bow and arrow, which initially had inferior performance, might have been used to hunt prey quietly and with less effort.[17]

While these views offer very important perspectives on the innovation of the bow and arrow, what this paper focuses more on is the scientific knowledge that created the new technology of the bow and arrow. Looking back at the long-term development, such scientific understanding (even if tacit) often played a critical role.The emergence of the new technology, the bow and arrow, probably occurred because humans could understand and utilise the energy stored in bent branches. The bent branches might have been used as a trap for catching small animals (Lombard and Philipson, 2010). However, in order to use this externally stored energy more effectively as a projectile weapon, it was necessary to combine various other forms of knowledge such as in-depth knowledge in regard to the wood, strings (or chords) and arrows. At the same time, there might have been a growing need to target smaller animals instead of larger ones.

In the evolution and change on the supply and demand side, the creation of projectile weaponry utilising external energy saw the emergence of a new technological paradigm in that scientific knowledge was required concerning external energy which was completely different from before. Nevertheless, the scientific knowledge, from the point of view of modern science, was primitive and superficial, and the hierarchical and systematic characteristics of scientific knowledge found in heat engines (Suenaga 2019), modern steelmaking technology (Suenaga 2018b) and semiconductors (Suenaga 2015a, b), which are more recent technologies, could not be seen. However, paradigm-disruptive innovations, such as silently launched weapons using external energy, had a much greater long-term impact on economic activity, technological progress, and globalisation than the structural classification of innovations would suggest.[18]

These paradigm-disruptive innovations dramatically raised technological and economic standards. The innovation of stone tools was largely based on 'the fracture dynamics of stone' (Mithen, 1996), in which the sharp or pointed fractured parts of the stone were used as tools, for purposes other than cracking. In addition, the discovery that the part of the stone tool with the handle became detached and flew away vigorously when swung down, might have led to the innovation of a spear-thrower using the (tacit) scientific knowledge of the principle of leverage. Moreover, unlike the spear with a stone point and the spear-thrower, where muscular strength was critical, the ability to use external energy stored in bent branches led to the invention of the bow and arrow, and the gradual acquisition of (primitive) chemical knowledge of poisons was a major catalyst for the innovation of the bow and arrow using poison. Furthermore, the increasing scientific knowledge of animals and plants enabled their domestication; this was 'genetic manipulation' (Watson 2003: p. 6), such as the selection of only the species suitable for cultivation and animal husbandry. This was also the emergence of a technological

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[17] See also Yu (2006) for relationships between the bow and arrow technology and climate changes.

[18] See also Crosby (2002) and Baldwin (2016) on this point.

paradigm based on new scientific knowledge.[19] Then, advances in scientific and technological knowledge concerning fire gave rise to bronze and iron tools.

Moreover, in heat engines (Suenaga, 2019a), modern steelmaking methods (Suenaga, 2020; 2021b) and semiconductors (Suenaga, 2015a), combined with new scientific knowledge, paradigm-disruptive innovations were produced, and technological and economic level improved significantly. In addition, scientific (and technological) knowledge, such as molecular biology and genetic recombination, has also played an important role in the recent development of gene therapy and mRNA vaccines (Suenaga, 2021a). In recent paradigm-disruptive innovations, modern science or academic disciplines, rather than primitive scientific understanding, have played a major role. The chemical industry and modern chemistry, the heat engine and thermodynamics, the semiconductor industry and quantum mechanics, the biotechnology industry and molecular biology, and so on, have been developed systematically through the mutual influence between industry and academia. These innovation systems also contain the hierarchy of scientific knowledge and technological paradigms, on the basis of which the hierarchical classification of paradigm-disruptive innovations has been made. Suenaga (2015a; 2015b; 2019a; 2021b) classifies paradigm-disruptive innovations into three categories: those involving the transformation or emergence of a discipline, those involving the emergence or change of an operating principle and those involving the change or birth of a connection method.

Then, in the long-term process described above, scientific knowledge has played a very important role in understanding natural phenomena, whether in modern or primitive science.[20] Of course, technological progress can be made with vague scientific understanding, and then, as scientific understanding advances, further technological progress can be achieved. Nevertheless, since technological paradigms based on existing scientific knowledge essentially face the law of diminishing returns, paradigm-disruptive innovations based on new scientific knowledge (regardless of whether scientific knowledge precedes technological knowledge or not) play a decisive role in overcoming these limitations. This has important implications that are not discussed in Christensen’s disruptive innovation that reduces performance, in Henderson and Clark’s radical innovation that combines modular and architectural innovation or in Carignani’s discussion of radical innovation as a horizontal transfer. Although the level of scientific knowledge is often taken as a given in economics and business administration, it is crucial to take an endogenous view of the progress of scientific knowledge in considering long-term development.

[19] See also Suenaga (2019b) for a detailed discussion.

[20] This is what Suenaga (2015b) calls a Rosenberg-type innovation.

4. Comparison of innovation theory

In this paper, we have discussed several theories of innovation, focusing on a primitive (but revolutionary) innovation. While the bow and arrow is an epoch-making innovation (comparable to Freeman's 'technological revolution') that had a profound impact on people's lives, on globalisation and on society as a whole,[21] the simplicity of the bow and arrow has the advantage of making it easier to clarify the differences between the various innovation theories. Although each theory has its own value in its own realm, what are the differences between these various theories? In this section, we compare various innovation theories, focusing on two viewpoints: one considers the structure of the artefact or on the primary factors involved in its creation, and the other emphasises scientific knowledge or takes it as a given (or neglects it)[22].

Christensen's (1997) discussion often focused on modules, such as auxiliary storage devices and printers, and Henderson and Clark (1990) also focused on architectural innovations. The discussion in Carignani (2016), based on the framework of Henderson and Clark, also pays attention to the structure of artefacts such as modules and architectures. Although Arthur (2009) insists that 'all technologies are combinations of elements' (p. 203) and that technology 'builds itself organically from itself' (p. 24), his discussion also shed light on the structure of artefacts rather than on the primary factors involved in the creation of innovation. Furthermore, Allen's (2009) argument, which takes notice of the ratio of factors of production (especially capital and labour), is also a theory that pay attention to the structure rather than the primary factors.

On the other hand, Schumpeter (1934), Mokyr (2002), Yamaguchi (2006) and others have focused on people as the primary factors in the creation of artefacts, rather than on the structure of artefacts, and have tried to clarify the factors and processes of innovation. However, while many arguments, such as Schumpeter and Dosi (1982), treat scientific knowledge as given, Mokyr and Yamaguchi take the progress of scientific knowledge as endogenous. Arthur (2009) also insists that 'Technology builds from harnessing phenomena largely uncovered by science' (p. 64), and emphasises the advances in scientific knowledge. Figure 3 shows a rough classification based on the above discussion.

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[21] See also Lombard (2018) for the impact of the bow and arrow on human's minds.

[22] Usually, when we speak of primary factors of production in economics, we refer to factors of production such as capital, labour and land, but in this paper we will refer to the scientists and technologists who are responsible for the advancement of scientific and technological knowledge.

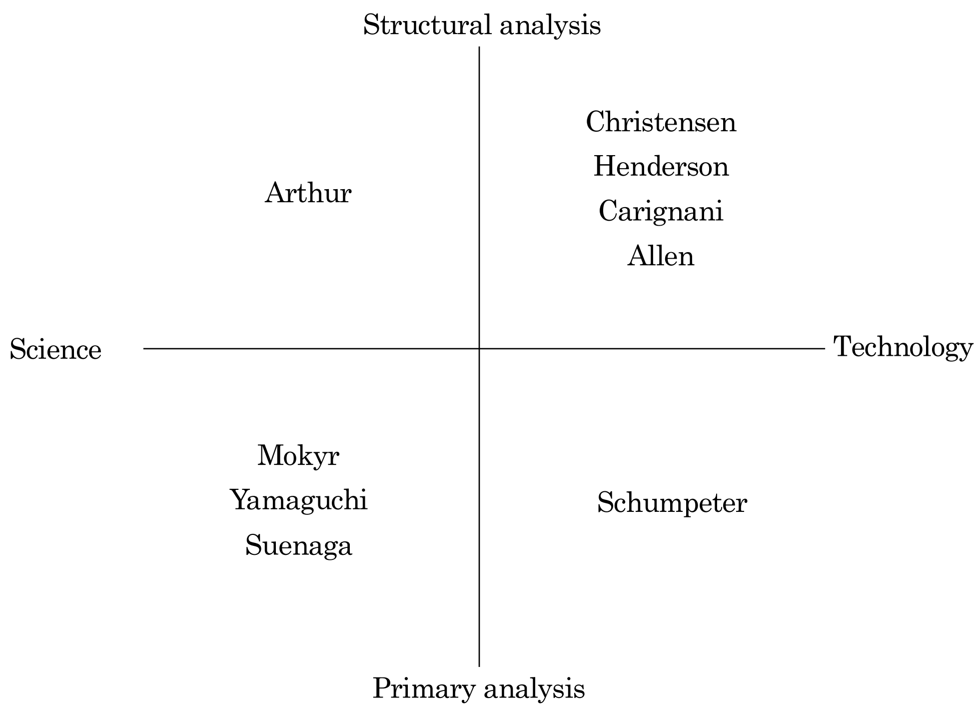

Figure 3: Classification of innovation theory

In addition, arguments that focus on the physical structure of artefacts and take the level of scientific knowledge as a given are more likely to have a managerial perspective, focusing on short- and medium-term themes, whereas arguments that shed light on the primary factors that create artefacts and scientific knowledge emphasise an economic perspective, focusing on long-term history. The arguments discussed above have been made for a variety of purposes and contexts, and it is not the case that any one argument is superior to the others, but it is important to note these differences in perspective when discussing innovation.

5. Concluding remarks

In this paper, we emphasise the importance of science from a long-term perspective, and focus our discussion on the human beings involved in the creation of innovations, rather than on the structural aspects of artefacts.[23] Another objective is to use the same model to analyse not only recent cases, but also innovations from the pre-industrial period, especially the Palaeolithic period, in order to build a theory of innovation that can deal with long-term history. This objective will be

[23] Of course, it is almost impossible to identify the person who invented the bow and arrow, but we imagined such an anonymous person in our discussion. Such inventions do not arise spontaneously in a growing population, nor do they come about unintentionally, as in mutation or horizontal transfer.

addressed in a book in the near future. This paper also compares a number of innovation theories. When considering innovation it is necessary to be aware of differences in perspective, and when examining long-term development it is indispensable to take account of advances in scientific knowledge.

The bow and arrow was a paradigm-disruptive innovation that harnessed new scientific knowledge and was a source of 'technological revolution' (Freeman, 1994a) that changed the standard of living and society of *Homo sapiens*. Although it is difficult to compare the benefits of different paradigm-disruptive innovations, these innovations are often produced in the face of difficulties under existing paradigms. Then, new paradigms based on the new scientific knowledge can often bring revolutionary benefits. Humans have gradually raised the level of technology by creating various new paradigms through a process of trial and error, while the level varied up and down.

Although not discussed in detail in this paper due to paper constraints, with regard to the new combinations of scientific and technological knowledge and their frequency, the information storage and communication technologies that connect them play a significant role (for more details, see Suenaga, 2019b). Information storage technology refers to symbols, letters, paper, printing and information storage devices; communication technology refers to vocalisation ability, language systems, translation systems and communication methods. In addition, in this new combination of knowledge, changes in values and demand also have a significant impact. While Baldwin (2016) examined long-term globalisation in terms of the bundling and unbundling of goods, ideas and people, this paper considers long-term innovation from the viewpoint of the combination (bundling) of scientific and technological knowledge. In the development of vaccines against Covid-19, scientific and technological knowledge were immediately combined through ICT, and new types of vaccine were developed at an astonishing speed (Suenaga, 2021a).

Last but not least, our civilisation originated in Africa tens of thousands of years ago and we have experienced globalisation and invasion with the advancement of technology. Nevertheless, we hope that by looking at history from a long-term perspective, we can put a stop to current conflicts and build a prosperous world.

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