Decreasing Return of Intra-industry RD and Economic Growth

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3 January 2014

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Abstract This paper presents a growth model with decreasing returns of intra-industry research and development. With the old industries fade away, more and more researchers come out to create new industries. This means growth can keep constant, stagnancy can breed prosperity, and it can also explain business cycle, structural change, the rise and fall of national economy, and the importance of freedom market which allowing abound trial and error to seek new growth engine.
Keywords Economic Growth, Decreasing Return, Research and Development

I. Introduction

Economists always find that economy tend to stagnant in the long run, such as in the theory of Solow model or Ramsey model. Economists can also easily find that there are so many nations keep stagnant. What's more, economic growth theory itself has not "grow" more than 10 years ironically, today few papers about this topic have been published in top journals, in contrast with 1990s, which are considered as the new era of growth theory[②].

Why there are so many stagnancies co-exist with growth, and we still believe economy and economic theory can develop in the future? How to explain it? This paper investigates a model which can not only explain the stagnancy, but also the growth accompanied by it. Stagnancy come from the decreasing return of input, which includes capital, human being and even R&D. Growth come from the creating of new industries, when old industries fade away, more and more input would come out to create new industries.

However, inducing the decreasing return of R&D into growth theory is a dangerous effort, although decreasing return of other input are considered as reasonable in economic theory. The J/K/S models (including Jones [1995b], Kortum [1997] and Segerstrom [1998]) aim to solve the Jones' critique, consider the production of new ideas as diminishing returns, that is, the past discoveries would make it more difficult to find new ideas. Thus with the rising of RD difficulty, exponential growth in per capita output would be stagnant in the absence of population growth.

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② The reason lies that recently more and more economists realize that the persistent driven force of economic growth is research and development efforts of profit-maximizing agents, while the conclusions of relevant papers always remind that the more R&D input, the higher growth rate is (important contributions to this literature include Romer (1990), Grossman and Helpman (1991a, 1991b), and Aghion and Howitt (1992)). Economists call this phenomenon "scale effects", which receive little support in empirical studies. For example, Jones (1995, 1999) found that the number of scientists engaged in R & D in advanced countries has grown dramatically, while the growth rates keep constant. As pointed out by Jones (1995a), the prediction of the first generation growth model is strongly at odds with 20th-century empirical evidence. After Jones' critique, subsequent growth models have attempted to eliminate this prediction, but it looks no perfect solution was found yet in the last decades. As a result, economic theory becomes stagnant recently. After Jones' critique, subsequent growth models have attempted to eliminate this prediction, but it looks no perfect solution was found yet in the last decades. As a result, economic theory becomes stagnant recently.

This paper shows that inducing a hypothesis, the return of R&D intra-industry is decreasing, can also get a result of economy continues to growth. Although this assumption has already been added to the endogenous growth literature by Jones (1995b), Kortum (1997) and Segerstrom (1998), they did not constrain the decreasing into intra industry, so can not explain the emergence of new industry, the structural change and so on.

Ngai and Pissarides(2007) have the similar hypotheses with us, they studied a multi-sector model of growth with difference in TFP growth rates across sector and derive sufficient conditions for the coexistence of a balanced aggregate growth path, and the conditions are goods should be poor substitutes and the inter-temporal elasticity of substitution should be one, but they did not give the micro mechanism based on profit-maximizing agents.

The paper is organized as follows. Section II summarizes some basic stylized facts, which is also the hypotheses of next section, about economic growth. Section III proposes a basic model, showing that even there is decreasing returns within industries, balanced aggregate growth path also coexist. In Section V we apply our viewpoint to explain business cycle, structural change, R&D and education outdated and disappearing scientists, the rise and fall of national economy, and the importance of freedom market which allowing seemingly absurd trial and error.

II. Some Stylized Facts about RD and Economic Growth

There is little doubt that technological progress through process innovations played the key role in initiating, accelerating, and sustaining economic growth in the modern era (e.g. Mokyr, 2005). Understanding innovation is central to understanding many important aspects of economics, from market structure to aggregate growth (Jones, 2008, RES). This paper considers that, although there are so many economists studying economic growth, however, they neglect two key facts. The first is about the economy, the second is about the characteristic of R&D. In a famous paper, Kaldor summarized economic growth into several "stylized facts", in this paper we also try to illustrate another 2 stylized facts.

Fact 1. There are only a few industries grow in one economy, GDP growth rate is just a weighted average vale

In most economic papers, the grow rate were calculated using explicitly formulas, for example, $g = s / v$ in Harrod and Dommer model, $g = l \log \lambda$ in Grossman and Helpman (1991)model, or $g = \lambda n / (1-\phi)$ in Segstrom model (1998) and so on. However, it does not exist a unique grow growth rate *g* at all. The so called growth rate g, which release every year by government, is just a weighted average value. Economists ignore a fundamental economic fact, say heterogeneous growth rate of industries. Not all the industries grow, or even grow with the same speed just like the well trained troops of Northern Korea or Russia, but only very few industries grow. For this point, Ngai and Pissarides (2007) found that "Economic growth takes place at uneven rates across different sectors of the economy". Although Jones have said:

"The discoveries of electricity, the incandescent light-bulb, the internal combustion engine, the airplane, penicillin, the transistor, the integrated circuit, just-in-time inventory methods, Wal–Mart's business model, and the polymerase chain reaction for replicating strands of DNA all represent new ideas that have been, in part, responsible for economic growth over the last two centuries."

However, even those industries which are the engine of the whole society, partly stagnant today, such as incandescent light-bulb industry. From Figure1 and 2, we can find that the GDP growth in U.S. is comparatively stable in the past 100 years, while some industries such as the machinery industry keep downward in the past 40 years; even it has been the main engine of industrial countries.

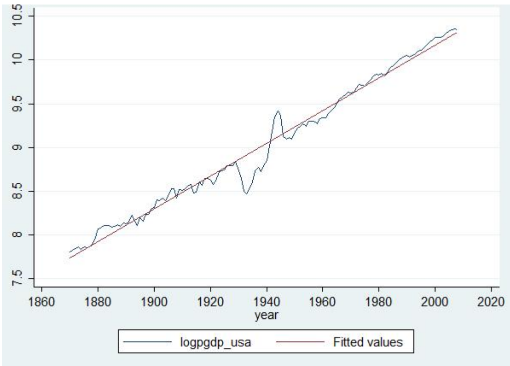

Figure 1. The GDP Growth in U.S. is just a weighted average value

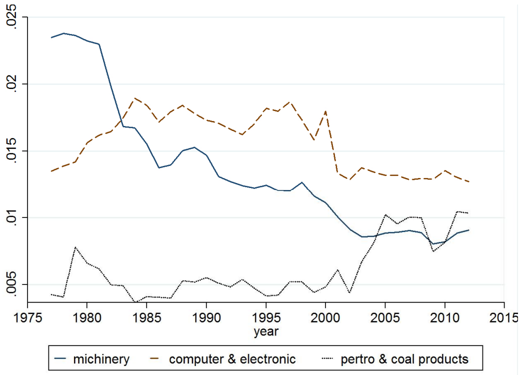

Figure 2. The industry output ratio in the manufacturing sector in U.S.

Jorgenson et al. (2007) analyzes the industry origins of the American growth resurgence by examining output, input, and productivity growth of 85 component industries for the period 1960 to 2005, and find that TFP growth rate of most industries in U.S. is stagnant between 1960-2005, see Figure 3. If there are immense growth rate difference among industries, the output function in growth model should not be Y=F(K,L,A), but should be

$$Y_i = f(A_i, K_i, L_i) \tag{1}$$

where i means industries.

Although there are very different growth rate and volatility among industries, the number of industries is very large, so the growth rate can be comparatively stable in the long run, just as Figure 1 shows. That is, the GDP growth rate is just the weighted average of industries. Although economists can justify that, they only want to illustrate a mechanism, not to draw all the society out, so making some abstraction is necessary. However, this paper considers paying attention to industry growth heterogeneity is very important to understand growth history, and should not be neglect.

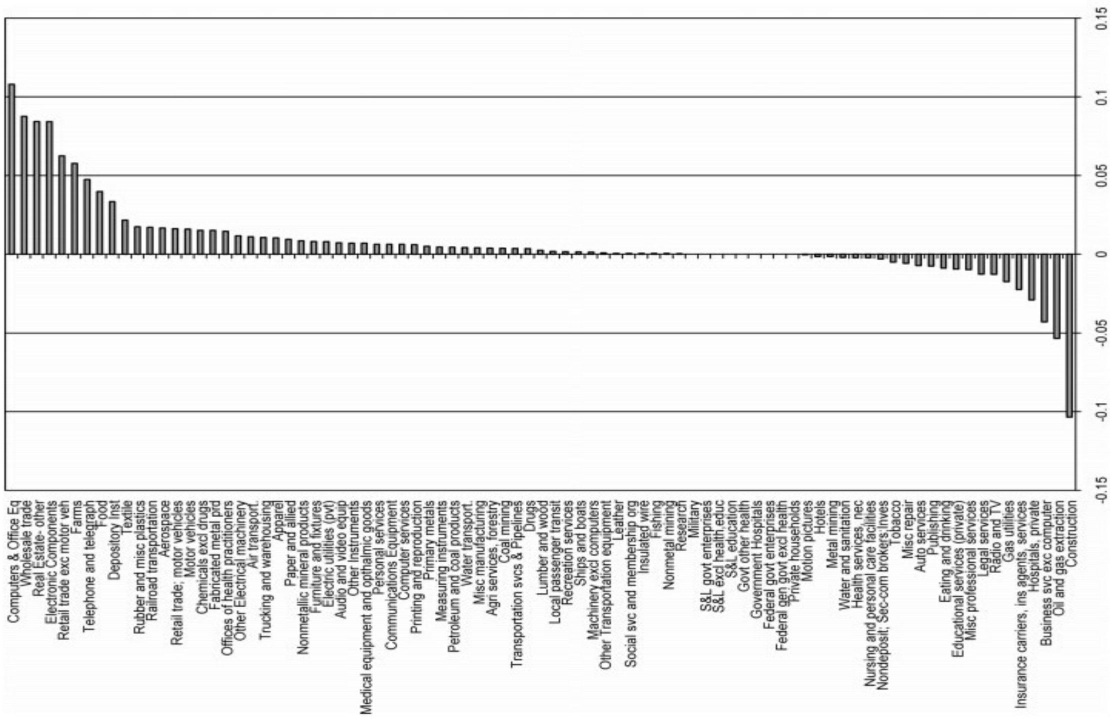

Figure 3. Industry contributions to total factor productivity growth, 1960– 2005(Jogensen, 2007)

Fact2. The output of RD are decreasing returns intra industries

In the Solow model (1956), there is positive and diminishing returns to private inputs. That is, for all K>0 and L > 0, F(*) exhibits positive and diminishing marginal products with respect to each input:

$$\frac{\partial F}{\partial K} > 0,\ \frac{\partial^2 F}{\partial K^2} < 0,\ and\ \frac{\partial F}{\partial L} > 0,\ \frac{\partial^2 F}{\partial L^2} < 0 \tag{2}$$

No one can deny that the existence of decreasing returns in the field of general producing, however, is there still in the field of knowledge producing? For the decreasing return of RD activities, Kortum(1997) make a good summary. As far back as the 1930's writers have blamed the decline in patents per researcher on diminishing technological opportunities. Machlup (1962) compiles evidence on patents per researcher from 1870-1960 and shows that this ratio declined consistently after 1920. Further evidence for the diminishing technological opportunities hypothesis is provided by Evenson (1984) who finds that the decline in patents per researcher is a world-wide phenomenon. Griliches (1990) reviews this early literature. Ngai and Samaniego(2011) found that long run industry differences in both productivity growth and R&D intensity mainly reflect differences in "technological opportunities", interpreted as the parameters of knowledge production, and they find that diminishing returns to research activity is the dominant factor. ViSúS, lópez-pueyo and Villarroya(2014) use the sectoral approach, find the estimates give great support to semi-endogenous growth theory, that is, RD activities is decreasing returns.

However, we must restrict the scope of decreasing returns. The current evidence only supports the decreasing returns within industries, rather than whole economy. Although J/K/S model consider the cost of RD is increasing, they think the scope is whole economy. We had to say, it is a dangerous and rude hypothesis, and easily lead to a dangerous conclusion, say stagnant if there is no population growth.

III. The Basic Model

This section presents a basic model. Following Young (1998) and Howitt (1999), I assume that there are two kinds of innovation, horizontal and vertical. Consider an economy populated by *L* consumers, each of whom in-elastically supplies one unit of labor at all times.

A. Production Relations

Consumption and R&D are both produced under perfect competition by a continuum of intermediate products, according to the same production function. Specifically, the total output of the economy at time t is

$$Y_t = \left[\int_0^{Nt} (\sum\nolimits_j q_{it} x_{it})^{\alpha} di \right]^{1/\alpha}, \tag{1}$$

where Y_t is gross output, C_t is consumption, N_t is the number of available products, x_{it} and q_{it} denote the quantity and quality, respectively, of intermediate input *i* used at time t. The elasticity of substitution between any two varieties is 1/(1−α).

From (1), for a given level of consumer expenditure, maximization on the part of final-output producers yields the equally familiar constant elasticity of substitution demand for each intermediate input:

$$\frac{x_{it}}{Y_t} = \frac{\left[p_{it}/q_{it}\right]^{-\sigma}}{q_{it}\cdot\left[\int_0^{Nt}(p_{it}/q_{it})^{1-\sigma}di\right]^{-\sigma/(1-\sigma)}} \tag{2}$$

where $\sigma = 1/(1-\alpha)$, p_{it} is the price of product i, p_{it}/q_{it} can be considered as the quality-adjusted price and $\left[\int_0^{Nt}(p_{it}/q_{it})^{1-\sigma}di\right]^{1/(1-\sigma)} \equiv \tilde{P}$ can be considered as aggregate quality adjusted price index. The Appendix1 gives the detail of calculation. Each intermediate product is produced using labor, according to the production function

$$x_{Mit} = L_{Mit} \tag{3}$$

where L_{it} is the input of labor in sector i. The total supply of labor Lt is fixed in-elastically at each date by the population, which grows at the constant exogenous rate. Integrating both sides of the equation (2), we can get the total employment L_{Mt} in manufacturing sector is

$$Y_t / Q_t = L_{Mt} \tag{3.2}$$

For the constant elasticity of substitution demand of the model, the price schedule of incumbent monopolist is given by the marginal product, and profit takes the following functional forms

$$\pi_{it} = (p-c)x_i = \frac{\left[(p-c)\right]\left[p_{it}/q_{it}\right]^{-\sigma} Y_t}{q_{it}\cdot\left[\int_0^{Nt}(p_{it}/q_{it})^{1-\sigma}di\right]^{-\sigma/(1-\sigma)}} \tag{4}$$

When the pricing strategy is known, we can calculate the specific profit using the equation (4).

B. Innovations

1. Vertical

Consider first the vertical innovations that produce quality improvements. We first consider pricing decisions of firms. Also, we will show that, in each industry, the leader always stands exactly one step ahead of its nearest rival. Then all state-of-the-art products bear the same "limit" price $p = \lambda w$. A state-of-the-art good producer uses this limit price to ensure that consumers are indifferent between his good and the second-highest quality good. With this pricing strategy, the profit of firms is

$$\pi_{it} = (p-c)x_i = \frac{\left[(\lambda-1)w\right]\left[q_{it}\right]^{\sigma} Y_t}{q_{it}\cdot\left[\int_0^{Nt}(q_{it})^{\sigma-1}di\right]^{-\sigma/(1-\sigma)}} = \frac{\left[(\lambda-1)w\right]Y_t}{q_{it}}\left[\frac{q_{it}}{Q_t}\right]^{\sigma} \tag{5}$$

Where $\left[\int_0^{Nt} (q_{it})^{\sigma-1} di\right]^{1/(\sigma-1)} \equiv Q$ can be considered as aggregate quality index, and the profit can be consider as the function of quality ratio q_{it} / Q_t. Quality improvement follows a stochastic process. Suppose R&D firm use l_{vit} works will succeed in generating an innovation with instantaneous probability[③] of

$$\phi_{it} = Al_{vit} / q_{it-1} \tag{6}$$

where A is a parameter indicating the productivity of vertical R&D, $q_{it}^{\max}$ means the highest technology in the industry at that time. We deflate R&D expenditures by to take into account the force of increasing complexity; as technology advances, the resource cost of further advances increases proportionally[④]. We let V_t denote the present value of the uncertain profit stream that accrues to an industry leader. Accordingly the value of a vertical innovation at date t is the expected present value of the future profits to be earned by the incumbent before being replaced by the next innovator in that product. We can express this as

$$V_t = \int_t^{\infty} \pi_{it\tau} e^{-\int_t^{\tau}(r_s+\phi_s)ds} d\tau \tag{7}$$

where r_s is the instantaneous rate of interest at date s, and $\pi_{t\tau}$ is the profit flow at date τ to any sector whose technology is of vintage t. The instantaneous discount rate is the rate of interest plus the rate of creative destruction ϕ_t, which is the instantaneous flow probability of being displaced by an innovation. If the success probability of innovation keep constant, then the formula (7) can be written as $V_t = \pi_{it} / (r + \phi_{it})$ as Aghion and Howitt (1991) calculated.

Then at each point in time t, each R&D firm i chooses its labor input l_{it} to maximize its expected profits

$$\phi_{it} \cdot V_{it} = w_{it} \cdot l_{vit} \tag{8}$$

Following the approach of Grossman and Helpman (1991), we solve the solution from the stock market. The stock market values the firm so that its expected rate of return just equals the safe interest rate r. Using formula (8) we can get $V_{it} = w_{it} \cdot l_{vit} / \phi_{it} = w_{it} q_{it}^{\max} / A$, and the "no-arbitrage " condition is

$$l_{vit} = (\lambda - 1) q_{it}^{\sigma-1} Y_t Q_t^{-\sigma} - r q_{it}^{\max} / A \tag{9}$$

Assume for simplicity that everyone has linear additive preferences over consumption at each date, with the constant rate of time preference r. Then the rate of interest is r at each date. From the

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③ Although based on the hypothesis of decreasing return of RD, we should suppose the l with decreasing returns. However, in order to comply with the tradition, and to simple the model, we give up the effort. We consider that, the decreasing returns only happen in the long run with the improvement by hundreds of firms, specific firm in a certain short time cannot make the research and development decreasing. This suppose is reasonable, for R&D are mainly use human's efforts, do not like the material producing process depending on the material tools.

④ Li(2003) tell an another story:" Consider the production of silicon chips, which are created by printing circuit patterns on wafers of silicon. As more and more transistors are condensed in a single chip (now in excess of forty million), the creation of the next generation chip becomes more and more difficult, and the conventional method is said to hit a "wall," at which circuit patterns begin to blur."

formula (8) we can find that as the industries become old, that are $\lambda_{it}^{\max}$ become larger, they will reduce the employment. When $\lambda_{it}^{\max}$ is large enough, there will be no R&D activities in these industries. The whole employments of vertical R&D are

$$L_{vt} = (\lambda - 1) Y_t Q_t^{-1} - \frac{r}{A} \int_0^{Nt} q_{it}^{\max} di \tag{10}$$

We can suppose the distribution of incumbent industries as even, then we can get a specific value of vertical research employment.

2. Horizontal Research and Development

Horizontal innovations result from R & D aimed at creating new products. However, how does the entrepreneur make the price for the totally new product? Li (2003) listed another case name *drastic innovation*, and considering increase the value of α slightly from zero with the price elasticity being 1/(1−α). The firm would charge $p = w / \alpha$ if no lower-quality goods were available. To simplifies, we suppose quality of any new industry is 1. Then the firm which succeed in R&D will earn the profit as following

$$\pi_{it} = \left[(1/\alpha - 1) w \right] Y_t q_{it}^{\sigma-1} / Q_t^{\sigma} \tag{12}$$

Why people want to create new products? For all the "old industries" lose their attractiveness, and it is very difficult to find new outlet to improvement in those old industries. Suppose entrepreneurs devote l_{hit} labor in order to bring out new products, then the Poisson arrival rate of new products is

$$\varphi_{it} = A \cdot l_{hit} \tag{13}$$

Free entry by entrepreneurs ensures that, whenever innovation takes place, the present value of the infinite stream of future profits exactly matches the cost of product development. Each horizontal innovation results in a new intermediate product whose productivity parameter is drawn randomly from the distribution of existing intermediate products.

Then at each point in time *t*, each R&D firm *i* chooses its labor input l_{it} to maximize its expected profits $\varphi_{it} \cdot V_{hit} - w_{it} \cdot l_{hit}$, just like the equation (7), then we can get the employment of horizontal R&D in one new industry is

$$l_{hit} = \left(\frac{1-\alpha}{\alpha} \right) Y_t Q_t^{-\sigma} \lambda^{\sigma-1} - r / A \tag{14}$$

And the whole employments of new industry are

$$L_{ht} = \left[\left(\frac{1-\alpha}{\alpha} \right) Y_t Q_t^{-\sigma} \lambda^{\sigma-1} - r / A \right] \left[N_t - N_{t-1} \right] \tag{15}$$

C. Steady State Analysis

1. The allocation of research and development

Howitt (1999) build equilibriums in which the amount of labor per product, the productivity adjusted amount of vertical R & D per product, and the fraction of GDP allocated to horizontal R & D are all constant, at the respective values. However, in our paper, the employment of researcher of whether new or old industries can be adjusted, while the aggregate growth rate still keeps balanced.

From the above analysis, we can know the manufacturing employment in vertical and horizontal industry is

$$L_M = L_{ht} + L_{vt} = Y_t / Q_t \tag{16}$$

The equation (16) can also be got from (2) directly. Y_t/Q_t can be seen as the aggregate quality adjusted output, just like X_t in most papers. Hence, we can get the following equations

$$L_{ht} = L_t - L_{vt} - Y_t / Q_t = L_t - (\lambda - 1) Y_t / Q_t + \frac{r}{A}\int_0^{Nt} q_{it}^{\max} di \tag{17}$$

From the equation (17) we can find the negative relationship between horizontal and vertical RD, just like the downward line in Figure 4. However, once the new industry was created, in the next stage, the new industry would become old industries and processing vertical innovation. As a result, if the vertical researchers are less, the new industry will be more; and if the new industry be more, then newer industry will be less in the next step, so the researchers in both R&D sectors are fixed if populations do not change.

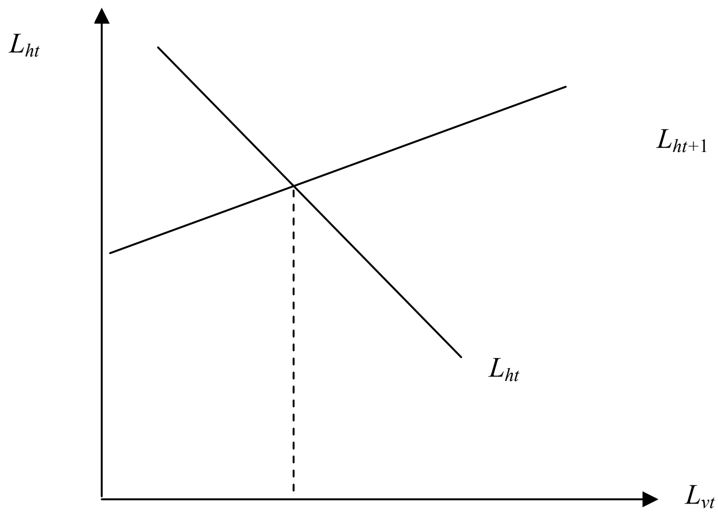

Figure 4. The steady status of allocation

2. The calculation of growth rate

After known the unique the value of the employment of vertical and horizontal RD, we can calculate the growth rate, which can be characterized by a mass Nt of industries. The growth can be written as following

$$Y_t = \left[\int_0^{N_{t-1}} (\textstyle\sum_j q_{it} x_{it})^{\alpha} di\right]^{1/\alpha} + \left[\int_{N_{t-1}}^{N_t} (\textstyle\sum_j \lambda x_{it})^{\alpha} di\right]^{1/\alpha} \tag{18}$$

At first, we can calculate the growth of vertical R&D sectors, which is the first part of equation (18). In the old industry, the quality will become λq_{it} with the probability ϕ_{it}. The growth rate of every industry according equation (1) is

$$\left(\lambda q_{it}\right)x_{it}\cdot\phi_{it}=\left[A\left(\lambda-1\right)q_{it}^{2\sigma-2}Y_t^2Q_t^{-2\sigma}-q^{\sigma}Q^{-\sigma}rY_t\right]$$

All the increment of old industries in the time t+1 would be

$$\int_0^{Nt}\left(\lambda q_{it}\right)x_{it}\cdot\phi_{it}di=A\left(\lambda-1\right)Y_t^2Q_t^{-2}-rY_t$$

Then we calculate the out of new industries

$$\left[\int_{N_{t-1}}^{N_t}(\sum_j\lambda x_{it})^{\alpha}di\right]^{1/\alpha}=\left[N_t-N_{t-1}\right]^{1/\alpha}\lambda x_{it}$$

The new industry would be created by other R&D activities, thus the number of new created industries would be

$$\left[N_t-N_{t-1}\right]=\frac{L_{ht}}{l_{hit}}=\frac{L_t-Y_t/Q_t+rQ_t/A}{\left[\left(\frac{1-\alpha}{\alpha}\right)Y_tQ_t^{-\sigma}\lambda^{\sigma-1}-r/A\right]}$$

Every new industry would produce the following output which is ratio to old industry, according to the equation (2), we can find

$$\lambda x_{it}=Y_t\left[\lambda/Q\right]^{\sigma}$$

Thus the total growth of old and new industries would be

$$A\left(\lambda-1\right)Y_t^2Q_t^{-2}-rY_t+\frac{L_t-Y_t/Q_t+rQ_t/A}{\left[\left(\frac{1-\alpha}{\alpha}\right)Y_tQ_t^{-\sigma}\lambda^{\sigma-1}-r/A\right]}Y_t\left[\lambda/Q\right]^{\sigma}$$

Thus the growth rate is constant at every time, even some industries fall and other industries rise. This result is consistent with Ngai and Pissarides (2007), who show that even with ongoing structural change, the economy's aggregate ratios can be constant; the advantage of this paper is to give the inner micro mechanism of structural change.

V. Applications and Reviews

1. No structural change, no economic growth?

The past economic history told us, we can not find the long term economic growth if the economy can not breed new industries out. From the appearing of agricultural society, to industrial economy, and then information economy we can find the hint. This paper not only explain how the economic growth, but also the structural change of economy. Without structural change, there is must not economic growth.

2. Why does depression last too long?

When economic crisis or stagnancy come, the majority of the people, government or even the economists are easily scared. Unemployment rising, firms bankrupt, and so on, would always make government expand its power; even become communist or Nazism regime at extreme condition. At this circumstance, free market economy theory would be given up at some extent.

The paper gives a new and optimistic viewpoint about economic depression. When old industries become stagnant, the talent such as Bill Gates would be find that it is boring working in these industries, and try to build new industry. While if those talent born at Iron Age, they would be absorbed by those booming fields. As a result, depression always breeds the next booming. The server the depression is, the more talent accumulates. As a result, depression should not continue too long in the world if governments do not deteriorate it.

3. Why are there great times in economy history?

When a new industries which are vital or provide immediate product to other immediate goods, such as iron or electricity, rises, the economy would appear booming. Bresnahan and Trajtenberg (1994) point out, technical progress in the real world appears to be driven by 'General Purpose Technologies (GPT), exemplified by the steam engine, the electric motor and semiconductors. We show that business cycles cannot be considered as temporary deviations from a trend and that there is a strong positive correlation between the persistence of short-term fluctuations and long-term growth rates. A simple endogenous growth model where business cycles affect growth can easily replicate this correlation. We then study the link between volatility and growth.

4. Freedom and Economic Growth

If R&D is the determinant factor of economic growth, planning economy or dictatorship would be the best institutions to promote economic growth by increasing R&D input. These situations really happened in the history. The rise of Japan, Korea and Singapore in its tyranny time, moreover, Hitler's Germany, Soviet Union and China can also have higher economy development in its planning economy. Today people always consider South Korea and North Korea as the best example of the advantage of free market, however, North Korea developed faster than the South.

The main or maybe the unique function of free market in the viewpoint of economists is allocating the resource effectively. However, it is the stationary function in one time span. Does freedom can boost economic growth dynamically? Intuition tells us yes, and empirical studies can also bring evidence to support the answer.

This paper give a viewpoint that the advantage of free market is finding the new industries, while planning economies are "good at imitation, bad at innovation", for it have not any researcher in unknown fields. Even in the computer socialism, planners can calculate all the information, but can not plan the fields that he does not know. Based on the decreasing return, this paper give us the insight that why Socialist countries lose their dominant position in the long run.

5**. Why do scientists disappear?**

In the famous Jones' Critique, there are more scientists and financial support after the Second World War, while the growth rate keeps constant. Economists hurry to cancel the Scale Effects, while this paper provide another answer, that is, old industries become stagnant, while its scientists still live in the field. The industry such as chemistry, iron, textile are shrink, while there are more and more students are recruited, Ph.D diploma were released, financial support was donated, with its own principle. There are only very little parts of scientists are allocated to new and potential industries.

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