Asian Journal of Innovation and Policy (2019) 8.2:274-287
DOI: http//dx.doi.org/10.7545/ajip.2019.8.2.274

Measuring the Economic Impact of Quantum-Dot Nanotechnology on Display/TV Industries

Jung-Sun Lim*

Abstract Governments are asking policymakers to quantify the economic and social impact of those advanced technologies they support, including nanotechnology. National policymakers and researchers who participated in OECD activities cooperated to develop a model for the economic impact assessment of nanotechnology with a relevant case study. The present research contributing to some recommendations from the OECD WPN (Working Party on Nanotechnology) finds a successful example of market creation by nanotechnology, and assesses the resulting economic impact of the DEFRA (Department of Environment, Food & Rural Affairs of UK) model. This study investigates the economic impact of Quantum-dot (Qdot) nanotechnology on flat panel TV manufacturers, which is an ideal case to apply the DEFRA model for the analysis of product innovation based on nanotechnology. Findings show that Qdot nanotechnology is expected to create an economic value of $3.32 billion for Korean TV manufacturers over the next decade.

Keywords Nanotechnology, Quantum-Dot, DEFRA, display, impact assessment

I. Introduction

Half a century ago, Richard Feynman (1965 Nobel laureate in Physics) presented a vision of innovation that could be achieved by understanding and controlling the phenomenon of nanoscale (1nm=10^{-9}m). His vision was discussed in academic circles over four decades, and one category of advanced technology called nanotechnology attracted attention as a new source of innovation to underpin the industrial revolution in the 21st century.

In 2000, the Clinton administration in the United States implemented the National Nanotechnology Initiative (NNI) program (National Nanotechnology Initiative, 2000), which later sparked global competition of nanotechnology development policies. The semiconductor industry is a representative example of nanotechnology that Feynman envisioned half a century ago.

Submitted, May 27, 2019; 1st Revised, August 2, 2019; Accepted, August 9, 2019
*R&D Investment Analysis Center, Korea Institute of Science and Technology Information (KISTI), Korea; jsunnylim@kisti.re.kr

In addition to semiconductor, nanotechnology provides the foundation for a wide range of other technologies including advanced manufacturing. Nanotechnology serves as key catalyst for manufacturing revitalization policies such as AMP (Advanced Manufacturing Partnership) by the United States, and KETs (Key Enabling Technologies) by the European Commission (Lim et al., 2015).

In the era of the 4th Industrial Revolution (Jeon et al., 2017), nanotechnology is still one of key technological triggers that promote national innovation. The main role of global nanotechnology development policy has shifted from technological advancement to commercialization and promotion of social contribution. To support the feasibility of policy implementation, government asks policymakers and experts to identify commercialization successes through quantifying the economic impacts of nanotechnology.

Relevant international coordination efforts by policymakers and experts were materialized through the WPN (Working Party on Nanotechnology) activities under the OECD (OECD Working Party on Nanotechnology, 2007; President's Council of Advisors on Science and Technology, 2005). Since 2007, WPN has been working on a variety of nanotechnology policy issues, including identifying successful cases of nanotech commercialization and developing economic impact assessment methodologies.

The results of these efforts were discussed at an international joint symposium held by OECD-NNI in 2012. Participants reached a consensus that the overall progress on the research of nanotechnology's economic impact assessment is still at an early stage. Specifically, it has been difficult to identify product innovation that entirely depends on nanotechnology, and relevant economic evaluation studies were scarce.

The quantum-dot (Qdot) application for panel/TV is an ideal example of nano-enabled product innovation that would be of interest to governments and OECD members as spillover effects of implementing nanotechnology development policies. Qdot is one representative outcome of federally-supported nanotechnology development policy. Qdot's existing applications were primarily in the field of biology, but recent Qdot applications for TV have created new product innovations in the advanced electronics market.

This study investigates the economic impact of Qdot nanotechnology applied to panel/TV products using the DEFRA methodology, and the economic assessment model of nanotechnology formulated by the OECD WPN (OECD, OECD and the National Nanotechnology Initiative, 2013; Walsh et al., 2010; Jung, 2012; Bae et al., 2015).

II. Research Background

As the major role of the global nanotechnology development policy shifted to the promotion of commercialization, the government was looking for evidences of direct/indirect innovation and market creation by supporting nanotechnology R&Ds. Since 2007, the OECD WPN has undertaken various projects to support international nanotechnology policy issues, including economic impact assessments.

The results of the WPN activities related to the economic impact assessment of nanotechnology by 2012 are summarized in Table 1 (Lim, 2012). WPN has contributed to the development of economic impact assessment methodologies of nanotechnology including the statistical framework, challenge /impact, business environment, and valuation model.

Table 1 Summary of economic impact assessment activities of OECD WPN by 2012

OECD WPN Project Title	Summary of Activities
Impacts and Business Environment	- Determine the scope of questionnaire survey and the security of enterprise information - Create a questionnaire for business environment surveys and a template for case study reports
Statistical framework for nanotechnology	- Exploring new indicators/statistics on the continuation of previous study (Nanotechnology: an overview based on indicators and statistics) - Improve the methodology to identify nanotechnology companies, development of questionnaire model to collect statistical indicator system through questionnaires
Addressing challenges in the business environment specific to nanotechnology	- Identify opportunities and challenges for industrialization of nanotechnology - Strengthen detailed quantitative analysis of existing case study (The Commercialization of Nanotechnology: Evidence, Impacts and Policy Implications)

In 2012, the OECD and the US NNI (National Nanotechnology Initiative) held a joint conference to review the past decade of efforts and discuss future work on the economic impact assessment of nanotechnology. The conference hosted by OECD-NNI examined the current status of economic impact assessment, identified challenges, and aggregated suggestions for future efforts.

The participants found that it was necessary to continue developing/improving metrics for impact assessments, and called for data to be more evidence-based to minimize assumptions (OECD and National Nanotechnology Initiative, 2013). There are various evaluation studies coming from academia, as well as the public and private sectors (Seol, 2000; Lim et al., 2015; Park et al., 2017).

However, it is rare to find evaluation approaches issued by policymakers, international organizations, or resulting from field/academia collaboration. The DEFRA assessment methodology was originally developed to support UK policy activities on nanotechnology, and discussed as a research model by the OECD WPN. Through the OECD-NNI joint symposium, academic, public and private researchers participated in its improvement.

In addition, the OECD WPN recommended expanding case studies to quantify the economic benefits of nanotechnology and using evaluation models such as the one by DEFRA. These suggestions from the OECD and OECD-NNI joint symposiums underpinned the research motivation for this current study. The application procedure of the DEFRA methodology proposed by Walsh et al. (2010) is summarized, with related explanations, in Table 2. The research literature related to the DEFRA research model is summarized in Table 3.

Table 2 Application procedures of the DEFRA methodology

	Procedures	Steps
Stage 1	1. Select Nano Enabled Product 2. Define the Functionality 3. Identify Incumbent 4. Select Scenario 5. Market Definition 6. Identify Data Requirements	Set Model
Stage 2	7. Determine Production Costs 8. Determine Sales Price 9. Establish Market Size 10. Determine Externalities	Data Collection
Stage 3	11. Calculate Surplus 12. Estimate Economic Value	Estimation of Economic Value

Economic Value = producer surplus + consumer surplus + external factor

- Producer surplus: The difference between benefits (wholesale price - production cost) of making existing products (incumbent) and the benefits (wholesale price - production cost) of producers making nanotechnology products
- Consumer surplus: Differences in the benefits of using nanotechnology products compared to existing products (incumbent)
- Externality: A collective term referring to the additional value that can be generated during the entire cycle from the development of nano-enabled products to their commercialization. It mainly reflects the increase or decrease of national tax revenue from sales of nanotechnology compared to existing products.

Examples of economic impact assessment studies of nanotechnology using the DEFRA method so far have been mainly carried out by the UK's DEFRA and the OECD WPN. Walsh et al. (2010) presented case studies that applied the DEFRA methodology to areas of food packaging, energy, gas sensors, ships and decontamination. One of the most successful examples was the case study of fuel catalyst for which Walsh calculated the economic benefits by comparing the fuel cost saved by utilizing nanocatalyst.

Studies to expand the field of application of the DEFRA methodology were presented at an international conference held by the OECD-NNI. Researchers have sought to study the economic impact of nanotechnology when applied to advanced electronics such as LED lighting, memory semiconductors and batteries (Jung, 2012; Bae et al., 2015).

As the DEFRA methodology is applied to high-tech electronic products using nanotechnology, various limitations have been identified. For example, manufacturing costs and sales volumes of products based on nanotechnology are difficult to collect because they are company trade secrets. Therefore, researchers who evaluate the economic value had to use models that simplify reality.

Table 3 Literature review on the DEFRA research model

Literature	Achievements
- Comparative methodology for estimating the economic value of innovation in nano-technologies (Walsh et al., 2010)	- The methodology is proposed by the UK Department of Environment, Food and Rural Affairs (DEFRA) in 2007 - Since 2007, OECD WPN has been utilized as a research model to evaluate the economic impact of nanotechnology
- Economic impact of nanotechnology: case study on LED lights (Jung, 2012)	- OECD WPN evaluated this work as an initial effort as economic impact analysis of nanotechnology for electronic products
- Symposium on Assessing the Economic Impact of Nano-technology: Synthesis Report (OECD and National Nano-technology Initiative, 2013)	- Ongoing Status and Progress of International Research on the Economic Impact of Nanotechnology (by 2012)
- An Analysis for Economic Value of Nano-Technologies : Focused on Secondary Batteries (Bae et al., 2015)	- The application of nanotechnology to the battery industry and its economic effects are analyzed through the DEFRA model
- The Economic Contributions of Nanotechnology to Green and Sustainable Growth (Shapira et al., 2015)	- Overview of case studies for DEFRA applied nano-enabled products

For example, to simplify the consumer/producer surplus calculation process, the researchers assumed a decade-long product market size or DEFRA's core model parameters. As an example of the major assumptions, the speed at which nano-enabled products replaces existing products is based on an estimation of the diffusion rate of replacement, and the decreasing market share of nano-enabled products by other emerging tech-based products are based on an estimation of the discount rate.

These key parameters such as diffusion and discount rates should be different depending on the application field of products. But they were cited from previous case studies even though application fields are totally different, or obtained from questionnaires based on personal opinion. (Bae et al., 2015).

In addition, existing studies using the DEFRA method have been designed to emphasize the public benefit and the economic effects between producers were oversimplified. For example, the case study on nanocatalyst by Walsh (Walsh et al., 2010) defined consumer surplus as the difference between the cost of purchasing nanocatalysts and the automobile fuel saved using nanocatalysts. While the profit of the fuel manufacturers decreases as consumers gain benefit, the study by Walsh reflected only a part of it in producer surplus calculation.

III. Research Method

The present research improves on the limitations of previous research related to the DEFRA model (Walsh et al., 2010; Jung, 2012; Bae et al., 2015). Previous researches have gained key model parameters and data for DEFRA model through assumptions or personal opinion-based questionnaire. Existing DEFRA research also underestimated manufacturers' losses/benefits to emphasize consumer benefits from nanotechnology.

Current research improves past researches by acquiring key model parameters from more evidence-based approach rather than assumptions or personal opinions. The study also uses the DEFRA model to analyze value chain between upstream and downstream manufacturers that were overlooked in previous studies.

IV. Research Outcomes

1. Selection of the Nanotechnology / Product and Major Scenarios

Qdot is a functional nanoparticle that acts as a rectifier by selectively converting input light energy to other light energy in a specific wavelength range.

Conventional LCD displays have 70% color reproduction (about 16 million colors reproduced). Qdot panels use Qdot color filters to realize 100% color reproduction with little change to existing LCD manufacturing processes. The physical price increases in Qdot panels are mainly due to Qdot color filters, and the main application area of Qdot panels is larger than 50 inches.

Korea has led the global flat panel/TV industry for the past decade, but its position is threatened (Kang, 2016). In addition, large flat panel/TV technology has entered a recession, and innovative products are needed to create a new demand. Consumers are increasingly interested in purchasing Qdot TVs at an additional cost, which is recognized as a product innovation in the large TV industry (Lee, 2014; Young et al., 2017).

2. Data Collection

The following is a summary of the key parameters, assumptions, and product/market information required to apply the DEFRA model for Qdot panel/TV. After the joint conferences of the OECD-NNI, further studies have been conducted to expand the coverage of the DEFRA methodology into various areas. Researchers have sought to study the economic impact assessment of nanotechnology when applied to advanced electronics such as LED lighting, memory semiconductors and batteries.

Table 4 Summary of major information with assumptions for applying DEFRA

Manufacturing/sales information of Qdot panel	- 35% increase in manufacturing cost compared to existing LCD panel due to adoption of Qdot color filter - All Qdot panels are used for Qdot TV in Korea (assumption)
Flat panel TV	- Product numbers in Korea are stagnated over decade (assumption) - Qdot TV replaces existing flat-panel TV in Korea
Qdot TV	- Qdot TV price in Korea is about 30% more expensive than LCD TV
Diffusion Rate	- Qdot TV replaces 50% of existing LCD TV in Korea over 7 years
Discount Rate	- 13.2% risk that Qdot TV will be replaced by other technology-based TV products in Korea

As the Qdot-added color filter is applied to the existing LCD display, the panel production cost and selling price are increased. According to the analytical data, the production cost of 55-inch Qdot panels was estimated to be 35% higher than conventional LCD panels (Lee, 2014). The manufacturer's panel manufacturing profit ratio was estimated as 85.7% by using three-year financial statements of Samsung SDI and LG Chem, obtained from the Financial Supervisory Service's electronic disclosure system (dart.fss.or.kr; Bae et al., 2015). This information is used to calculate the producer surplus that occurs when the existing LCD panel is replaced with a Qdot panel. Qdot panels are mainly used in large-sized TVs, and Qdot panels are assumed to be sold in proportion to the number of Qdot TV sales.

According to the report from Export-Import Bank of Korea, which cites IHS data (Lee et al., 2016), the large-panel and TV markets are expected to remain stagnant or shrinking until 2020. The report forecasts the international TV market in 2019 to be worth $96 billion. According to a report from the Korea Electronics and Telecommunications Industry Promotion Association, which quotes the Yearbook of World Electronics Data (Korea Electronics Association Research Center, 2017), Korea accounts for 2% of the global household appliances industry. By applying this two-percent share to the global TV market, then domestic the TV market of Korea is estimated at $1.92 billion.

This study assumes that the number of flat panel TVs will stagnant for the next 10 years from 2019. Currently, customers are willing to purchase large TVs using Qdot technology, despite the fact that they are currently priced at more than 30% (Newspim, 2017) higher than conventional UHD LCD-based TVs in the world including North America. In Korea, Qdot TV prices are often double the price of general UHD LCD TVs, and 30% price increases are conservative estimates.

As a reminder, previous studies of DEFRA make assumption about diffusion rate and discount rate rather than base them on field product data. In studies by Walsh et al. (2010), a diffusion rate of half penetration was posited at four years when new nano-enabled product appears on market, and eight years when nano-enabled products are replacing existing products. The discount rate was assumed to be 4% when nano-enabled products are replacing existing products, and 8% when new nano-enabled products appear on the market. The DEFRA methodology has limitations in obtaining key model parameters from existing research results or reliance on surveys (Bae et al., 2015). These limitations are even more apparent when applying the DEFRA methodology to high-tech products such as ICT.

In this study, the diffusion rate of replacement is estimated based on market research data, and the discount rate is obtained from field databases. According to a report by Display Supply Chain Consultant (Young et al., 2017), Qdot panels will account for 33.7% of all TV panels by 2021. If this trend is converted to CAGR growth rate, Qdot panels will account for 50% of the market within seven years (diffusion rate of replacement). Diffusion values for this half market penetration within seven years are obtained from calculation made by Walsh

(Walsh et al., 2010). From 2019 to 2028, the annual diffusion rates are estimated as 0.002, 0.009, 0.03, 0.079, 0.174, 0.319, 0.05, 0.681, 0.826, and 0.95.

The discount rate reflects the various risks inherent in the technology commercialization process. Korea ICT Technology Valuation Manual (Institute for Information & communications Technology Promotion, 2014) defines discount rate estimation tables by sector/firm size, based on accumulated field data. From this manual, the risk discount rate was calculated as 13.2% by applying the information relating to 'television manufacturing'.

This approach can more realistically reflect the discount rate on Korea's advanced appliances with various technology-based products including TV. The discount rates are calculated with the equation of Rt = 1/((1+δ)^t) with δ = 13.2. Over the 2019-2028 period, the annual discount rates are calculated as 0.88, 0.78, 0.69, 0.61, 0.54, 0.48, 0.42, 0.37, 0.33, and 0.29.

3. Calculation Results of Economic Benefits

Table 4 shows information and assumptions with related explanations applied to the DEFRA model to estimate the economic impact of Qdot nanotechnology utilized for flat panel/TV products in Korea. The original DEFRA frame suggests that the total economic value is the sum of producer surplus, consumer surplus, and external factor. But in the current Qdot TV case, consumers are willing to pay extra for high-quality TV sets.

Table 5 Benefit/loss estimation in 2 areas and tax increase ($ billion)

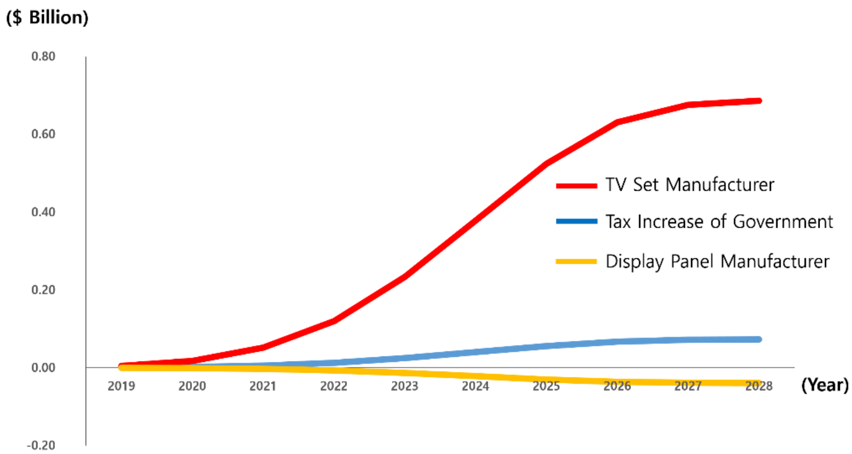
Year	Tax Increase of Government	Additional Value Creation by Qdot TV Manufacturer	Additional Production Cost of Qdot Panel Manufacturer
2019	0.0005	0.004	0.000
2020	0.002	0.018	-0.001
2021	0.005	0.052	-0.003
2022	0.013	0.120	-0.007
2023	0.025	0.234	-0.013
2024	0.040	0.378	-0.022
2025	0.055	0.524	-0.030
2026	0.067	0.630	-0.036
2027	0.071	0.675	-0.039
2028	0.073	0.686	-0.040

In the case of producer surplus, the obvious manufacturing cost increase is due to the utilization of Qdot, which increases the cost of a panel by about 35%. The relation between producer surplus and consumer surplus in the conventional DEFRA framework could be redefined as the value chain relation between downstream (Qdot panel manufacturer) and upstream (Qdot TV manufacturer).

The above term 'producer surplus' can be referred to as additional production cost for Qdot panel manufacturer, and 'consumer surplus' as additional value creation by Qdot TV manufacturer.

The first year of additional value creation by the Qdot TV manufacturer compared to conventional LCD TV is calculated by multiplying the market size ($1.92 billion) by the first-year diffusion rate (0.002), the first-year discount rate (0.82), and the value creation ratio (1.3), that is, $1.92 billon*0.002*0.82*1.3 = $4.4 million. The first year of additional cost to the panel manufacturer is calculated by multiplying the market size ($1.92 billion), the first-year diffusion rate (0.002), the first-year discount rate (0.82), the panel price ratio per TV (0.25), and the Qdot panel production cost increase ratio (1.3), that is, $1.92 billon*0.002*0.88*0.25*(1-1.35) = - $0.25 million.

The first year of externality is calculated by a tax rate increase of 0.1, resulting ($4.4 + $0.29 million)*0.1 = $0.47 million. Such calculation procedures are applied throughout the 10-year period and the results are summarized in Figure 1 and Table 5.



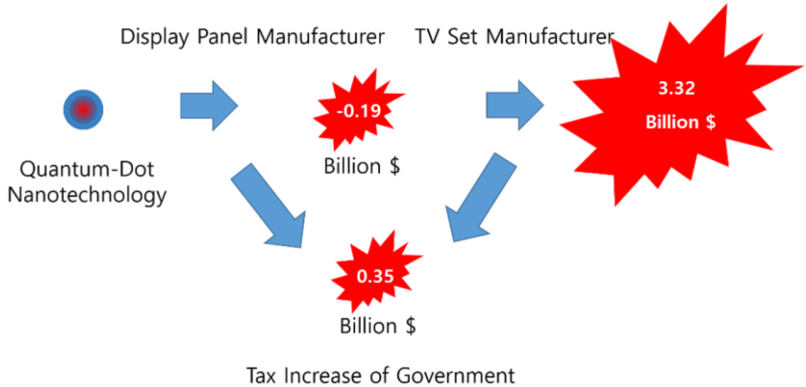


Figure 1 Estimated 10-year economic impact in Korea

Over the next ten years, Qdot panel production costs are expected to increase to $0.19 billion, and Qdot TV manufacturers are expected to generate an added value of $3.32 billion. On the external side, the Qdot panel/TV sector is expected to generate $0.35 billion in tax over ten years for the government.

V. Conclusion

DEFRA is a unique impact assessment model originally developed to support government policy activities, and is considered by the OECD via international cooperation as a policy support methodology to measure innovation and market creation by nano-enabled products.

Qdot panels/TVs are the latest example of product innovation by nanotechnology, and an ideal case for studying the economic impact of nanotechnology using the DEFRA model. Previous studies of the DEFRA methodology had limitations such as obtaining key model parameters from pure assumptions or expert questionnaire (Walsh et al., 2010; Jung, 2012; Bae et al. 2015). This study improves on these limitations by obtaining key model parameters through a data-driven approach, therefore potentially extending the application of the DEFRA model from environmental products to broad ranges of products including advanced ICT.

This research obtained diffusion and discount rates of the TV manufacturing industry from field-driven database research (Korea Institute for Advancement of Technology, 2014; Institute for Information & communications Technology Promotion, 2015; Young et al., 2017) that have not yet been considered in previous studies. Also, this study extends the DEFRA methodology to the analysis of the value chain relationship between panel manufacturers and TV manufacturers. According to the analysis, Qdots are expected to create $3.32 billion in added value to TV manufacturers, and an increase of $0.35 billion in tax revenues in Korea over the next decade.

References

Bae, S.H., Lim, J.S. Shin, K.M. and Yoon, J.S. (2015) An analysis for economic value of nano-technologies: focused on secondary batteries, Journal of Society of Korea Industrial and Systems Engineering, 38(1), 131-142.

Institute for Information & communications Technology Promotion (2014) Practical Guideline for ICT Technology Valuation, Institute for Information & Communications Technology Promotion, Daejeon, Korea, 64-74.

Jeon, J.H. and Suh, Y.Y. (2017) Analyzing the major issues of the 4th industrial revolution, Asian Journal of Innovation and Policy, 6(3), 262-273

Jung, E.M. (2012) A study on the measurement of economic impact of nanotechnology - case study for LED industry, Journal of Industrial Economics & Trade, 25(6), 38-46.

Kang, M.S. (2016) Domestic Display Industry on the Brink of Reorganization, Industrial Bank of Korea, Seoul, Korea, 1.

Korea Institute for Advancement of Technology (2014) Practical Guideline for Technology Valuation, Ministry of Trade Industry & Energy, Sejong, Korea, 77.

Korea Electronics Association Research Center (2017) Current Status and Issues of China's Home Appliances Industry, Korea Electronics Association, Seoul, Korea, 6.

Lee, J. (2014) LCD-TV Market is expected to grow and expand steadily in 2015, Eugene Investment Co. LTD, Seoul, Korea, 41.

Lee, J.W. and Lee, M.H. (2016) OLED Display Market Status and Forecast, The Export-Import Bank of Korea, Seoul, Korea, 3.

Lim, J.S. (2012) Analysis of OECD WPN Activities for Nanotechnology Policy, Korea Institute of Science and Technology Information, Seoul, Korea, 13.

Lim, J.S., Shin, K.M. Yoon, J.S. and Bae, S.H. (2015) Study of US/EU national innovation policies based on nanotechnology development, and implications for Korea, Journal of Information Science Theory and Practice, 3(1), 50-65.

Lim, S.M., Kim, S.K. and Park, H.W. (2015) A study on an conceptual model for technology valuation based on market approach, Journal of Korea Technology Innovation Society, 18(1), 204-231.

Newspim (2017) Samsung-LG TV front-match in US, 'Price-Breakdown' competition, Http://www.newspim.com/news/view/20171120000004.

National Nanotechnology Initiative (2000) Leading to the Next Industrial Revolution, National Science and Technology Council, Washington DC, USA, 14.

OECD and National Nanotechnology Initiative (2013) Symposium on Assessing the Economic Impact of Nanotechnology: Synthesis Report, OECD Publications, 1.

Park J.M., Lim, S.I. and Seol, S.S. (2017) Measurement of public research outcomes: a technology valuation method, Asian Journal of Innovation and Policy, 6(2), 206-224.

Seol, S.S. (2000) A theoretical framework for the valuation of technology, Journal of Korea Technology Innovation Society, 3(1), 5-21.

Shapira, P. and Youtie J. (2015) The Economic Contributions of Nanotechnology to Green and Sustainable Growth from Green Processes for Nanotechnology, Springer, 409-434.

Walsh, B., Willis, P. and MacGregor, A. (2010) A Comparative Methodology for Estimating the Economic Value of Innovation in Nanotechnologies, Report for DEFRA, Oakdene Hollins, Brussels, Belgium, 86.
Young, R., O'Brien, B. and Tamura, Y. (2017) Quantum Dots or OLEDs - which technology will dominate the TV market of the future?, Display Supply Chain Consultants, Austin, US, 22.