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Investigation of Japan's value chain through R&D and innovation under demographic change: Implications for digitalization in the post-COVID-19 era

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ADB Working Paper Series

**INVESTIGATION OF JAPAN'S VALUE
CHAIN THROUGH R&D AND INNOVATION
UNDER DEMOGRAPHIC CHANGE:
IMPLICATIONS FOR DIGITALIZATION
IN THE POST-COVID-19 ERA**

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Abstract

The global COVID-19 pandemic has substantially changed the structure of the economy from the pattern of a supply chain system driven by massive production and consumption to effectual demand through information and communication technology (ICT). Moreover, the transition of work style based on telecommunication stimulates a radical movement toward the Internet of Things (IoT) and artificial intelligence (AI), contributing to the creation of an environment that fosters a super-smart society. To accommodate this trend, advocacy for the creation of Japan's Digitalization Agency in 2020 was a symbolic turning point. This paper aims to investigate the change in Japan's value chain in the circumstances of the demographic transition by using the SciREX Policy Intelligence Assistance System–Economic Simulator (SPIAS-e) for a 50-year projection. The simulation results showed that public investment could increase the productivity for intra-firm ICT and intra-firm R&D activity, while the price index of main product sectors would drop significantly. The demonstration of disguised employment also provides implications for deregulation of working hours and the increasing demand for R&D human resources. An active structural reform for promoting innovation is desirable in the conditions of drastic demographic changes and the post-COVID-19 era.

Keywords: CGE model, value chain, STI policy, SPIAS-e, Japan, R&D, innovation

JEL Classification: C68, O14, J11

Contents

1.	BACKGROUND AND MOTIVATION	1
1.1	Technology and Demographic Change	1
1.2	Japan's Public R&D Policy	2
1.3	R&D Policy and its Spillover Effect on the Value Chain.....	4
1.4	Evaluating Structural Change and R&D Policymaking	5
2.	METHODOLOGY.....	6
2.1	The Creation of SPIAS-e as Policy Simulator	6
2.2	The Challenge of SPIAS-e and the Value Chain Transition.....	7
3.	SCENARIOS	8
3.1	The Compilation of R&D Activity.....	8
3.2	Scenario Setting	9
3.3	Assumptions for the BAU (Business-as-usual for Baseline Scenario).....	10
4.	SIMULATION RESULTS	11
4.1	GDP and Value-Added Breakdown.....	11
4.2	Employment	12
4.3	Price Change of Capital Goods	13
4.4	Disguised Unemployment	20
5.	CONCLUDING REMARKS.....	21
5.1	Policy Implications	21
5.2	Research Limitations and Future Perspective	21
	REFERENCES.....	23

1. BACKGROUND AND MOTIVATION

1.1 Technology and Demographic Change

The rapid development of information and communication technology (ICT) has drastically reshaped the socioeconomic structure since the boom of internet services aimed at facilitating human prosperity in a human-centered society. Unlike traditional services based on the provision of tangible capital such as land, communication, and printed media, intangible capital contributes to a more significant economic activity platform. Such a trend during the global pandemic was evident in the extraordinary growth among GAFAM, namely Google, Apple, Facebook, Amazon, and Microsoft, due to their innovative service provision in systems that are reshaping e-commerce and work styles.

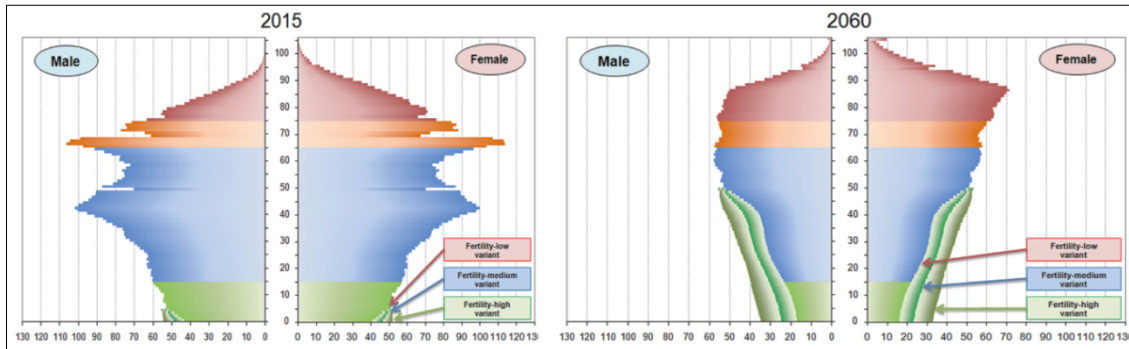
The advanced fusion of cyberspace and physical space is achieving a balance between economic growth and solving social problems related to rapidly aging and shrinking populations. Meanwhile, the global COVID-19 pandemic has also, since 2020, speeded up the transition of lifestyle toward digitalization, which requires more input of electronic equipment, nontangible investment, and a more flexible workforce.

Based on the latest results of the Population Census of Japan and the Vital Statistics of Japan (Figure 1), the National Institute of Population and Social Security Research in Japan (IPSS) has conducted a new national population projection exercise (Population Projections for Japan: 2016–2065), covering the whole population of Japan, including foreign nationals. This is the same framework as the Japanese national census. The population projection assumes future trends in fertility, mortality, and international migration by calculating variants based on alternative scenarios (i.e., births, deaths, and international migration by gender and age) and using the cohort component method. The cohort component method is used to forecast future demographic trends by gender and age. Assumptions are made based on actual statistics for each component using the demographic method.

Vital statistics of the total fertility rate:

$$\begin{aligned} & \textit{Total fertility rate} \\ = & \sum_{\substack{\textit{Sum for age} \\ (15-49)}} \frac{\textit{Births by Japanese women} + \textit{Births by} \\ & \textit{non-Japanese women in a relationship with Japanese nationals}}{\textit{Population of Japanese women}} \end{aligned}$$

International migration is greatly affected by internationalization, changes in socioeconomic conditions, and policies and regulations concerning international migration. International migration also fluctuates significantly due to domestic and international socioeconomic events and disasters. Looking at international migration statistics involving foreign nationals, the number of net migrants in Japan has generally been increasing continuously, although there are irregular fluctuations. For this reason, data from years with large fluctuations were excluded from the estimation of net foreign migration since the 1970s because of the large temporary changes caused by socioeconomic events and disasters. The results were then projected as the long-term trend of the net migration numbers and used as the assumption for the period until 2035.

Figure 1: Japan's Population Projection in 2015 and 2060 (Unit: 10,000 People)

Source: IPSS website (<http://www.ipss.go.jp/index-e.asp>).

By using the regression method and single-country data for Japan for the period 1975–2011, the population aging in Japan is related to economic growth as measured by real GDP per capita. An increase in the number of people aged 70–74 is associated with a lower economic growth rate, while an increase in the number of people aged 75 and above is associated with a higher rate of economic growth. One possible approach to promote sustainable economic growth in the context of population aging is to devise a comprehensive policy that focuses on demographics (Oliver 2015).

In addition, changes in society have necessitated the development of policy alternatives to address the identified challenges and the ex-ante and ex-post evaluation of policies. Stakeholders are advised by academia to identify social issues, expect science to deal with them, design policy options, promote mutual understanding, implement the policies, conduct impact assessments and evaluations of those policies and respond to the social challenges. The policy formation process can develop in a cyclical manner. There is an institutional need to build the strategy.

1.2 Japan's Public R&D Policy

The Fifth Science and Technology Basic Plan (Cabinet Office 2016) in Japan advocates a shift from an information society to a “Society 5.0,” a human-centered society that combines economic development and solutions to social problems through a system that integrates cyberspace and physical space. This will require a significant investment in ICT products for domestic infrastructure and efficient and effective realization of productivity in smart manufacturing and smart city development. Domestic production could be restimulated and public investment in R&D and innovation could act as a positive shock with spillover effects to accelerate production transitions in global supply chains to prepare for such a transition. Such a society would be one that is able to provide the right goods and services at the right time and in the right quantity to those who need them, precisely addressing the diverse social needs of all people, regardless of age, gender, region, or language, with easy access to quality services.

Furthermore, the Sixth Science and Technology Basic Plan (MEXT 2020) was formulated from the perspective of investment in science and technology; policy recommendations should be made to maximize national value through optimal investment by linking science, technology, and innovation policies not only to the science and technology budget but also to the government budget as a whole.

In order to maximize national value through the power of digital transformation, all intellectual resources (research seeds, human resources, research data, etc.) held by the government, universities, companies, etc. should be grasped and shared as much as possible in order to achieve a breakthrough in productivity. The specific initiatives to strengthen research capabilities include “Digital transformation of research as a whole and response to accelerating open science,” “Development of world-class infrastructure to support research,” and “Promotion of shared use, new international joint research, and international brain circulation” in the post-COVID-19 era.

To achieve these objectives, data-driven innovation is becoming mainstream. It is necessary to promote both the utilization of personal data and the protection of privacy, the development of cybersecurity infrastructure, the release of public data by the government, and the construction of a typical architecture for the public and private sectors in the area of their collaboration as the essential environmental infrastructure for this. It is desirable to promote the development of cyber infrastructure to accelerate the platform efficiency while utilizing the use of data through intangible capital investment (Haskel and Westlake 2018). While tangible capital investment confronts various limitation of on-site operation and mobility, the improvement of system connectivity such as distant meeting and working require more input from the intra-firm ICT and R&D activity.

According to the Statistics Bureau of the Ministry of Internal Affairs and Communications (2019), Japan’s R&D spending has steadily increased from \$150 billion to \$185 billion since 2009. The private sector accounts for most of the increase. On the other hand, the ratio of R&D expenditure to GDP has been hovering around 3.5%, which is relatively higher than that of other OECD (Organisation for Economic Co-operation and Development) countries (2.4%) except for the Republic of Korea (4.2%). However, government-led R&D spending as a percentage of GDP remains low at 0.5%, below the average for OECD countries (0.6%) and most developed countries (0.5%), including the Republic of Korea (1.0%), Germany (0.8%), and the United States (0.7%) (METI 2019).

Although the scale of public investment in R&D is much smaller than that of private investment compared to the amount of R&D spending, public R&D investment in basic science can generate more spillover effects and promote productivity growth in multiple sectors. Much of this R&D investment comes in the form of competitive research funding to research institutions and universities (Huang, Liou, and Iwaki 2020). This situation calls for the creation of a public-private platform in the field of public data release and collaboration. Increasing productivity is not simply a matter of aiming for greater efficiency. Unlike the results of private R&D investments, which are usually focused on protecting patents and ensuring profitability, publicly funded research results may be released and shared with society after a certain period of time (usually five years), requiring a more systematic consideration of policy cost-effectiveness (Kuroda et al. 2018).

Creating a knowledge-based society through industries of data-driven innovation platform would require more capital and human resources input for intra-ICT and intra-R&D activity to improve the production efficiency to enable the provision of high value-added goods and services to sustain the economic growth with less material input under demographic change. The increasing number of creative people may contribute to the rise of wage and price transition in the business model and education system.

1.3 R&D Policy and its Spillover Effect on the Value Chain

Public R&D policy can be divided into three categories: R&D tax credits and direct subsidies; support for university research systems and the formation of highly qualified human resources; and support for public R&D cooperation among various institutions. The importance of R&D investment in explaining economic growth is well documented, as modern governments increasingly recognize the benefits of supporting R&D investment. However, in times of fiscal crisis and economic austerity, government funding is increasingly scarce. Therefore, it is important to evaluate the investment outcomes through an evidence-based approach in order to make the best use of limited resources (Becker 2015).

Observations of the 17 OECD member countries over the past two decades reveal that public R&D investment, including grants, procurement, tax incentives, and direct implementation of research in public laboratories and universities, is the preferred policy instrument to accelerate the development of science, technology, and innovation. Government funding has a positive effect on R&D carried out by private enterprises, directly or indirectly raising the level of enterprise R&D. This observation suggests that the stimulative effect of government funding varies with its generosity, increasing up to a threshold of about 10% of firms' R&D and decreasing above the threshold (Guellec and Potterie 2003).

The value chain in the second half of the 20th century is closely related to technological change, which is also evident in the input-output table's intermediate goods complex. In the case of Japan, the relative share of electronics and machinery has increased substantially as the manufacturing sector developed (Kuroda and Nomura 2004), but the next driver of rapid development since the 2000s has been the area of information technology through platform economies with intangible services. The value chain in such innovation can refer to the system of bridging ideas in the market (Hansen and Birkinshaw 2007). It may be indicated by the sourcing of knowledge or the initiation of a new product or process in the form of transformation, as well as the process of exploitation that may result in improved performance by the innovative business (Roper, Du, and Love 2008).

In other words, innovation in both products and processes contributes positively to firm growth, while product innovation has a short-term effect on labor productivity. Therefore, modeling the entire innovation value chain can assist policymakers by highlighting the structure and complexity of converting knowledge into business value and highlighting the role of firm skills, capital investment, and other resources in the value creation process.

It may be debatable whether public R&D investment complements and acts as an "add-on" to private R&D investment, or whether it tends to replace and "crowd out" private R&D. The overall results of a 35-year cross-sectional survey of laboratories, firms, and industries have been criticized for being ambiguous, lacking empirical support, and not sufficiently specifying the nature of the "experiments" that researchers envision (David, Hall, and Toole 2000).

In the financing of R&D and innovation, conditional on the absence of underinvestment due to externalities and "financing gap" in the financial markets, while SMEs and new innovators face a high cost of experience capital, and evidence that the cost of R&D capital for large firms is a mixed bag (Hall and Lerner 2010). On the other hand, in countries with highly developed public stock markets that can take advantage of spillover effects from public R&D investments. R&D subsidies can be considered a derivative means of encouraging firms' innovation efforts and making the way firms

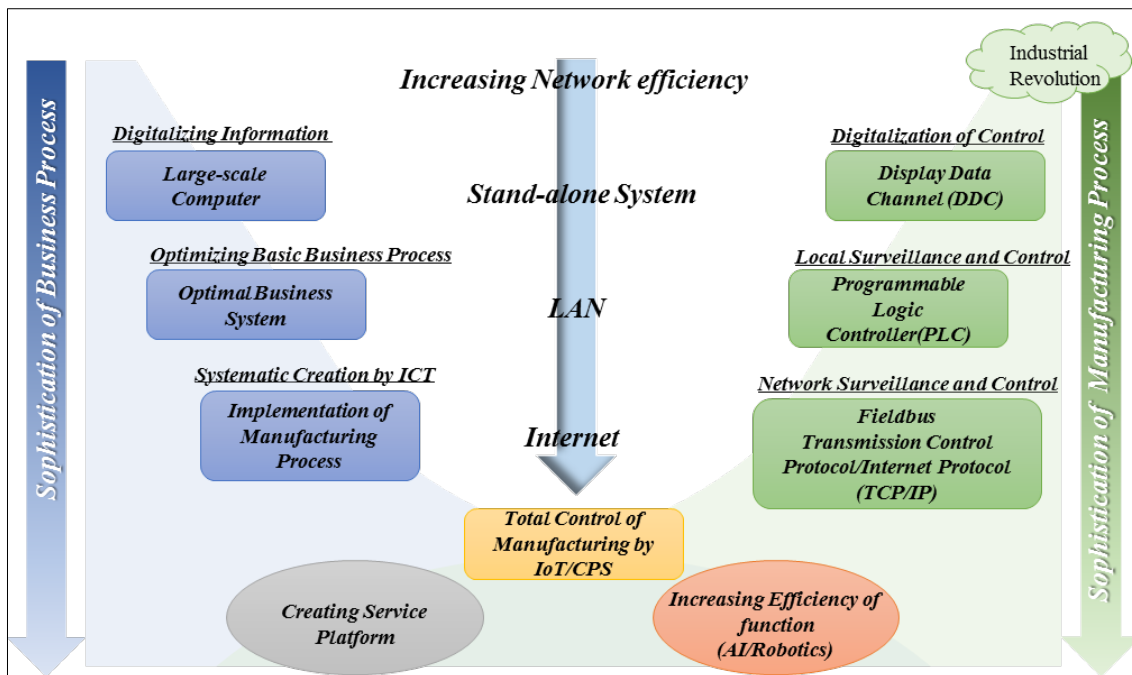
organize their innovation process more positive. It is not clear whether receiving public R&D subsidies affects the probability that a firm will form R&D alliances with other firms in the research institution or production network. Public support significantly increases the likelihood that a firm will collaborate with a public research institution, and it also increases the likelihood that a firm will enter into a private partnership, but only to a small extent and only if the firm possesses intangible knowledge assets (Busom and Fernández-Ribas 2008). The spillover effect generated by public R&D investment could accelerate the creation of innovation platform.

1.4 Evaluating Structural Change and R&D Policymaking

The main channels through which university research influences industrial R&D are through research literature and reports, public meetings and conferences, informal information exchange, and consulting. After controlling for industry, the influence of public research on industrial R&D is disproportionately large in large and emerging companies (Cohen, Nelson, and Walsh 2002). Technological change will accelerate access to healthcare through affordable and seamless marketing on cyber platforms (Biswas 2014).

Connectivity to remote prescribing of medical services via electronic devices may also accelerate the application of electronic machines, ICT, and the pharmaceutical industry as the world deregulates. These interactions and productivity gains deserve more attention through continuous observation. As shown in Figure 2, the innovation platform facilitates the production process with an automated feedback system for network efficiency.

Figure 2: Increasing the Importance of the New Design for a Digital Economy



Source: GRIPS SciREX Center.

In 2021, with the COVID-19 pandemic sweeping the world and the post-Abe era, the Suga administration, which took office in 2020, proposed the establishment of a Digitization Agency. Inevitably, the demand for electronics, machinery, and transportation equipment will increase significantly, forcing the government to formulate appropriate science, technology, and innovation (STI) policies and take more pragmatic measures to improve economic growth and welfare. It is now more difficult than ever to identify STI policies in response to these radical socioeconomic changes. It is essential to be able to assess policymakers' reflections on their policy engagement in a more quantitative manner. This will require connecting the conscience between scientists and policymakers for policy evaluation.

This requires redesigning STI policy to reconstruct the STI policy's planning and implementation and develop it as a science. This paper includes three main sections: (1) examining the value chain transition along with the demographic change; (2) displaying the simulation results, economic impact, and implications for the key sectors that will be subjected to the most significant changes; and (3) providing policy recommendations for a new form of society in the post-pandemic era.

This paper proceeds as follows. The Methodology section presents the structure of the model and the equations selected for analysis. The Data and Scenarios section discusses the data sources, the scope of the study, parameter settings, and calibration. In the simulation results section, we present numerical values for key economic indicators such as output, labor endowment in age quantiles, and prices index, as well as an analysis of GDP disguised unemployment. Finally, we present a conclusion with policy implications, research limitations, and future prospects.

2. METHODOLOGY

2.1 The Creation of SPIAS-e as Policy Simulator

Policy assessment is a vital process for allocating resources and priorities based on time series observation for a continuity analysis. The creation of a policy simulator could enable the assessment of the impact of policy instruments on the economic structure as alternative policy options and interpret the science linkage between public R&D investment and knowledge stock, and further, the knowledge capital service to be applied for production activity as an industry linkage. For this purpose, the SciREX Policy Intelligence Assistance System (SPIAS) was constructed, affiliated to an economic simulator (SPIAS-e)¹ and based on a recursive CGE model that illustrates the new business platforms reflecting the investment in R&D for facilitating capital service flow from three dimensions: (a) main product; (b) intra-firm ICT activity; and (c) R&D activity.

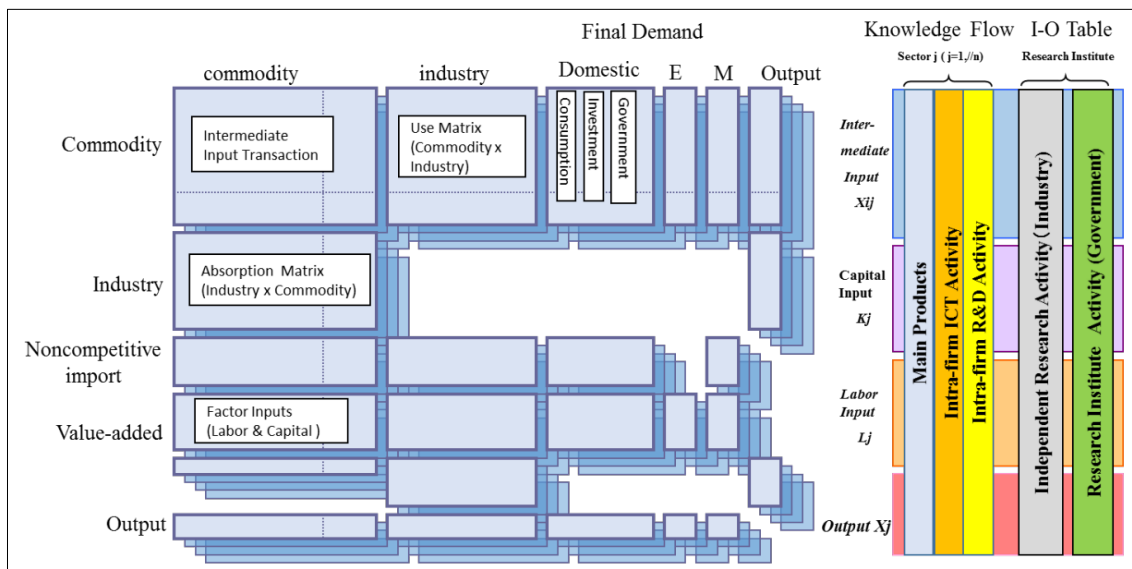
SPIAS-e provides a 50-year forecast of productivity parameters resulting from public R&D investment. The system performs recursive computable general equilibrium (CGE) simulations based on time series data and demographic data obtained from the input-output table for Japan since 1995. The capital stock is estimated using the perpetual inventory method of tangible and intangible assets for each industrial activity. We have been able to show a theoretical framework that explicitly measures R&D activities in the conventional input-output framework and recursively measures how accumulated intangible assets (knowledge stock) generate efficiency in production

¹ For details concerning the CGE model and formula, refer to Kuroda et al. (2018) and the SciREX website: <https://scirex.grips.ac.jp/en/>.

activities. Here, it is assumed that each R&D investment is accumulated as an intangible asset and that the accumulated intangible asset generates capital service flows as technical knowledge (Kuroda et al. 2018).

Activity areas such as marketing, planning, research and development, procurement, operations and sales, and maintenance have different levels of process/productive efficiency set by technical parameters. These productivity parameters are adjusted through SPIAS and include research grants, academic outputs based on scientific papers, patents, press releases, etc. In order to revitalize science and technology capabilities and capture social value, SPIAS was established as an independent research organization that divides the R&D activities of industry and government into five research areas, namely, (1) Life science; (2) ICT; (3) Materials; (4) Environment and energy; and (5) Others. In the process, changes in capital and labor services were observed, indicating a gap between income and capital formation. A graphical summary of the capital stock in the input-output table is shown in Figure 3.

Figure 3: Structure of Input-Output Data Layers and Production Activity by Sector



Source: Kuroda et al. (2018).

2.2 The Challenge of SPIAS-e and the Value Chain Transition

The SPIAS-e framework aims to identify societal challenges such as policy options design, mutual understanding acquisition, policy implementation, impact assessment and evaluation. To support the development of science and technology to identify social issues, it is important for scientists to observe the current state of science and then accurately understand society’s expectations for science and changes in the social structure. In order to discover social issues, an interdisciplinary collaboration between social and natural sciences is essential. This requires the formulation of policy alternatives to address the identified issues and the *ex-ante* and *ex-post* evaluation of policies.

In the scope of the model, factor inputs are the capitalization of intangible assets from R&D stock and IT stock, measured by the quantity and price of capital services imputed from capital stock and cost of capital. The capital stock and cost of capital are

measured consistently using the input-output tables for tangible and intangible assets in Japan (1995–2011). Intangible assets are estimated separately using the knowledge stock of software and research fields. In addition, the capital formation matrix with flows and stocks of tangible and intangible assets is estimated annually. On the other hand, labor input is estimated by gender and age group by sector and activity.

Under such fragmentation, ICT/IoT may systematically capture the flow of capital services that facilitate the distribution and processing of information to improve manufacturing productivity in a changing demographic. Furthermore, information management may benefit from outsourcing and externalization, and a cross-cutting platform for information management may be established. The simulation results show the short- and long-term effects of ICT/IoT advancements on employment and production sectors. By quantifying the spillover effects across industries as process and product innovations, it is now possible to analyze productivity and competitiveness under economic and social structural changes.

3. SCENARIOS

In order to analyze the impact of the development of scientific and technological knowledge on the economy and society, it is very important to establish the analytical tools to observe the impact both theoretically and empirically. Based on the theory and model building of Kuroda et al. (2018), we can observe the impact of the development of science and technology on the economic structure. They attempted to capitalize R&D expenditures as intangible assets.

The sources of investment in R&D activities were provided by the government and the private sector. The investments were based on scientific and technological knowledge creation and were divided into several scientific fields. R&D activities were introduced by public research institutes, such as universities and affiliated research institutes, and private research institutes such as private independent research institutes, and in-house R&D activities belonging to private enterprises.

3.1 The Compilation of R&D Activity

The R&D products and services created by these agencies are accumulated in knowledge stocks as intangible assets in each agency. Knowledge stocks accumulated in these agents are assumed to have an impact through static and dynamic interdependency among sectors. We revised Japan's input-output table for 1995–2011 with the estimation and introduced the observed facts concerning the R&D expenditures in Japan. The following points describe the contents of R&D activities explicitly classified in the input-output table:

- i. Agents of the R&D.
- ii. Capital formation in tangible and intangible investments is recorded in the capital formation matrices (capital flow matrices [commodity x activity]).
- iii. From the capital formation matrices, we can estimate capital stock by each activity, separately in the tangible and intangible assets by using perpetual inventory method.
- iv. As regards the treatment of patent activity, we try to follow the concept of the current IO. Consequently, the activity creating a patent entity is not classified separately from the main production; the patent entity is an auxiliary product of

the main products, and the licensing fee transaction is treated as a transaction of property income among sectors.

The agents of the R&D activities are divided as follows:

- a. Intra-firm R&D activities by the market producer; R&D activity inside enterprises, except for independent private research institutes.
- b. R&D activities by private nonprofit organizations and public R&D institutions as special and independent corporations.
- c. R&D activities by research institutes affiliated with public and private universities.
- d. R&D activities by research institutes independent from market producers.
- e. R&D activities, except for educational activities by public universities and their affiliated hospitals.
- f. R&D activities, except for educational activities by private universities and their affiliated hospitals as market producers.
- g. R&D activities by nonprofit research institutes, which provide professional and related services for science and technology.

Intra-firm R&D and ICT activities are classified separately from the main production activity within the enterprise. The enterprise's knowledge services are counted as the capital formation of intangible assets which are accumulated by the capital formation investments in the intra-firm R&D and intra-firm ICT activities separately. On the other hand, tangible capital used in R&D activities and intra-firm activities of software development is counted as tangible capital formation investment and accumulated in tangible assets of these two R&D activities by research institutes independent from market producers, who are separately classified as an independent sector by which knowledge is produced as marketable products. These activities by independent research institutes are divided into seven natural science fields, "life science," "information," "environment," "materials," "nanosciences," "energy," "space exploration and ocean development", plus one "social science" field.

The above categories classified as R&D activities (b, c, e, f, and g) are aggregated into R&D activity by private nonprofit and public research institutions, including public and private universities, their affiliated research institutes, and hospitals. However, the fields of R&D activity are separately classified in the science field (natural sciences and one social science). These R&D activities create science and technological knowledge as the investment of intangible assets, and knowledge is accumulated in intangible assets. In addition, fixed capital formation for R&D activity in these sectors will be recorded as fixed capital formation in each sector's final demand and accumulated into their tangible assets.

3.2 Scenario Setting

To simulate the policy of promoting science and technology, we thus increased public R&D investment by 20% (compared with 2005) in all fields in both tangible (infrastructure) and intangible (research grant) capital accumulation.² Based on the

² The amount of public investment is equivalent to USD74 billion, while the public R&D budget for Japan in FY 2018 was USD193 billion (<https://www.stat.go.jp/english/data/kagaku/1546.html>). Given that the methodology is based on an IO analysis and a CGE model, the estimated proportion could be reasonable.

model assumption that productivity improvement would take five years, the volume of public R&D investment is demonstrated in Table 1.

Table 1: Five-year Public R&D Investment in Basic Science
(Unit: Million \$ / \$1 = JPY105)

Category	Intangible	Tangible	20% Investment	Sum
Life	20,528	3,991	4,904	29,424
Information	4,380	904	1,057	6,341
Materials	4,288	799	1,017	6,104
Energy	1,996	981	595	3,572
Others	13,129	10,747	4,775	28,651

Source: SPIAS-e.

3.3 Assumptions for the BAU (Business-as-usual for Baseline Scenario)

In the BAU scenario, the above propositions are exogenously assumed to provide an overview of the economic and social trend until 2050 from the year 2005. There are no positive science policies or economic policies by the government, although the population's structural changes by age and gender will be assumed exogenously. This will be the basic scenario to describe any additional policy options and discover the problems to be presumably realized in the future until 2050. The assumptions for the BAU path are stated as follows:

- i. Between 2005 and 2050, the level of government R&D expenditures will be nominally fixed at the 2005 level. In other words, there will be no policy-driven aggressive expansion of government R&D spending between 2005 and 2050.
- ii. The scientific knowledge stock accumulated by government R&D expenditures is assumed to affect the private sector's productivity growth as a public good, but not to affect the parameters of the production function of the private industrial sector.
- iii. Tax rates for personal income tax, corporate income tax, consumption tax, indirect tax, taxation, and property tax are fixed at 2005 levels.
- iv. Government expenditure is assumed to be endogenous and proportional to nominal GDP. Social security and education expenditures are assumed to be demographically independent.
- v. Government capital formation in tangible and intangible assets is fixed at 2005 levels in nominal terms. This implies that the government does not intend to create positive effective demand.
- vi. The population structure is assumed to change in line with the medium-variable fertility projections of the IPSS.

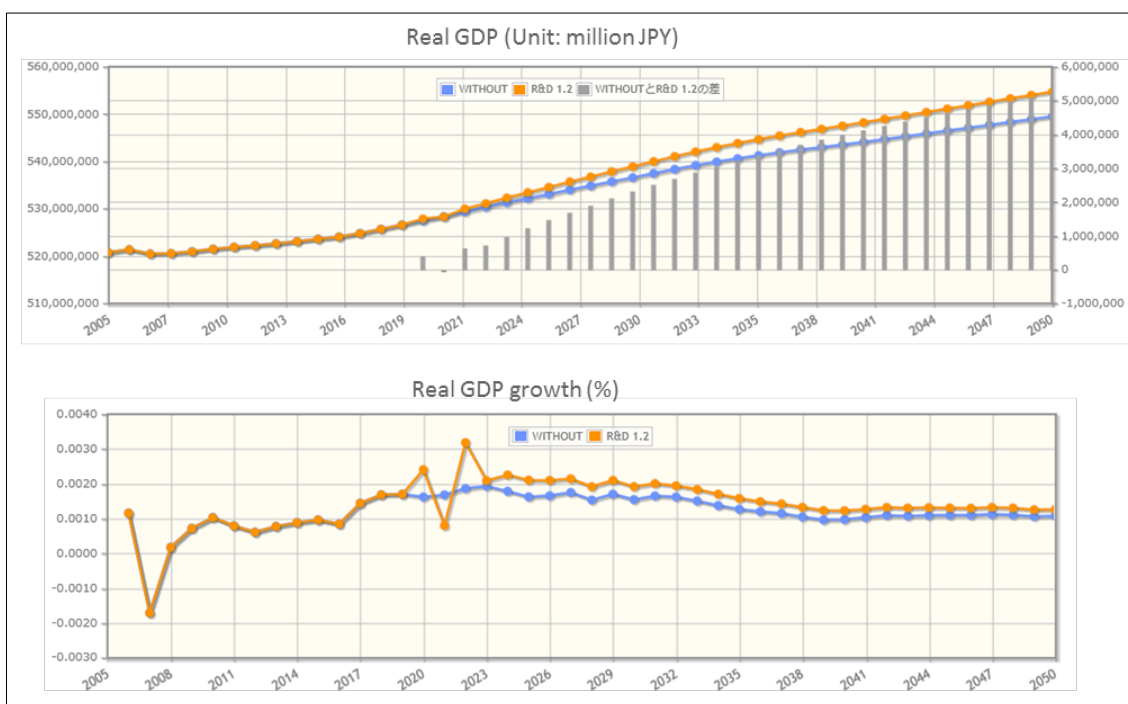
4. SIMULATION RESULTS

After making 1.2 times the public R&D investment in the SPIAS-e, we present the 50-year simulation results present in the process of capital accumulation that contributes to output, price change, and income based on the initial data setting sourced from the 1995–2011 input-output table and demographic changes. The simulation results calculated by SPIAS-e do not serve as a forecast of economic conditions. Instead, the various variables and projections illustrate a possible picture of Japan’s development in a society of an aging and shrinking population. The growing dependence on ICT technology with electronic equipment and e-commerce in the post-COVID-19 era also implies that various systems and reforms should be established to cope with changes in social structure as well as new service platforms. We thus demonstrate the simulation results of GDP, value-added breakdown, employment, and price change of tangible and intangible capital.

4.1 GDP and Value-Added Breakdown

Public R&D investment increases productivity. GDP in Figure 4 shows growth from the BAU level after 2021 (after a five-year investment) and how it continues to grow steadily (upper panel). Although the growth rate is 0.01%, the positive growth under the aging society’s critical threats and shrinking population is already an encouraging sign for public investment. Although the level of change could be too small to have statistical meaning for evaluation, under the inevitable trend of Japan’s shrinking population, the ability to maintain a real GDP growth could be regarded as both symbolic and noteworthy.

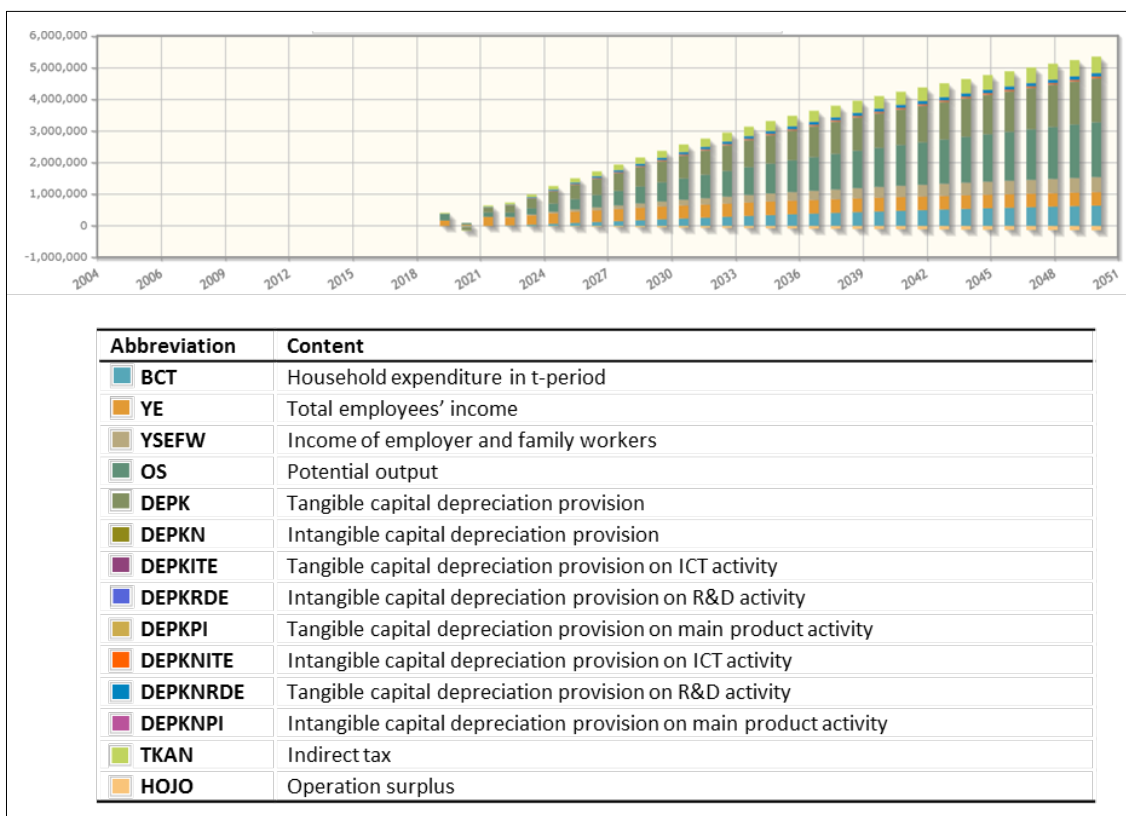
Figure 4: Projection of GDP and Growth Rate



Source: The authors.

The breakdown of the change in value-added GDP (Figure 5) under the shrinking population shows that the potential output (OS), the share of intangible capital depreciation (DEPKN) capital, has increased steadily and substantially. Such a trend could imply that intangible capital accumulation could lead to more output if productivity growth were actualized in the long term. On the other hand, other kinds of capital depreciation provisions do not show significant change, indicating a low level of integration. In addition, the income of employers and family workers has grown gradually while the total employees' income has shown limited growth, implying that the work could switch to a self-employed style. The operation surplus (HOJO) shows a slight decrease, which could be interpreted as traditional manufacturing being unable to create a huge surplus, as it used to be under the foreseen circumstances.

Figure 5: Breakdown of Value-Added and Composition



Source: The authors.

4.2 Employment

The simulation results for employment were categorized according to gender and five quantiles, while the data were sourced from the time-series census to accommodate the 93 classifications. We sorted the ten sectors with the most drastic change in employment to further investigate the sectoral transitions among the main products, intra-firm ICT activity, and intra-firm R&D. The general trends show that employment in younger generations declines steadily until the fourth quantile.

At the same time, no significant difference appears in gender. For the fifth quantile of senior citizens aged over 65, employment increases gradually, reflecting extended employment after the official retirement age. Most notably, such employment trends in

intra-firm ICT and intra-firm R&D activity even show growth, implying that senior citizens could continue to contribute to ICT and R&D activities partially because of a lower physical barrier and knowledge accumulation.

4.2.1 Main Product

The decreasing trend was the most significant in the chemical, energy manufacturing, and agriculture sectors. Employment in these sectors could be the most affected by the shrinking population. On the other hand, private R&D sectors also showed the most significant decreasing trend. The employment is far lower than in manufacturing sector and thus is not substantial in Figure 6.

4.2.2 Intra-firm ICT Activities

The intra-firm ICT sectors represent the connectivity link between consumers and producers. The total employment may be far smaller than in the main production sectors, but it has implications for whether other sectors are able to respond to market demand quickly and effectively. We found that heavy machinery and transportation equipment dropped rather sharply, followed by precise machinery, transportation, and miscellaneous manufacturing. The sectors of petroleum, coal, semiconductor devices, and semiconductor manufacturing also showed a decrease, but the number was quite small (Figure 7).

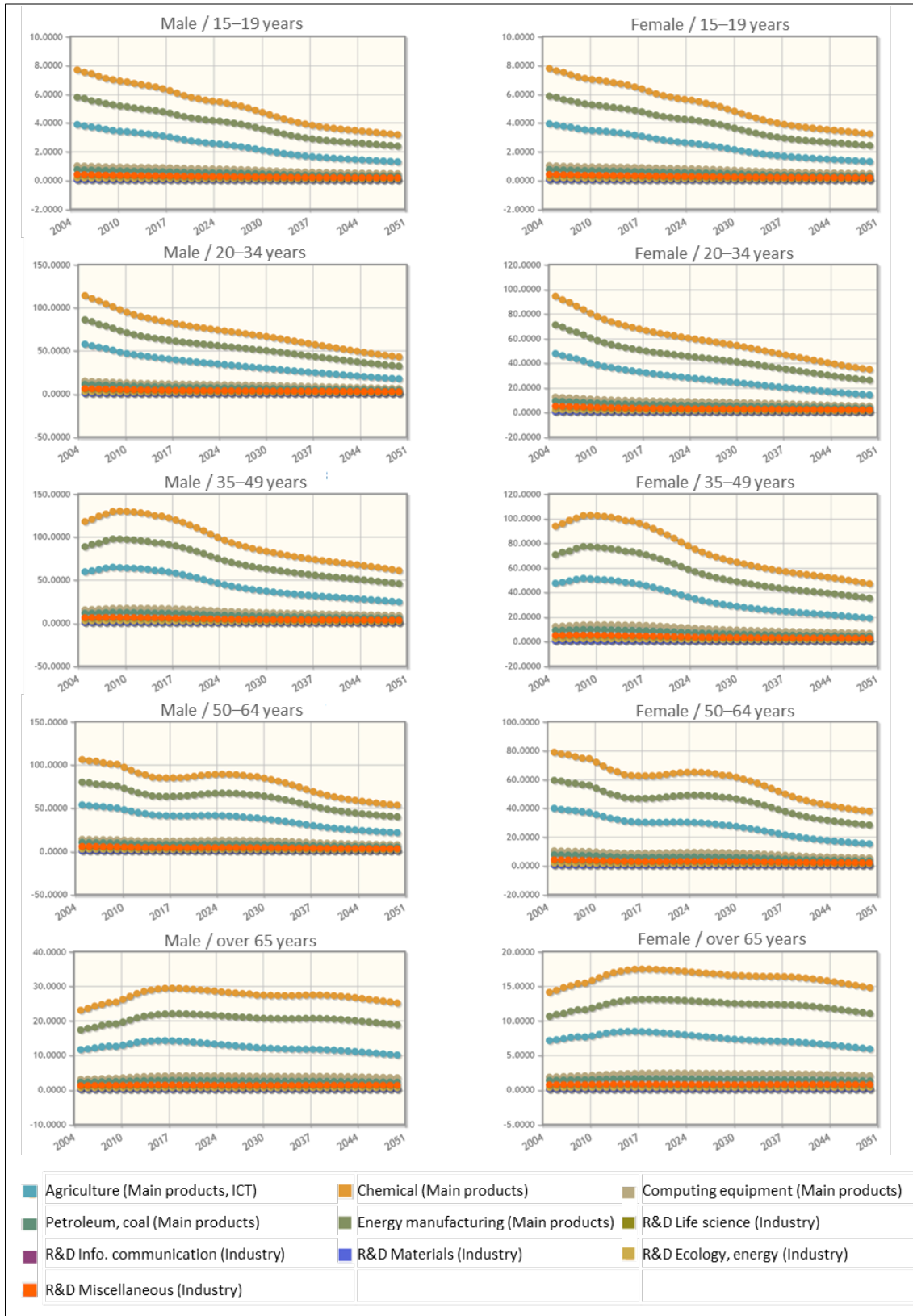
4.2.3 Intra-firm R&D Activity

The intra-firm R&D sectors present an innovative response to a changing society. Despite their decreasing direction, the trend was milder than in the other two sectors, implying that competitiveness comes from R&D and innovation activity. The heavy machinery, transportation equipment, and chemical sectors accounted for the largest share of employment. The employment trends of workers over the age of 65 actually showed an increase, indicating that experienced human capital is desirable regardless of age in R&D sectors. This provides empirical evidence that the official retirement age of 65 should not be imposed on R&D sectors, as in them accumulated skill is highly valued. The petroleum and coal sector had the smallest share but showed a positive trend (Figure 8).

4.3 Price Change of Capital Goods

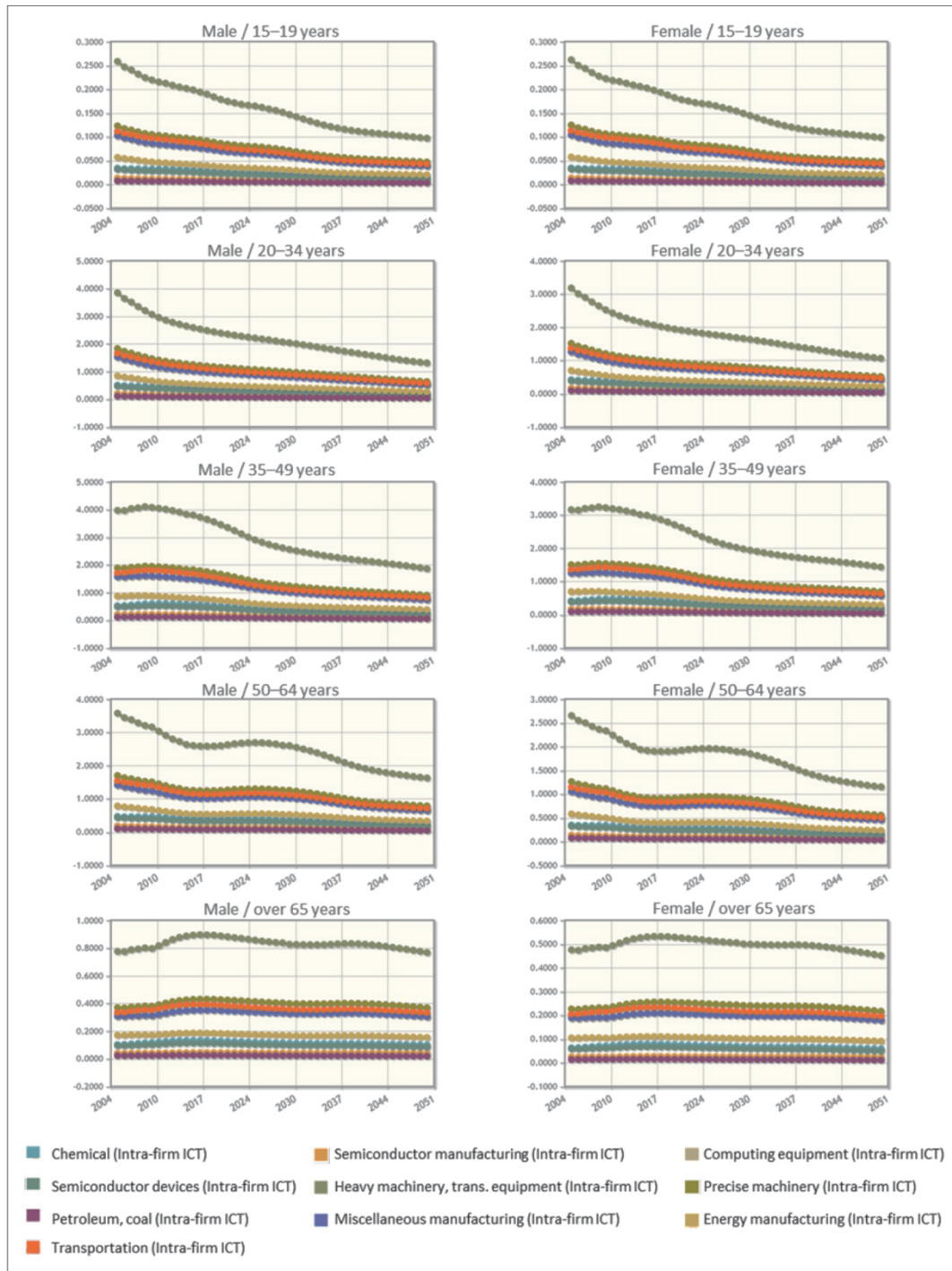
R&D and innovation are necessary in order to strengthen productivity so that the products can be made at a lower price, and this could result in higher social welfare. In the scope of the SPIAS-e model, the tangible and intangible capital goods were separated to provide insight into capital accumulation from the base year of 2005. We also selected the ten most drastic price change indices for capital goods according to the main product categories, intra-firm ICT activity, and intra-firm R&D activity in tangible (Figure 9) and intangible capital (Figure 10).

Figure 6: Employment of Main Product Sectors
(Unit: Thousand People)



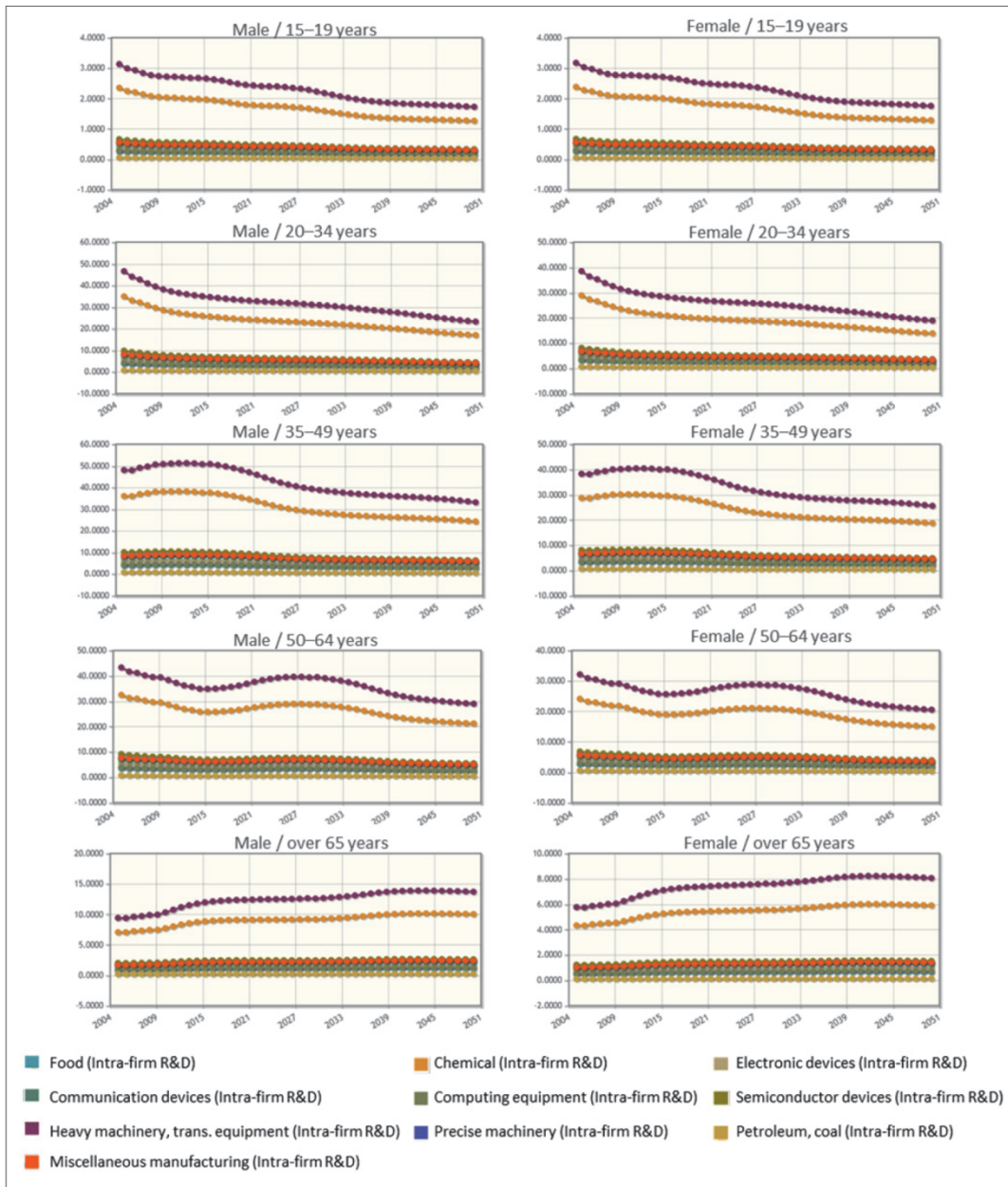
Source: The authors.

Figure 7: Employment of Intra-firm ICT Sectors
(Unit: Thousand People)



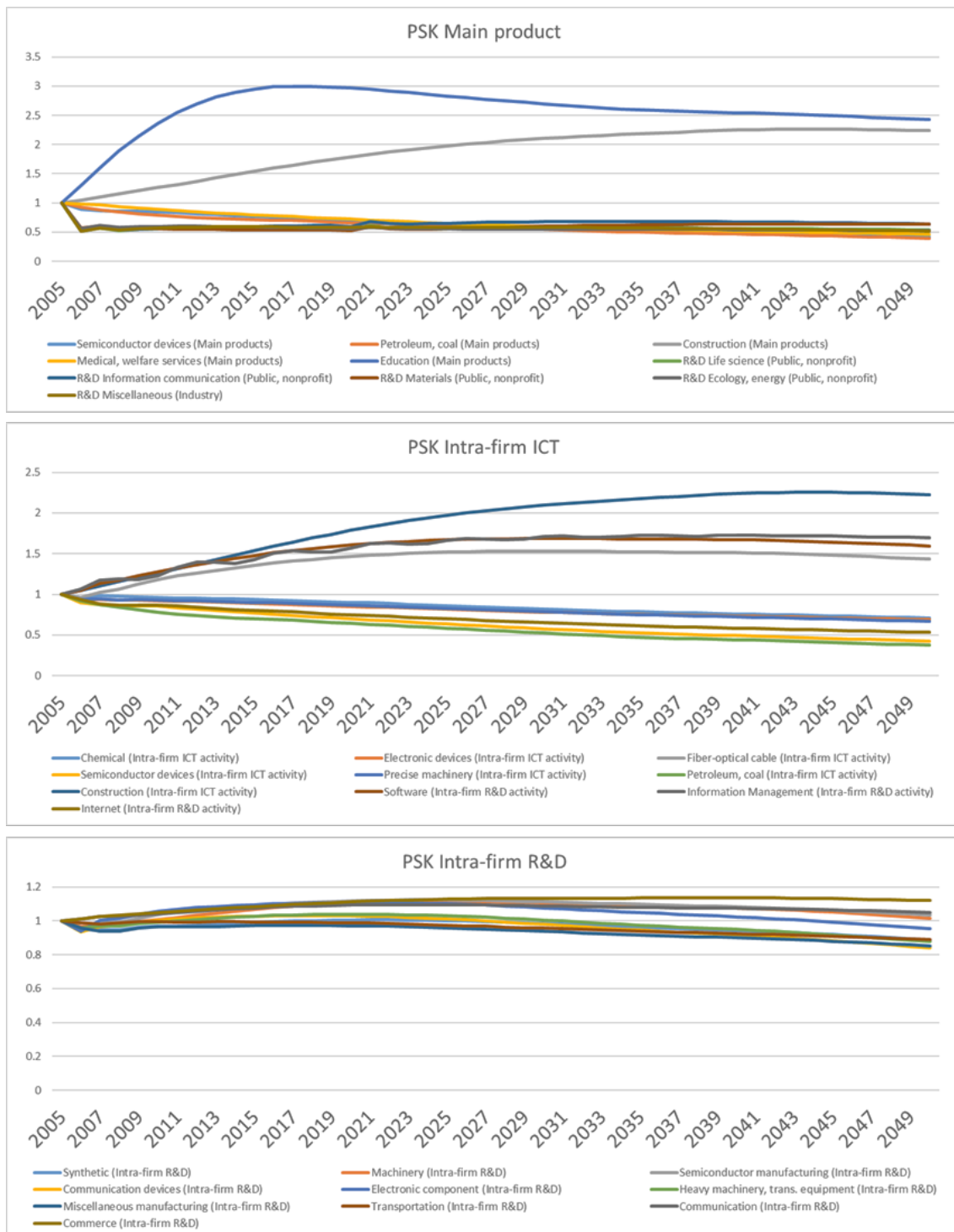
Source: The authors.

Figure 8: Employment of Intra-firm R&D Sectors
(Unit: Thousand People)



Source: The authors.

Figure 9: Price Change of Tangible Capital



Source: The authors.

4.3.1 Tangible Capital

The prices in education and construction grew significantly for the main product, indicating that the cost of tangible capital formation for these two sectors was still high. Given the circumstances of a shrinking population, it is understandable that the cost of construction would remain high. In contrast, the capital price of the medical, materials, information communication, and R&D miscellaneous sectors was lower, implying that steady development could be sustained.

As for intra-firm ICT activity, similarly to the main product trend, the construction sector still showed a significant price growth. Intra-ICT is still an expensive input because people need to see the actual product to make a decision whether to purchase or not. Meanwhile, the price index increased steadily for the software and fiber-optic cable sectors, as there is a need to provide desirable ICT connectivity services between all sectors. It is interesting to see the volatility in information management, which is partly due to the time span of services. On the other hand, the price indexes in the petroleum, semiconductor, and internet sectors decreased, indicating mature development using ICT.

The price index for intra-firm R&D did not change significantly. The slight growth trend in the commerce sector could mean that the traditional sector is also seeking innovative solutions. The electronic component and communication device sectors showed a mild decreasing trend, indicating their continuous support for R&D. Furthermore, the price index's drastic fall shows that the value chain has gradually switched from main product to intra-ICT and intra-R&D activities.

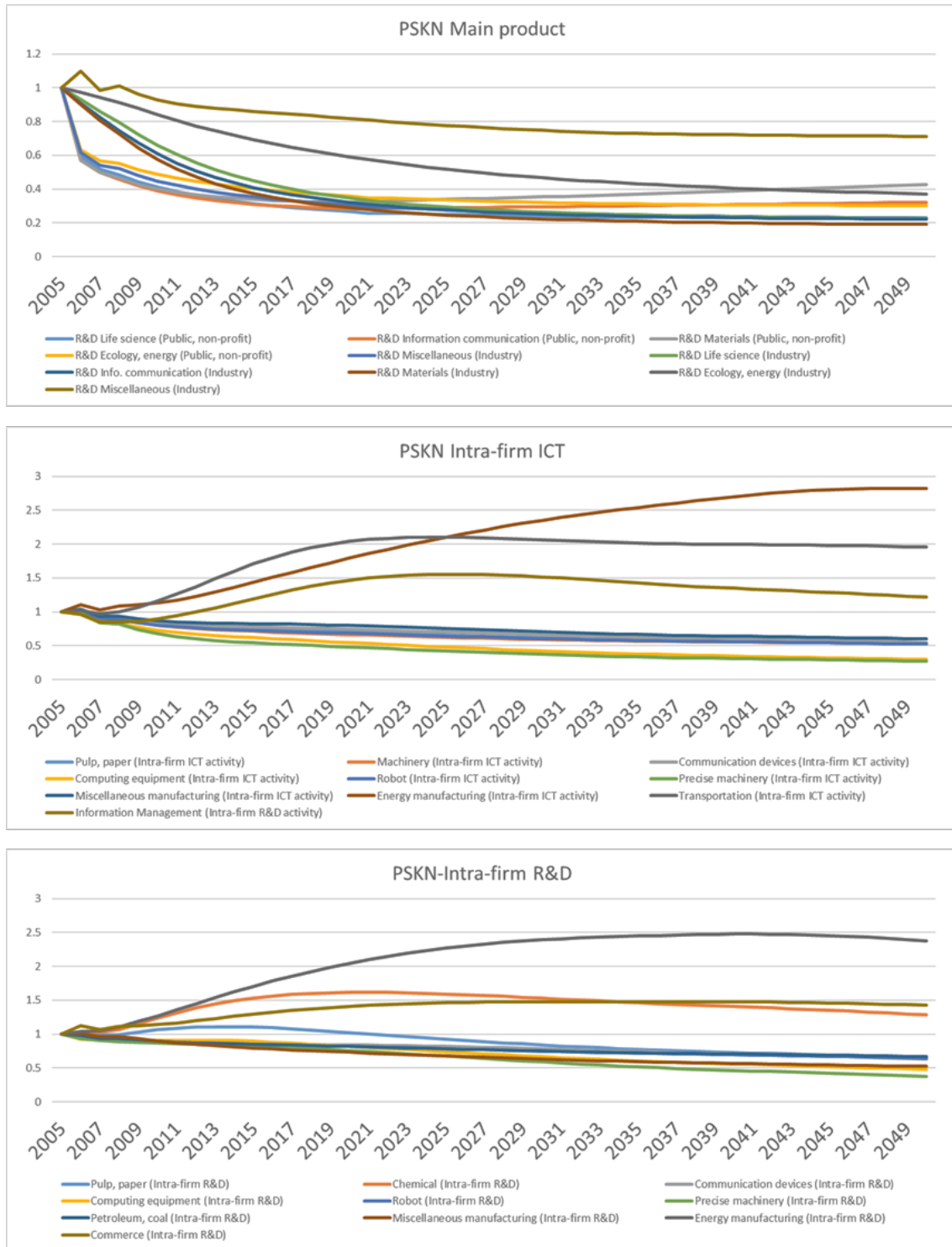
4.3.2 Intangible Capital

The main product price index shows a significant decrease for most sectors, indicating that the intangible R&D investment may provide the key element to increasing productivity, especially for research institutes and think tanks because their primary product is R&D activity. The price decrease in private R&D miscellaneous and private R&D ecology and energy was lower than for other R&D sectors, partly because of less interdependence with public R&D investment. In contrast, the substantial price index drop in public and private R&D information and communication, public R&D ecology and energy, and public R&D life science shows that public R&D investment could be operated effectively in these sectors for overall development projects.

For in-firm-ICT activity, the price index increased significantly in the sectors of energy manufacturing, miscellaneous manufacturing, and information management, indicating the importance of more efficient and effective resource management. However, the growing price index also reveals the concern that productivity in such sectors may not be competitive globally under the ever-increasing service trade liberalization. As for the sectors of precise machinery, computing equipment, robots, and communication devices, the maintenance of lower price indexes indicates Japan's comparative advantage in these sectors.

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Figure 10: Price Change of Tangible Capital



Source: The authors.

For intra-firm R&D activity, the price indexes of the energy manufacturing, chemical, and miscellaneous manufacturing sectors remained high, suggesting that the energy-related sectors are still the main concern for Japan due to its low self-sufficiency even under the trend of a shrinking population. Meanwhile, the price indexes for the precise machinery, computing equipment, miscellaneous manufacturing, and robot

sectors could stay at the lower level and become the growth engine to sustain the next generation of infrastructure development.

4.4 Disguised Unemployment

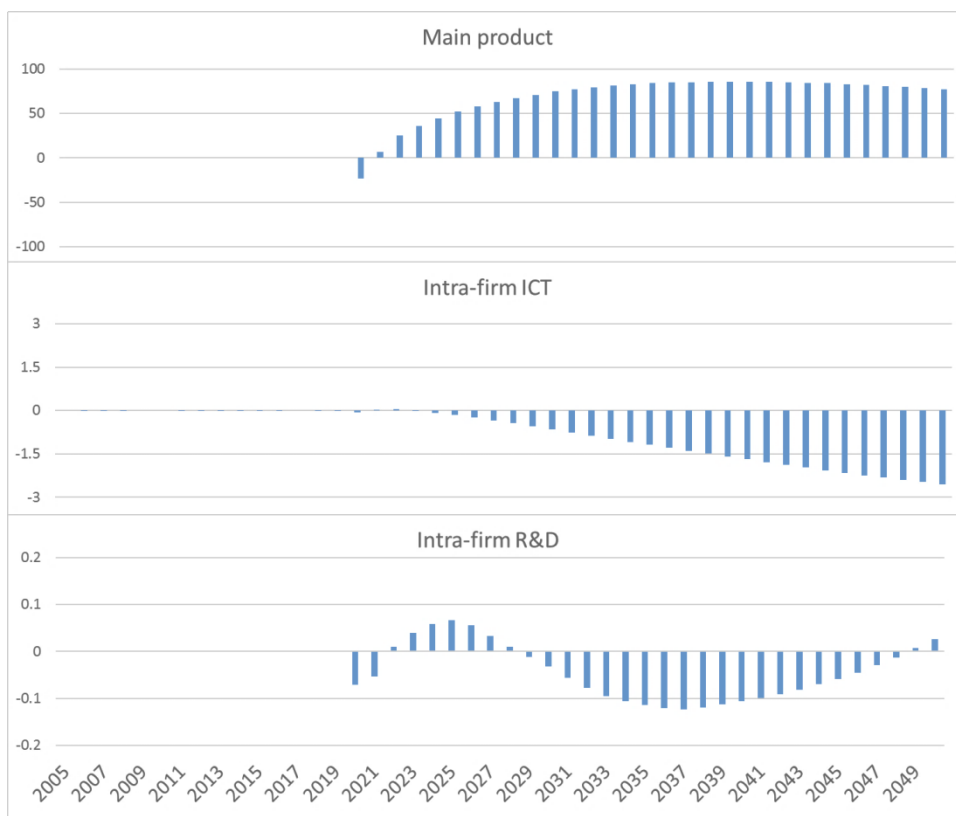
In the structural equations and the prescribed intertemporal equations of this model, full employment is assumed. The decline in labor supply due to an aging society and a shrinking population, especially the decline in working hours, may imply that many labor-intensive household chores will be done by the elderly with the help of ICT and robots. The decrease in working hours and the fact that human labor is even being replaced by ICT and robots through “work sharing” may be creating the phenomenon of “disguised unemployment.”

Disguised unemployment is defined as unemployment in which people are visibly employed but are actually unemployed. In such a situation, more people are engaged in work than required, which could be derived from the following formula:

$$Disguised\ employment = Employment - \frac{Employment \times working\ hours}{1775}$$

(current annual working hours)

Figure 11: Disguised Unemployment (Unit: Thousand People)



Source: The authors.

Based on our simulation results, from the year of 2029, there showed a substantial demand for human resources for intra-firm ICT and intra-firm R&D. In the simulation results (Figure 11), the amount of disguised unemployment in the main product is growing, implying low productivity with inefficiency under the current regulations. In contrast, for intra-firm ICT and intra-firm R&D, the number becomes negative, especially after the year 2027, indicating that the human resources in these two categories are actually insufficient. Thus, human development to accommodate the structural change in the next generation is not only desirable and but also urgent.

As of 2020, a full-time job still means that one must work 8 hours a day, 40 hours a week. However, the number of working hours is expected to decrease in response to the global COVID-19, pandemic as technology advances to increase production efficiency. Large-scale R&D inputs are expected to strengthen the cyberinfrastructure with the support of communication systems. With fewer working hours and more leisure time, humans will be free to think about the complex challenges of achieving a sustainable socio-economy based on a newer and more established service platform.

5. CONCLUDING REMARKS

5.1 Policy Implications

The policy simulator was not made for economic forecasting. Preferably, it could be utilized as a tool for the policy assessment regarding effectiveness of government investment in science, technology, and innovation. As regards the manufacturing sector, improved efficiency would increase production, and public and private R&D investment, and consolidate the knowledge stock for knowledge infrastructure that increases total factor productivity. From our observation of the price indexes, we can conclude that the fall of the main product index indicates that effective production cannot be achieved without intra-ICT and intra-R&D activity, which contribute to maintaining its productivity.

While Japan is facing looming challenges of digital transition and recession due to the global COVID-19 pandemic, a hyper-aging society, and shrinking population, the solutions need to be holistic and fundamental. Our simulation results make possible an in-depth analysis of the factors of R&D capital formation and the potential employment transition, showing that the sectors of intra-firm ICT activity have not been sufficiently connected with the main product and intra-firm R&D sectors. Such problems should be tackled well through deregulation and promotion of innovative sectors.

On the other hand, an increase in the human resources, along with higher professional education and enhanced information, services, and private R&D sectors is evident. The evolution of industries may increase knowledge gaps that contribute to technological unemployment, and analytical frameworks will help provide evidence-based policy-making systems.

5.2 Research Limitations and Future Perspective

Due to the model scope, our study mainly interprets domestic production, neglecting the effects of external trade, although they can be observed from the production indicators. However, the export of tangible products is also vital for developing an overall global strategy and future platform and regulation for intangible goods. Therefore, it is essential to extend the model with wider analytical coverage or to link to other methods to capture the key indicators.

During the economic structure transition, the demand for electronic equipment and related infrastructure is expected to expand substantially. Furthermore, reform of working hours should be made more flexible to accommodate the new type of life-work balance. Leisure time and the generation of value-added are worth more attention.

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