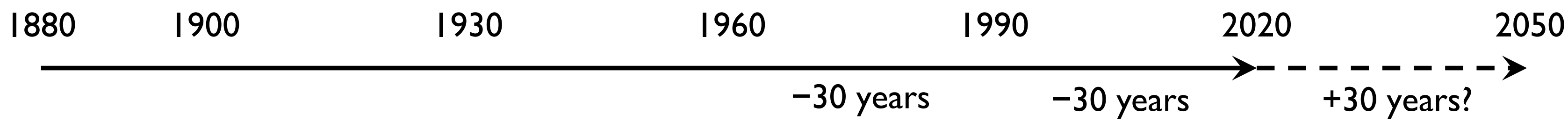

Are We Entering a New Golden Age of Energy Productivity Improvement?

−Lessons from the Japanese economy in the 20th century and the prospects for 2050

Koji Nomura
Keio Economic Observatory, Keio University

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−Challenges to harmonized achievement of economic growth and long-term deep emissions reduction−

CALAMVS GLADIO FORTIOR

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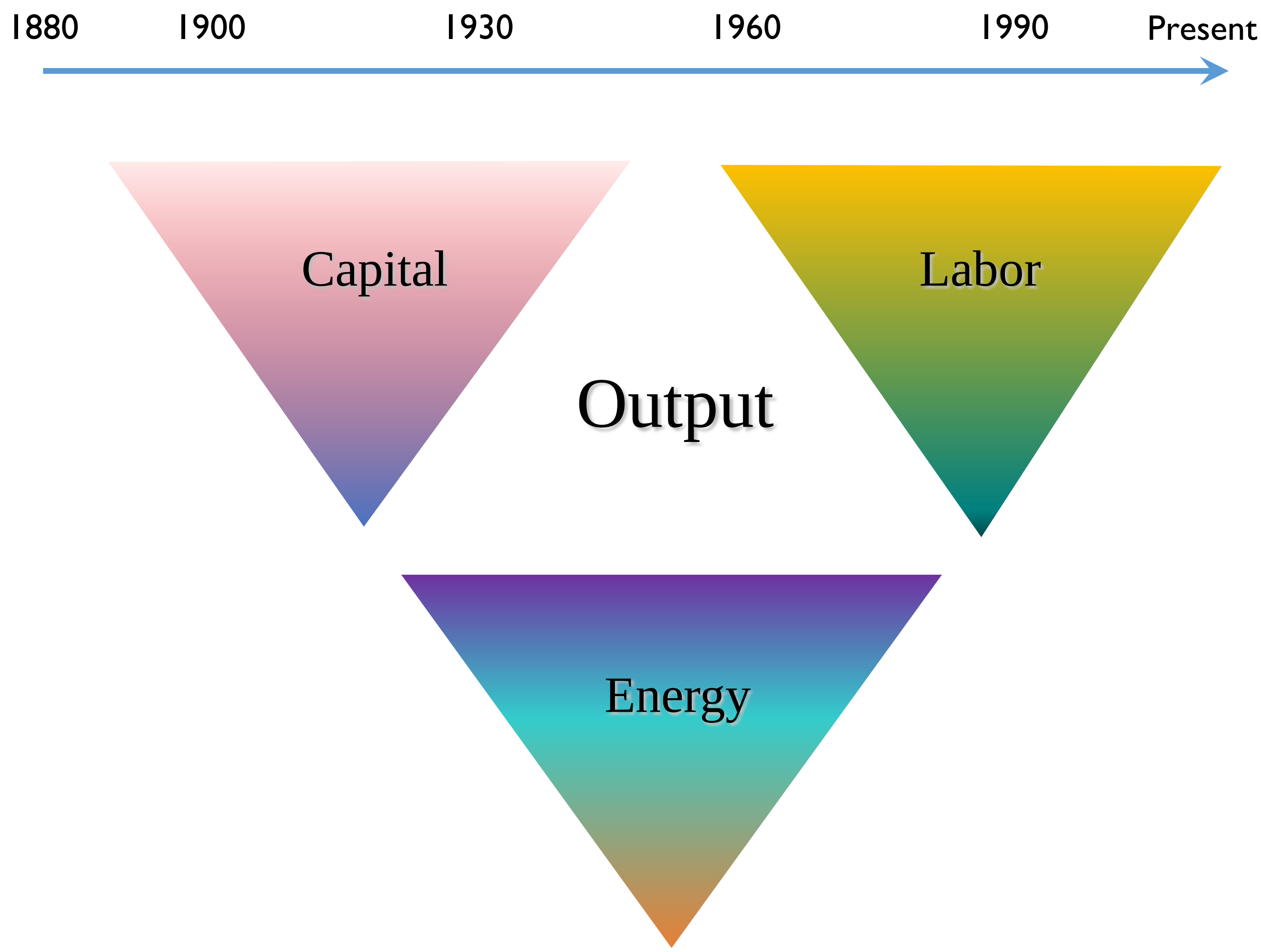
(1) Japan's Economic Growth, Energy, and Capital and Labor Inputs



Energy Productivity Improvement (EPI)

① Output (X)=f (Capital (K) , Labor (O), Energy (E), ･･･)

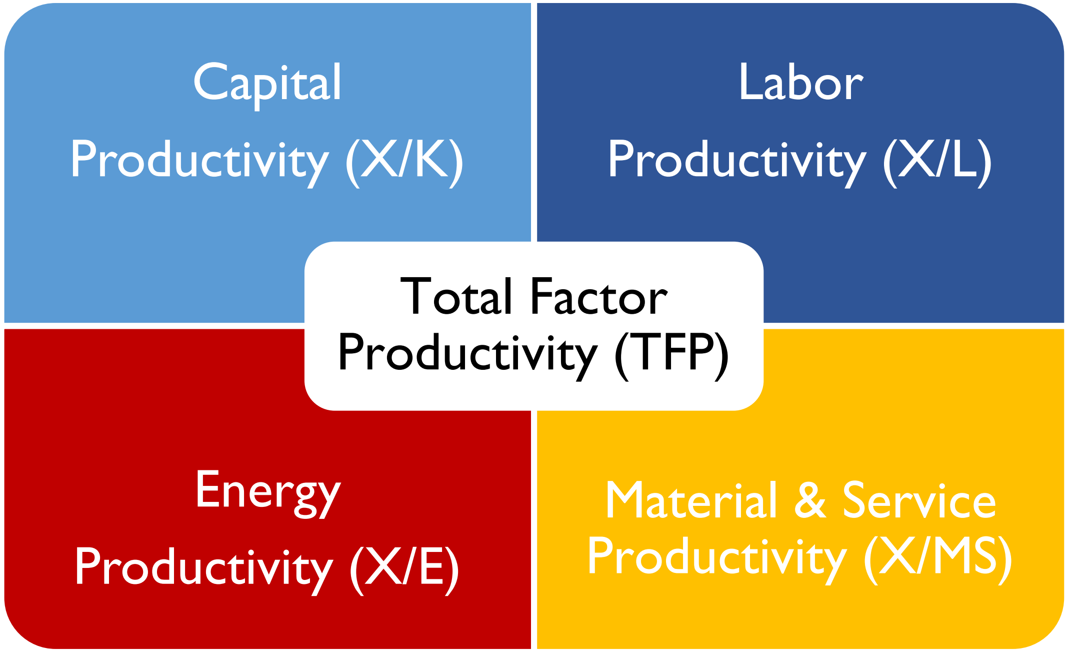
➢Energy is one of factor inputs.

② Energy Productivity = X/E. (an inverse of energy intensity: E/X) .

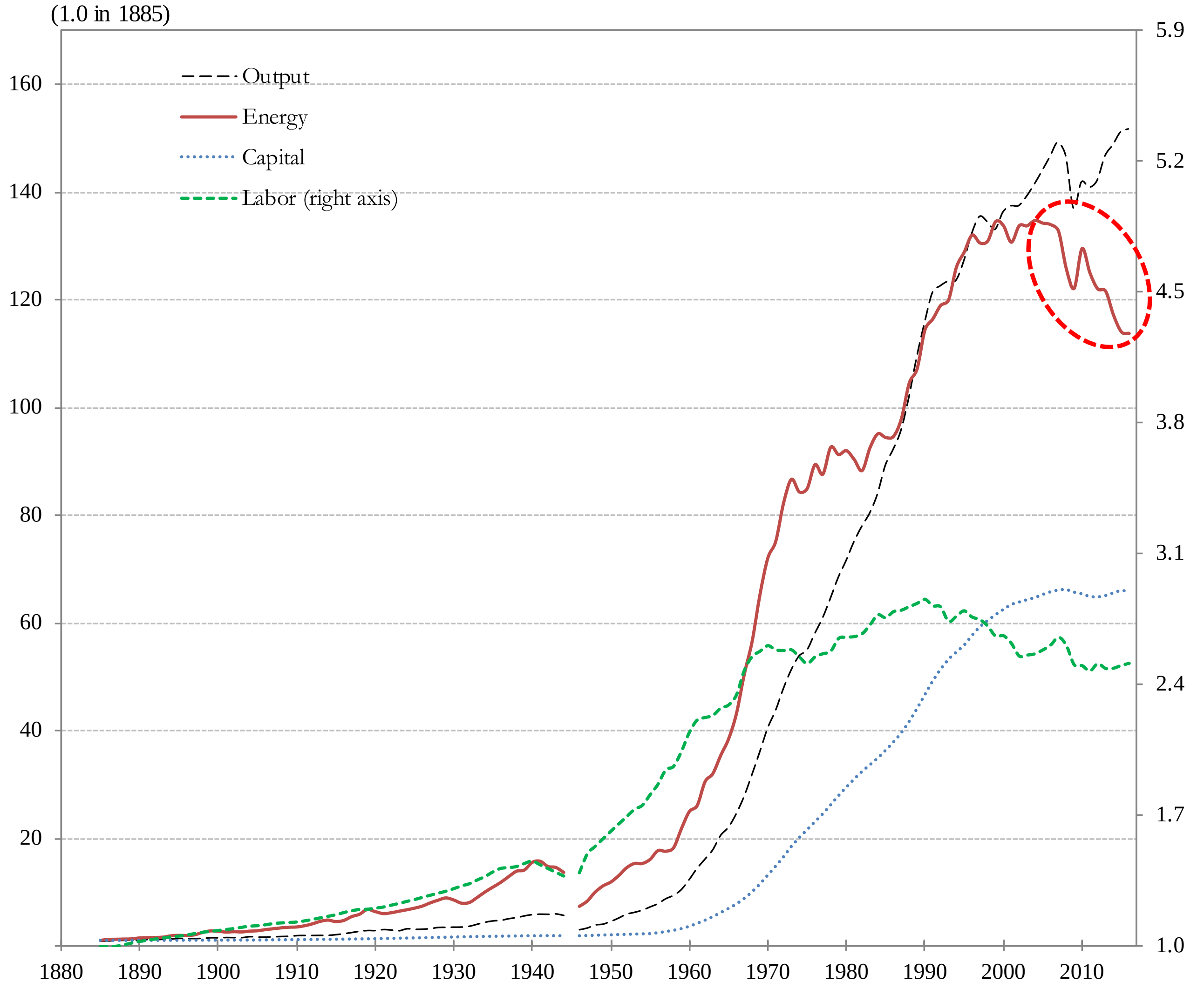
➢Partial factor productivity; X/E, Capital productivity (X/K), Labor productivity (X/L), ･･･

③ Total Factor Productivity (TFP) =(X/E contribution) +(X/K contribution) +･･･

➢Energy productivity improvement (EPI)= "deterioration" in capital productivity (X/K) + "improvement" of TFP + ･･･



Output and Inputs of Energy, Capital, and Labor, 1885-2016



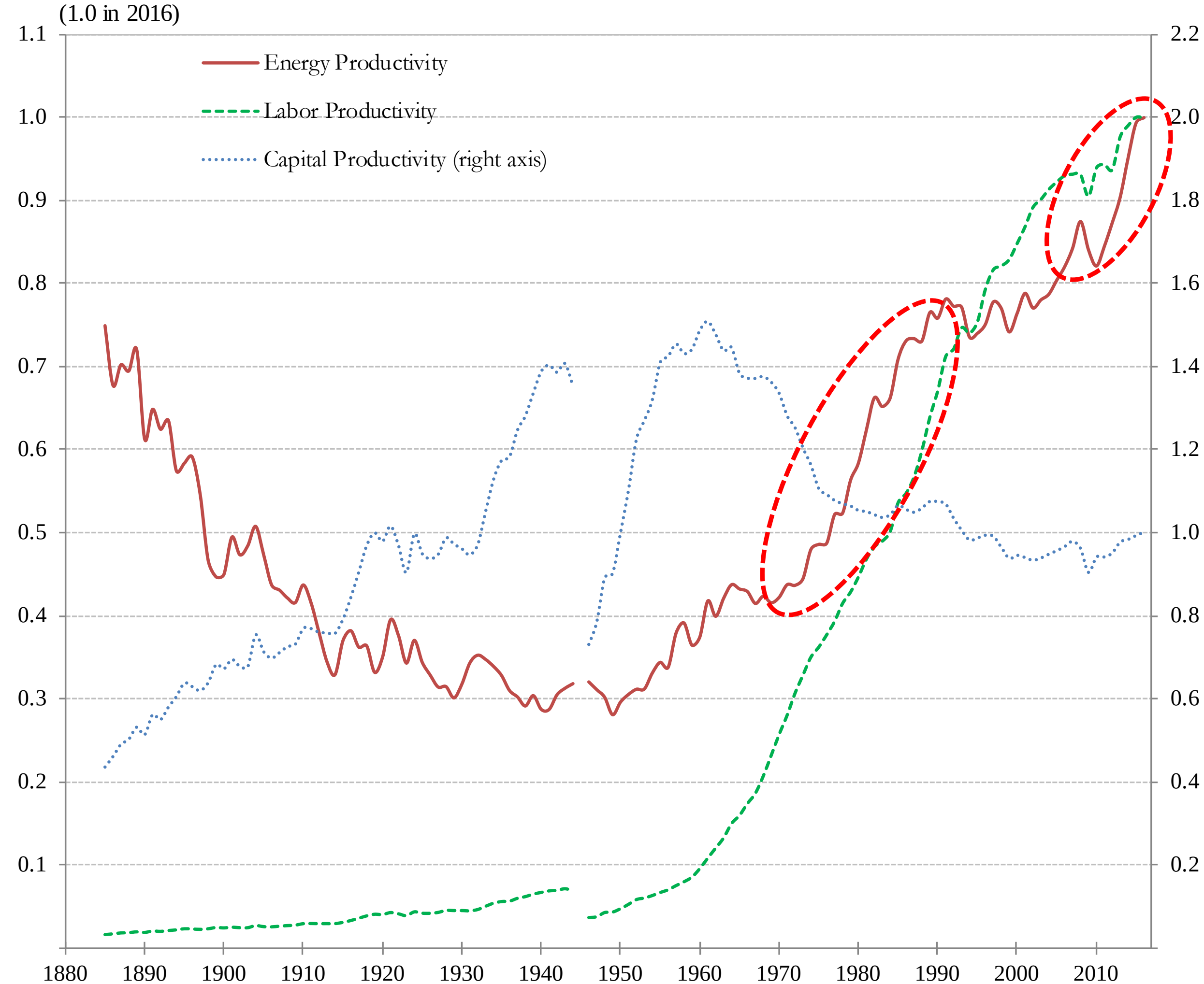
a. Japan's economic growth in the 20th century has required the same primary energy consumption as production expansion.

b. Labor input (hours worked) decreased from 1991. Capital input also stagnated after the global financial crisis.

c. After the global financial crisis and the Great East Japan Earthquake, energy consumption dropped sharply. The decline continues for nearly 10 years for the first time after the war.

Unit: index (1.0 in 1885). Definitions: Output=GDP at constant basic prices; Energy input= Final energy consumption (primary energy equivalent); Capital input=net capital stock at constant prices; Labor input (right axis)=hours worked for the whole economy. Source: Nomura, Koji (2018) “Long-term Economic Growth and Energy Productivity Improvement in Japan - Changes in Energy Quality and Industry Outputs,” RCGW Discussion Paper No.61, Research Center on Global Warming, Development Bank of Japan. (in Japanese)

Productivities of Energy, Capital and Labor, 1885-2016



a. Labor productivity has improved consistently.

b. Energy productivity improvement has a U-shape.

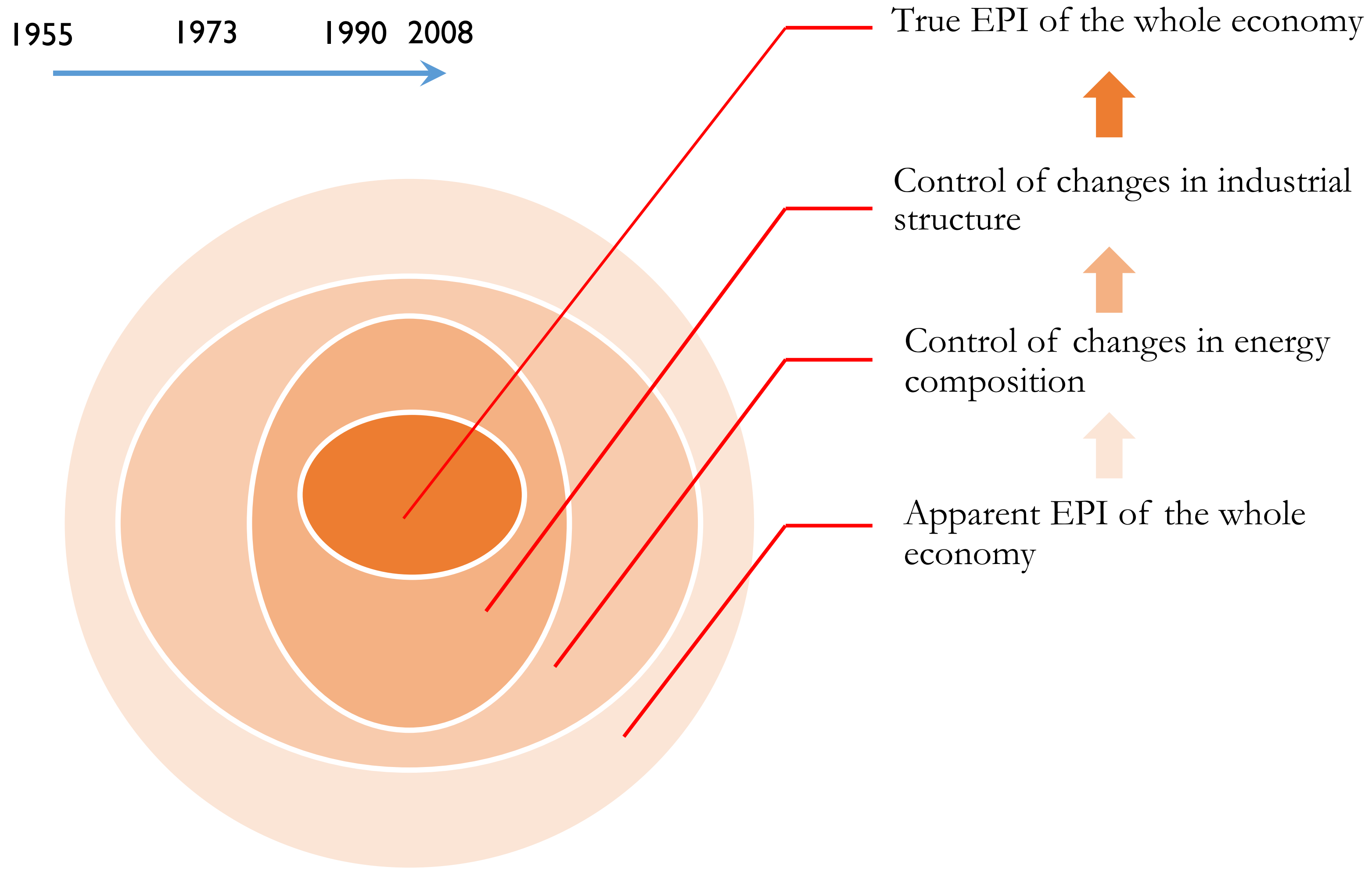
c. In contrast, Capital productivity has an inverse-U-shape. It is flat after 1990.

d. After the first oil shock, the speed of energy productivity improvement (EPI) recorded 3.1% per annum (1973–1990). =Golden age of EPI=

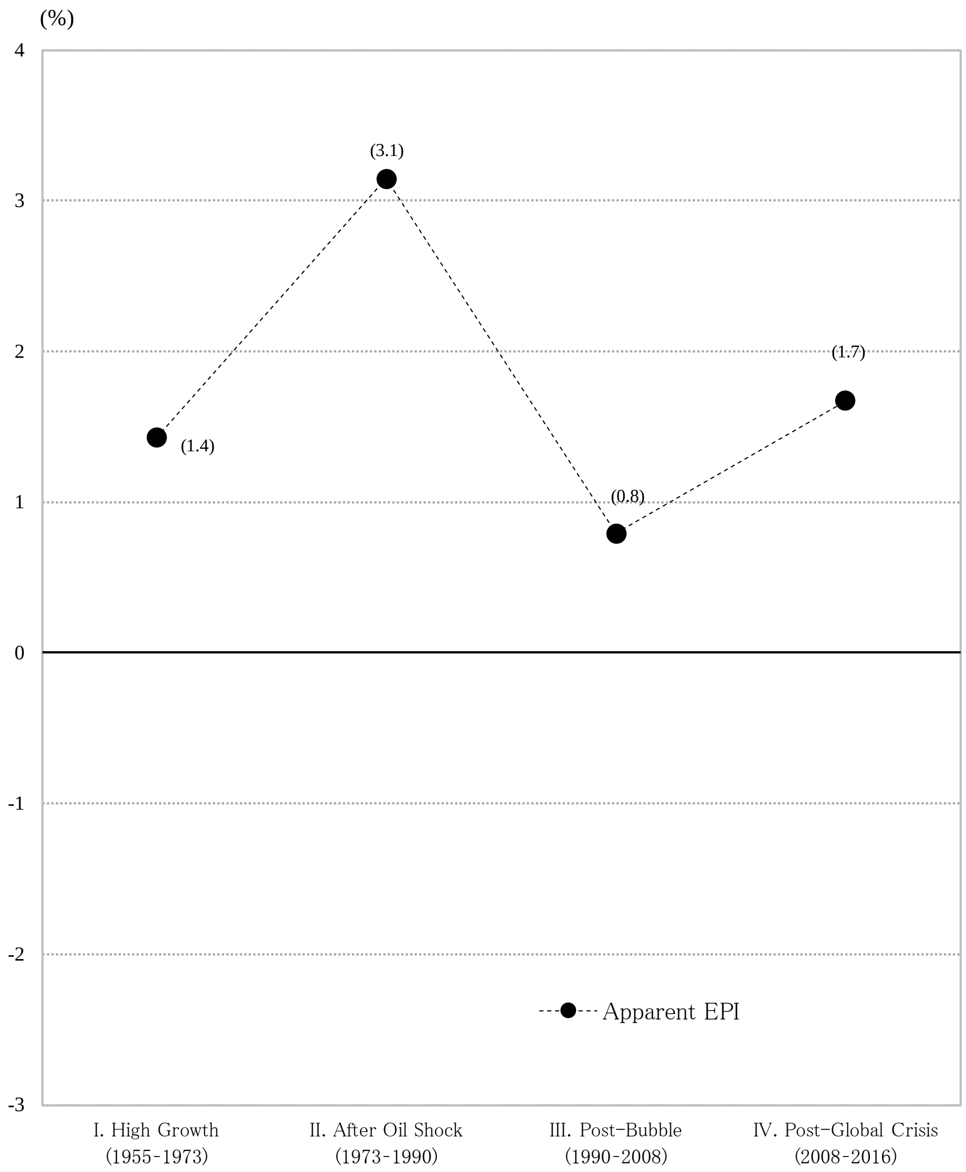
e. In 2008–16, EPI recovered as 1.7% . Are we entering a new golden age of EPI? It can be sustainable?

Unit: index (1.0 in 2016). Definitions: Output=GDP at constant basic prices; Energy input= Final energy consumption (primary energy equivalent); Capital input=net capital stock at constant prices; Labor input (right axis)=hours worked for the whole economy. Source: Nomura, Koji (2018) "Long-term Economic Growth and Energy Productivity Improvement in Japan - Changes in Energy Quality and Industry Outputs," RCGW Discussion Paper No.61, Research Center on Global Warming, Development Bank of Japan. (in Japanese)

(2) Decline of the Speed of True EPI (Energy Productivity Improvement)



Apparent EPI of the Whole Economy

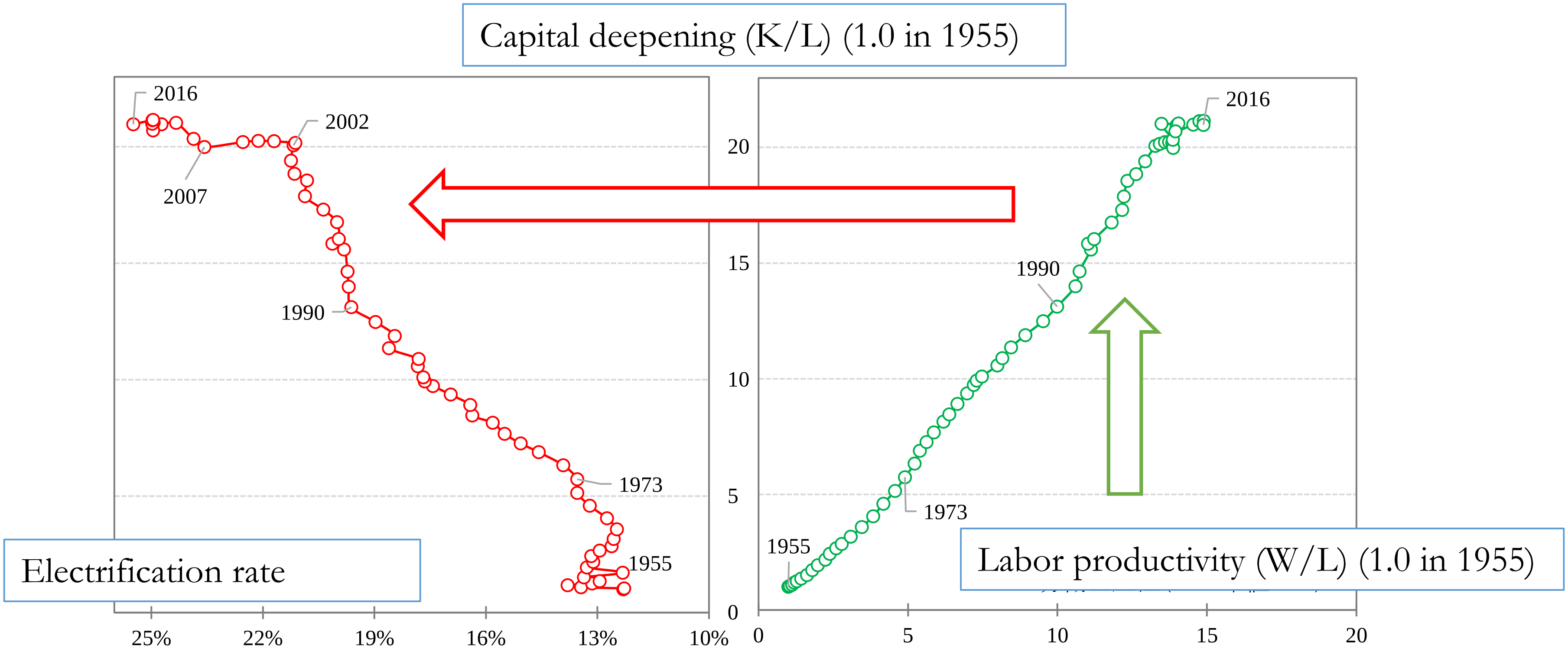


a. The period of II.1973-1990 is the Golden Age of the apparent EPI.

b. Considerations of changes in electrification or compositions of energy and changes in industry structures should revise the true picture of EPI?

Unit: average annual growth rate (%).
Source: Nomura, Koji (2018) “Long-term Economic Growth and Energy Productivity Improvement in Japan - Changes in Energy Quality and Industry Outputs,” RCGW Discussion Paper No.61, Research Center on Global Warming, Development Bank of Japan. (in Japanese)

Labor Productivity, Capital Deepening, and Electrification



a. The progress of capital deepening is the biggest factor to explain labor productivity growth.
b. In high economic growth period in the 1960s, the rise in electricity rate remain slight, although capital deepened.
c. Since 1973, electrification rate has increased as capital has deepened.
d. In the 2000s, capital deepening has stagnated, but only electrification has progressed. (impact of IT technology?)

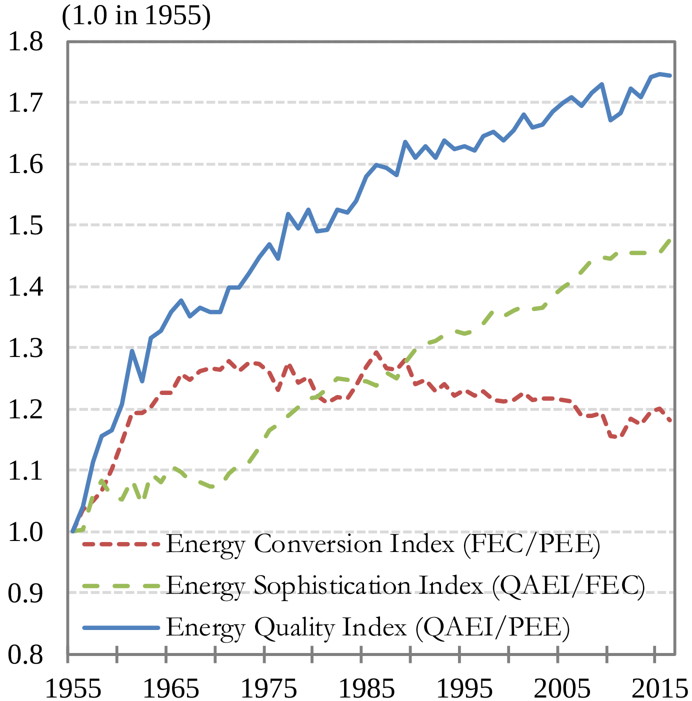
Unit: index (1.0 in 1955). Definitions: Labor productivity= GDP at constant basic prices per hour worked; Capital deepening=net capital stock at constant prices per hour worked; Electrification rate= electricity consumption /Final energy consumption. Source: Nomura, Koji (2018) “Long-term Economic Growth and Energy Productivity Improvement in Japan - Changes in Energy Quality and Industry Outputs,” RCGW Discussion Paper No.61, Research Center on Global Warming, Development Bank of Japan. (in Japanese)

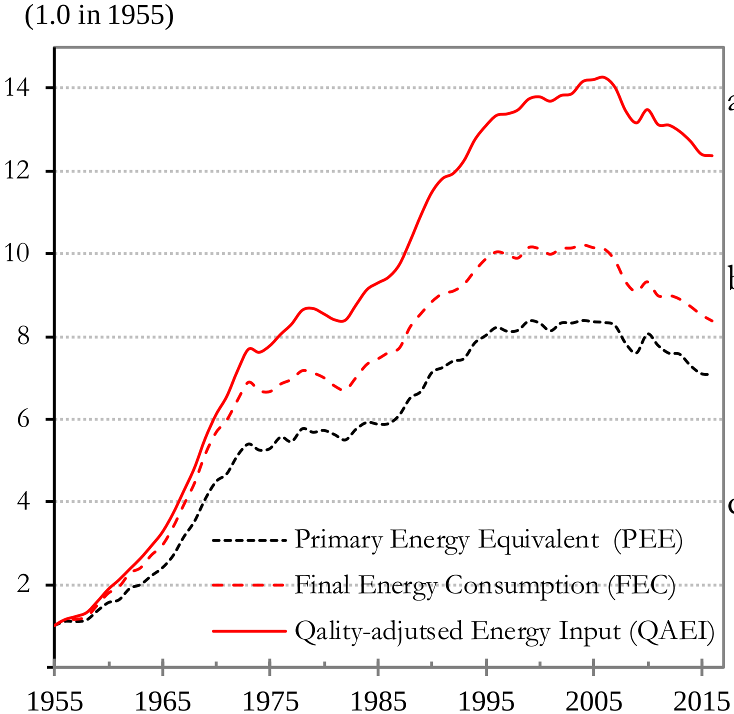
Quality-adjusted Energy Input (QAEI)

$$E = E_{fp}\left(\frac{E_f}{E_{fp}}\right)\left(\frac{E}{E_f}\right)$$

- Sophistication index (QAEI)/final energy consumption FEC))
- Conversion index (=FEC/ FEC's primary energy equivalent (PEE))

} Energy quality index





a. The conversion index increased in the 1950s. (due to improvement in thermal efficiency).
b. Since 1960, it has been stagnated. (An increase in electrification rate offset improvement in thermal efficiency)
c. Since the oil shock, sophistication index has increased.

Unit: index (1.0 in 1955). Definitions: QALI is defined as a trans-log index Source: Nomura, Koji (2018) "Long-term Economic Growth and Energy Productivity Improvement in Japan - Changes in Energy Quality and Industry Outputs," RCGW Discussion Paper No.61, Research Center on Global Warming, Development Bank of Japan. (in Japanese)

Industry Origins of Quality-adjusted EPI (1955-1973)

Industry contributions of the growth of energy consumption (11.2%)

Industry contributions of the quality-adjusted EPI (2.0% per year)

a. A half of the growth in total energy consumption is originated by the expansions in 18.iron&steel and 12.chemical industry, in which the EPIs were outstanding.

b. The true EPI (in which, the changes in industry structure are controlled) of the whole economy is revised to 2.0%, from the apparent EPI (1.4%).

c. The contributions of 18&12 industries are 2.4 percentage point, which is higher than the true EPI. ⇒"Hidden Golden Age of EPI" !

Source: Nomura, Koji (2018) "Long-term Economic Growth and Energy Productivity Improvement in Japan - Changes in Energy Quality and Industry Outputs," RCGW Discussion Paper No.61, Research Center on Global Warming, Development Bank of Japan. (in Japanese)

Industry Origins of Quality-adjusted EPI (1973–1990)

a. Expansions of energy consumption in 45. Household sector, 45.Other services, and so on. In contrast, consumption in 18.Iron & Steel industry has decreased.

b. The true EPI is 1.5% per year, downwardly revised from 3.1% of the apparent EPI.

c. The true EPI is lower than that in the period of 1955-1973.
⇒"Apparent Golden Age of EPI"

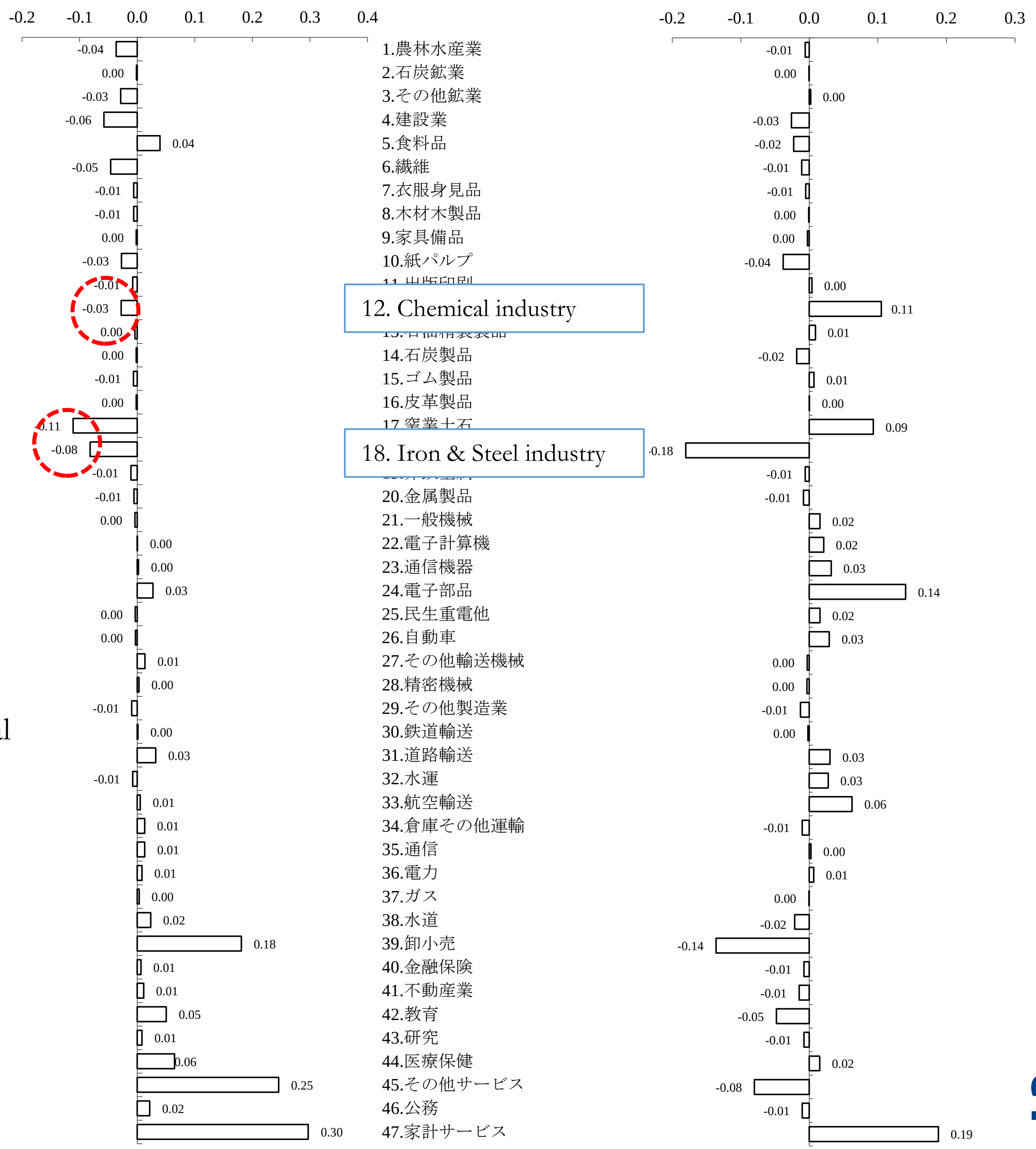
Source: Nomura, Koji (2018) "Long-term Economic Growth and Energy Productivity Improvement in Japan - Changes in Energy Quality and Industry Outputs," RCGW Discussion Paper No.61, Research Center on Global Warming, Development Bank of Japan. (in Japanese)

Industry Origins of Quality-adjusted EPI (1990–2008)

a. Changes in industry structure has a large impact in apparent EPI.
b. The true EPI is only 0.1% per year, downwardly revised from 0.8% of the apparent EPI.
c. The Japanese economy faced a considerable rise in energy prices relative to capital cost or general prices in this period, but the EPI was minor. This may reflect the increasing marginal costs for EPI.

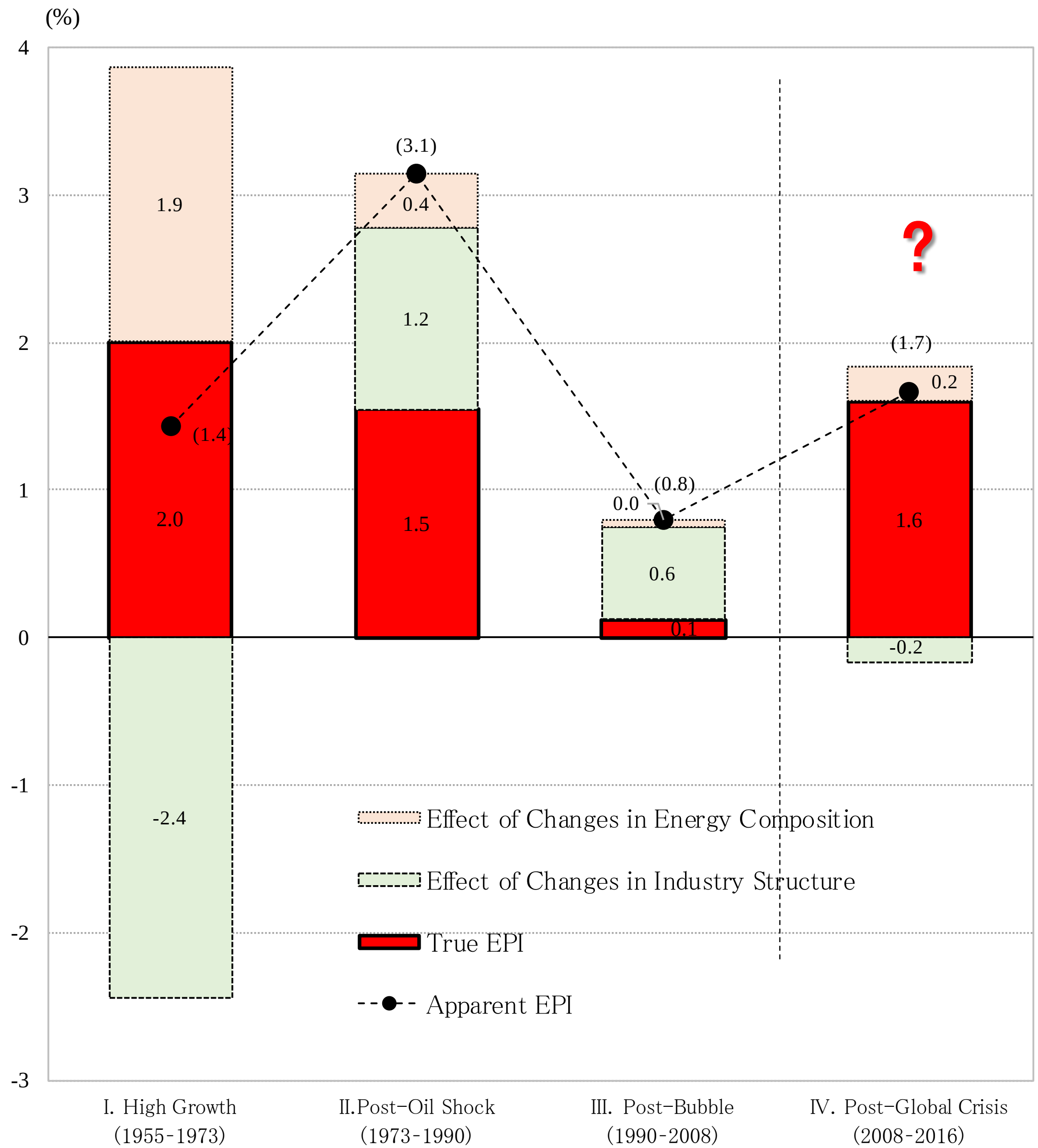
Industry contributions of the growth of energy consumption (0.6%)

Industry contributions of the quality-adjusted EPI (0.1% per year)



Source: Nomura, Koji (2018) “Long-term Economic Growth and Energy Productivity Improvement in Japan - Changes in Energy Quality and Industry Outputs,” RCGW Discussion Paper No.61, Research Center on Global Warming, Development Bank of Japan. (in Japanese)

True EPI vs Apparent EPI



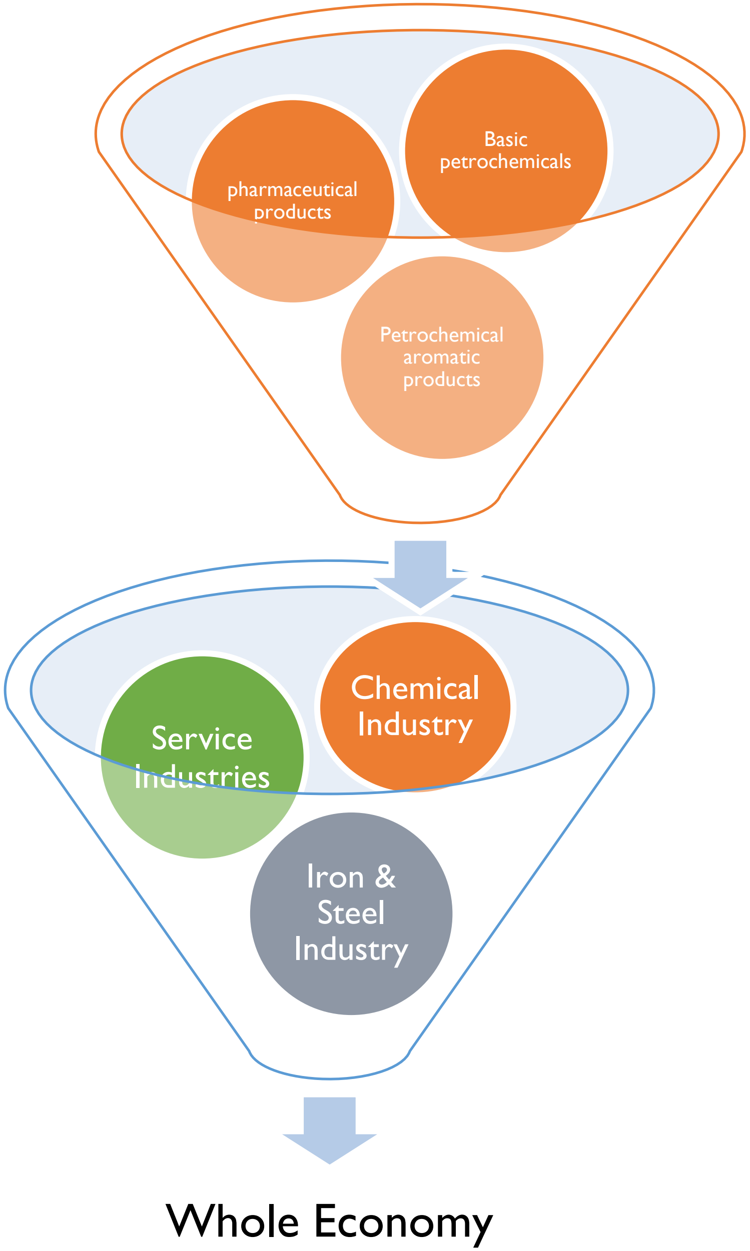
a. Apparent EPI: 1.4%⇒ 3.1%⇒ 0.8%⇒ 1.7%.
b. In the measure of true EPI, it changes as 2.0%⇒ 1.5%⇒ 0.1%⇒ 1.6%.
c. From 1955 to 2008, the possibility of EPI has been saturated.

d. But, since 2008, the EPI recovered to the level of the Post-oil shock period. --> Why? Is it sustainable?

Unit: average annual growth rate (%).
Source: Nomura, Koji (2018) “Long-term Economic Growth and Energy Productivity Improvement in Japan - Changes in Energy Quality and Industry Outputs,” RCGW Discussion Paper No.61, Research Center on Global Warming, Development Bank of Japan. (in Japanese)

(3) Are We Entering a Golden Age of EPI after the Global Financial Crisis?

2008 → Present



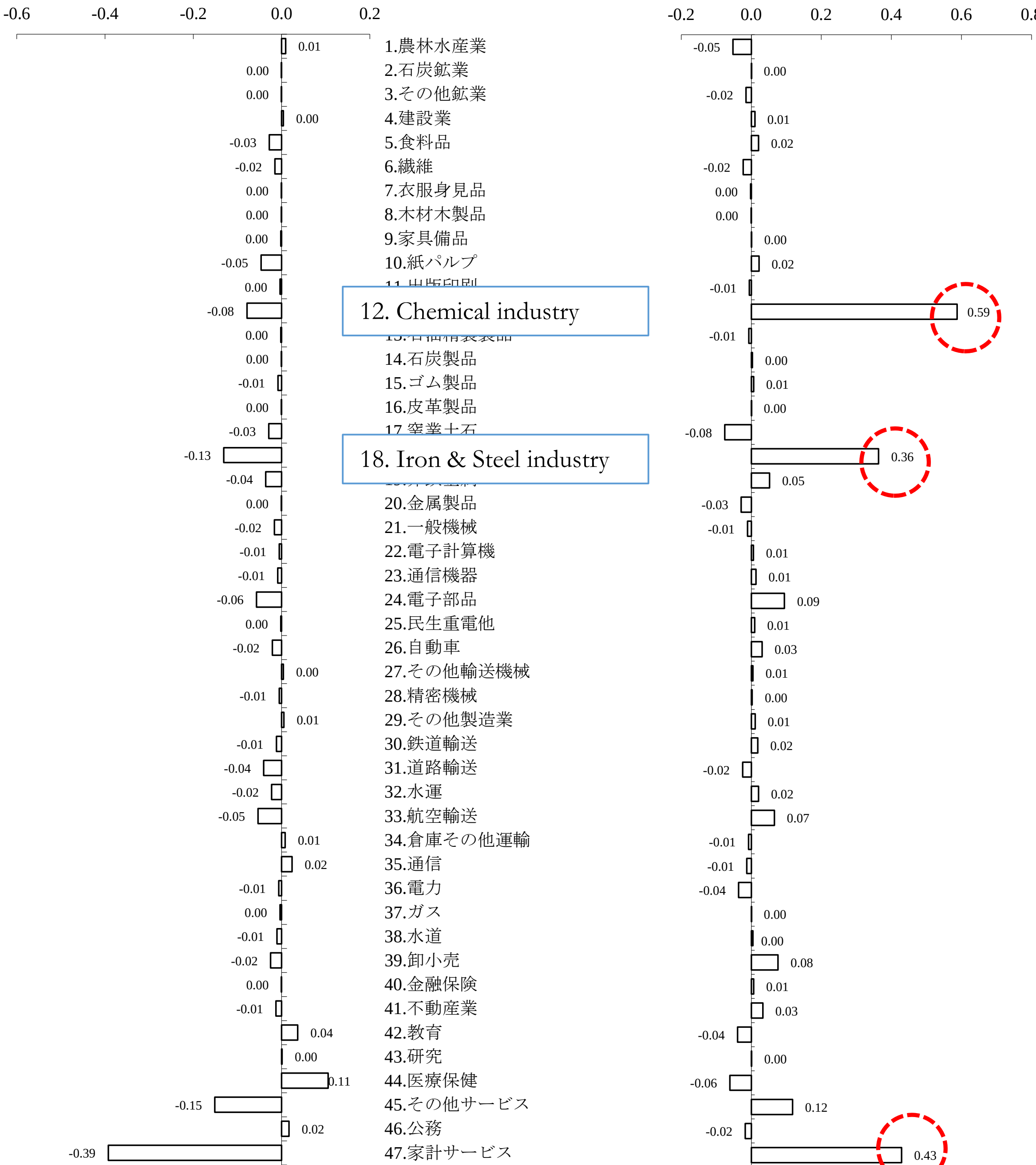
Industry Origins of Quality-adjusted EPI (2008–2016)

a. The EPI in the post global financial crisis has recovered to 1.6% per year.

b. Of the EPI in the whole economy, the contributions of 12.Chemical industry and 18. Iron & Steel industry explains about 60% .
⇒Any reasons?

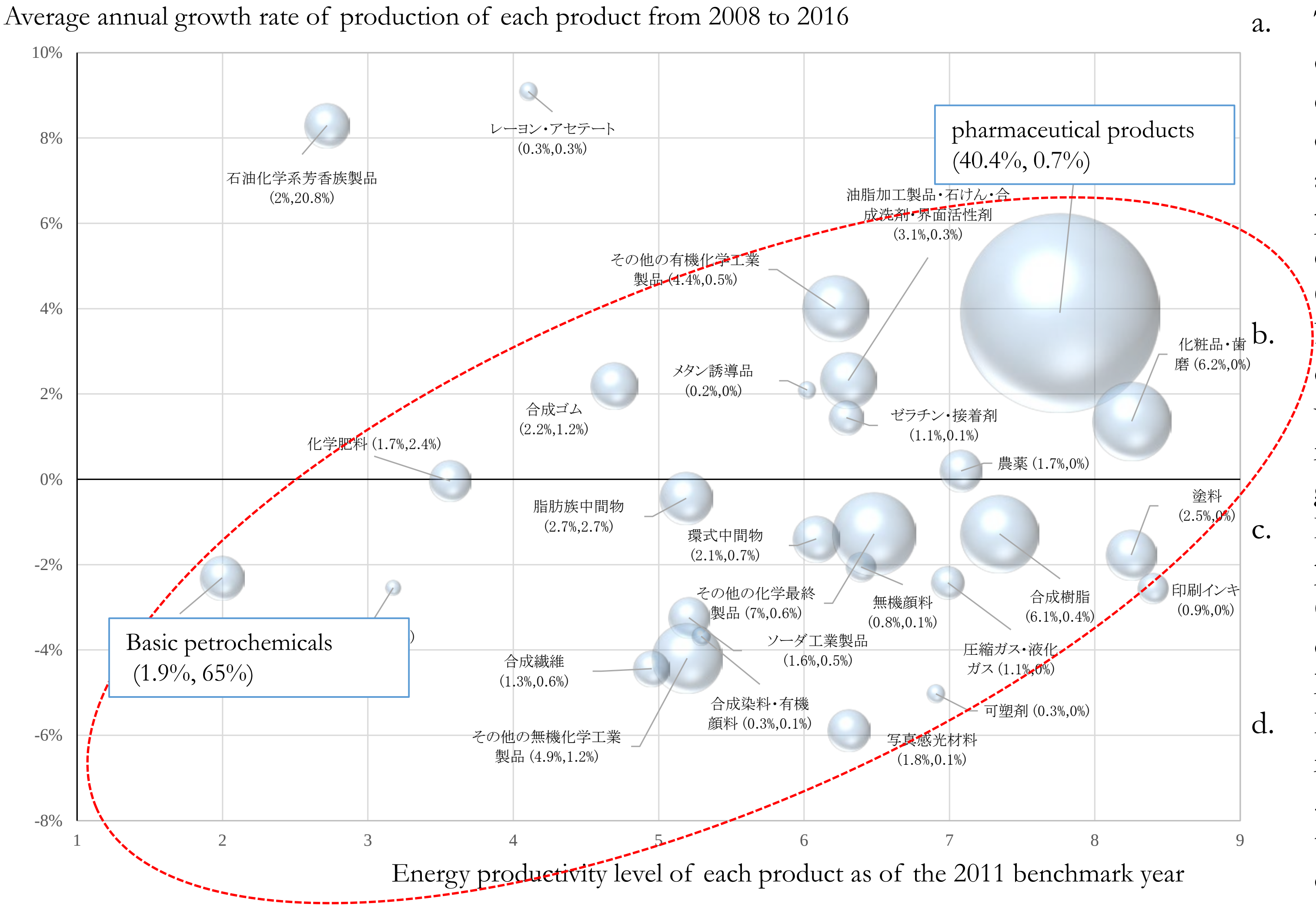
Industry contributions of the growth of energy consumption (▲1.0%)

Industry contributions of the quality-adjusted EPI (1.6% per year)



Source: Nomura, Koji (2018) "Long-term Economic Growth and Energy Productivity Improvement in Japan - Changes in Energy Quality and Industry Outputs," RCGW Discussion Paper No.61, Research Center on Global Warming, Development Bank of Japan. (in Japanese)

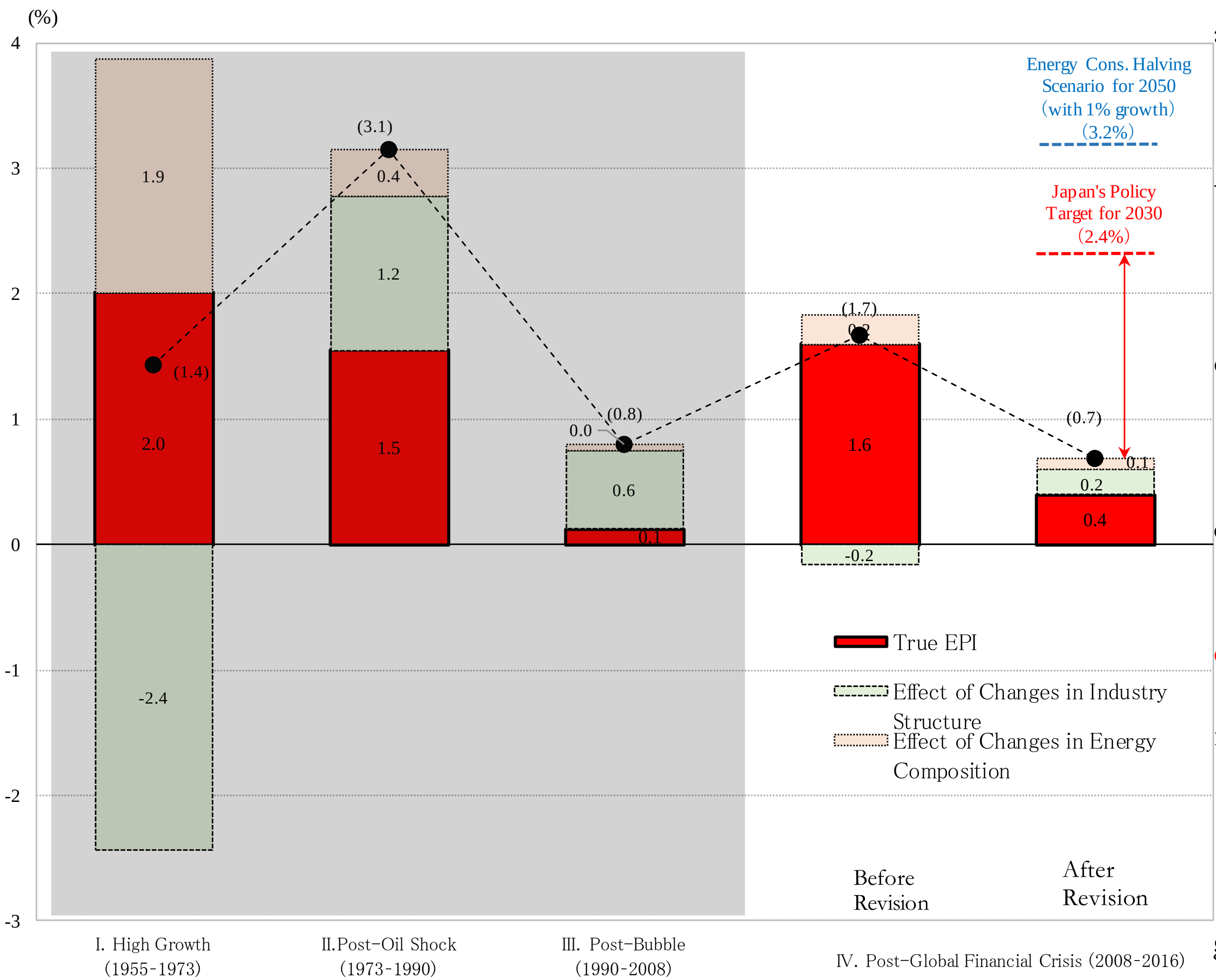
Change in Product Composition in Chemical Industry



a. There is a positive correlation between energy productivity level of each product (x-axis) and growth of production (y-axis) in each product in Chemical industry.
b. Pharmaceutical product counts for 40.4% of value added of this industry in 2011 and the growth rate is higher.
c. In contrast, basic petrochemicals with 65.0% of energy consumption has a lower growth rate.
d. EPI in Chemistry industry is revised to 3.3% (from 5.0%), if these changes are considered.

Unit: product groups (% (value added share), % (energy consumption share)). Definitions: the size of bubble presents the size of value added in 2011. Source: Nomura, Koji (2018) "Long-term Economic Growth and Energy Productivity Improvement in Japan - Changes in Energy Quality and Industry Outputs," RCGW Discussion Paper No.61, Research Center on Global Warming, Development Bank of Japan. (in Japanese)

Revised True EPI as Baseline Estimate



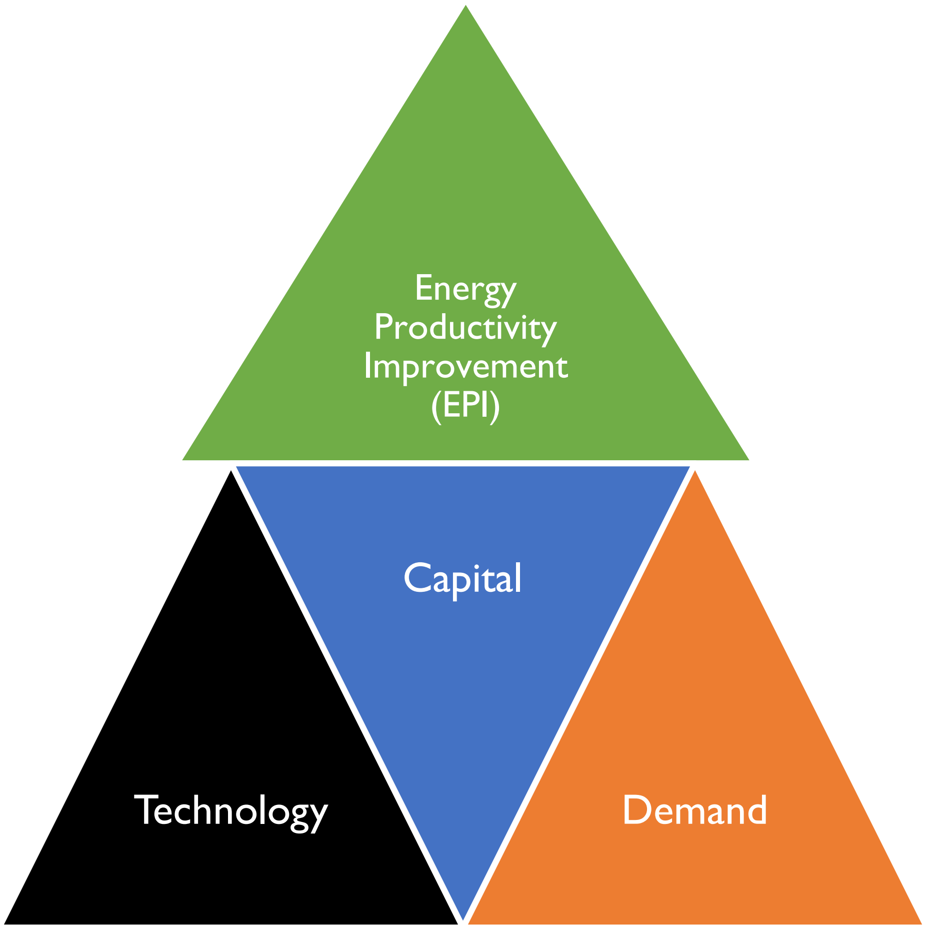
True EPI observed in 2008–16 (1.6% per year) is revised

a. by -0.39 pp, if changed in product compositions in Chemical industry is considered,
b. by -0.36 pp, if a transient impact of consolidation in Iron & Steel industry is adjusted,
c. by -0.24 pp, if EPI in household sector is normalized (by easing the impact of Great Earthquake), and
d. by -0.20 pp, if the impact of economic recovery of this period is considered,
e. to 0.4% as the baseline estimate of EPI.
f. Adding normal contributions of changes in energy composition and industrial structure, the baseline estimate of apparent EPI is 0.7%.
g. This is much lower than the policy target for 2030.

Unit: average annual growth rate (%).

Source: Nomura, Koji (2018) "Long-term Economic Growth and Energy Productivity Improvement in Japan - Changes in Energy Quality and Industry Outputs," RCGW Discussion Paper No.61, Research Center on Global Warming, Development Bank of Japan. (in Japanese)

(4) Will we Have a New Golden Age for 2050?



Technological Changes and EPI

Energy Productivity Improvement (EPI)

$$= f\big(\underbrace{\underbrace{S_t(T_t), S_{t-1}(T_{t-1}), S_{t-2}(T_{t-2}), \ldots,}_{①}\ TFP_t, \underbrace{\Delta Y_N, \Delta Y}_{②}}_{③}, \ldots\big)$$

① Capital Stocks, which reflect the level of technology as of the periods of investment

② Changes in demand side

1. Impact of demand expansion (ΔY) : $\partial EPI/\partial \Delta Y > 0$
2. Impact of emergence of new products (ΔY_N) : probably $\partial EPI/\partial \Delta Y_N < 0$

③ Technological Changes

(a). Capital embodied technology (=①)

(b). Technological progress (not embodied in capital) (TFP_t)

(c). Emergence of new products (ΔY_N) (=②.2)

⇒Lessons from Japan's economic growth

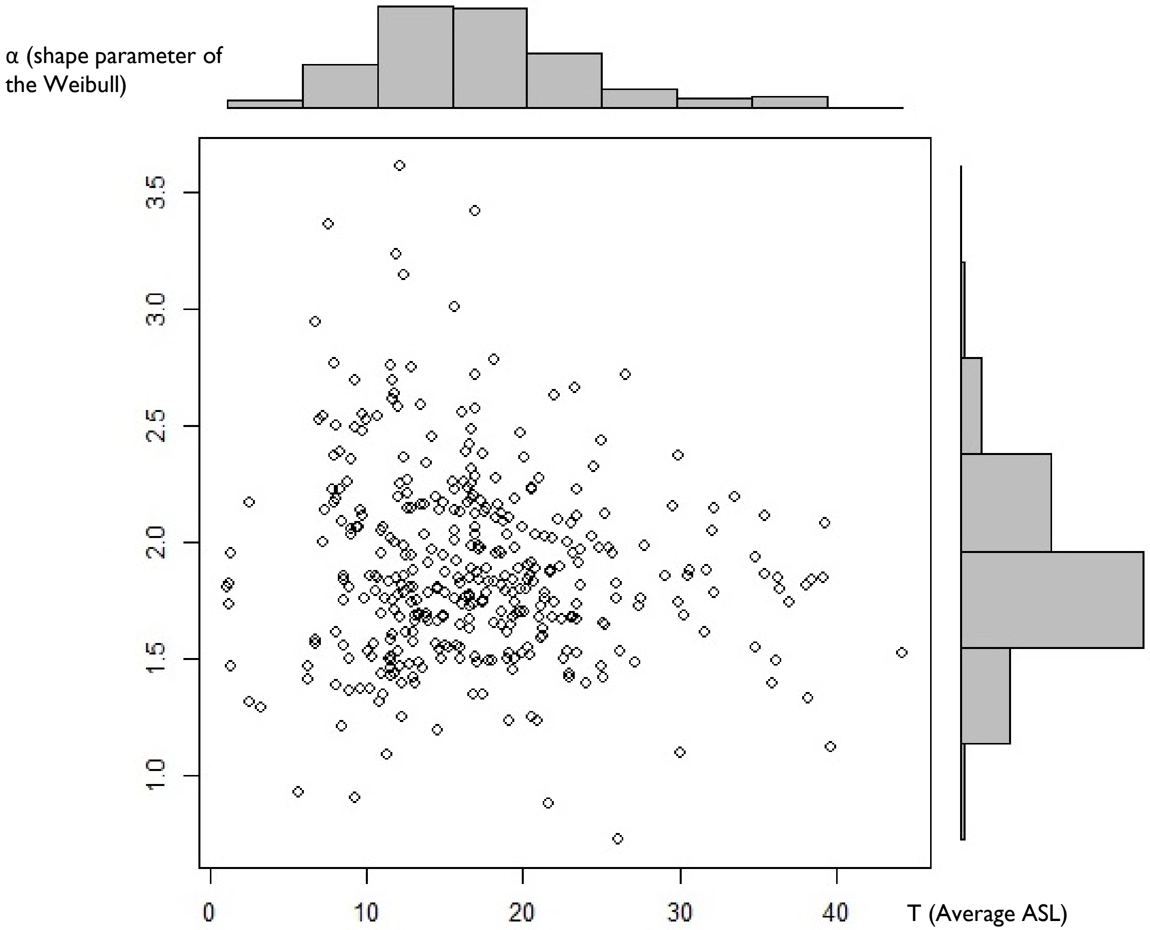
I. The speed of EPI considerably depends on the capital embodied technologies (a).

II. There is a considerable time-lag to realize the impacts of (a) and (b).

III. Technical change must generate new products. As a whole, technological changes do not necessarily induce EPI. Rather, (a)+(b)< (c).

Asset Service Lives (ASL)

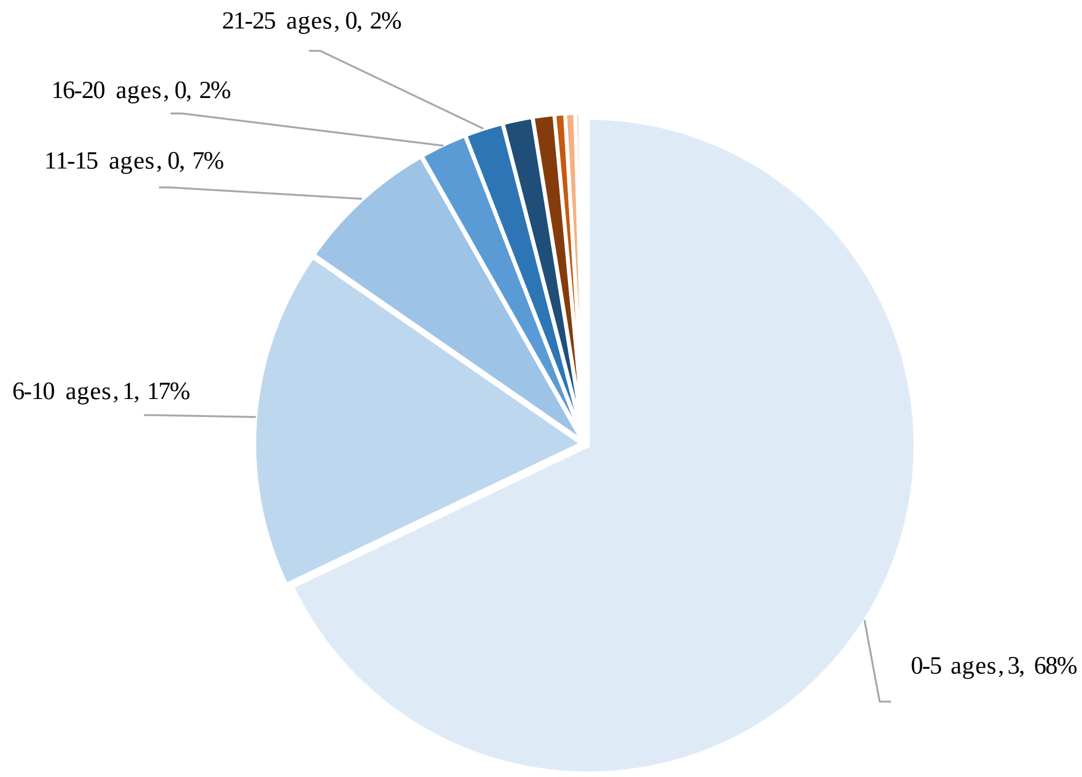
—Estimated Weibull Survival Profiles using Japan's Data



- Economic ASL may be shorter than Physical ASL. But the economic ASL is prolonged with many assets.
- 61% out of the 369 assets has an average ASL between 10 to 20 years
- 30% of the 369 assets have progressively increasing hazard rates (2<α).

Source: Nomura, Koji and Yutaka Suga (2018) "Measurement of Depreciation Rates using Microdata from Disposal Survey of Japan," The 35th IARIW General Conference, Copenhagen, Denmark.
Unit: years (ASL). Note: Estimates of the Weibull survival profile based on 369 types of assets, based on the observations (937 thousand) of retired assets collected by CED 2006–2014.

Estimated Age Structure of Assets in ICT Manufacturing Industry as of the end of 2016



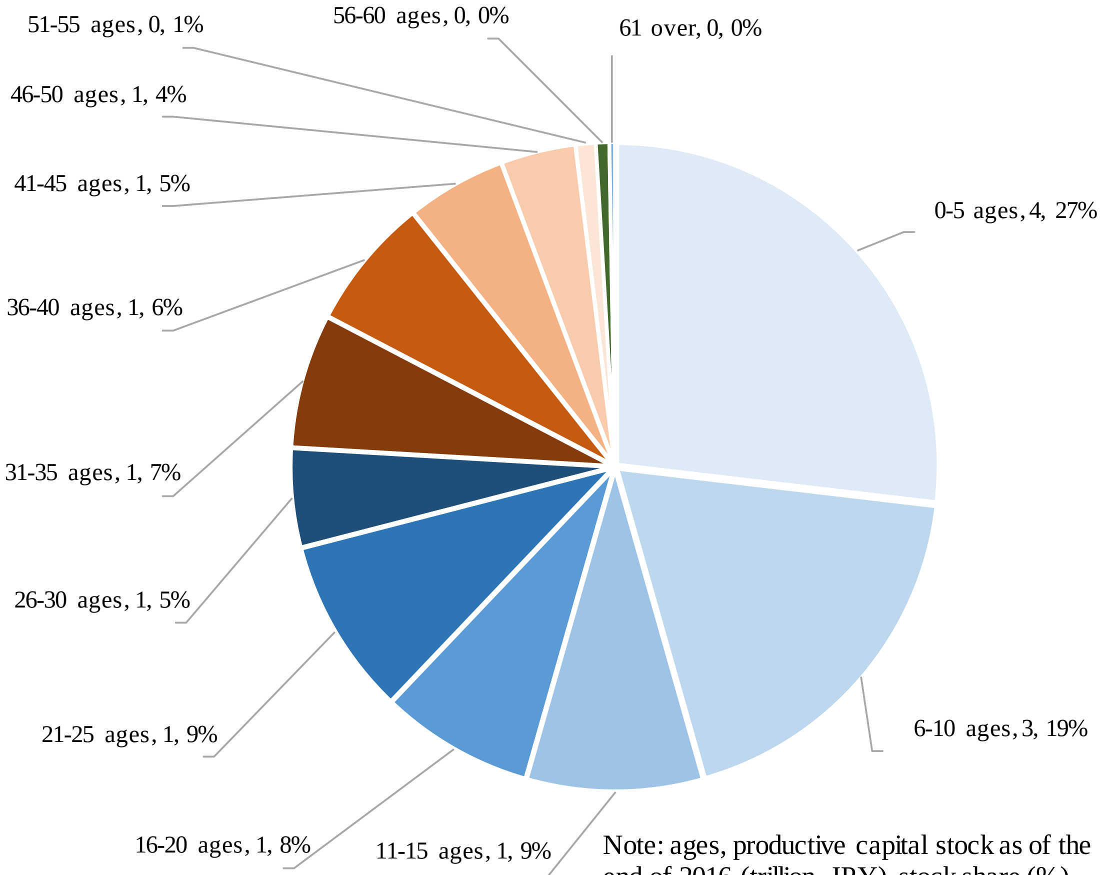
Note: ages, productive capital stock as of the end of 2016 (trillion JPY), stock share (%)

- 85% of the total capital stock existing at the end of 2016 in ICT manufacturing industry is the assets aged less than 10 years (invested since 2006).

⇒This industry could incorporate technical changes within this decade.

Source: Nomura's estimate of productive capital stock, based on the Perpetual Inventory Method with 95 types of assets. The stocks do not include R&D stock and military equipment.

Estimated Age Structure of Assets in Iron & Steel Industry as of the end of 2016



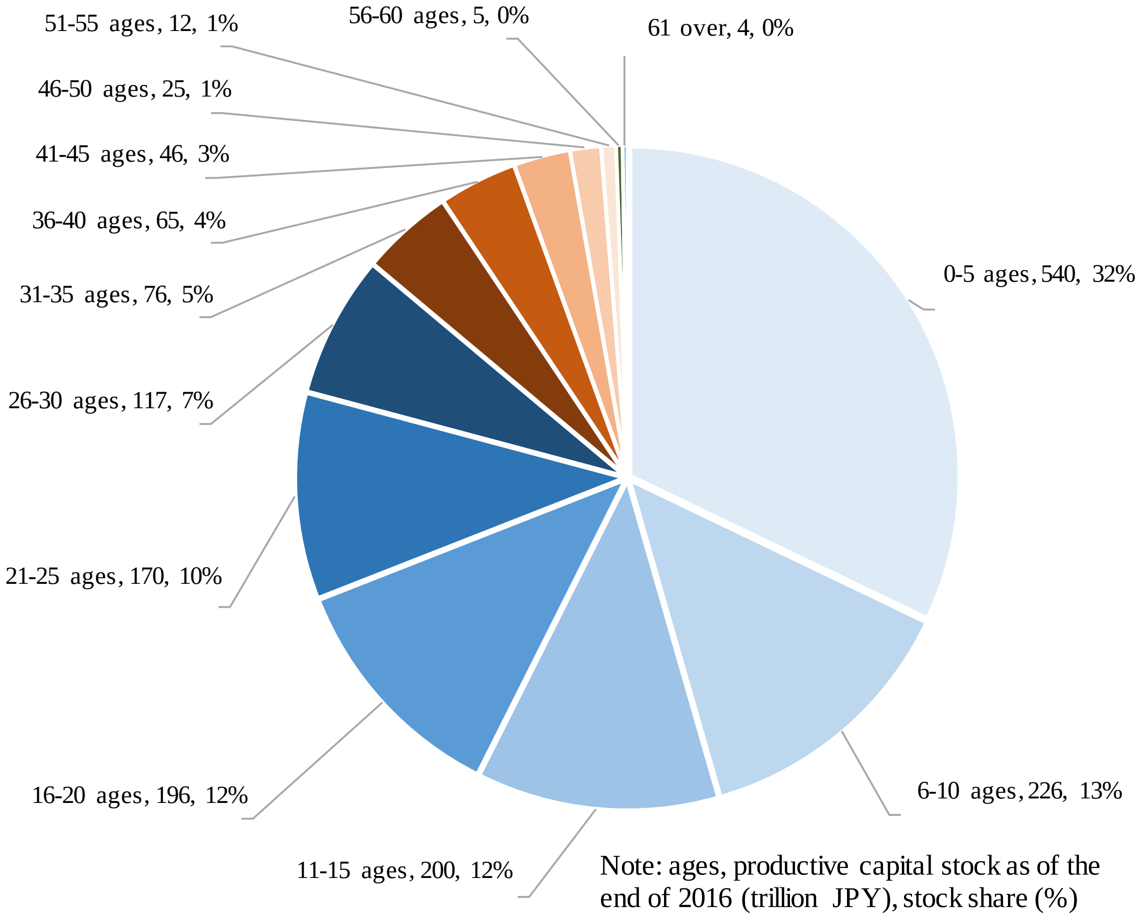
Note: ages, productive capital stock as of the end of 2016 (trillion JPY), stock share (%)

- In iron & steel industry, less than half (46%) of the total capital stock existing at the end of 2016 is the assets aged less than 10 years.
- Assets aged 10-20 counts for 17% of total capital stock; 14% for assets aged 20-30 , 13% for assets aged 30-40, and 9% for assets aged 40-50.

⇒about 40% of current production depends on the technologies of assets invested up to 2000.

Source: Nomura's estimate of productive capital stock, based on the Perpetual Inventory Method with 95 types of assets. The stocks do not include R&D stock and military equipment.

Estimated Age Structure of Assets of the Whole Economy as of the end of 2016



Note: ages, productive capital stock as of the end of 2016 (trillion JPY), stock share (%)

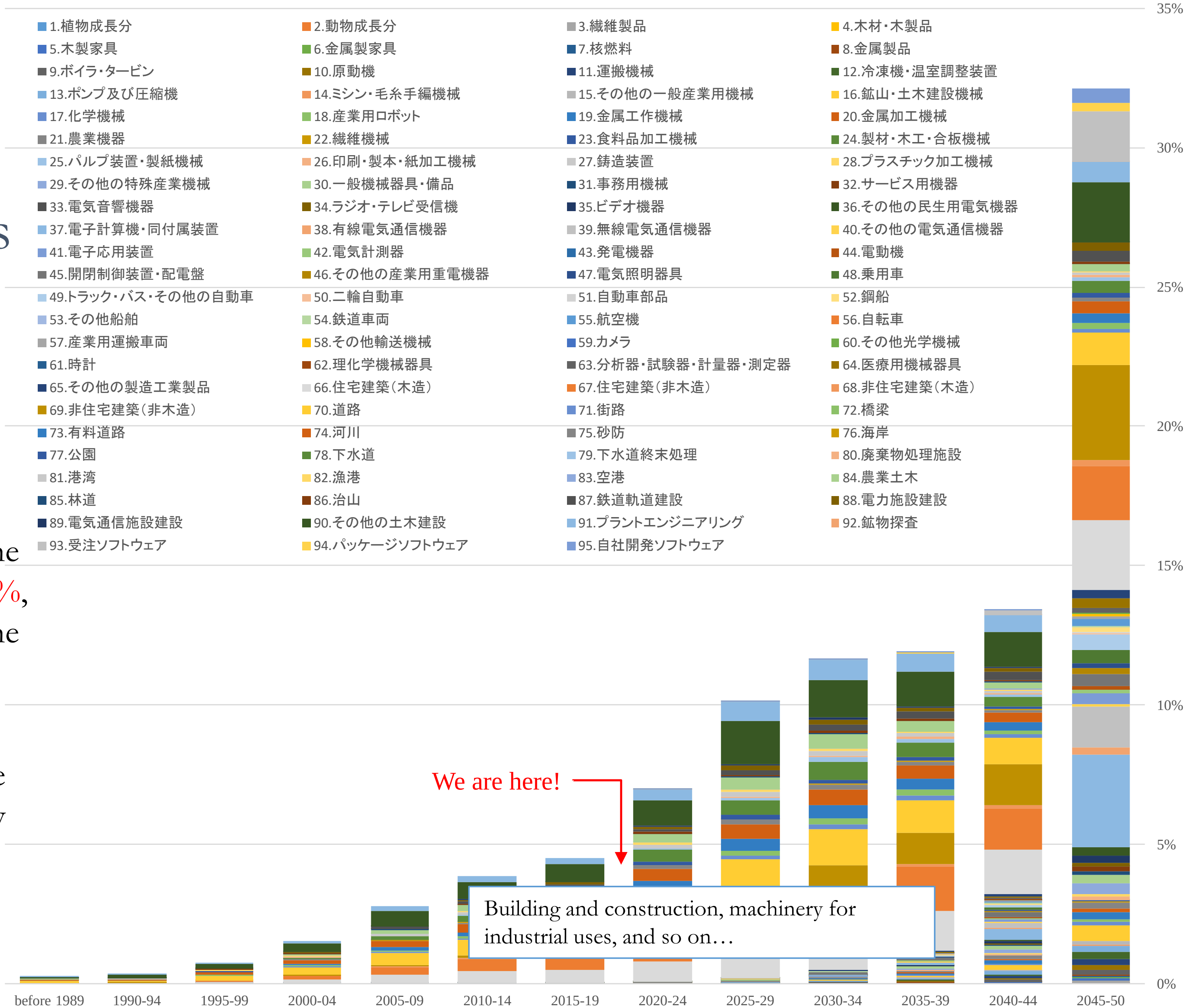
- In the whole economy (including infrastructure), 45% of the total capital stock existing at the end of 2016 is the assets aged less than 10 years.
- 24% for assets aged 10-20; 17% for 20-30 age; 9% for 30-40 age, and 4% for 40-50 age.

⇒about 30% of current production depends on the technologies of assets invested up to 2000.

Source: Nomura's estimate of productive capital stock, based on the Perpetual Inventory Method with 95 types of assets. The stocks do not include R&D stock and military equipment.

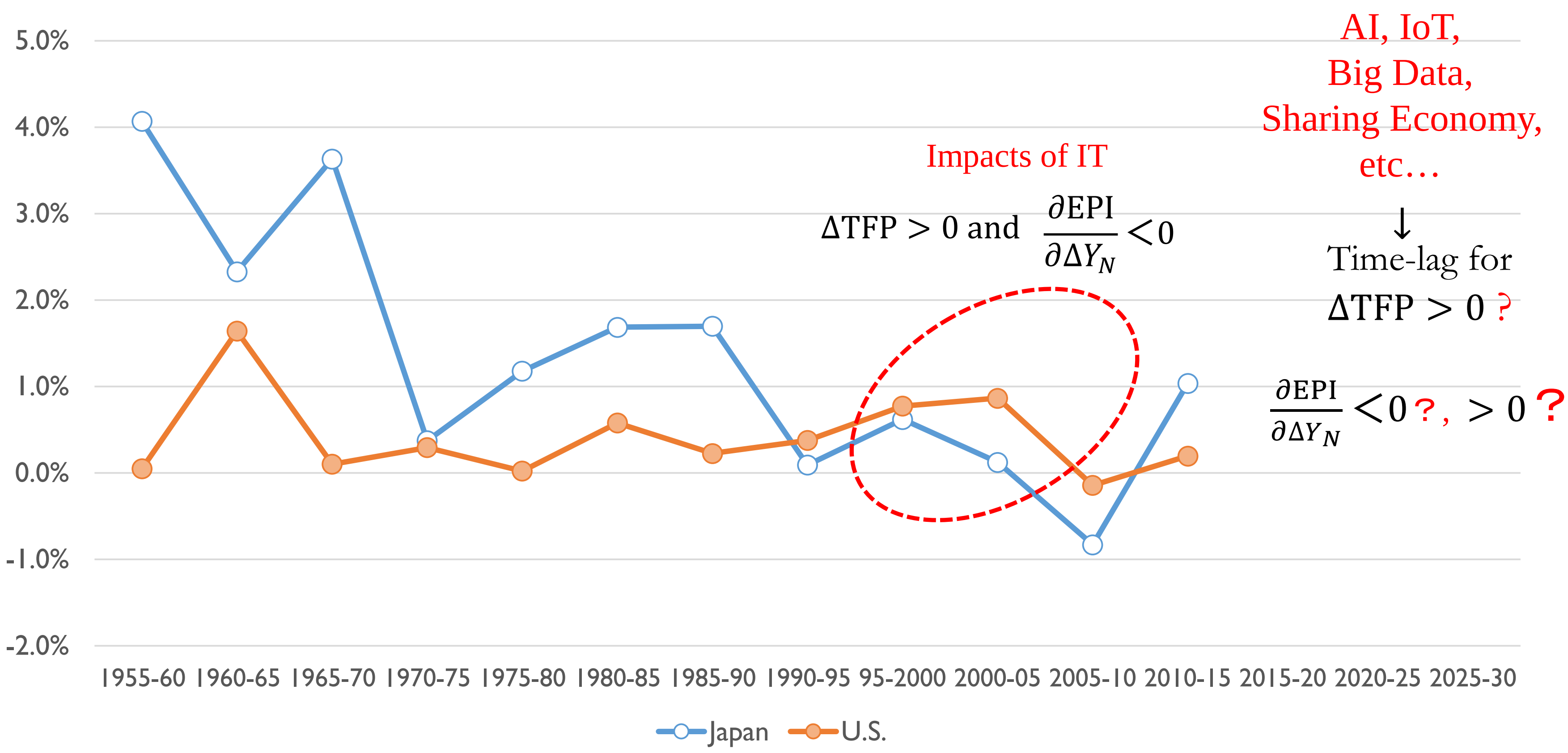
Vintage Structure of Assets as of 2050

- In production system as of 2050, assets invested in the 2030s are about 25%, assets invested in the 2020s and earlier account for 30%.
- It takes a log time to make use of new technologies in an economic system.



Source: Nomura's estimate of productive capital stock, based on the Perpetual Inventory Method with 95 types of assets. The stocks do not include R&D stock and military equipment.

TFP Growths in the U.S. and Japan
－Impact of Innovation on IT?



Source: Dale W. Jorgenson, Koji Nomura, and Jon D. Samuels (2018) "Progress on Measuring the Industry Origins of the Japan-U.S. Productivity Gap", Fifth World KLEMS Conference, Harvard University June 2018.

(5) Conclusion

1. Slowdown of True EPI in the latter half of the 20th Century

   ▪Decreasing: Although apparent Golden Age of EPI is observed in the post-oil shock period, the Ture EPI has decreased from 2.0% in 1955–73, to 1.5% in 1973–90 and 0.1% in 1990–2008.

2. In the post-global financial crisis, it may not tell the revisit of the Golden Age of EPI

   ▪Hollowing out and temporary: The EPI in 2008–2016 is overestimated due to the change in products composition in Chemical industry, some temporary impacts by the East Japan Great Earthquake, and so on. The baseline estimate of EPI is estimated as 0.7% per year, much lower than Japan's government target (2.4%) for 2030 and the energy-consumption halving scenario for 2050 (3.2%) (with 1.0% growth of real GDP) .

3. Toward 2050, its hard to support an optimistic view on a new golden age of EPI

   ▪Long time-lag: About half of the production system in 2050 may depend on technologies that were embodied into capital by the 2030s. There is a considerable time lag for innovation to be incorporated as a social system.

   ▪New products: Rather, innovation has created new products and services. As a rule of thumb, a new products would be energy consuming (e.g., semiconductor, data center, household robot, ...). Afterwards, EPI will come gradually.

   ▪Bias of micro approach: There are many examples of technologies that may accelerate EPI due to new innovation toward 2050 at micro levels. But it is difficult to find evidence that EPI as a whole economic system will accelerate.

   ▪Policy distortion: It is important to continue to save energy in corporations and household. But, if promoting EPI excessively by energy policies, there is a large concern that hollowing out of domestic industry will accelerate.