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Forecasting the Environmental Change of Technological Innovation System in South Korea in the COVID-19 Era

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Abstract Korean economy has experienced a very rapid growth largely due to the change of the innovation system since the last half century. The recent outbreak of COVID-19 impacts the global economy as well as Korea's innovation system. In order to understand the influence of the shock to the Korean technological system, we have forecast the future of the system combining qualitative and quantitative techniques such as expert panel, cross impact analysis, and scenario planning. According to the results, we have identified 39 driving forces influencing the change of Korea's technological innovation system. Four scenarios have been suggested based on the predetermined factors and core uncertainties. In other words, uncertainties of emergence of the regions and global value chains generate four scenarios: regional growth, unstable hope, returning to the past, and regional conflicts. The 'regional growth' scenario is regarded as the most preferable, whereas the 'regional conflicts' scenario is unavoidable. In conclusion, we put forward some policy implications to boost the regional innovation system by exploiting the weakened global value chains in order to move on to the most preferable scenario away from the return to the past regime.

Keywords COVID-19, Future Studies, Technological Innovation, NIS, South Korea

I. Introduction

South Korea has developed a technological innovation system in a very short period (Kim, 1997). Adapting a new technological paradigm has been an essential factor for Korean economic catch-up. For example, in the 1980s, Korean innovation system has chosen ICT technologies, so they opened the windows of opportunities in the global market (Lee, 2017). Technologies such

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as AI and big data are widely recognized as an upcoming technical paradigm in the communities of innovation policy as well as in those of policymakers. Various efforts have been made to understand and prepare the upcoming technical change and its impact on the national economy.

Since the outbreak of COVID-19 in South Korea, we have observed that the Korean technological system has been experiencing fundamental change as regards the social, technical, economic, environmental, and political factors (Park & Kim, 2020). Probably, these external factors generate a new path of Korean technological innovation as well as socio-economic system, which was unexpected before the wide spreading of the diseases.

Based upon this backdrop, this paper aims to identify driving factors triggered by COVID-19 for changing the technological innovation system of South Korea. To do so, this paper constructs a mixed method combining different qualitative and quantitative methods. Thereafter, the different scenarios for the upcoming technological system are put forward, together with the policy implications to prepare for upcoming risks and opportunities.

II. Forecasting national innovation system since the COVID-19 outbreak

Historically, the disease or pandemic has profoundly changed society in terms of culture, economy, and social structure. Now, the COVID-19 has brought an unprecedented world to us. The 'untact' culture starts to be recognized as normal (Kim et al., 2020). People prefer to communicate through on-line meeting, rather than face-to-face. Food delivery service is a more popular option for people than before. Economic structure also has been shifted from traditional manufacturing and traveling industry to e-commerce and on-line education industry including the so-called 4th Industrial Revolution. This has accelerated customers' adaption to newly-emerging technologies such as virtual reality, AI, and big data. Considering these changes in our everyday life, it is not difficult to predict our society is undergoing big changes. In order to identify systematically these changes, a more scientific approach is required.

Future studies have developed various methods to forecast the change of the society in a qualitative and quantitative way (Popper, 2008). Qualitative method, panel discussion, conference, and workshop are useful methods, while time-series analysis, statistical modeling, and extrapolation are regarded as quantitative ways. In general, trend analysis and Delphi method are more appropriate for short-term foresight, whereas mega trend and scenarios have strength in long-term foresight. However, in reality, those methods are used together considering various circumstances such as aims and resources of the practices (Jung, 2006). In order to produce a more valid forecast of the future, we attempt to combine different methods as shown in the next section.

III. Mixed method: combining qualitative and quantitative forecasting techniques

In order to identify factors influencing technological innovation in South Korea, we have sequentially combined different methods of forecast studies such as expert panel, cross-impact analysis, and scenario planning. Those different approaches help us to unveil richer details of uncertain futures and to implement the forecasting in a more balanced way. A similar combined method has been proposed by Popper and Medina (2008). They introduced a combination known as 'Forwarding Method Y' consisting of six steps: brain storming, scanning, SWOT, Delphi, roadmap, and scenario.

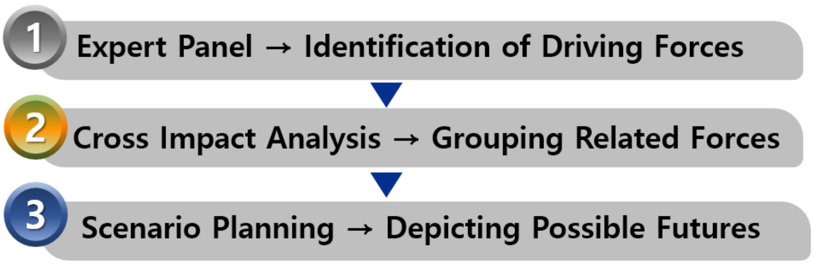

Figure 1 Process combining qualitative and quantitative method sequentially

Firstly, identifying upcoming factors, ten experts in the fields of innovation studies as well as technological areas have participated in panels from June to July of 2020 in Daejeon, South Korea. Relevant experts are selected by professionalism and balanced distribution of the disciplines of the experts (Lee et al., 2008). This panel has been organized through three alternate on- and off-line stages as follows.

In the first stage, participants are encouraged to comment on influences of the COVID-19 with regard to technological change in Korean innovation system. After a one-hour panel discussion, the authors were asked to submit the driving forces according to five categories known as STEEP (i.e., society, technology, economy, environment, and politics). The second stage consists of on-line exchange of their opinion on the submitted items on the drivers. At this stage, participants adjust their opinion, revising the submitted driving factors. Some participants have deleted and changed the driving factors they submitted previously. In the third stage of the off-line meeting, the final list of driving factors has been determined. Thereafter, the participants are asked to chose and measure the magnitude of uncertainty and impact from a scale from 0 to 10. Based on this figures, we have identified predetermined and core uncertainty factors, which provide information for scenario planning. Moreover, the relationship between driving forces are quantified from 0 to 10, which is linked to the CIA method in the next step.

Secondly, Gordon and Helmer developed the Cross Impact Analysis (CIA) in 1966 (Gordon, 2003). This method focuses on how future events or forces interact with each other and how this affects our forecasting results. Here, we adopt the social network analyzing the relational matrix representing the degree of relationship between driving forces evaluated by the experts. These figures have been produced in the second on-line communication and have been confirmed again in the third off-line panel discussion. We have carried out a visualization of the relations between the driving factors as well as their clustering by the social network program NetMiner 4.0. Section 4 addresses the results of this analysis as well as its implication in detail.

Thirdly, we have drafted future scenarios on the condition of technological innovation based on the predetermined factors and core-uncertainty factors. The predetermined factors are selected among those with high impact and low uncertainty, which functioned as background information for the scenarios. The core-uncertainty factors provide critical information for the creation of different scenarios, as present status tends to bifurcate into various futures meeting on important certainty. In our analysis, combining core-uncertainty factors, we have identified four scenarios such as preferable, feasible, unstable, and avoidable futures.

IV. Factors Influencing Technological Innovation System

The figures indicating the intensity of the relationship between the driving forces produce a matrix (see Appendix Table 1). For example, the relationship intensity between driving factors ‘well-being’ and ‘expansion of bio-health and leisure industry’ shows the strongest relationship (i.e. 10), whereas ‘leisure culture’ and ‘surveillance technology and social technology (e.g. infodemic)’ have a least inter-relationship. With regard to social network analysis, those figures are regarded as a weighted values of the link between the nodes (i.e., driving forces). Moreover, the uncertainties and impacts of the driving forces are depicted by the size and the color of nodes. In this way, we present a comprehensive picture overarching the forces stimulating the technological innovation system as shown in the figure below.

According to the figure, the darkness of the nodes represents the driving forces’ impacts, while the size of the nodes is proportional to uncertainties of the driving forces. Therefore, the big pale nodes and the big dark node can be regarded as predetermined factors and core uncertainties each. As shown in the figure below, we have identified four axes such as pollution continuation, emergence of the regions, increased flexibility of large manufacturing industry, and rearrangement of global value chains. These axes generate different future scenarios, as each axis gives two possible options.

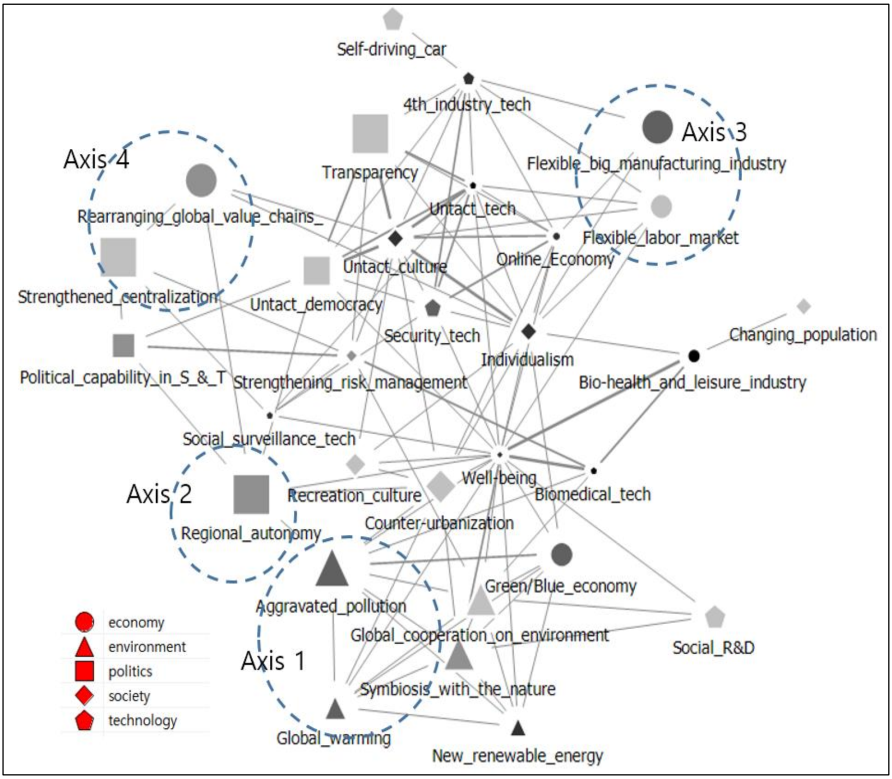

Figure 2 Network based on the relationship between driving forces

Note: the size of the nodes is proportional to the uncertainties, while the darkness to the impact.

Based on the evaluation of impact and uncertainty of the factors, we have identified predetermined factors and core uncertainties as shown below.

Table 1 List of Predetermined Factors and Core Uncertainties

	Driving forces
Pre-determined factors	Well-being, Untact tech, Bio-health tech, surveillance tech, Online Economy, strengthening of risk management, 4th industry tech, Bio-health and leisure industry, individualism, Untact culture, population structure, security tech, Renewable energy, Recreation culture, Self-driving car, social R&D, Flexible labor market, Green/Blue economy, Global warming, political capability in S&T, Untact democracy
Core uncertainties	axis 1: aggravated pollution axis 2: emergence of the regions axis 3: increased flexibility of large manufacturing industry axis 4: rearrangement of global value chain

V. Scenario for Technological Innovation in South Korea

So far, we have identified driving forces that could affect innovation system changes caused by COVID-19. We also evaluate the impacts and uncertainties of each driver through experts' assessment. Thereafter, the network has been drawn through Cross Impact Analysis (CIA) among influential driving forces, and finally the key pillars are identified: pollution continuation, emergence of the region, increased flexibility of large manufacturing industries, and rearrangement of global value chains. Especially for driving forces with high uncertainty, it is important to use the scenario method to predict various possibilities and their details in the future, and to suggest appropriate strategies. Prior to this, we examine the combined possibilities, which are based on the four core axes, then we select the final key possibilities producing final scenarios.

Table 2 Six combined possibilities based on four core axes

Combinative possibilities	**2x2 scenarios based on four core axes**
1	Pollution continuation vs. Emergence of the regions
2	Pollution continuation vs. Increased flexibility of large manufacturing industry
3	Pollution continuation vs. Rearrangement of global value chain
4	Emergence of the regions vs. Increased flexibility of large manufacturing industry
5	Emergence of the regions vs. Rearrangement of global value chain
6	Increased flexibility of large manufacturing industry vs. Rearrangement of global value chain

As shown in the table below, the axis of 'the emergence of the regions' can be decoupled by whether the decentralization (i.e., autonomy and political power of the regions) would be strengthened or whether, maintaining the current centralized system, the empowerment has been partially carried out. Global mobility is still slow due to the prolonged COVID-19. The scenarios based on the axis of 'rearrangement of global value chains' can be drafted by whether international collaboration can be maintained through the partial restoration of the value chain or whether the function of global value chains continually disappeared by production system within their own country territory.

Creating scenarios mainly based on the four core axis, we also extensively include the predetermined factors (e.g., the expansion of untact technology, the vitalization of online economy, the acceleration of development and application of the 4th Industrial Revolution technology, and the flexibility of labor system due to remote and automation technology).

Strengthened emergence of the regions

Restored global value chain	2. Fragile hope	1. Green light for regional growth <u>**(the most preferable)**</u>	**Weakened global value chain**
	3. Return to the old regime <u>**(the most possible scenario)**</u>	4. Growth by innovation and regional conflict <u>**(the avoidable)**</u>	

Maintained centralized system

Figure 3 Identification of scenarios based on final core drivers

1. Green light for regional growth: the most preferred scenario

As the regional innovation system is strengthened and the global value chains are weakened, the regional area is facing new opportunities. In other words, as overseas production is reorganized into domestically-oriented production system, the increasing concentration of the capital area (i.e., Seoul, Incheon and Kyung-gi) could spill economic benefit over to the regions. In order to maximize the overall economic benefit at the national level, the regional industrial policy and science and technology policy at the regional level should be strengthened. The green light scenario for regional growth has been evaluated to be the most preferred scenario by experts who participated in this study. Accordingly, we observed the paradigm shift from overconcentration of the capital region, which is currently causing many problems, to balanced development of regions, and to the autonomy, authority and responsibility of the region. The change in the overseas supply chain triggered by the COVID-19 could open new windows of opportunities for the regions and, if exploited well, could not only restore the regional competitiveness, but also improve the quality of local life.

However, it will be still necessary for the central government to coordinate resource allocation and to mediate the conflict with the regions according to the region's unique circumstances as well as overall benefit of the country. In particular, we can suppose that the global value chain is weakened and the actual R&D function remain overseas, whereas the production function is moved to domestic territory. In this case, as the local knowledge production function will still have limitations, it is necessary to secure the competitiveness of local knowledge infrastructure through the fundamental change of universities' research and education.

2. Fragile hope

In spite of the strengthened regional innovation system, if the global value chain is restored to the previous level, we can expect a hopeful future depending on the competitiveness of the region. In other words, after COVID-19, the restoration of the global value chains will be slowly taking place, and this may be an opportunity for the regions to promote innovative growth. By utilizing related technologies such as automation, mechanization, and untact, we can increase the labor efficiency of the region and strengthen the attractiveness of industrial locations. Also, this can accelerate the innovation in the value chains through reshoring. However, as innovation in the global value chains is hard to be achieved in a short period of time, and there is a very complex economic mechanism involved, we can cautiously anticipate that this scenario will be a positive sign for regional innovation. However, considering the possibility that such a situation could occur, we should seek ways in advance to respond to changes in the global value chains.

3. Return to the old regime: the most possible scenario

If the global value chains are restored to the same level as in the previous period, and if a centralized system is maintained, it can be seen as de facto returning to the world before the COVID-19. The science and technology policy experts who participated in this study concluded that this scenario to be the most likely. Although the influence of COVID-19 is obviously immense, it is unlikely that changes in the global value chains will occur rapidly in a short period of time, and it is expected that the shift of initiative from central to regional government will also be gradually expanded at a limited level, such as the current level.

Thus, in this situation, the regional economic inequality and polarization could be intensified, because the region still has limitations in securing autonomous innovation competitiveness. As many long-term future forecasts predict, extinction of a region may threaten the survival of all the regions. We should not stop exerting efforts to discover new regional growth engines and encourage cooperation with the central government by adapting technology trends aggressively, which could be a new opportunity since COVID-19.

4. Growth by innovation and regional conflict: the avoidable scenario

We may suppose that rearrangement of the global value chains has been taken place, whereas the current centralized system is maintained. A scenario of innovative growth and regional conflict can be suggested. The experts concluded this is an avoidable scenario. In other words, maintenance of the centralized system in the short term gives rise to a spontaneous response to turbulence of the external environment. However, considering the current situation in which policies cannot keep up with the pace of innovative growth, the policy responses are expected to fall behind. In this vein, changes in the global value chains can also result in various mismatch linked to regional innovation engines. This could cause the regional economic inequality and polarization to be aggravated. Therefore, in these circumstances, the central government's conflict resolution function is critical. This could lead to strengthening the authority of the central government.

VI. Conclusion

In order to prepare life in the COVID-19 era effectively, we need to forecast the upcoming environments of national technological system, as the Korean economy has been heavily dependent on technological innovations. In the previous sections, based on a mixed method of future studies, we constructed a three-stage process sequentially: expert panel, CIA, and scenario planning. Based on this process, we have suggested scenarios based on the emergence of the regions and rearrangement of global value chains. That is to say, we predicted the future that could occur in each quadrant situation.

As noted earlier, a majority of the panel experts emphasized the need for a encouraging policy to move from 'a return to the past' to 'a green light scenario for regional growth', and a preventing policy to 'return to the past' from 'an innovative growth and a regional conflict' scenario. In other words, the government has to develop innovation capabilities in order to enhance the endogenous competitiveness of the region and stimulate efforts to find new opportunities among environmental challenges caused by the pandemic.

In other words, it is time for the region to create a virtuous cycle of an innovative system that generate novel knowledge and technologies, not only with huge commercial potential, but also with remarkable job creation, rather than simply replacing global production functions. The central government can enhance its problem-solving capabilities and focus more on building a consensus in the community to coordinate regional conflicts that may arise in this process. Industrial policies and science and technology policies require prompt policy solutions, so the central authority should boldly devolve its power to the regions and strengthen the autonomy of the regions by increasing the general budgets so that the region can nurture its own territories.

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Appendix Table 1 Impacts and uncertainties of the drivers

Driving Factors	impact	uncertainty	sectors
Untact culture	9	3	society
Individualism	9	3	society
Well-being	9	1	society
Strengthening risk management	7	2	society
Counter-urbanization	6	6	society
Recreation culture	6	4	society
Changing population	6	3	society
Untact tech	10	1	technology
Biomedical tech	10	1	technology
4th industry tech	9	2	technology
Social surveillance tech	9	1	technology
Security tech	8	3	technology
Self-driving car	6	4	technology
Social R&D	6	4	technology
Bio-health and leisure industry	10	2	economy
Online Economy	9	1	economy
Flexible big manufacturing industry	8	6	economy
Green/Blue economy	8	4	economy
Rearranging global value chains	7	6	economy
Flexible labor market	6	4	economy
New renewable energy	9	3	environment
Aggravated pollution	8	7	environment

Global warming	8	4	environment
Symbiosis with the nature	7	6	environment
Global cooperation on environment	6	6	environment
Regional autonomy	7	7	politics
Political capability in S & T	7	4	politics
Strengthened centralization	6	7	politics
Transparency	6	7	politics
Untact democracy	6	5	politics

Appendix Table 2 Matrix based on relationship between driving forces

Codes	Drivers	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	a	b	c	d
A	Well-being	0	7	6	4	7	7	6	7	7	10	6	6	8	8	7	5	10	7	6	7	8	7	7	9	8	7	6	6	7	6
B	Individualism	7	0	10	4	8	7	5	8	7	5	6	5	5	6	7	7	7	7	7	7	5	5	6	4	3	6	7	4	6	3
C	Untact_culture	6	10	0	4	7	7	7	10	7	6	5	7	4	6	9	7	5	8	6	4	4	4	5	6	4	5	10	4	10	3
D	Changing_population	4	4	4	0	6	4	5	5	5	6	3	5	6	4	6	4	7	6	6	4	5	4	3	4	3	5	4	5	5	4
E	Counter-urbanization	7	8	7	6	0	8	6	6	6	5	3	4	3	3	7	5	4	6	6	6	7	7	5	8	5	8	6	4	6	5
F	Recreation_culture	7	7	7	4	8	0	2	6	5	5	6	3	2	1	6	2	1	2	1	1	6	3	1	6	1	6	6	1	2	2
G	Strengthening_risk_management	6	5	7	5	6	2	0	6	6	9	2	3	5	7	3	6	2	3	3	3	5	6	3	6	7	6	7	8	6	9
H	Untact_tech	7	8	10	5	6	6	6	0	9	5	5	7	5	7	8	5	5	7	5	4	5	4	3	5	5	6	9	3	9	6
I	Security_tech	7	7	7	5	6	5	6	9	0	5	6	9	4	7	9	5	3	6	4	1	1	1	3	2	2	5	6	1	7	6
J	Biomedical_tech	10	5	6	6	5	5	9	5	5	0	2	5	6	5	5	3	9	3	2	6	7	4	3	6	8	3	2	5	2	6
K	Self-driving_car	6	6	5	3	3	6	2	5	6	2	0	8	1	2	2	1	4	2	1	2	3	3	6	3	1	1	3	1	1	1
L	4th_industry_tech	6	5	7	5	4	3	3	7	9	5	8	0	5	6	7	3	6	7	8	2	2	1	5	2	3	5	7	5	7	5
M	Social_R&D	8	5	4	6	3	2	5	5	4	6	1	5	0	5	3	3	5	3	6	4	6	6	4	7	7	6	4	6	5	6
N	Social_surveillance_tech	8	6	6	4	3	1	7	7	7	5	2	6	5	0	3	1	1	2	1	1	3	2	2	3	4	4	4	7	6	5
O	Online_Economy	7	7	9	6	7	6	3	8	9	5	2	7	3	3	0	5	6	6	7	4	2	2	3	2	4	5	7	5	6	4
P	Rearranging_global_value_chains_	5	7	7	4	5	2	6	5	5	3	1	3	3	1	5	0	1	2	4	3	5	5	2	5	3	7	5	7	2	5
Q	Bio-health_and_leisure_industry	10	7	5	7	4	1	2	5	3	9	4	6	5	1	6	1	0	6	5	6	6	3	3	6	5	6	3	3	2	5
R	Flexible_labor_market	7	7	8	6	6	2	3	7	6	3	2	7	3	2	6	2	6	0	7	1	3	1	3	3	1	4	6	5	3	2
S	Flexible_big_manufacturing_industry	6	7	6	6	6	1	3	5	4	2	1	8	6	1	7	4	5	7	0	4	3	1	5	1	3	6	5	5	3	2
T	Green/Blue_economy	7	7	4	4	6	1	3	4	1	6	2	2	4	1	4	3	6	1	4	0	9	8	7	8	8	5	2	5	2	6
U	Aggravated_pollution	8	5	4	5	7	6	5	5	1	7	3	2	6	3	2	5	6	3	3	9	0	7	8	8	8	7	5	6	2	5
V	Global_warming	7	5	4	4	7	3	6	4	1	4	3	1	6	2	2	5	3	1	1	8	7	0	8	7	8	5	3	6	2	6
W	New_renewable_energy	7	6	5	3	5	1	3	3	3	3	6	5	4	2	3	2	3	3	5	7	8	8	0	7	7	3	2	6	1	5
X	Symbiosis_with_the_nature	9	4	6	4	8	6	6	5	2	6	3	2	7	3	2	5	6	3	1	8	8	7	7	0	8	6	3	5	1	6
Y	Global_cooperation_on_environment	8	3	4	3	5	1	7	5	2	8	1	3	7	4	4	3	5	1	3	8	8	8	7	8	0	5	3	6	3	6
Z	Regional_autonomy	7	6	5	5	8	6	6	6	5	3	1	5	6	4	5	7	6	4	6	5	7	5	3	6	5	0	6	6	7	7
a	Transparency	6	7	10	4	6	6	7	9	6	2	3	7	4	4	7	5	3	6	5	2	5	3	2	3	3	6	0	5	9	6
b	Strengthened_centralization	6	4	4	5	4	1	8	3	1	5	1	5	6	7	5	7	3	5	5	5	6	6	6	5	6	6	5	0	6	8
c	Untact_democracy	7	6	10	5	6	2	6	9	7	2	1	7	5	6	6	2	2	3	3	2	2	2	1	1	3	7	9	6	0	8
d	Political_capability_in_S_&_T	6	3	3	4	5	2	9	6	6	6	1	5	6	5	4	5	5	2	2	6	5	6	5	6	6	7	6	8	8	0

Appendix Table 3 List of Participants in the Expert Panel

Code	Gender	Age	Affiliation	Specialized Disciplines
C	M	48	ETRI	ICT Policy/Industrial Policy
H	M	62	Daejeon Univ	BT Policy/MOT
I	M	58	STEPI	S&T Policy /RIS
K1	M	57	KRICT	S&T Innovation Strategy
K2	M	44	NAFI	S&T Policy /Future Prediction
K3	M	51	HBNU	S&T Policy
L	M	66	UST	S&T Policy/MOT
P	M	48	SUNY-Buffalo	Regional Planning/City Economy Modeling
P1	M	48	HBNU	S&T Policy /Technology Economy
S	M	65	Seol & Value	Technology Innovation/ Technology Policy