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A conceptual understanding of macroeconomic interrelationships among science, engineering, technology, industry and national economy

Jae Chun Hyun*
Department of Chemical and Biological Engineering, The Applied Rheology Center, Korea University, Seoul 136-701, Korea

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Abstract

A systematic approach is employed to elucidate the interrelationships among macroeconomic entities such as science, engineering, technology, industry and national economy. Specifically, a conceptual, sequential method has been developed to clearly identify the essential ingredients needed for each macroeconomic entity starting from science to transform to the next one, and all the way to the national economy where the production of added-value is of overriding importance. The results thus obtained can then be utilized for macroeconomists to readily apply the engineering theory and knowledge to various macroeconomics situations, while engineers can likewise utilize the results on top of the microeconomic knowledge already prevalent in many engineering fields in getting better grasp of the seemingly difficult nation's macroeconomic picture. Other peripheral concepts and issues such as the evolutionary development of industry, the perspectives of the 21^{st} century civilization, an analogy between macroeconomics and chemical engineering, and national policies for each macroeconomic entity are also presented in this study.

1. Introduction

It's often not quite clear how engineering advancement leads to the national economic development, albeit looking plausible and sometimes obvious. This frequently woeful situation seems to stem from the deficiency in basic conceptual understanding on the part of participants in the modern society of the general interrelationships among the essential macroeconomic entities comprising the nation's economic activities. The entities at issue here are science, engineering, technology, industry and national economy, all of which lie in the sequential pathway starting from science and ending in the national economy where the production of added-value matters.

In this paper, a systematic approach is employed to elucidate the interrelationships among these entities beginning with science, the most fundamental logical base of the human civilization, and ending with national economy, the most encompassing realization in the civilization. Following along this pathway, a conceptualization effort has been undertaken to seek out the necessary conditions for each entity leading to the next stage, revealing crucially important knowledge components therein, which then play the pivotal role in helping us grasp the meaning of the whole sequential pathway.

This type of understanding is universally required of the society's all participants and particularly of the engineers and scientists whose roles in technology-oriented society are increasingly influential yet irreplaceable by those of other participants, regardless of whether the roles are limited to research and development alone or expanded to social leadership at the helm of the civilization. One aim of this study is thus to enrich these technocrats with not only the intellectual capacities for contriving new designs for the 21^{st} century but more importantly with the leadership capabilities for leading the knowledge-based society. Educators in universities, researchers in laboratories, and CEO's at the corporate levels all can become more effective in executing their societal functions on both the individual and collective basis when they are equipped with sound understanding of the above macroeconomic entities. Hopefully they will then contribute significantly more to building a better human civilization where every one of us will feel happier and more content.

The study begins with the macroeconomic interrelationships among science, engineering, technology, industry and national economy followed by the analysis of the various concepts like civilization, academic and industrial R&D, technology, industry evolution and national policies. The coherent theme here is a macroeconomic concept with focus on the added-value realization. The paper ends presenting various national policies in terms of the objects and methods involved thereof for each category such as sci-

*Corresponding author: jchyun@grtrkr.korea.ac.kr

ence, technology, industry, nation's economy and nation's administration, respectively.

2. The basic macroeconomic concept

Suppose there has been made a rheological breakthrough in science or engineering. Does this lead to an economic development of the nation? To this simple question, a plausible or sometimes an obvious answer might be "Yes, of course". But is it really so? As explained in this study, the answer is rather "Not necessarily so" unless several important assumptions are satisfied. The reason for this cautious and qualified answer lies in the fact that in order for a scientific or engineering breakthrough to be able to contribute to the economic development, it should be, above all, able to generate the added-value or equivalently part of the national GDP (gross domestic product) because this GDP counts as the growth of the national economy. Then the generation of this added-value doesn't automatically come from science or engineering breakthrough but does only when the particular breakthrough can be sequentially transformed into a few important macroeconomic entities. The fundamental issue just described here is illustrated in Fig. 1 along with the macroeconomic approach in this study to address that issue.

Each transformation process in this sequential pathway requires indispensable ingredients to be added as the necessary condition for the step. This paper elucidates this sequential transformation process starting from science and ending in the national economy by clearly identifying each macroeconomic entity with the crucial ingredients added into the each step. When all this sequential consideration is completed, then the answer to the original question "Does a rheological breakthrough in science or engineering lead to the national economic development?" can become clear

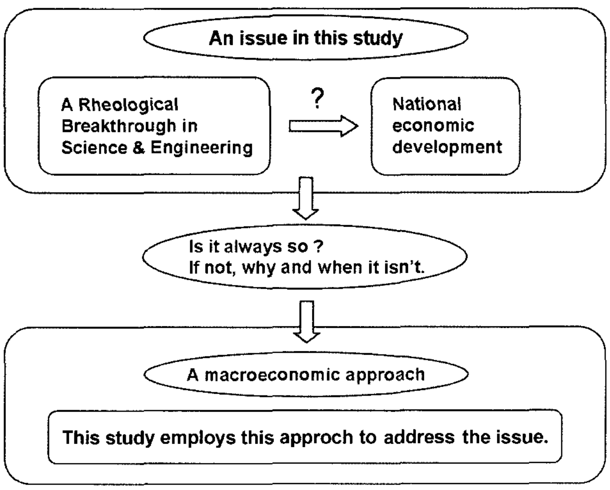

Fig. 1. The fundamental issue and the macroeconomic approach of this study.

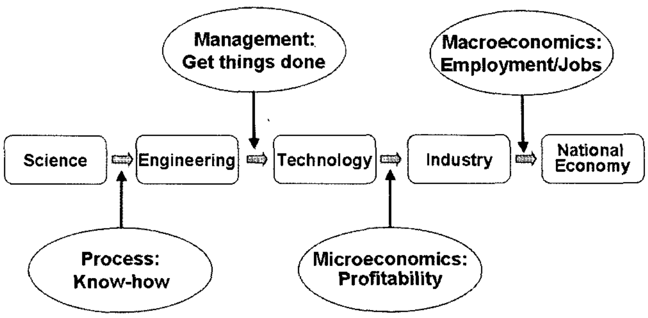

Fig. 2. The sequential pathway of macroeconomic entities from science to national economy with essential additional concepts required for each transformation step.

and even obvious.

Now, Fig. 2 is shown here explaining the above-mentioned transformation of the macroeconomic entities comprising the economic activities starting with science. This sequential logic illustrates an example of the methodology to conceptually synthesize the pathway from science to national economy in terms of required essential components.

First, science will lead to engineering when a process concept is added. Here science is used in broad sense, i.e., learning, rather than physical science in a narrow sense. The reason for this segment of the pathway is obvious: science always concerns itself with some sort of proof or disproof, while engineering is always concerned with something realized satisfying some clear needs, usually either manufacturing something or design of something. This means that engineering innately involves a process concept for its realization whereas science is not necessarily connected to it. The second segment shows that the management concept is required to make technology out of engineering. This is because securing a technology always needs proper, coordinated managing effort to put together various pertinent engineering components to yield technology as a product of a combined art. It can be said that engineering doesn't become technology spontaneously. It rather requires managing energy to be added.

Next, to establish an industry out of technology, we need the concept of profitability and competitiveness to be added. In other words, the microeconomic concept of optimization, i.e., maximization of profit and minimization of cost, is the requirement for technology to transform to industry, because industry cannot stand alone on its own without the buttress called profitability concept. Finally, these industries will then constitute a national economy by contributing to the production of the nation's output, GDP, or added-value. The macroeconomic concept required here is the national employment that provides jobs to the nation, generating income for everybody.

Fig. 2 displays the above basic macroeconomic concept in the format of a sequential pathway from science to

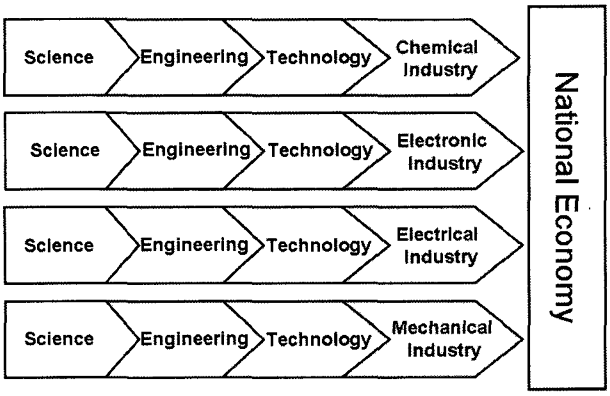

Fig. 3. The sequential pathways when there are four industries.

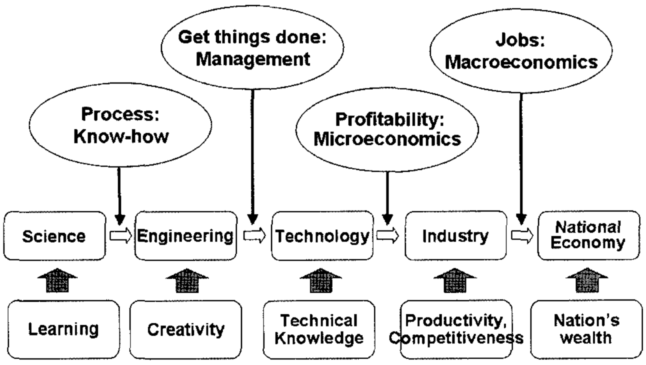

Fig. 4. The sequential pathway of macroeconomic entities with both additional concepts and objects of each entity shown.

national economy illustrating the synthesis procedure of each entity. When four typical manufacturing industries are considered as an example, e.g., chemical, electrical, mechanical and electronic industries, Fig. 3 can be conceived depicting the general macroeconomic picture. Whatever other industries, e.g., banking or hospital industry, can also be analyzed in the same fashion.

Next, we consider what the fundamental objects are involved in each entity in Fig. 2 or 3. As revealed in Fig. 4, those fundamental objects are learning, creativity, technical knowledge, competitiveness and nation's wealth for the entities of science, engineering, technology, industry and national economy, respectively. Listing "creativity" as the object for engineering here is not because other entities including science don't need it, but because it is engineering that requires some sort of creative ideas to satisfy perceived needs of the society, as mentioned earlier. Of course these objects listed here are what the present author believes essential for each macroeconomic entity constituting the core idea therein. The object of technology is the technical knowledge, not technical proficiency or efficiency. This is because the latter are derivable from the knowledge, not the other way around. So what is most important in technology is technical knowledge, more than anything else. These objects then help us better understand the interrelationships among those macroeconomic entities. They are also of paramount importance for developing respective national policies later on for each entity, namely, the national science, engineering, technology, industry and economic policy, respectively. How different and how similar these national policies are among themselves hinges on how well we can conceptually understand their interrelationships.

In summary, the sequential transformation starting from science and ending in the national economy is really the necessary pathway for any scientific or engineering breakthrough to go through before contributing to the economic development. If anywhere in the pathway does a disconnection exist, the whole transformation process then becomes unrealizable. For example, it is rather easy to find the cases of individual nations where automobile industry doesn't exist despite their high automobile technology levels. The reason is obviously the link between technology and industry missing or broken for various reasons in that particular nation.

3. Historical review of the 20th century civilization and perspectives of the 21st century civilization

Looking back into the 20th century, myriads of different developments can be cited to have occurred in the world in many different arenas of the human civilization. To name but a few, examples could include the birth of the technology-oriented society, the civilization based on the material value with the alienation of humanity, the severity and the destructive power of world wars, catastrophic implications of nuclear wars, rise and fall of communism, importance of the environmental sustainability concept, space technologies, electronic technologies including computers, cell phones, TVs and Internet, eternal challenges in life and medical sciences and so on and so forth.

Instead of merely enumerating the above items of the 20th century civilization, in this study a coherent story is sought to summarize the essential consequences of the various developments that had occurred during the century. In other words, we want to present a plausible story enabling us to grasp the gist of the civilization that can smoothly connect the 20th and 21st centuries. This is an overly simplified picture of the human civilization of both the last hundred years and the next, in a nutshell envisioned by a chemical engineer. Yet it will serve its purpose well in helping us gain a sound understanding of the macroeconomic entities explained above.

First, we'd like to say that the first half of the 20th century can be summarized as the period where the basic needs of mankind such as clothing, food and shelter have been largely solved in the most of the developed countries with of course the reservations that much of the under-developed part of the world still struggles in the sustenance levels yet. Due to the very nature of the macroeconomic analysis of this study evolving around the entities from science to national economy, our understanding of the simplified version of the civilization is necessarily tied to the developed part of the world.

With the advent of automobiles and concomitant petrochemicals at the start of the 20^{th} century, the human civilization had steadily developed following a natural, ascending curve in terms of the devices and materials satisfying the above-mentioned, three basic human needs, despite occasional ups and downs owing to wars, economic system failures and so forth.

After the basic needs have been largely satisfied, the next challenges of the mankind turn to the issues of how to enjoy the living. This is nothing more than the natural transition of human desires and aspirations from basic needs to life enjoyment. So here comes the entertainment era where audio and video culture plays a dominant role with the blossoming electronics industry catering to these new one-step-elevated human needs above the basic ones mentioned above. While the second half of the 20^{th} century can be viewed as the period where this life enjoyment through entertainment occupies the center stage of the civilization, the last quarter of the century had witnessed another budding, new era where human desires pursue above and beyond the simple entertainment satisfaction.

We are seeing now this new era where a trend moves with a most convincing likelihood to carry us throughout the 21^{st} century, the enjoy-healthy-life-longer trend. Again this transition is quite natural just as the transition from the satisfaction of basic human needs to the life enjoyment was in the second half of the 20^{th} century. With this new era and focus being staunchly entrenched in the civilization of the 21^{st} century, our new task is now invariably finding out what are needed to pursue this new civilization and how to maintain their level in a sustained manner.

Fig. 5 shows an example of the industries and disciplines needed to sustain this new era in which among many disciplines chemical engineering saliently plays the spearheading role in encompassing those industries with the common theme of the new era, i.e., enjoy-healthy-life-longer. This is because at the core of the chemical engineering discipline and profession lie among other things three vital fields of energy, environment, and life and medical, all of which play the crucial role in the civilization of enjoy-healthy-life-longer in the new era.

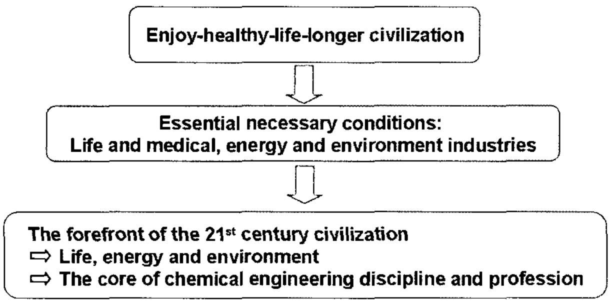

Fig. 5. Summary of the 21^{st} century civilization with the theme of enjoy-healthy-life-longer.

4. Details on engineering, technology, industry and macroeconomics

4.1. Engineering

Now we proceed to discuss some detailed aspects of the several macroeconomic entities, starting with engineering. The first issue to be dealt with is engineering research and development. In general, there are two main subjects involved here, i.e., industrial R&D and academic R&D. Although they look very similar at first glance, they possess fundamentally different characteristics as explained below and these differences should be understood in the context of the main basic macroeconomic concept expounded in Figs. 2-4.

As shown in Fig. 6, it can be said that in the academic R&D, with given principles and fundamentals, applicable cases and processes are sought and studied, whereas in the industrial R&D, with given particular processes pertaining to their industries, explaining principles are sought and studied. Because of these basic differences, the academic R&D is viewed, as shown in Fig. 7, more akin to research while the industrial R&D is to innovation. Both research and innovation can then be defined as the transformation

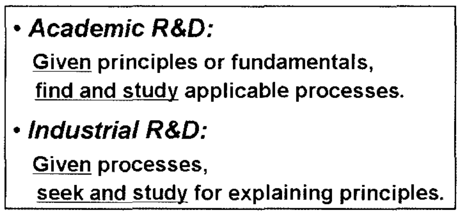

Fig. 6. Industrial R&D versus academic R&D.

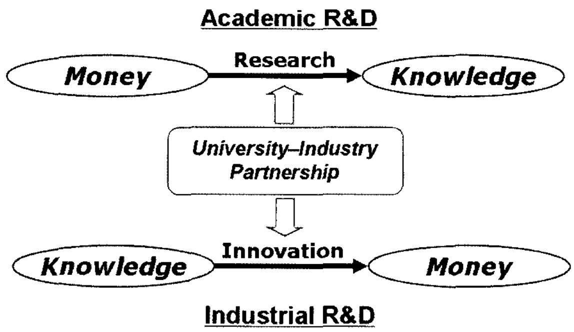

Fig. 7. Definition of research and innovation as practiced in academic and industrial R&D.

between money and knowledge but in opposite direction: research is the transformation of money into knowledge whereas innovation is the transformation of knowledge into money. (This is a quotation from the presentation at The Korea Rheology Conference '99 commemorating the tenth anniversary of the Korean Society of Rheology, 1999, by G. Nicholson, R&D V.P. of 3M Company). Adopting these definitions, two points could be deduced: research and innovation belong, but not necessarily limited, to the academic and industrial purviews, respectively, and they are also complementary to each other.

One more conclusion of the above explanation of the research and innovation is that the academic R&D thus occurs between the segments of science, engineering and technology in Figs. 2-4 while the industrial R&D between technology and industry as displayed in Fig. 8. In other words, in the basic macroeconomic concept explained above, the academic R&D should precede the industrial R&D. But once these two are in place they should exist together in a dynamic, perpetual motion for the sustainable, successful execution of the macroeconomic concept embodied in the sequential pathway from science to national economy.

4.2. Technology

The essential component and basis of technology is technical knowledge as explained earlier and the five main characteristics of this technical knowledge are listed in Fig. 9. First, the effort to obtain technical knowledge should be long-range and continuous, and second, it should also be voluntary and independent, not to be coerced or ordered by others. Third, the obtained technical knowledge should be accurate, and thus if inaccuracy is involved, it can't be technical knowledge. Likewise, the technical knowledge should also be of creative and honest nature. Nurtured under the philosophy of these five characteristics, technical knowledge can be created and accumulated.

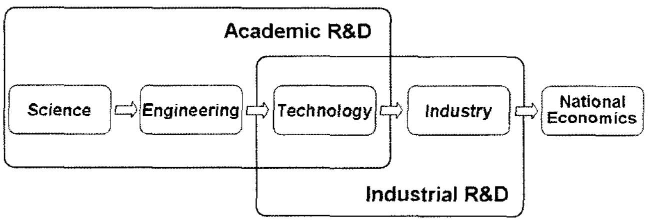

Fig. 8. Academic and industrial R&D illustrated in the sequential pathway of macroeconomic entities.

1. Long-range and continuous efforts (never by short-range efforts or for quick results)
2. Voluntary and independent efforts (never by orders)
3. Accuracy is a life-or-death issue. (Inaccuracy never represents technical knowledge.)
4. Creative
5. Honest (Cheating never makes technical knowledge.)

Fig. 9. Five Characteristics of technical knowledge.

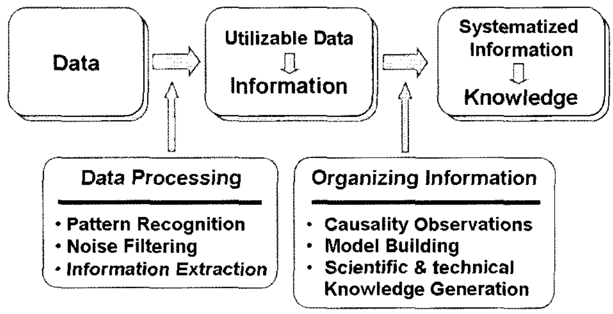

Fig. 10. Deductive process of the knowledge creation.

The process of obtaining the technical knowledge is illustrated in Fig. 10. First, gathered data are transformed into information through data processing stage consisting of steps like pattern recognition, noise filtering, information extraction, etc. This information will then be transformed into knowledge through organization stage consisting of steps like causality observations, model building, scientific and technical knowledge generation, etc. These two transformations are undoubtedly entropy-reducing processes, meaning that energy and efforts are required for their successful execution: "no free lunch", so to speak, possible in any technical knowledge acquisition.

4.3. An evolutionary development of the chemical industry

Fig. 11 illustrates an example of the chemical industry development viewed from the standpoints of evolution. Starting from crude oil and petrochemicals, and then going through bulk chemicals followed by specialty chemicals, and finally high-tech solutions, Fig. 11 shows the evolutionary process the chemical industry has experienced during the last hundred years. (Well-known corporation names taken from Dow Industrial 30 could be easily attached to each stage of this evolution process for an easier understanding.) This is a continuous transition from product-, process-oriented to solution-oriented, and also from

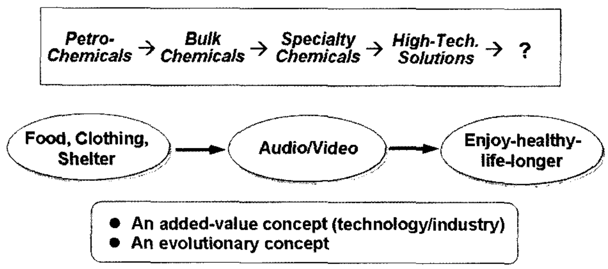

Fig. 11. An evolutionary development of the chemical industry.

upstream- to downstream-oriented. This transition can be succinctly characterized as moving in the direction of increasing added-value if it is analyzed from a macroeconomic standpoint. The prediction of the next evolution in the chemical industry into bio-related fields is thus not so hard to make, because that is in the direction of increasing added-value. Regarding other industries whether they are manufacturing, financial or even cultural, similar analysis and prediction like those in Fig. 11 can be made without much difficulty.

4.4. Macroeconomics as the most relevant branch of the civilization

Next, the realm of macroeconomics will be studied briefly before presenting an analogy between macroeconomics and chemical engineering in the next sub-section. By definition, the macroeconomics studies the behavior of the economy as a whole in contrast to microeconomics studying individual economies and markets. The basic questions in macroeconomics are how to sustain the nation's economic growth while maintaining the economy stabilized with less inflation and minimum unemployment. Examples of the characteristics of the study of macroeconomics include such diverse items as importance of people's expectations about the future of economy, growing importance of international linkages (open macroeconomics), paramount importance of proper government role in pursuing economic policies, and inseparability of macroeconomics from national and international politics, and also from historical events, both natural and man-made. It can be said that macroeconomics is truly one of the most encompassing branch of science and human endeavors that are intimately interwoven into the human civilization itself.

4.5. Analogy between macroeconomics and chemical engineering: an example

Before presenting an analogy between macroeconomics and chemical engineering as an example of inter-disciplinary analogy, the general structure of the macroeconomic model of a nation is shown in Fig. 12, adopting from the textbook of macroeconomics by Dornbush, Fischer and Startz (2001) with some additional information attached. The national macroeconomy can be conveniently explained using the goods and assets markets with fiscal and monetary national economic policies working on either of these two markets. While the microeconomic foundation gives the theoretical backgrounds for macroeconomic functions like consumption and investment, two aggregate demand curves called IS (investment/saving) and LM (liquidity/money) curves represent the equilibrium in the goods and assets markets, respectively, providing linkages among endogenous variables. The most important, endogenous intensive variable of the model is the interest rate that supplies the indispensable connection between the two markets and also makes the two economic policies, fiscal and monetary, capable of influencing the national macroeconomic system relying on the inherent nonlinear couplings existing between the two markets.

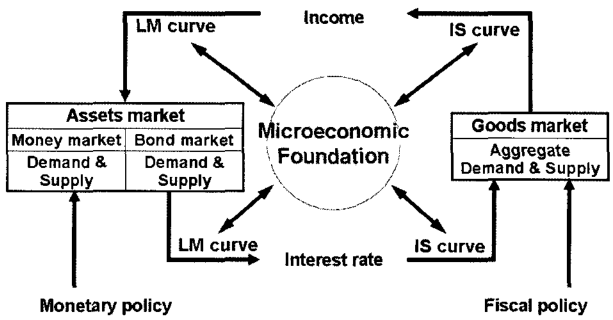

Fig. 12. Structure of macroeconomic (IS-LM) model with the two essential markets and microeconomic foundations.

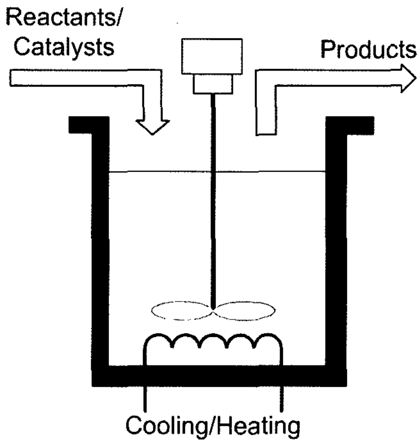

Fig. 13. Schematic of a continuous stirred tank reactor (CSTR).

Next, as an example in chemical engineering, a continuous stirred tank reactor (CSTR) is depicted in Fig. 13. (Any chemical reaction engineering textbook provides the background information about this CSTR, e.g., Aris, 1965; Fogler, 1998) The analogy between the CSTR and macroeconomics is illustrated in Fig. 14 where the exactly same structure of the chemical model of a CSTR is presented with all the macroeconomic components of Fig. 12 replaced by the corresponding chemical reactor components. As vividly shown in Fig. 14, every concept of the macroeconomic model of a nation in Fig. 12 has the corresponding counterpart in the CSTR. In other words, the analogy is amazingly a perfect one in that both macroeconomists and chemical engineers can enthusiastically agree with an exclamation of eureka.

Mass and energy in the reactor system can be likened to the goods and assets markets in the macroeconomic model while the constitutive equations of rheology, energy and

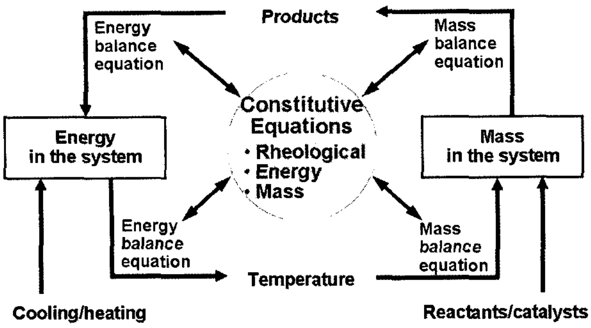

Fig. 14. CSTR model fitted into the macroeconomic model of Fig. 12.

mass for the reactor are likened to the microeconomic foundation about macroeconomic functions. The control of cooling/heating and reactants of the reactor to the energy and mass of the CSTR, respectively, are what monetary and fiscal policies to the assets and goods markets, respectively. Just as in the macroeconomic picture, the couplings exist between the mass and energy balances of the system to make the two control policies of heat and reactants equally effective in bringing about the control effects in the CSTR. The coupling role here is played by the nonlinear reaction term that exist in both mass and energy balance equations of the reactor. The intensive variable of temperature of the reactor is footed on the same concept as that of interest rate, albeit the reciprocal of temperature being likened to the interest rate. This is because increasing temperature over the reference point increases efflux of heat whereas increasing interest rate increases capital influx. The same second thermodynamics law governs all of these fluxes with the slopes of the intensive variables of the system determining the direction and magnitude of the fluxes whether they are in the reactor model or the macroeconomic model.

The utility of this analogy could be far-reaching. An example: based on the fact that the two systems possess the same dynamics and the similar governing equations model either system, the same kind of control strategies can be employed to meet the desired control objectives. In other words, macroeconomists can readily employ the engineering control theory to the macroeconomic situations while engineers can better grasp the seemingly difficult nation's macroeconomic picture using this analogy information on top of the microeconomic knowledge that is already prevalent in many engineering fields.

Table 1 summarizes the analogy between the CSTR and the macroeconomic models in terms of the corresponding variables to be paired with each other. Mass in the CSTR = goods market, energy in the CSTR = assets market, reciprocal of temperature = interest rate, mass balance equation = IS (investment/saving) curve, energy balance equation = LM (liquidity/money) curve, constitutive equations = microeconomic foundation of macroeconomic functions, cooling/heating control in the CSTR = monetary policy, reactants control in the CSTR = fiscal policy, etc.

Table 1. Illustrating the analogy between CSTR and macroeconomic systems, corresponding variables and equations are paired together

CSTR	Macroeconomic model
Mass in the system	Goods market
Energy in the system	Assets market
Reciprocal of temperature	Interest rate
Mass balance equation	IS curve
Energy balance equation	LM curve
Constitutive equations	Microeconomic foundation of macroeconomic functions like consumption and investment
Cooling/Heating control	Monetary policy
Reactants control	Fiscal policy

5. National policies for each macroeconomic entity

Finally, the nation's policies for each macroeconomic entity in Figs. 2-4 are discussed and explained. But the reasons why the control of national economies is so difficult are listed first. Large process lags in both measurements and implementations in macroeconomic systems, time-varying parameters in the system, inherent modeling difficulties due to the human nature entrenched in the macroeconomics, unavoidable business fluctuations due to the cyclic nature of many economic activities, interference from politics, unpredictable international developments, different opinions held by different macroeconomics schools, etc.

Now, each national policy of science, engineering, technology, industry, economy and administration is presented in Table 2 with the key words as per the two categories of "object" and "method." For example, the object of the nation's science policy should be learning while the method of that policy is education. The object of engineering policy is creativity on the part of students and the method is the same education as in science. Likewise, the nation's technology policy has technical knowledge as its object, and creation and accumulation of the technical knowledge as its method. The nation's industry policy should have international competitiveness as its object and implementation of the free enterprise principle (fittest survival in the market) as its method. The nation's economic policy has national wealth and people's well-being, and efficiency and effectiveness as its object and method respectively. Finally, the object of the nation's adminis-

Table 2. Nation's policies for science, engineering, technology, industry, economy and administration

Science policy	Object	Learning
	Method	Education
Engineering policy	Object	Creativity
	Method	Education
Technology policy	Object	Technical knowledge
	Method	Creation and accumulation
Industry policy	Object	International competitiveness
	Method	Free enterprise principle
Economy policy	Object	National wealth and people's well-being
	Method	Efficiency and effectiveness
Administration policy	Object	Transparency and accountability
	Method	Justice and fairness

tration policy should be transparency and accountability while the method should be justice and fairness.

One reason for stipulating the object and method for each national policy can be easily explained considering an example. Quite often in political arenas on the local and national levels, the words of science and technology are used in a confusing manner: Instead of treating the two national policies separately, it is used as one compound terminology, say science-technology policy. As explained above, these two cannot be compounded together but rather should be treated as separate entities because learning and education are for the object and method of science whereas technical knowledge and its creation and accumulation are for the object and method of technology. Consequently, the science policy should be inherently different from technology policy from the drawing board stage to the final implementation stage.

6. Conclusion

Using the macroeconomic concept embodied in the format of a sequential pathway from science to national economy, a conceptual understanding of interrelationships among macroeconomic entities such as science, engineering, technology, industry and national economy has been established. This kind of information and knowledge can be utilized to facilitate the leadership capabilities of engineers and macroeconomists in leading the knowledge-based society of the 21^{st} century. Specifically, engineers can enhance their much-needed understanding of the nation's macroeconomy as to how technology and industry are related to the national economy, and macroeconomists can also enhance their understanding of technology as to how important technology is related to other macroeconomic entities of industry and national economy. Educators in universities, researchers in laboratories and CEO's at the corporate levels can all become more effective in executing their societal functions on both individual and collective basis when they are equipped with sound understanding of the macroeconomic entities explained in this study. This way, the new era of enjoy-healthy-life-longer in the 21^{st} century will be upon us with everybody feeling happier and more content. Other macroeconomic concepts have also been presented in this paper to establish a larger picture of coherent macroeconomic foundation for participants of the modern society to fully grasp the meaning of the human civilization in the new era of the 21^{st} century.

Acknowledgments

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