Scale Invariant Endogenous Growth Model with Long-Run Cycles *

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Abstract

This article constructs scale-invariant endogenous growth model with long-run cycles: New technologies are innovated continuously, while scientific knowledge is invented discontinuously. Scientific revolution increases the productivity of technologists temporarily, which keeps decreeing again. These cycles repeats infinitely. The negative effect of scientific anti-common on scientific productivity is also considered, in other words, as more technological innovations are progressed, the requirement to acquire a patent was more relaxed, and scientists in universities also take out patents for their results. As a result, getting out patent disturbs scientific researchers who willing to develop it further in other university, using former scientific achievements. Consequently, positive effects of increase in researchers for technology and science on per-capita growth are offset.

JEL classifications: O10, O30

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1 Introduction

Many economists [1] since old days have been considerably written many articles about a long-term cycles and per-capita growth rate. For example, Kondratiev confirmed the existence of long-run cycles using the industrial date of prices, interest rates, and wage series, foreign trade, industrial production and consumption in the France, Britain, and the United states. Kondratiev concluded the business cycles in the economy are the causality of the cycles in the innovation.

On the other hand, Schumpeter considered the firms' innovation and destructive creation as the sources of the economic growth: A firm, which innovated more efficient technology earns positive profits, and existing firms must leave the market if they cannot innovate it. In other words, competition to earn a profit is the cause of the long-run cycles of economy. A lot of firm imitates technology exploited by incumbents, and the rates of innovations rise in its industry or sectors for a period of time, and this boom stops in later some time because existing knowledge, habits and beliefs resists new technology. These cumulative processes continue infinitely.

More recently, Perez (1985) considered the general-purpose technology, which leads to vast decrease in the cost, as a cause of long run cycles: If general purpose technology is innovated, many industries which producing new technologies grow faster because a lot of firm intensively use its technology and cost reductions enable industries using new technology to grow faster. But old groups slow its diffusion and growth rate down in the result as Schumpeter explained. Clark, et al. (1981) also emphasized the importance of diffusion process of new technology for economic growth, not a new technology occurs.

[1] Please refer to Rosenberg (1994) and Fagerberg (2003)

Is there cycles or long run cycles in the economy? Recently, the empirical literatures on R&D and economic growth suggest that for US country there are cycles in economy and there is a procyclical property, which denotes that when growth rate is high, R&D expenditure is also large between 1961 and 1999 (Fatas, 2000a). For G-7 countries there are procyclical properties between 1973 and 2000 (Walde 2004).

The reason why technology as well as science is introduced into this article is that they have different natures and, plays an important role in generating a long run cycles: This article[2] distinguishes the roles of technology and science in that the former is innovated so as to take out patents for technology, in other words, to earn a profits, and the later are not invented for not economical reason, rather for winning the colleague reputation, writing the influential papers or presenting their papers in the conferences or seminars. The second big different nature between them is that former are innovated continuously, while the latter are invented stochastically, which plays a significant role in this paper. New scientific knowledge increases the productivity of technologists temporarily, which causes a higher per-capita growth rate and decline along transition dynamics after scientific revolution.

These cumulative phenomenons repeat infinitely. In other worlds, long-run cycles happen in this article.

The difference between Li (2001) and this paper is that the former has a property of scale effect in the mean that although the size of workers are constant, the average periods for scientific invention contract when its size is expand. As a result, it leads to an increase in average of time trend of per-capita output and its growth rate in the steady state increases. A lot of models of endogenous growth model developed by mid 1990s have this

[2]The definition of their follows Stoneman (1995).

property called scale effect, for example, Romer (1990) and Grossman and Helpman (1991) and so on, however, this property is criticized by empirical literatures. For example, Jones (1995a, b) showed empirical evidence, which is not consistent with above property: although the number of the researchers increased by 500%, dates of innovation in the OECD countries remains constant between 1950 and 1990.

To remove the scale effect property, we introduced the anti-common effect of scientific world caused by development of technology or patents:

For example, Nelson (2004) considered that the relaxed requirement for patentability leads to a scientific uncommon as the technology progress: Researchers in the university take out a patent and defend the diffusion of research results to other researchers or license their results so as to make other researcher pays much money. These things are not good for further scientific research because patent-holders can delay the diffusion of scientific results.

Murray and Stern (2005) estimated the difference of citation rates between before taking out and after taking out a patent using the date of Journal Nature Biotechnology between 1997 and 1999, and concluded that citation rates are fall between 9 % and 17 %. This evidence supports the Anti-common assumption and is consistent with our assumption about substitution relation between science and technology.

Azoulay, Ding and Stuart (2006) found that the effect of patents on the rate of publishing the scientific academic papers are positive, and the quality of academic paper is constant. Although these things are not consistent with Nelson (2004) and assumptions in this article, scientists have altered the content of paper nearer to the world of commerce, and high productive researchers in the university tends to exit the university and entry into commerce.

Geunan and Nesta (2006) also listed other possible negative impacts of larger patents in the university on publishing papers: (i)If researchers innovated a lot of patents since they are young, their productivity for publishing papers could be low. (ii) Researchers in the university devote a larger time to applied researches, not fundamental researches.

From these articles, we can conclude that technologies and sciences can be substitute: developments of technologies i.e., patents can lead to delay in the developments of science. The article is organized as follows. Section 2 develops the setup of model. section 3 develops the transition dynamics under constant scientific knowledge. Section 4 develops the transition dynamics under variable knowledge.

2 Consumers

There are risk averse consumers who grows at a constant rate of g_L. A fraction $1 > s > 0$ workers are skilled workers H_t and a fraction $1 > (1-s) > 0$ workers are un-skilled workers L_t. Skilled workers invent the scientific knowledge or innovates new technologies and un-skilled workers produce only intermediate goods.

The intertemporal utility function of consumers are time-separable and their instaneous utility function is natural logarithm of the final output. Consumer's dynamic optimization problem yields famous euler equation[3] and it is given by

$$r_t = \rho. \tag{1}$$

[3]per-capita expenditure are normalized to 1

2.1 Final good sector

The final output Y_t are produced using differentiated intermediate goods by competitive firm according to the following technology,

$$Y_t = \left[\int_0^{n_t} x_{it}^{\alpha} \mathrm{d}i\right]^{\frac{1}{\alpha}},\ 0 < \alpha < 1, \tag{2}$$

where x_{it} denotes amount of input or intermediate good and n_t represents the number of a varieties available in the market at time t and Parameter $1/(\alpha - 1)$ shows price elasticity of demand between intermediate goods.

Notice that productivity of intermediate goods increase with the number of the variety n_t.

The price of final output is given by

$$P_Y = \left[\int_0^{n_t} p_{it}^{\frac{\alpha}{\alpha-1}} \mathrm{d}i\right]^{\frac{\alpha-1}{\alpha}}, \tag{3}$$

where p_{it} is the price of that input. The factor demand function for intermediate good i is derived from Shepard's lemma, and is given by

$$x_{it} = \frac{p_{it}^{\frac{1}{\alpha-1}} Y_t}{\left[\int_0^{n_t} p_{it}^{\frac{\alpha}{\alpha-1}} \mathrm{d}i\right]^{\frac{1}{\alpha}}}. \tag{4}$$

2.2 Intermediate good firms

Each monopoly firm monopolizes each intermediate good and producing one unit of intermediate goods requires one unit of un-skilled workers. Each firms sets the same price at $p(i) = \alpha/w_t^{\ell}$ [4] due to the nature of Dixit-Stigltiz production function, which leads to symmetry demand of each variety. The cost of researching on science which accelerates the speed of the innovating

[4]Price elasticity of demand $\dfrac{1}{\alpha - 1}$ is used.

on new varieties are financed by a tax rate of $0 < \tau < 1$ on intermediate profits. Summarizing these things up, each firm profit are given by

$$\pi_t = \frac{(1-\tau)(1-\alpha)(L_t + H_t)}{n_t}. \tag{5}$$

To finance the cost of R&D activity for inventing new blueprint, firms issue the ownership shares and bonds. In the equilibrium, the risk-free rate of return on bond and the rate of return of shares are equal and its condition (asset equation i.e., no-arbitrage condition) is given by

$$\frac{\dot{V}_t}{V_t} + \frac{\pi_t}{V_t} = \rho, \qquad \text{'no-arbitrage condition'} \tag{6}$$

where V_t is the value of one variety, in other way, the net present value of profits accruing to firm. The left hand side represents the expected return to share. The first term is capital gain or loss and the other term is a dividend rate. The right-hand side denotes the return rate of risk-free bond.

2.3 Technological Research

The production function for blueprints of technological innovation is given by

$$\dot{n}_t = \delta R_t K_t, \quad K_t = n_t^{\varepsilon} q_t, \quad 0 < \varepsilon < 1, \tag{7}$$

where n_t denotes a number of varieties (intermediate goods) and $\dot{n}_t$ shows the flow of technological innovations which proportional to R_t represents a number of technological researchers, and which K_t denotes a stock of general knowledge are benefited from the stock of scientific knowledge q_t and technological knowledge n_t invented before time t.

The reason why we assumed the parameter specification $\varepsilon < 1$ is that although the number of technologists is fivefold after 1950s, per-capita growth rate remains constant or even decrease in the OECD countries. The assumption of $\varepsilon = 1$ is not consistent with above evidence and following parameter restrictions are proposed: For $0 < \varepsilon < 1$, the productivity of inventing new patents increasing over time and for $\varepsilon < 0$, the productivity of inventing new patents decreasing over time (Charles Jones, 1995a,b). The research on science measured by q_t positively affects the productivity of technologists K_t.

MacGarvie and Furman (2005) showed that the research output between 1927 and 1946 in U.S. pharmaceutical industry are positively and significantly related to the research in a university.

Macmillan and Narin and Deeds (2000) also supports above assumption because 70% of biotechnological innovations quoted scientific papers by public institution.

So as to acquire the infinitely-lived patent, Firms entering the R&D sector solve following problem. $\max_{R_t} V_t \delta R_t K_t - w_t^h R_t$ which leads to

$$V_{it} = \frac{w_t^h}{\delta K_t}, \quad R_t > 0, \tag{8}$$

where w_t^h is the wage rate of skilled workers. This means that skilled workers do not have an incentive to move between two sectors, research on science or technology in the sense that wage rates of skilled workers are equal and free entry of firms means up front fixed cost and present discounted value of profits are equal in the equilibrium if positive firms entering the market. Note also that this condition means that all intermediate goods are symmetry in the sense that profits are same for all varieties.

2.4 Scientific knowledge

The level of scientific knowledge is given by

$$q_t = \lambda^{m_t}, m_t = 0, 1, 2 \cdots , \tag{9}$$

where q_t represents the level of scientific knowledge measured by successes of scientific research and the parameter $\lambda > 1$ is the size of invention and m_t is a cumulative numbers of invention before time t. To stress the difference between science and technology that the former are invented discontinuously and the later are innovated continuously,

hence the poisson arrival rate of science is given by

$$h(q_t, n_t) \cdot S_t = \frac{q_t S_t}{n_t^{1-\varepsilon}}, \tag{10}$$

where S_t is the number of the scientists and $h(q_t, n_t)$ is per-capita poisson arrival rate.

This function form is consistent with the literatures on the scientific common in which Nelson (2004) questions whether the enlarge in the patentability stimulates the research on the science because patent holder acts aggressively if university researchers are using their results and university defends the research results, patenting or licensing their results as they choose and achievements of scientific research cannot be intermediate Inputs of future scientific researches. since Bayh-Dole Act allowing scientists to patent their results have come into force and considered the research on technology as decreasing the productivity for inventing science.

This form solves the problem of scale effect indicated by Jones (1995a, 1995b) unlike Li (2001) who suggested complementarity between science and technology and the productivity of scientists' increases as technology progress.

2.5 Labor market

Skilled workers supply H_t units of labor and they are researching on science or technology and un-skilled workers supplies L_t units of labor for producing the intermediate goods. The labor market for skilled workers clears if

$$H_t = \frac{\dot{n}_t}{\delta K_t} + \frac{\tau(1-\alpha)(L_t + H_t)}{w_t^h}, \tag{11}$$

and the labor market for un-skilled workers clears if

$$L_t = \frac{\alpha(L_t + H_t)}{w_t^\ell}. \tag{12}$$

3 Transition dynamics without scientific revolution.

To analyze the transition dynamics without scientific revolution (m_t is constant.) in the market equilibrium, it proves useful to describe the dynamic evolution of the economy in two variables, $\chi_t = q_t H_t/(n_t^{1-\varepsilon})$ and $\omega_t = 1/w_t^h$, where χ_t denotes growth rate of varieties when all skilled workers are devoted to innovating on technology or the poisson arrival rate when all skilled workers are working on inventing scientific knowledge and ω_t denotes the inverse of the wage rate of skilled worker. From the definition of χ_t and (11), the dynamics of χ_t are given by

$$\frac{\dot{\chi}_t}{\chi_t} = g_L - \delta(1-\varepsilon)\chi_t\left[1 - \frac{\tau(1-\alpha)\omega_t}{s}\right]. \tag{13}$$

Using (6), (8)–(11), the dynamics of ω_t are derived and given by

$$\frac{\dot{\omega}_t}{\omega_t} = \frac{\delta(1-\tau)(1-\alpha)\omega_t\chi_t}{s} - \delta\varepsilon\left[1 - \frac{\tau(1-\alpha)\omega_t}{s}\right]\chi_t - \frac{\tau(1-\alpha)(\ln\lambda)\chi_t\omega_t}{s} - \rho, \tag{14}$$

where $\Gamma = \delta(1-\tau)(1-\alpha)/s + \delta\varepsilon\tau(1-\alpha)/s - \tau(1-\alpha)(\ln\lambda)/s > 0$[5] These equations can be explained using the phase diagram in the figure 1.

The locus JJ shows the combination of χ and ω in which the growth rate of varieties is constant. It is not hard to see that the locus JJ is upward sloping and extends asymptotically to the $+\infty$ at $\omega = s/\tau(1-\alpha)$, the share of technologists converges to zero. The increase in ω leads to a decrease in a share of the technologists' which in turn leads to lowering growth rate of varieties but productivity of technologists χ increases so that the growth rate of varieties remain constant as a result.

Locus $D-D$ shows the combination of χ and ω, which fulfills the asset equation. The downward sloping of this curve can be easily understood. The increase in the ω increases the return on shares, for example, capital gain or loss plus dividend rate. To fulfill the asset equation, put differently, the rate of return on riskless bond equal to the return on shares, the value of χ must fall. $D-D$ is not difficult to see that its curve extends asymptotically to $+\infty$ at $\omega = \delta\varepsilon/\Gamma$.

Let us assume that economy inherits A_m on the transition dynamics. Let us also consider several dynamics except for starting from this initial endowment in the Fig. 1 along which the inverse of wage rates of skilled workers and growth rate of varieties when all skilled workers are devoted to technologists obey the required laws of motion.

The economy starting from the point above A_{m+1} can not be equilibrium path because all skilled workers are working for inventing new scientific knowledge. It violates free entry condition, which requires positive skilled workers are inventing new technologies

The economy starting from a point between A_{m+1} and the locus JJ

[5] (14) can be written as $\dfrac{\dot{\omega}_t}{\omega_t} = \chi_t\left[\Gamma\omega_t - \delta\varepsilon\right] - \rho$

also cannot be equilibrium path because all skilled workers are working for inventing new technologies. It violates that intermediate firms earn positive profits, and a fraction $1 > \tau > 0$ of profits are used for costs of research on the science.

Thus, only starting from point A_{m+1} can be equilibrium path. Same argument can be applied to explain the stability of transition dynamics in the southeast area of steady state.

Summarizing these things up, the transition dynamic is unique for any initial condition. Along any point on transition dynamics to a North-West area of steady state, the growth rates of technology are decreasing, and it leads to decrease in demand of technologists. Furthermore it reduces the wage rates of skilled workers and the fractions of technologists' decreases. As a result, per-capita growth rates keep falling as economy arrives at steady state.

the fixed costs of new varieties, that is to say, wage rate of skilled workers is higher than steady state and the demands for them is lower than steady state for the above reason and it leads to wage rates of them decreases and thus, the ratio of technologists to skilled workers also decreases and growth rate of varieties and final output decrease in the result. On the other hand, in any points on transition dynamics to a North-West area of steady state, opposite things happen: the fixed costs of new varieties, that is to say, wage rate of skilled workers is lower than steady state and the demands for them is higher than steady state for the above reason and it leads to increase in the wage rates of them and thus, the ratio of technologists also increase and growth rate of varieties and final output increase in the result.

4 Scientific revolution

Next turn to the effect of scientific revolution on per-capita growth rate. The scientific revolution shifts the locus of JJ and DD themselves do not change but the locus of the economy on the transition dynamics does change. Let us assume economy is at A_m in the figure 1, a scientific revolution increases the productivity of technologists by $\lambda^{m+1} - \lambda^m$, and it further leads an increase in the skilled-workers' wage rates, for example, ω_m jumps to ω_{m+1} in the moment scientific revolution happen. Moreover increases the χ_m by $\chi_{m+1} - \chi_m$. As a result, the effect of scientific revolution on the per-capita growth rate of varieties g_n are given by

$$g_{n,m+1} - g_{n,m} = \delta\lambda^m \left[\lambda \left(1 - \frac{\tau(1-\alpha)\omega_{m+1}}{s} \right) - \left(1 - \frac{\tau(1-\alpha)\omega_m}{s} \right) \right], \quad (15)$$

where $g_{n,m+1}$ denotes the growth rate of varieties at $m+1$ th scientific knowledge. Let us note that the first term is larger than second term because ω_{m+1} at $m+1$ th scientific knowledge is larger than ω_m. The productivity of skilled workers increased by scientific revolution leads to the increase in ratio of technologists to skilled workers. As a result, per-capita growth rate also increased by both direct and indirect effect.

The empirical literatures on long-run cycles also supports above results: Silverberg and Verspagen (2003) estimated the function form fitted to time series date between 1760 and 1980, and found that the negative binomial model is fitter than constant arrival rate in that the former displays the high and low innovation periods. Moreover, Groot and Franses , using time series dates [6](2005) confirmed various cycles in innovations and it is associated with economic cycles. The periods of cycle are 5, 13, 24, 34, 61 years and there are clustering of innovations and it happens at the end of the down-

[6]5. Interpretation of results is summarized

swing than at the beginning of upswing. Branstetter and Ogura (2005) also showed that patents increasingly cite scientific academic paper from 1980s. More recently, Fatas (2000a) confirmed positive and significant relation between persistent endogenous short-term fluctuations and long run per-capita growth rates, using time series dates in the G-7 countries, between 1955 and 1993. Furthermore, Fatas (2000b) confirmed the same relation using cross section of 120 countries.

So far, the effect of one scientific revolution on per-capita growth rate has been investigated. Let us turn to the effect of number of scientific revolutions on per-capita growth rate, that is to say, investigates the long run cycles arose by scientific revolutions.

Let us note that even if economy starts from the South-East area to steady state and then jump to the North-West area by repeated scientific revolutions, eventually per capita-growth rate will fall to steady state along transition dynamics.

Let us define the potential[7] output as output in the steady state under current scientific knowledge, and it is represented by y_t^* which is associated with the number of varieties in the steady state n_t^*:

$$\ln y_t^* = \left(\frac{1-\alpha}{\alpha}\right) \ln n_t^*, \tag{16}$$

$$\ln n_t^* = \left(\frac{1}{1-\varepsilon}\right) \left(m_t \ln \lambda - \ln \chi_t^* + \ln H_t\right). \tag{17}$$

Notice that the scientific revolution leads to an increase in a level of the varieties and potential output so that potential output depends on the degree of the scientific researches.

[7] In the Fig. 3 illustrates the potential output and output along transition dynamics. The stepwise function is potential output and kinked curve is a transition dynamics, respectively.

Next turn to the time trend number of varieties and the level of per-capita output is given by

$$E[\ln y_t^*] = \left(\frac{1-\alpha}{\alpha}\right) E[\ln n_t^*], \tag{18}$$

$$E[\ln n_t^*] = -\frac{E[\ln \chi_t^*]}{1-\varepsilon} + \frac{(\ln \lambda)\zeta \cdot t}{1-\varepsilon} + \frac{H_t}{1-\varepsilon}, \tag{19}$$

where $\zeta = (1/t)\int_0^t (\tau(1-\alpha)\chi_\theta^{1-\varepsilon}\omega_\theta/s)\mathrm{d}\theta$ which denotes average poisson arrival rate of scientific research from time 0 to θ.

$$g_y^* = \left(\frac{\alpha}{1-\alpha}\right) g_n^* \tag{20}$$

$$g_n^* = \frac{\tau(1-\alpha)\chi^*\omega^*}{s} + \frac{g_L}{1-\varepsilon} \tag{21}$$

From (20) and (21), the growth rate of trend of potential output can be concluded as constant.

One of differences between Li (2001) and this article is that the former paper is a scale variant endogenous growth model featuring that the level of skilled workers are constant over time and there are complement[8] between scientific invention and technological innovations so that the level of scientific knowledge are increased, which leads to increase in production of new varieties, and also opens the opportunity for inventing new science when technologists facing problems during innovation process ask scientists. such problems motivate scientists to solve more fundamental law. Moreover, knowledge explored by scientists helps technologists to innovate new innovations. This complementarity repeats infinitely. Thus, per-capita growth rate of potential output increase infinitely. But, this is not consistent with empirical research by Jones (1995a,1995b). This article modified the complementarity between science and technology by including the effect of sci-

[8]Rosenberg (1974), Rosenberg (1982)

entific Anti-common into the poisson arrival rate of scientific research: the requirement for patentability is generous as technological research progress and something can be patented also expanding over time. As explained, university refrain other researchers using their achievements and it offset the effect of an increase in the skilled workers on the growth rate of varieties. Therefore, this model removed the scale effect.

5 Subsidy to technological research

Let us consider a policy effect that government pays a fraction $1 > \Xi > 0$ fixed costs of technologies[9] on per-capita growth rate. Free entry condition changes to $V_i = (1 - \Xi)/\delta K_t$ and dividend rates also changes to $\delta(1-\tau)(1-\alpha)\chi_t\omega_t/\left[(1-\Xi)s\right]$ and its increase in the return rate for shares motivates consumers to supply more their saving in the financial market. To firms entering R&D sector, they innovates blue prints at the lower costs of skilled workers which leads to enter the market so that demands more skilled workers at the same time. Furthermore, wage rate of skilled workers rise , which shifts the locus DD down. Consequently, the rate of technologists to skilled workers increases and per-capita growth rates increase but the growth rate for potential outputs decreases because the ratio of scientists to skilled workers decreases in the result.

Government finds himself on the horns of a dilemma: Fraction technologists of skilled workers increases and real per-capita growth rate increase as well as a growth rate of potential output decreases when government subsidies the costs for technology, but on the other hand a fraction scientists of

[9]Fig.2 explains the effects of lump sum subsidy for technology. The effects of subsidy to research on science are ambiguous.

skilled workers increases and real per-capita growth rate decrease as well as a growth rate of potential output increases when government taxes the costs for technology. Whether former policy or latter policy are enforced depends on the taste of government: If government would consider time trend of per-capita growth rate in the longer period as important, government chooses the latter policy, but on the other hand if government would consider per-capita growth rate only in the shorter period or in the present as important, government chooses the former policy.

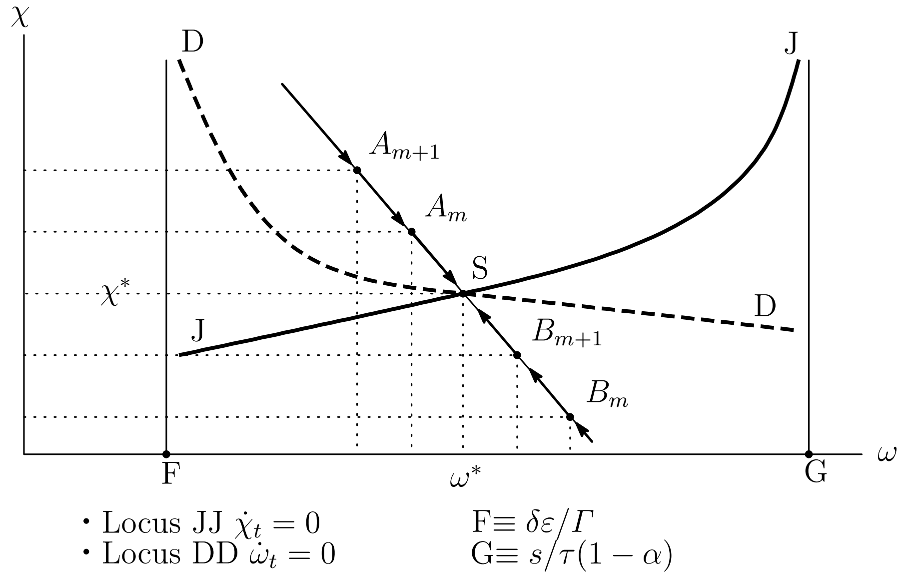

*Fig.*1

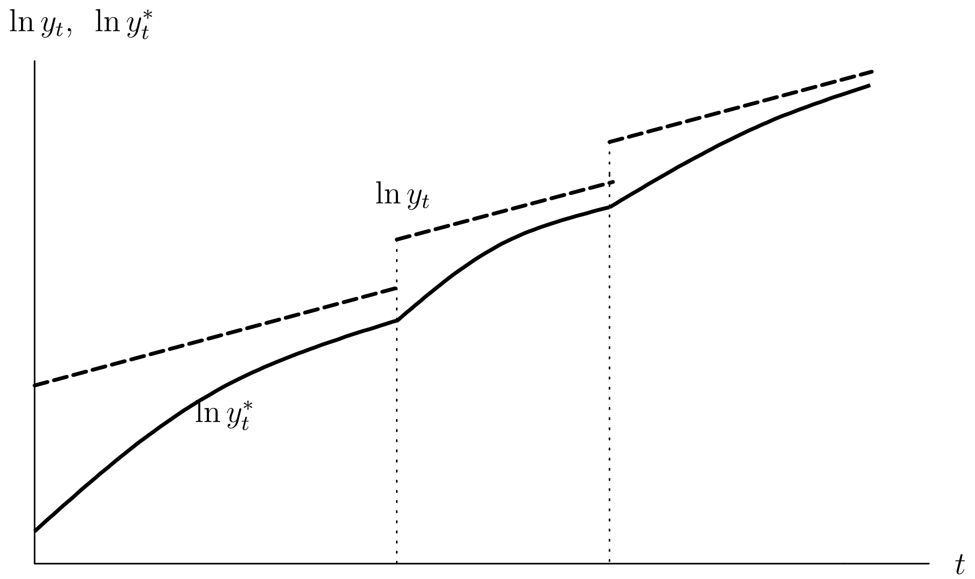

*Fig.*2

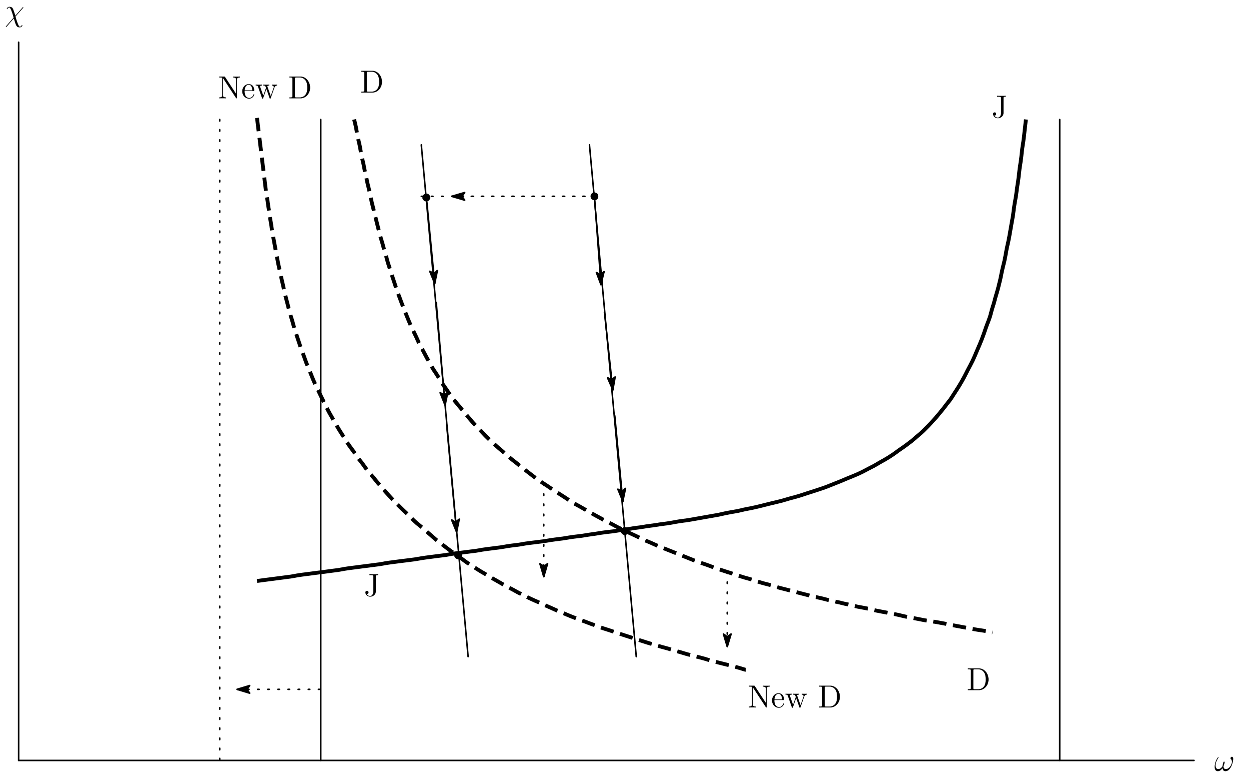

*Fig*3

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