The Evolution of Economic Structure Under Biotechnological Progress

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Abstract: There are obvious gaps between long-term change of economic structure and its principle driving force – technological progress. History has shown the influence of technological progress on economy and current insights in technological development can almost foresee the coming technological waves in next 50 years, but their possible impacts on economy are not yet assessed. In this paper, we define that R&D investment drives the development of biotechnology, capacity building brings new bio-technical processes into sectoral production, new or old technical processes within a sector exchange their relative positions as phasing in and out, and sectors evolve or transform along time. An exercise on US economy will be done to assess potential influence of biotechnological progress in next 50 years.

Keywords: Evolution, economic structure, biotechnological change

1 INTRODUCTION

Two big issues currently challenging human society are sustainable development and global change. Both of these issues have a long-term dimension, which demands consideration over the next 50-100 years. The current policy regime aimed to support sustainable development and deal with global change will have profound implication for future society, thus the present assessment of the policy regime demands for at least understanding, even if it is impossible to predict, the future. Combating global warming will transform the present fossil-fuel society into a non-carbon world, what could be the vision of the future world influenced by today's environmental policy therefore draws policy maker's top attention. Historical perspective tells us that technological revolution is the fundamental driving force of long-term change in human society. Although oncoming technological change is to some extent foreseeable, human society is still incapable of assessing the potential influence of new technologies on the society. In the past, we have always identified technological influences *ex post*; even today, at current stage of development of new technologies, we are not yet clear what will be brought about by the technologies to the society.

The socio-economic system is so complex that its structural change remains intractable. Mainstream economics regards economic change to be a process of static or dynamic equilibrium, based on the ideas of Newtonian's mechanicas. It views the economic system as deterministic, controllable, homogenous, reversible, and moving toward equilibrium (Janssen, 1998). It avoids the problem of structural change by assuming a constant structure in the short and medium terms, but fails to prove itself in long-term projection. Its mechanical extrapolation, often based on capital stock, into the future receives most criticisms from non-mainstream economists including historical and evolutionary economists, who have been theoretically challenging mainstream economics' ideas on economic change by arguing that economic system is undeterministic, uncontrollable, heterogeneous, irreversible, and a system in disequilibrium. They recommend an evolutionary perspective to link changes in production inputs including intermediate and primary inputs, in consumption patterns, and in investment structure with technological progress (Van den Bergh and Gowdy, 2000).

What could be the implications for economic structural change of the development in biotechnology? This question deserves effort in exploration for several reasons. First, better understanding of the direction of structural change will shed great light on current sustainable development and global change problems. Ernst & Young's report (2001) analyses that biotechnology will bring hope to the hungry people, nearly one-third of world population, by significantly improving agricultural production. But, when, to what extent, and how cannot be answered in the absence of structural change context. Second, the new analysis of structural change under biotechnology will add important new policy implications to the existing policy research on sustainable development and global change issues, e.g. climate change. It is now well known that if technological progress can lower the costs of complying with climate change imperatives, the resulted gross costs could be much lower than is naively expected with exogenous technological progress. The question is whether biotechnological development will drive economic structure in a direction favourable to climate change and lower resource use. The difficulty of simulating structural change under endogenous technological progress has been a bottleneck for the advancement of modelling work on socio-economic, environmental, and natural resource issues. Finally, structural change through biotechnology is critical for the clarification of the implications on other economic variables of biotechnological development. The structural change will alter industrial position and production relations, influence future labour markets, reflect changes of consumers' preferences, and guide investment behaviour. On all these aspects, biotechnology will have great implications.

In this research we aim to simulate the evolution of economic structure under biotechnological development[1]. The basic unit that we study is technical or production processes, which are regarded to constitute a sector's production and to represent specific layers of technology, old or new. The phasing out or in of the old or new technical processes changes a sector's production form, which in turn induces structural change of economy. The relative position of a technical process in a sector is determined by the installed capacity or capital stock required by the process and that the capacity is investment-driven. We distinguish between two types of investment in technology: namely investment in R&D and investment in application of the R&D achievement to production processes. The former depends on both the public and private sectors' investment behaviour and policy regime. The latter follows the descriptive theory of the technology life cycle, which in turn depends on the investment in R&D. Driven by these two sorts of investment, technologies develop, production processes change their position, and economic structure evolves along the trajectory of technological development. Thus, the method in this research entails an endogenous Input-output structural change, which likes an evolution mechanism or Schumpeterian creative destruction.

Section 2 will briefly review previous studies on structural change and technological change. Section 3 will introduce the method in this research. Second 4 will apply the method to US economy. Finally, Section 5 concludes this research.

2 REVIEW

The central position of Input-output analysis in the description of economic structure is reckoned by modern economic modelling exercises, which employ the explicit presentation of inter-industry relations from Input-output tables.

Input-output table essentially presents technologies at sector level, with an assumption of fixed input coefficients. However, many studies find a paradox that the change Input-output coefficients is not corresponding to technological change, in particular in short and medium term (e.g. Carter, 1970), probably because the Input-output coefficients result from the effects of various factors, which offset each other in most cases. On other hand, looking back longer term of history economic structure did change in accordance with technological progress. In order to capture influence of technological progress on economic structure, economists have devoted a lot of effort to adjust the fixed Input-output coefficients. Traditional methods mechanically adjust Input-output coefficients, generally regard technology as a name of a factor explaining the changes over time without explicit treatment of different technologies, and lack an analysis of new technologies and their role in influencing the economy. The traditional methods, isolating the change of Input-output technical coefficients from economic behaviour, say investment in innovation and diffusion, seem incapable of long-term projection. Carter (1970) explicitly incorporated the new technology into Input-output coefficient change but with an assumption that future coefficients are known. Leontief and Duchin (1986) were the first who explicitly explored the influence on Input-output technical coefficients of information technology in the US economy. They designed both qualitatively and quantitatively four scenarios tracing the possible paths of influence of information technology for the period 1980-2000. While their research did capture the evolution of information technology to some extent, it did not relate the information technological change with R&D investment and consider other potential technologies. In other words, technological change is exogenous in their research. Los (2001) attempted to model the change of Input-output

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[1] The "evolution" here means the change of economic structure in accordance with technological progress. It may differ from the evolution proposed in typical evolutionary economics, which adopts the Darwinian evolution in biology.

coefficients with endogenous growth theory, but his treatment on technology, a pure labour-saving process, is oversimplified and not suitable for specific technologies.

It is widely noted that neoclassical approaches, both exogenous and endogenous, on technological change are over-simplistic, ignoring a comprehensive analysis of technological characteristics. This is reflected in a number of applied economic models based on such theories. The exogenous growth economic models commonly assume that technological change is a deterministic time trend with exponential or whatever form of exogenous factor growth. As an updating version to endogenous growth theory, some formerly exogenous growth models use cumulative knowledge or capacity to represent technological progress to claim itself as an endogenous growth model.

There has been a movement including historical and evolutionary economics and some new thinkers to criticise neoclassical economic theory on economic growth in relation to technological change (e.g. Freeman and Soete, 1997; Janssen, 1998; Freeman and Louçã , 2001). They propose to economy an undeterministic, uncontrollable, heterogeneous, irreversible, evolutionary, and a disequilibrium, process.

Long-term technological change has not been properly modeled so far with either neoclassic or evolutionary approach, recently emerges a renewed interest in long wave theory, a subject that describes economic change with long-term Kondratiev waves driven by Schumpeterian radical technological change (Freeman and Soete, 1997). This is a good descriptive theory on the life cycle of a technology. Freeman and Louçã (2001) elaborate the life cycle of a technology by six phases as shown below.

- The laboratory-invention phase, with early prototypes, patents, small scale demonstrations and early applications;*
- decisive demonstrations of technical and commercial feasibility, with widespread potential applications;
- explosive take-off and turbulent growth, characterized by heavy investment and many business startups and failures;
- Continued high growth, as the new technology system becomes the defining characteristic of the economy; *
- slowdown, as the technology is challenged by new technologies, leading to the next crisis of structural adjustment;
- Maturity, leading to a (smaller) continuing role of the technology in the economy or slow disappearance.

Köhler (2003) fits the six phases into a S shape. Grübler (1998) points out that the analyses on the development of many technologies confirm the S shape description, a logistic curve that has been widely used without definite reason.

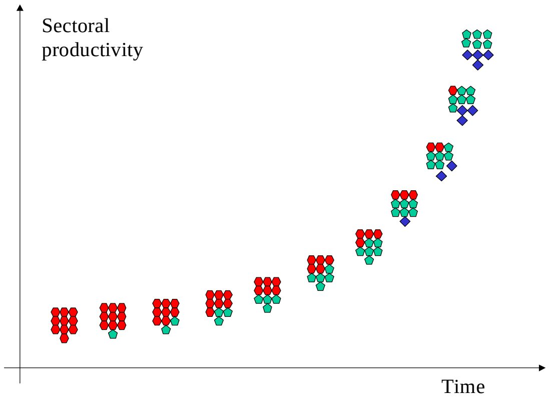
3 THE METHOD

The method in this research bases on Pan (2004), where specific technologies can be modelled to induce the change of Input-output analysis. The method regards a sector as a cluster of production processes, each of which represents a sort of technological layer. The structure of intermediate and primary inputs of a production or technical process is the technical structure of the process, which is assumed fixed throughout time by its nature. The dynamics of a sectoral input structure depends on the phasing in and out of its new and old technical processes. The method further defines that the relative position of a technical process in a sector is determined by the installed capacity required by the process and that the capacity is investment-driven.

The method specifies two types of investment in technology: namely investment in R&D and investment in application of the R&D achievement to production processes. The former depends on both the public and private sectors’ investment behaviour and policy regime. The latter follows the descriptive theory of the technology life cycle, which in turn depends on the investment in R&D. Driven by these two sorts of investment, technologies develop, production processes change their position, and economic structure evolves along the trajectory of technological development. Thus, the method in this research entails an endogenous Input-output structural change, which likes an evolution mechanism or Schumpeterian creative destruction.

Figure 1 shows the evolutionary process of sectoral production process. In period 1 the sector consists of ten old technical processes (the hexagons), but in period 2 a new technical process (the pentagon) emerges. The new process, driven by investment, will gradually expand its share in the sector production and kick out the old processes. In period 8, a newest process (the diamond) appears and will increase its share in the sector during following periods. It is clear that in the last period in Figure 2 the old technical processes will be eliminated out of the sector, the new technical process will dominate the sector production, and the newest technical process will compete with the dominator. As a result, the sector will completely transform its production techniques.

Figure 1. The evolution of sectoral production process



Denote intermediate input coefficient matrix as *A*, the elements of which are a_{ij}, which we assume consists of an ordinary technical process with technical coefficient a_{ij}^{O} and a new technical process with technical coefficient a_{ij}^{N}. Let x_{ij}^{O} indicate the input of sector *i*'s product in sector *j*'s ordinary process and x_{ij}^{N} in sector *j*'s new technical process, and X_j^{O} and X_j^{N} are sector *j*'s total output from ordinary and new technical process respectively. Let P_i indicate the price of sector *i*'s product, P_i^{O} and P_i^{N} are the prices of ordinary and new production process, respectively. We have the following coefficients,

For the ordinary technical process,

$$a_{ij}^{O} = \frac{P_i^{O} x_{ij}^{O}}{P_j^{O} X_j^{O}} \tag{1}$$

For the new technical process

$$a_{ij}^{N} = \frac{P_i^{N} x_{ij}^{N}}{P_j^{N} X_j^{N}} \tag{2}$$

The coefficient from Input-output table is

$$\begin{aligned} a_{ij} &= a_{ij}^{O} \cdot \frac{P_j^{O} X_j^{O}}{P_j^{O} X_j^{O} + P_j^{N} X_j^{N}} \\ &+ a_{ij}^{N} \cdot \frac{P_j^{N} X_j^{N}}{P_j^{O} X_j^{O} + P_j^{N} X_j^{N}} \end{aligned} \tag{3}$$

Above says that the combined Input-output coefficient is the average of coefficients of ordinary and new technical processes, weighted by the share of the product of each process in total product.

Denote k_j^{N} as the coefficient of new-technology-specific capacity use in sector *j*, we have

$$k_j^{N} = \frac{r_j^{N} K_j^{N}}{P_j^{N} X_j^{N}} \tag{4}$$

Where capital K_j^{N} indicates new-technology-specific capacity or capital stock built in sector *j* and γ_j^{N} the rental rate of the capacity or capital stock. Similarly, the coefficient of ordinary capacity use in sector *j* is

$$k_j^{O} = \frac{r_j^{O} K_j^{O}}{P_j^{O} X_j^{O}} \tag{5}$$

Assuming the capacity in each sector is fully utilised, the output from new and old technical process can be derived (4) and (5) respectively, substituting them into (3), the combined coefficient of intermediate use becomes dependent to capacity

$$\begin{aligned} a_{ij} &= a_{ij}^{O} \cdot \frac{k_j^{N} K_j^{O}}{k_j^{N} K_j^{O} + k_j^{O} K_j^{N}} \\ &+ a_{ij}^{N} \cdot \frac{k_j^{O} K_j^{N}}{k_j^{N} K_j^{O} + k_j^{O} K_j^{N}}. \end{aligned} \tag{6}$$

The formula (6) shows that a combined Input-output coefficient is dependent to the input structure and capacity of each process. If each process's input structure is fixed, the combined Input-output coefficient changes with capacity change in each process. We further discuss investment and capacity accumulation below.

Denote[2] δ as depreciation rate and *I* as investment; the capacity is accumulated in a classical way

$$K_{j,1} = (1-\delta)K_{j,0} + I_{j,1} \tag{7}$$

which says that the capacity at period 1 is the investment in the period plus the capacity net of depreciation in period 0.

We further define the investment in technological deployment dependent on technology development, which will go along its life cycle - a logistic-like

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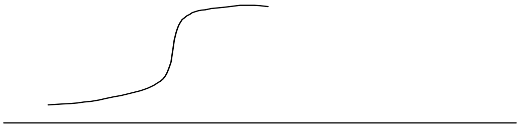
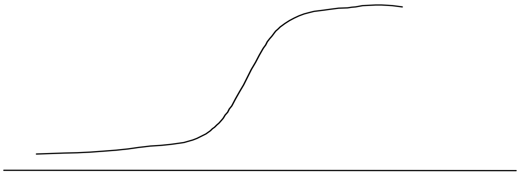
[2] Thereafter, for simplicity, we do not distinguish between new and old processes.

curve. In this research, the logistic curve is not fixed; how fast a new technology will go through the cycle depends both on the nature of the technology and on the R&D investment in the technology. As Figure 2 shows, if a technology will go through a life of 60 years with a normal level of investment, additional investment to the level will accelerate the development of the technology and shorten its life span to, e.g. 30 year. This perspective is for example particularly important in assessing induced technological change. Heavy investment in environmental technology will rapidly develop the technology, which in turn will assist in solving environmental problems.

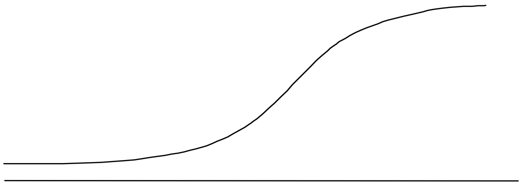
Figure 2. The dependence on R&D investment of the life span of a technology



30 years - heavy investment



60 years - moderate investment



90 years - light investment

Define

$$I_t = \frac{\theta_j}{1 + e^{-\alpha t + \beta}} \tag{7}$$

Where θ_j is parameter vector, β determines the lower tail span. In terms of technology development, it describes the process of phase 1 and 2 and defines their spans. We empirically specify its value. Here α is a variable, which defines the logistic curve's span from very low to top. In terms of technology development, it describes how fast a technology will reach its peak of life. We relate this variable to R&D investment, assuming that additional investment will accelerate a technology's development and therefore shorten its life cycle. Denote $I_t^{R\&D}$ as index of R&D investment in new technology R&D sector; we assume a linear relationship between the index and α

$$\alpha_t = \tau \cdot I_t^{R\&D} \tag{8}$$

Again, parameter τ can be empirically determined. In a multinational context, the R&D investment includes both domestic and foreign investment and therefore reflects spillover effect across nations. We will approach the R&D investment behaviour in an integrated macroeconomic system, which currently is beyond the scope of this paper.

4 A STUDY ON US ECONOMY

According to the method described above, this study specifically projects US Input-output coefficients for next 50 years (attempting to cover the entire course of biotechnological development) purely from the perspective of biotechnological change. The projection is then incorporated into a macroeconomic model, E3MG, to assess the influence of biotechnology on US economy.

Biotechnology is further considered with respect to three sub-layers, namely agricultural biotechnology, environmental biotechnology and life science biotechnology as commonly defined in the area (Senker, 2000; Ernst & Young, various years). Currently, the different types of biotechnology show different pattern of development and investment. They may have different implications on economic system in future. Within Input-output framework this study accounts for biotechnological products separately. For example, universities and research institutes produce biotechnology patents, while food, chemical or pharmaceutical giants provide dedicated biotechnology firms (DBFs) with key inputs. The method allows substitution among primary and intermediate inputs as biotechnology phases in to the economic system, and therefore generates a mechanism of evolution or Schumpeterian creative destruction. This study also specifies biotechnology-specific labour and capacity. The new labour may be readily available through training and education, but the capacity building depends on biotechnology investment, which entails the endogenity of biotechnology. It is important to notice that this method addresses the productivity growth enhanced by biotechnological progress through the phasing in of biotechnological processes where both labour and overall intermediate input are made to decrease their shares in total input in each sector. This feature implies the factor productivity improvements.

To project the Input-output coefficients under biotechnological progress, it is the best to have the Input-output data in terms of each bio-technical process, which in fact requires the establishment of un-precedent biotechnological Input-output tables. However, existing statistics has not yet provided with such detailed and updated data. The construction of such biotechnological Input-output tables based on observation is beyond our ability and resources, we thus adopt hypothetical tables based on experts' view, literature review, and special surveys, wherever they are necessary.

5 CONCLUSION

This study critically relies on identification of the new bio-technical process. It is ideal to use biotechnological Input-output tables, but the data unfortunately is unavailable at present or doesn't exist at all. The second best way is to use engineering data to specify the input structures of biotechnology in different sectors. In the exercise with US economy, a hypothetical biotechnological Input-output table will be used.

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