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Rapid innovation to mitigate global warming

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Abstract

The dynamics of recent innovations of Information and Communication Technologies (ICT) and others is better captured by the complex systems theory than traditional innovation systems theory. The analysis based upon complex systems theory leads us to distinct and more positive future prospects and cost-effective policy implications for mitigating global warming. Massive emission cut of greenhouse gas will be possible through the policies that promote innovation and economic development.

1. 2 degree C scenario by existing IAM

The International Panel on Climate Change (IPCC) has published a variety of scenarios to keep the global temperature rise below 2 degree C by using the Integrated Assessment Models (IAM). In those scenarios, heroic, but hard-to-believe assumptions have been made. Politically, perfect international cooperation was assumed. Economically, high carbon tax across the world was assumed. Technologically, heavy use of Bio-Energy with Carbon and Capture Storage (BECCS) was assumed (IPCC 2014). As such, it is quite unlikely that 2 degree C target can actually be achieved without innovation other than BECCS.

Innovation has been expressed in various ways in IAM. On macroscopic scale, improvement rate of total factor productivity, and so-called autonomous energy efficiency improvement were used. On the microscopic scale, individual technological forecasts were used; technical costs were assumed to decrease at a fixed rate over time; and/or learning curves were used, in which the cost drops according to the power law as a function of cumulative production. However, there remain intrinsic uncertainties in future events, and there is an obvious limit to the prophetic ability of these methodologies. For example, with regard to individual technologies, the forecasts were forced to base on existing technology alone, and it was not possible to incorporate unknown technologies.

2. Recent innovation

Let us look back what have been the remarkable innovations for mitigation technologies of global warming in recent several years –as a precursor of future mitigation technology.

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The cost of the solar cell sharply declined, and the bid price dropped to as low as 3 cents per kilowatt-hour (kWh) in the United Arab Emirates (UAE). This is well below the price typically paid by consumers around the world. The cost of battery sharply declined, thanks to R&D and mass production for portable equipment applications (Nykvist and Nilsson 2015) . It resulted in cheaper electric vehicles. Artificial Intelligence (AI) has been advanced dramatically, by the invention of "deep learning" technology. AI, in combination with other Information and Communication Technologies (ICT), brought about self-driving cars, and energy management systems have been drastically improved and put in use in factories, offices, and homes (JEITA 2016, GeSI 2015). The rapid and steady improvement of computing power enabled detailed simulation of material science, and development of highly functional yet inexpensive materials. For example, the cost of hydrogen fuel cell vehicles has drastically declined (Iguma and Kidori 2016).

There is a common thread of the above innovations. The general progress of science and technology, in particular ICT such as semiconductors, AI, the Internet of Things (IOT), and robotics, have been rapid. Such progress greatly benefited the energy production and utilization technologies that naturally relating to global warming problem (METI 2016; Sugiyama 2016a; Sugiyama2016b).

How can we, then, understand such dynamics of innovation theoretically?

3. Innovation system theory and complex systems theory

The traditional way of dealing with innovation was innovation system theory (for details GEA 2012 Chapter 24, Kimura 2015 chapter 1; and the IPCC 2014 report, in particular section 15.5.8, was written with the same framework). It focuses on a certain technology. And it identifies research & development (R&D), demonstration and diffusion stages. Then it argues there are appropriate ways of governmental intervention on each stage. The major reason for which governmental intervention is necessary is called appropriability problem. The benefit of R&D is widely shared by society as a whole, but the burden of risky R&D is born by a private entity, if the government does not intervene at all. As such, it would result in insufficient R&D investment compared to the desired level for the society as a whole, in the absence of governmental intervention. Regarding global warming technologies, internalization of environmental externalities is added as another reason.

However, as already mentioned, advances in mitigation technologies are often not directly related to dedicated mitigation technology policy. Instead, they have been greatly benefited from the advance of technology in general (for more examples of such interaction of climate technologies and technologies in general, see Sugiyama 2017; 2016a; 2016b; for other examples and patent analyses, see Nemet 2012). Complex systems theory is the appropriate framework to capture these dynamics.

4. Innovation of mitigation technologies in the complex systems theory

The treatment of innovation in the complex systems theory was initiated by Kaufmann, Arthur and others. New technology emerges by a combination of old technologies. And technological progress has a similarity to biological evolution. Technologies evolve by chance, and they are path dependent. As such, it is intrinsically difficult to predict what kind of technologies will emerge in the future (Kauffman 2000, 1995; Arthur 2015, 2009; Solée et al. 2013; Arthur and Polak, 2006). With accumulation of existing technologies, and by the advance of ICT, pace of innovation is accelerating further and further (Kelly 2016; 2010).

From the viewpoint of the complex systems theory, any technologies, including mitigation technologies, emerge by a combination of existing technologies, benefited from the progress of technology in general, not by itself alone.

The theory is useful to understand dynamics of innovation of energy saving by AI, for example.

Deep learning, which is the core technology of the AI, was invented by using three prior arts when it was born. First is Perceptron, an old AI technology. Second is Graphic Processor Unit (GPU), which is the game machine technology for parallel computing. Third is the big data for hobby purpose on the web site (Kelly 2016).

Utilizing deep learning, a wide range of global warming mitigation technologies such as intelligent energy saving and precision agriculture are becoming possible (for a broad range of such ICT enabled mitigation technologies, see NEDO 2016; JEITA 2016, GeSI 2015).

In complex systems theory, the enough accumulation of prior arts, that enable the emergence of new technologies, is named as "adjacent possibility" (for mathematical formulation see Montemurro and Zanette 2016; for popular writing see Jonson 2010; for theoretical explanation see Kauffman 2000).

It has been observed, for many technologies in history, that once a new technology falls within the realm of adjacent possibility, that is, prior arts accumulate to the point they enable the new one to emerge by their combination, the new one emerge before too long.

As adjacent possibility established, several innovators actively research and develop the new technology, often in competition. As the result, innovation tends to occur simultaneously, carried out by many different people in many different places across the world (for reader friendly explanation of simultaneous innovation, see Jones 2016; Ridley 2015; for academic paper, Voss 1984; original idea dates back to Ogburn and Thomas 1922).

As such, we can expect that, in the future, the development of AI and IOT will expand the range of adjacent possibilities. It will result in innovative mitigation technologies that enable massive emission cut.

The dynamics of innovation explained above is illustrated in the figure.

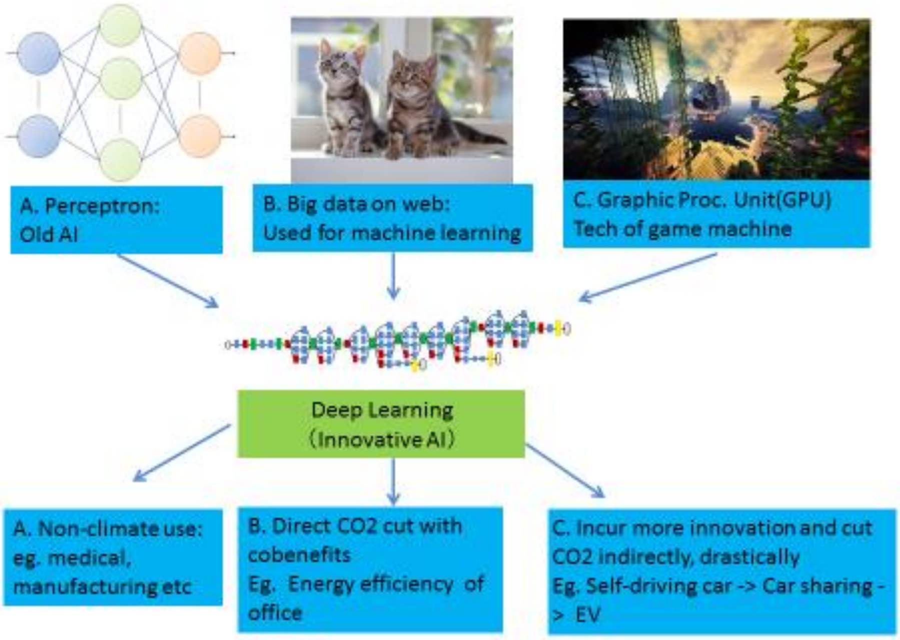

Fig. How innovation of mitigation technologies occurs: example of deep learning and its applications.

Innovation always occurs by a combination of preceding technologies. In this case, deep learning, which is an innovative artificial intelligence technology, emerges by the combination of Perceptron (A) which is the preceding artificial intelligence technology, image data (B) accumulated for hobby purpose on the web, and GPU (C) which is parallel computing technology developed for game machines (Kelly 2016). All of the above technologies have been developed for reasons not related to global warming at all.

There are many application of deep learning. They include, of course, technologies other than mitigation purpose (A), but also there are innovative mitigation technologies. As CO2 cut technology, for example, deep learning is used for fine estimate and control of the load of air-conditioning equipment by image analysis of a room and save energy in the office (B). Furthermore, it may incur more innovation and massive CO2 cut in indirect manner. When deep-learning is applied to self-driving technology, it may incur car sharing and electric cars, resulting in massive CO2 cut (C).

5. Estimates of greenhouse gas emission cut potential by ICT

Estimation of emission cut potential by ICT was first done by Laitner (2003). GeSI argued that ICT promotes economic growth and improves various welfare of mankind, and as a byproduct, energy efficiency can be greatly improved and CO2 can be drastically reduced. They estimated the potential of CO2 cut through energy saving and agricultural greenhouse gas emissions cut by ICT, and argued that 20% of global greenhouse gas emissions in 2030 can be reduced (GeSI 2015). Similarly, Laitner et al. (2012) suggested that an array of energy efficiency investments could reduce total primary energy demand by 50 percent compared to standard projections by 2050 in the United States. The estimates were done by adding up the emission cut by sector and technologies against baseline.

However, it was argued that such methodologies tended to under-estimate. It was argued that ICT's key importance lies in causing decoupling of GDP and energy consumption by increasing the efficiency of overall economic activity (Laitner 2010). There are also views that such decoupling may have been occurring in developed countries (Laitner 2015). Such estimates are still under studies.

Some economies are developing roadmaps that lead to a buildout of a digital infrastructure that moves to large-scale energy efficiency gains which also enables 100% renewables by 2050. They argue near-zero energy-related carbon emissions are possible while sustaining economic growth (See Luxembourg Economic Ministry 2016; MRDH 2016; and Rifkin et al. 2013).

On the other hand, it was argued that the rebound effect, that the energy consumption increases due to enhanced economic activity by ICT, may be large and result in more CO2 emissions in the end. But there has not been definitive conclusion about the rebound effect of ICT yet (for an example of the estimate of rebound effect of self-driving cars, see Wadud 2015; GeSI 2015 simply assumes rebound effect to be small).

6. Contribution to rapid cut of emission on a global scale

The rapid progress of technology in general, including ICT, is likely to bring about innovative mitigation technologies, which enable sharp decline in emission on global scale. For example, the cost of solar cells and electric vehicles will further decrease to the extent that the cost difference with existing technologies will be affordable, and then explosive popularization will occur (note: it is not guaranteed that low-carbon technologies will be eventually cheaper than fossil fuel technologies, since the latter will also benefit from innovation. See Covert and Knittel (2016), Mills (2015). However, it will be likely that the cost difference will be eventually affordable). Energy saving using AI and IOT, and reconstruction of the transport sector utilizing self-driving cars, can dramatically reduce energy consumption.

In the past, one of the major barriers to energy saving were asymmetry of information (that is, the lack of man-power and skills to collect and process information as to how to save energy and cut costs). ICT removes the very barrier (Rogers et al 2015). Self-driving cars not only improve fuel economy (as human beings are poor and wasteful driver, it makes sense to replace him or her by AI), but also drastically reduce the number of cars required to meet certain transport service demand. It results in less input of materials and energy to manufacture the cars.

Just these two example of the above have a huge potential of emission cut, even as early as in 2030. However, it is very difficult to predict the potential in quantitative manner, since we do not know how wise AI will be in 2030 at all. AI may outperform human-beings to the extent it replaces labor at many workspace (Brynjolfsson and McAfee 2011; Ford 2009). If AI outperforms human-beings, it can cut energy consumption drastically too as human-beings are poor and wasteful energy manager. Furthermore, it will improve the manufacturing process of the solar cell, and the installation work of photovoltaic systems (PV) will also be carried out by robots, cutting so-called Balance of Systems (BOS) costs. As such the cost of the PV will further plummet.

7. Advances in technology and economic growth

It is widely agreed among economists that technological progress is important for economic growth. Improvement of the total factor productivity is one of key element in economic growth accounting. In contrast, the inverse, that the higher economic growth results in the faster technological progress, has not been systematically argued, although it seems almost obvious.

Instead, the following three are known as a mechanism of virtuous cycle of economic growth and advances in technology.

The first is the theory of general-purpose technology. Steam engine, electric technology and ICT are the examples of general-purpose technologies (GPT). It is argued that the progress of GPT promotes economic growth, and vice versa (Helpman 2004; Bresnahan et al 1995; Iguma and Kidori 2015). The second is the theory of industrial clustering. A cluster of geographically accumulated industries serves as the core of a virtuous cycle. An example is the ICT cluster of the West Coast of the United States (Moretti 2012; Florida 2008). Thirdly, it is argued that the market economy is always trying new combination of fragmented knowledge to create new products. As such, more active market activities result in more innovation (Ridley 2015; Friedman 1980; Read 1958).

8. Policy implications

There are some policy implications from this paper. First, the advance of technology in general, including ICT such as IOT, AI, robot, etc., is very important for the innovation of mitigation technologies. To promote this, economic activity must be vigorous, and regulatory systems must support it. It was argued that ICT innovation in Europe had been greatly delayed to the United States due to heavy security regulations that impeded free corporate activities (Thierer 2014).

Dedicated policies for mitigation technologies remain important, as supported by the traditional innovation systems theory. Such policies help firms to explore the adjacent possibilities of the time of the targeted technologies.

However, it should be noted that the dedicated climate policies alone cannot bring about the new technologies, as they will heavily benefit from the progress of technology in general. Also, care should be taken that dedicated mitigation technology policy should not hamper innovation in general and undermine macro-economy in the way it slows the technological progress. Such consideration becomes more relevant as nations aim at more ambitious emissions cut (Sugiyama 2016a; 2016b).

Finally, although innovation holds the potential to cut massive emissions, it may cause a huge rebound effect, because it brings about unprecedented economic wealth. Hence it is necessary to cut greenhouse gas emissions through policy interventions, again without impeding innovation in general.

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