrumental implications to innovation study.

As part of the innovation study, gendered innovations came into spotlight in science and technology since it not only improves equality among people in S&T, but also it ensures scientific excellence. It is defined as a "process that integrates sex and gender analysis into all phases of basic and applied research to assure excellence and quality in outcomes" (Schiebinger & Schraudner, 2011). Another definition was proposed as "changes in the personnel, cultures and content of science and engineering brought about by efforts to bring more women into these fields and to reform practices that have disadvantaged women" (Schiebinger, 2008). All things considered, gender issues in science and technology is not limited to traditional gender issues, such as participation or empowerment. It covers practical R&D and innovation methodologies, which have been adduced to explain the significance of gender factor in R&D and innovation process. Although gendered innovations is an issue of innovation study, related measurement methodology or indicators have not been fully developed to map how gendered innovations take place in a country and to draw what the relevant policy measures are to promote gendered innovations.

In this context, this research proposes a practical framework which could be used to develop indicators related to gendered innovations by using the concept of National Innovation Systems (Freeman, 1987; Lundvall, 1992; Metcalfe, 1995) and categorizing the elements shaping gendered innovations in a system. In addition, this research derives several indicators to reveal national capabilities of gendered innovations from the framework and suggest an indicator system, called Gendered Innovations Index (GII). Lastly, future research agendas in gender policy, especially gender indicator development, in science and technology are suggested. It is time to develop practical policy tools that deal with a number of gender issues in science and technology.

2. Challenges of Gender Policy in Science and Technology

As gender issues proliferated, many policies have been adopted in science and technology fields. To begin with, before 2000, limited issues such as equal opportunities and health issues were addressed. Well-known examples are Women's Health Initiative in the U.S. and European Commission Report on Mobilizing Women to Enrich European Research. However, there has been advancement in our understanding of gender issues in S&T, which has in turn prompted policy advancement. When we look at R&D funding policy, there are a myriad of funding policies that incorporate gender-related criteria. These criteria can be found in many R&D programs in Horizon 2020, Bill & Melinda Gates Foundation, WHO, etc. In case of academic journal, whether research provides gender-related data and analysis have become important criteria in evaluating scientific integrity. Such review policy can be found in many prestigious journals, such as The Lancet and Nature.

However, there are many challenges in gender policy in science and technology. There still is lack of policy study and development, compared to the area of S&T and innovation policy. Many studies in gendered innovations have been conducted, but limited systematic policy package has been developed. This policy package may include national R&D investment, R&D evaluation, and S&T related laws. Secondly, there is a lack of evidence to systemically address gender issues in science and technology. Limited gender-sensitive statistics are provided, and therefore leads to the lack of policy evidence. There are a number of indicators and indices focused on gender gap such as The Global Gender Gap Index developed by World Economic Forum and Gender Inequality Index developed by UNDP. However, the data reveal general inequality and do not demonstrate participation of women or use of knowledge in science and technology. In case of data collections on science, technology and innovations, gender issues are not addressed in general. Specifically, gender-related R&D issues are often overlooked. Moreover, data collections which deals with gender issues in science and technology, such as SHE Figure developed by European Commission, focus on women participation and empowerment. To sum up, there is limited data to investigate whole landscape of gender issues in science and technology.

Table 1. Selected gender-related indicators and indices

Title	Published by	Key Areas	Number of Listed Countries
The Global Gender Gap Index	World Economic Forum	Relative gaps between women and men across health, education, economy, and politics.	142
Gender Inequality Index	UNDP	Measuring gender inequality across birth, politics, education, and labor force	187

Table 2. Selected innovation-related indicators and indices

Title	Published by	Key Areas	Number of Listed Countries
OECD Science, Technology and Industry (STI) Scoreboard	OECD	Trends and features of science, technology, and industry as future sources of long-term sustainable growth	61
The Global Innovation Index	Cornell Univ., INSEAD, WIPO	Multidimensional facets of innovation as a driver of economic growth and well-being	143
IMD World Competitiveness Yearbook	IMD	Economic performance, government efficiency, business efficiency, and infrastructure	60
WEF Global Competitiveness Index	WEF	Institutions, infrastructure, macroeconomic stability, health and primary education, higher education and training, goods market efficiency, labor market efficiency, financial market development, technological readiness, market size, business sophistication, innovation	144

3. Why are Indicators Needed?: Lessons from Innovation Policy

Innovation policy has evolved with its solid theoretical foundations, such as National Innovation Systems (Freeman, 1987; Lundvall, 1992; Metcalfe, 1995) and Univeristy-Industry-Government (UIG) Triple-Helix model of innovation (Etzkowitz, 1993; Etzkowitz & Leydesdorff , 1995). As innovation policy is regarded as an imperative leverage in global S&T and industry landscape, many countries and international organizations have developed specific policy tools to stimulate innovation at industry, national and global levels. As a result, policy makers are now utilizing its policy practice accumulated by a number of experiences and policy studies.

What are the main lessons from innovation policy to gender policy in science and technology? First of all, evaluation is widely applied for policy learning as strategic intelligence. There is increasing emphasis on the need for evidence-based policy in S&T and innovation area because policymakers endeavor to make best policy and investment decisions on the best available empirical evidence. Evaluation is the systematic collection and analysis of information about the characteristics and outcomes of programs and projects as a basis for judgments, to improve effectiveness, and/or inform decisions about current and future programming (USAID, 2011). By implementing evaluation in policy learning process, policymakers can obtain systematic and meaningful feedback about the success and shortcomings of its past policies.

Secondly, innovation policy is marked by its systematic and holistic approach in policy designing. It cannot be denied that most of economic and societal key changes have been brought about by technological advances deriving from scientific research. However, other types of innovations derive from sources other than research and development and they have a significant impact as the origin of new industries and growth. Moreover, the development of any new industry needs a complex set of activities and competencies beyond technology or R&D activities (World Bank, 2010). Therefore, innovation policy requires multifaceted policies which include not just R&D investment but also innovation framework conditions such as patent and tax systems, and cultural elements.

Thirdly, it is widely accepted to learn from experiences of key competitor and emerging countries in order to build best policy practices. R&D and innovation activities in emerging countries have grown enormously over the last few decades. They are set to compete with Europe and North America in the coming future. This means that global R&D and innovation landscape have been diversified, and thus, a myriad of policy implementations and outcomes from each country have taken place. Therefore, policy case studies from each country are now produced and these serve as knowledge sharing platform among countries.

In innovation policy studies, statistics and indicators which represent each aspect of innovation systems form the foundation of aforementioned policy evaluation, design and knowledge sharing. For example, OECD Main Science and Technology Indicators (OECD MSTI) gives basic R&D statistics of OECD member countries and World Economic Forum's The Global Competitiveness Index (WEF GCI) provide various qualitative and quantitative indicators reveal competitiveness of a nation. These statistics and indicators play a role as scientific evidences of innovation policy.

4. Conceptual Framework for Developing Gender Indicators in Science and Technology

How should we develop gender indicators for science and technology from an innovation systems perspective? The easiest way to generate gender indicators in science and technology is probably to collect data and indicators which reveal innovation capabilities of a country and to select data and indicators related to gender policy context. Similarly, existing gender indicators could be candidates and it could be selected from an innovation policy perspective. However, these approaches cannot provide information on what we want to know as a whole. These approaches only provide limited information in limited indicators. In order to generate overall indicators in theoretical concept of gender and innovation policy, we should define the domains which show gender and innovation issues in a system.

As we try to develop gender indicators from an innovation policy context, the theory of National Innovations Systems (NIS) (Freeman, 1987; Lundvall, 1992; Metcalfe, 1995) provides useful theoretical tools to define domains in a system. NIS is defined as

"...the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman, 1987)

Another definition is

"....the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge ... and are either located within or rooted inside the borders of a nation state" (Lundvall, 1992).

Specifically, Kuhlmann and Arnolds (2001) divide NIS into industrial system, education and research system, intermediaries, political system, demand, infrastructure, and framework conditions. All things considered, it is vital to categorize innovations systems into institutional aspects and flow of knowledge to understand how it works and how actors in the system interact with each other.

In order to address gender issues in science and technology, we considered two main aspects of gender policy, which are empowering women researchers in S&T fields and creating better knowledge with gender analysis. According to Pollitzer (2014), the development of gender issues in science and technology can be categorized into four stages: fixing women, fixing institutions, fixing knowledge and fixing problems. Fixing women indicates interventions to help women fit in better into the existing world of science and fixing institutions stands how institutions can improve their process and practices to ensure men and women are treated equally. Furthermore, fixing knowledge illustrates how research community can improve science knowledge creation through integrating sex and gender analysis into the research process. Lastly,

Table 3. Conceptual elements of National Innovation Systems

Institutions	Social norms of behaviors, habits, routines aspirations; law and regulations, all of which are social constructs rooted in culture of a society (Berdegue, 2005)
Creation	Measures to capture knowledge creation activities. Investment, human resource, process as the inputs of creation activities.
Diffusion/Linkage	Measures to capture mobilization of knowledge among different levels of system and actors. Investment, human resource, process as the inputs of diffusion/linkage activities.
Utilization	Measures to capture utilization of knowledge in research and industries Investment, human resource, process as the inputs of utilization activities.

fixing problem implies how integration of the gender dimension can improve innovation and collective capability to achieve technological change and human wellbeing. With this argument, we categorize four issues into two main aspects in gender policy; women empowerment and better knowledge.

Indicators must reflect the policy context. In other words, indicators should give policy implications through evaluation framework. Then, why do we need to consider the evaluation aspect in developing gender indicators in science and technology? There are many definitions of evaluation, one being

"Evaluation is the systematic acquisition and assessment of information to provide useful feedback about some object." (Trochim, 1999)

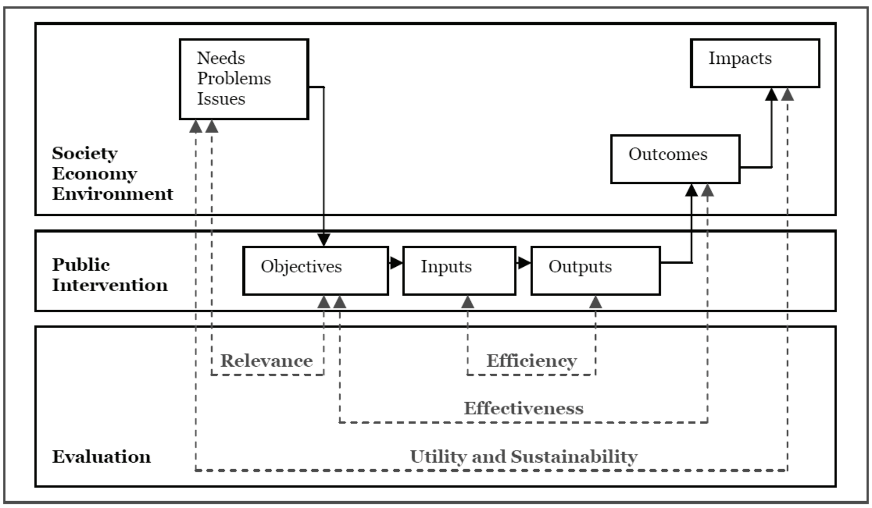
Public policy-oriented definition of evaluation could be given as

"Evaluation examines the outturn of a policy, program or project against what was expected and is designed to ensure that the lessons are fed back into the decision-making process. This ensures government action is continually refined to reflect what best achieves objectives and promotes public interest." (HM Treasury, 2003)

According to Arnold et al. (2009), evaluation can be conducted at four levels; policy, organizations, programs, and projects. Since the main purpose of developing an indicator in this research is to understand policy context of gender issues from National Innovation Systems perspective, indicators that reflect policy evaluation concepts are needed. Then our interest is what the logic of evaluation is and what the elements of policy evaluation are. Logical Framework Analysis (LFA) consists of a chain-link logic that essentially says "If we do certain activities, they will produce outputs that trigger outcomes and eventually contribute to achieving our overall objective". I-O-O-I evaluation model (Inputs-Outputs-Outcomes-Impacts) represents logical steps of LFA and defines what indicators should be verified to evaluate policy. The logic consists of the following steps (Arnolds et al., 2009).

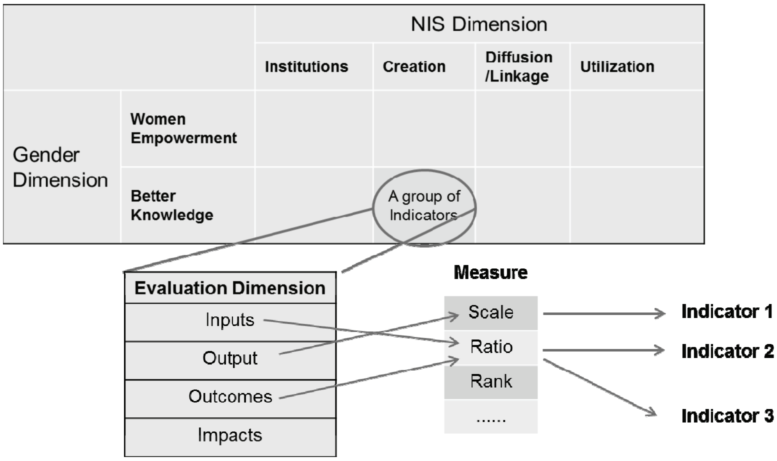
- An analysis of problems, needs or issues that need intervention, in that markets and other normal social processes will not correct them
- This analysis implies a set of objectives − essentially to fix the problems
- An intervention therefore provides inputs − typically money and other resources, normally in the world of research and innovation in the form of project funding.

Figure 1. The Inputs-Outputs-Outcomes-Impacts (I-O-O-I) model



Source: Arnolds et al., 2009

Figure 2. Framework for developing gender indicator in science and technology



- These enable activities that are expected to lead to outputs − direct results of the work enabled by the inputs.
- The outputs enable wider effects to be created.
- The outcomes enable wider social impacts. For example, the increased competitiveness of participants in the intervention may flow through into increased GDP and national wealth.

Among these steps, inputs, outputs, outcomes and impacts could be monitored by developing indicators which reflect each step. By defining each step and developing indicators of I-O-O-I, policymakers or evaluators can consider evaluation issues such as relevance, effectiveness, efficiency, utility and sustainability. In this study, we adopt the I-O-O-I model to represent the gender policy context and impart policy implications for policymakers.

How can we generate gender indicators considering NIS, gender policy issues and evaluation model? By placing each element of NIS, gender policy issues and evaluation model along three dimensions and making a dimensional cube, we can obtain several indicator groups, which in turn provide conceptual indicators. Figure 2 shows the concept of indicator development of this research.

Three-dimension framework with elements of NIS, gender policy and evaluation would be useful in drawing conceptual indicators which are candidates for an indicator in Gendered Innovations Index (GII) because it serves as a tool for indicator development with mutually-exclusive, collectively-exhaustive principle. After drawing a conceptual indicator from a domain of framework, we should consider what measure, such as scale, ratio and rank, would be the best description. Table 4 shows some examples of conceptual indicators from the framework.

Table 4. Examples of conceptual indicators

Conceptual indicator / Dimension and measure	The amount of national R&D investment on research using gender analysis	Percentage (%) of women entrepreneur in newly formed start-ups	Existence of criteria about gender analysis in national R&D program screening process
National Innovation Systems	Creation	Utilization	Institutions
Gender	Better knowledge	Women empowerment	Better knowledge
Evaluation	Inputs	Outcomes	Outputs
Measure	Scale	Ratio	Score

5. A Building Block for Gender Policy in Science and Technology: Gendered Innovations Index (GII)

Several conceptual indicators are generated from aforementioned framework and 16 indicators are selected for indicators in Gendered Innovations Index (GII). Among a wide array of conceptual indicators, we need to select an indicator set that is as comprehensive as possible, both with respect to measurable aspects and (time and country) coverage. Four selection criteria are used to draw the indicator set; temporal and peer comparability, low data collection and management cost, non-overlapping, and easy aggregation & disaggregation. Temporal and peer comparability enable us to conduct policy

Table 5. Indicator system for Gendered Innovations Index (GII)

Category	Sub-category	Indicators	Description
Social Foundation	Culture	Female estimated eared income over male value	Gender Gap Index (female to male ratio)
		Openness toward accepting and applying new research methods and gender analysis	Survey (1-7 scale)
		Level of discrimination against women's participation in R&D	Survey (1-7 scale)
	Institution	Effectiveness of the government policy for development and employment of women researcher	Survey (1-7 scale)
		Effectiveness of the government policy for development and spread of R&D methods based on gendered innovation	Survey (1-7 scale)
		Importance in public distribution of financial and other resources whether research proposal adopt gender analysis	Survey (1-7 scale)
Women Empowerment	Education	Percentage of students enrolled in science programs in tertiary education who are female	UNESCO (% of female)
		Percentage of students enrolled in engineering, manufacturing and construction programs in tertiary education who are female	UNESCO (% of female)
	Participation	Total R&D personnel	UNESCO (head count, % of female)
		Increase rate of female R&D personnel	UNESCO (head count, CAGR for 4 years)
	Linkage	Women researchers' mobility (professional experience in foreign countries, more than 6 months)	Survey (female to male ratio)
		Existence of effective policies to encourage and promote networking for women researchers	Survey (1-7 scale)
Better Knowledge	Knowledge Infrastructure	Gross domestic expenditure on R&D	UNESCO (as a percentage of GDP)
		Existence of educational programs or research projects for gender-based analysis	Survey (1-7 scale)
	R&D Activities	Percentage of SCIE papers based on gendered analysis	Thomson Reuter DB (% of SCIE papers)
		Number of US patents based on gendered analysis	USPTO (# of total patents for 10 years)

study by analyzing temporal trends and doing international comparative studies. Non-overlapping characteristic among indicators is needed to assure the indicator system is not biased to any particular aspects of gender policy in science and technology. The rest of the selection criteria are related to data management issues.

Including 6 indicators from existing database, we develop 16 indicators in total. For pilot study, we investigate five Asian countries including China, Japan, Korea, Malaysia, and Singapore. We surveyed about 10,000 researchers from these countries and the average response rate was about 2.5%. We also analyzed US patents and SCIE papers to check R&D activities related to gendered innovations. In the process of bibliometric analysis for US patents and SCIE papers, search words and academic fields should be carefully selected because noisy results which are not related to gendered innovations could be extracted from the analysis. To illustrate, in the case of US patent analysis, a patent that has the word "male" in the patent title, abstract or exemplary claim could be a patent that is related gender analysis. However, if it has the word "device", it is possible that the patent is recognized by its male-related physical shape not by its biological or social consideration of gender. Details of bibliometric analysis can be found in the appendix.

Indicator system must be intuitive, so that anybody can easily interpret, and must reflect policy relevance for utilization of the indicators. In this regard, we categorized the indicator system into three categories; social foundation, women empowerment, and better knowledge, and seven sub-categories; culture, institution, education, participation, linkage, knowledge infrastructure, and R&D activities. Women empowerment and better knowledge are main aspects of gender policy. Social foundation is vital to illustrate how culture and institution are established to improve gender equality and promote gendered innovations. Table 5 shows the indicators system and specifications of each indicator in Gendered Innovations Index (GII).

6. Conclusion and Future Research Agenda

We have suggested a framework for developing a gender indicator in science and technology from innovation policy perspective and have drawn up 16 indicators for GII. This is the first attempt to develop gender indicator that covers not only human resource issues but also R&D and innovation issues in science and technology. Another significance of this research is that it suggests how NIS perspective can be used to develop indicators in the field of policy, and thus provides a practical framework for indicator development. However, due to the limited availability of detailed policy and statistics in each country, there are some limitations in developing indicators. For example, national investment on R&D projects related to gender analysis could be a useful indicator as a knowledge input. However, if we are to obtain such data on investment, we need a whole project-level government budget data, and it requires comparable budget structure among countries and data collection in each country.

In order to bolster the statistical quality of GII and provide more comprehensive data, it is necessary to build gender policy research networks to investigate policy context and collect basic gender-sensitive statistics. Gendered innovations have entered the field of policy study recently and thus fundamental definitions for each of its aspects have not been fully made. In order to develop a gender indicator in science and technology, we should build a concrete consensus on practical definitions of many aspects of gendered innovations and make a statistical manual to collect more effective gender indicators. Furthermore, it is necessary to generate systematic policy evaluation reports on gender issues in science and technology and share with global networks based on the index in the future.

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Appendix 1. Rescaling of indicators and results of rescaled score in each category

Since each indicator has different measure, it is difficult to compare national level of gendered innovations capabilities with the original data set. In this regards, rescaling of indicators is needed to understand relative the position of each country and make an index which represents the overall capability as a number. An indicator can be rescaled with following equation.

$$q_i = \frac{Q_i - \min Q_i}{\max Q_i - \min Q_i}$$

where i = country, q_i is rescaled score for an indicator, Q_i is original score for an indicator, and $0 \leq q_i \leq 1$.

In order to make single index, average scores in each sub-categories are calculated and these score integrated into single index with same weight on three categories. There are a few missing value and this is replaced by an average value of rescaled score in the corresponding sub-category. Table A.1 shows average rescaled score, and total rank and score.

Table A.1. Score for Selected Asian Countries

	China	Japan	Rep. of Korea	Malaysia	Singapore
Social Foundation	0.429	0.138	0.241	0.761	0.465
Culture	0.534	0.164	0.122	0.522	0.457
Institution	0.323	0.111	0.359	1	0.473
Women Empowerment	0.287	0.005	0.169	1	0.428
Education	0.287	0	0.238	1	0.694
Participation	0.254	0	0.161	1	0.28
Linkage	0.319	0.015	0.108	1	0.31
Better Knowledge	0.439	0.73	0.819	0.151	0.202
Knowledge Infrastructure	0.653	0.46	0.914	0	0.204
R&D Activities	0.225	1	0.724	0.301	0.2
Total	0.385	0.291	0.409	0.637	0.365
Rank	3	5	2	1	4

Appendix 2. Analysis on Strengths and Weaknesses

Figure A.1. Analysis on Strength and Weakness for Selected Asian Countries