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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

ENDOGENOUS GROWTH AND DEVELOPING COUNTRIES
: TIME SERIES ANALYSIS OF THE ROLE OF TRADE
WITH SPECIAL REFERENCE TO KOREA

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

Doctor of Philosophy

By

DONGCHUL JUNG

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ENDOGENOUS GROWTH AND DEVELOPING COUNTRIES
: TIME SERIES ANALYSIS OF THE ROLE OF TRADE
WITH SPECIAL REFERENCE TO KOREA

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF ECONOMICS

BY

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Abstract

This dissertation tests the endogenous growth theories for the developing country(S.Korea) using time series analysis: especially, the role of trade for economic development. To overcome several potential problem of the previous studies, this paper adopts two cointegration tests such as Engle-Granger(1987) test and Johansen(1988) test, applying them to a special form of production function $Y=A(X,M)\bullet f(K,L)$, which treats export(X) and import(M) as a kind of production factor. Trade is hypothesized to exert externalities through international knowledge spillover etc..

Major findings of the tests are as following: (1)Dickey-Fuller test and Phillips-Perron test reveal that all the variables are nonstationary I(1) variables. (2)The conclusion from the two cointegration tests is first of all the conclusion that there exists at least one cointegrating vector with which export has played a significant role to produce co-movement of the variables in the national production function. (3) Johansen test also reveals that neither export nor import can be excluded for the cointegration of the production function, and their signs are positive. (4) The other conclusion is drawn from Error Correction Model about the causality between output and trade: both tests admit a bi-directional causality between trade and output. (5)The interaction analysis reveals that the growth rate of total factor productivity is well explained by the growth rates of export and/or import, which statistically justifies the special form of production function used in the above cointegration test. All of these results imply that export and import have exerted some externalities for economic growth which is not explained by the other production

factors such as capital and labor in case of Korea as suggested by the endogenous growth theories, and that opening and increasing the international trade can be one of the greatest way for economic development of small developing countries.

The last part of this paper re-interprets several previous studies to support the hypothesis of growth slowing-down empirically that can be distinguished in the later stage of export-oriented development strategy. The mathematical proof in this dissertation and the survey of the endogenous growth theories have introduced the possibility of S-shaped path of technology transfers: accelerating and then decelerating.

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Chapter 1. Introduction

The rapid growth of the Asian NICs(newly industrializing countries) such as Hong Kong, Korea, Singapore and Taiwan can't be easily explained in the context of the neoclassical model which mainly cares about the accumulation of physical capital.

Besides, by 1960, most of the NICs already had a higher level of education. But many other poor countries that didn't grow, had also similarly high level of education. This means that the human capital theory is not sufficient to explain the past experience of economic development.

According to the recent endogenous growth theories (The Neo-schumpeterian theory etc.), nations are in low income, because they lack not only physical capital(equipment and plant), but also valuable knowledge about production and marketing. An knowledge-like good such as technology is something that you can give to someone else, yet still retain for your own use.

Considering the effect of international knowledge spillover, we may plausibly suppose that foreign contribution to the local knowledge stock increases with the number of commercial interaction between domestic and foreign agents, and that the economic development of small developing countries can be significantly promoted by the openness of the economies. First of all, "import" may embody differentiated intermediates that are not available in the local economy. The greater the quantity of such imports, the greater perhaps will be the number of insights that local researchers gain from inspecting and using these goods. When local goods are "exported", the foreign purchasing agents may suggest ways to improve the manufacturing process.

Thus, expanded international trade increases the number of embodied specialized intermediate inputs and many types of useful knowledge which are not embodied in material inputs such as production engineering and information about changing product patterns. Therefore, it can be hypothesized as following: if there is important technology or knowledge gap and these can be exploited by the export process and/or "imported equipment" from developed economies, one would hope to be able to find some significant signs of those in the aggregate data

This paper has two main purposes. The first purpose is to set up a model and prove it mathematically to test the endogenous growth theories for developing countries.

To address the role of export and import as suggested by the endogenous growth theories, this paper first specifies a special form of production function which includes export(X) and import(M) as a kind of production factor like physical capital(K) and labor(L) :i.e. $Y= F(K,L,X,M)$ or $Y= A(X,M)\bullet f(K,L)$.

It is known that the Korean economy has depended heavily on export and import(i.e. reverse engineering) rather than on foreign direct investment for the technological development as shown in <Table 1.3>.[1] Thus, time series analysis of the Korean case to test the endogenous growth theories needs to be focused on export and import rather than on foreign direct investment.

Including the production function in a simple macro-economic equilibrium model, this dissertation tries to show mathematically how export and import as a kind of production factor will affect the growth rate of output in the steady-state. The mathematical manipulation also shows that the developing country adopting the export-oriented development strategy will face the growth slowing-down under the assumption that the externality effect of trade will diminish as the country attains higher income.

The second purpose of this dissertation is to apply the actual time series data of the Korean economy to the test model to check if the endogenous growth theories(or implication by the endogenous growth theories) has worked in the real economic development process of a developing country.

Since South Korea has been so often referred to as an exemplary of export-oriented (or outward) development strategy, the time series analysis of the Korea case can be an useful contribution of the time series analysis of the endogenous growth theories.

Even though there are bunch of empirical tests of the endogenous growth literature, most of them are confined to the cross-sectional analysis. However, the cross-sectional analysis contains severe problem in generalization. Even though a cross-sectional test

[1] Cha and Kim(1995,p432-6)

supports the endogenous growth theory or the role of export, it can't be said that the general conclusion will be applied to a specific country until time series analysis supports the new theory.

Recognizing those problem, several studies have adopted time series analysis. As surveyed in section 2.3.4 and section 4.5.6, empirical studies on export (or trade)-economic growth nexus have been conducted along either causality test or regression analysis using production function type model. However, these studies contain several defects in econometric technique or in including the appropriate variables.

Most of the early time series studies such as Jung and Marshall(1985), Chow(1987), Hsiao(1987) and Dodaro(1993) used simple bi-variate causality tests such as Granger (1969), Sims(1972) and Hsiao(1981) test. However, these tests have been criticized on the grounds that they are valid only if the original time series are stationary. Bahmani-Oskooee and Alse(1993) and Dutt and Ghosh (1996) apply the bi-variate Engle-Granger cointegration test finding mixed results of causality in Korea. Their tests were done on the basis of the preliminary tests in which export and real GDP are confirmed to be nonstationary unit root processes. However, overall speaking, these bi-variate causality tests lack a theoretical foundation, and so can lead to a omitted variable bias.

In contrast, several studies such as Greenway and Sapsford(1994), Ram(1987), Salvatore and Hatcher(1991), Sengupta(1991,1993) apply regression analysis to the production function type equation. Their results are mixed, even though the sign of export is commonly significant in case of Korea.

However, since those studies use the variables in the form of rate of change that are close to the concept of first differencing to avoid the nonstationarity problem, they could lose much of the information included in the original variable. As indicated by Bahmani-Oskooee and Alse(1993), first differencing filters out low-frequency (long-run) information.[2] Moreover, their single equation models don't deal with the simultaneity problem.

Therefore, the potential problem from the existing time series analyses can be listed as (1)measurement error (2)misspecification(or missing variables) (3)nonstationarity (4)endogeneity.

To deal with these problem, Berg(1996) first applies unit-root tests(Dickey-Fuller (1979,1981) test and KPSS(1992) test) to the time series data of 10 Asian NICs including Korea, and concludes that most variables(GDP, investment, export and import) except population[3] are stationary I(0) variables. To deal with the simultaneity issue, this study applies 3SLS estimation to the simultaneous equation system.

However, it must be noted that the estimation of Berg(1996) is based on the results of unit-root test. If the variables in the model are not stationary, which has often been

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[2] Refer to Bahmani-Oskooee and Alse(1993,p536). To remedy those problem, they recommended the cointegration technique and error correction modeling. ECM tries to establish causality between two variables after reintroducing the low-frequency information through the error correction term into the analysis.

[3] In Berg(1996), population is used as a proxy for labor input.

confirmed by several studies such as Bahmani-Oskooee and Alse(1991), Dutt and Ghosh (1996) through the same unit-root tests,[4] then the Berg's models may imply a misspecification.[5] Berg's model also contains several other limitations.[6]

In this case, cointegration test and estimation of Error Correction Model based on a production function can be a good solution, as tried in this dissertation. Besides, to minimize the problem of measurement error, this dissertation uses capital stock directly instead of using investment.

Even though each variable is nonstationary, the variables in the system can show a co-movement(i.e. cointegrating relationship) driven by the same fundamental forces in the economy. If export and/or import decisively contribute to the cointegration of the variables(i.e. production inputs) in the production function, it implies that export and/or import are required factors for the cointegration, and that they have worked as a kind of production factors like capital and labor. Exclusion test(i.e. restriction test) can also show that export and/or import can't be excluded from the cointegrating relationships. Then, the

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[4] Dutt and Ghosh(1996) uses annual data, and applies Engle-Granger cointegration test for 14 countries including 4 Asian countries. Their unit root tests(i.e. Phillips-Perron(1988) test and KPSS(1992) test) find that export and output are nonstationary unit root processes in most countries including Korea.

[5] Berg(1996)'s first equation is specified as: $Y=c + \alpha(I/Y) + \beta \hat{N} + \gamma X + \delta M$, mixing level variables and a differenced variable($\hat{N}$: growth rate of population). This paper uses real values(1954-94) for output(Y), investment(I), export(X) and import(M). Berg(1996)'s sample is based on the IMF IFS data denoted in US$ and evaluated by the US GDP deflator to get real values of the variables, while this dissertation uses real value data denoted in Korea currency unit (billion Won).

In case some variables other than population are nonstationary, then the estimation by Berg(1996) contains severe problem of nonstationarity. Since Berg didn't provide any diagnostic statistics of the regressed equations, it is impossible to check if the residuals from the estimated equations by Berg are stationary and so meaningful.

[6] Since Berg(1996) uses population as a proxy of labor and uses investment before depreciation, it can't avoid the measurement problem. To avoid these problem, this dissertation uses employment and physical capital stock respectively instead of population and investment.

role of export and import can be admitted, which is to exert the externalities through the economies of scale, international knowledge spillover etc., as suggested by the endogenous growth theories.

Estimation of ECM(Error Correction Model) following the cointegration test enables us to get over the endogeneity problem.[7] Besides, estimating the ECM enables it possible to induce the Granger-causality between output and export.

To achieve these purposes, this dissertation first applies the unit-root test(Dickey-Fuller(1979,1981) test, Phillips-Perron(1988) test) to the annual time series data of S.Korea for the period of 1963-1994, finding that all the variables under consideration are nonstationary I(1) variables. Then, this dissertation applies two kind of cointegration test(Engle-Granger (1987), Johansen(1988) test) to the special form of production function in which export and/or import are included as production inputs. Estimation of cointegrating long-run equilibrium relationships and ECM reaches the similar conclusion as Berg(1996)[8]: (1) significant and positive externality effect(or knowledge spillover effect) of trade as suggested by the endogenous growth theories and (2) the bi-directional causality between output growth and trade growth.

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[7] This is because ECM(Error Correction Model) has the characteristics of near VAR(Vector Autoregression) model except that ECM considers error correction terms(i.e. cointegrating long-run equilibrium relationship) additionally as well as the autoregressive short-run adjustment mechanism.
[8] Berg finds not only that the signs of export and import in output equation are significant. but also that the signs of output in export equation and in import equation are significant, which implies a bi-directional causality between output and trade.

To justifies the special form of production function statistically which is used in the above cointegration test, this dissertation adopts the interaction analysis. It will show that the growth rate of TFP(total factor productivity) isn't explained by the growth rates of capital(K) and labor(L). Instead, the growth rates of export and/or import well explain the TFP growth, which will justify that trade is working as a kind of production factor in the national production function.

The last part of this paper will treat the issue of **growth slowing-down**, which implies that growth of the small developing economy can be slowed down and converge on the steady-state rate as the general knowledge gap narrows down. Several existing studies will be re-interpreted to support the hypothesis empirically, since they didn't indicate the phenomenon and the reason explicitly. In advance, both the mathematical proof in the section 4.1.1 and the survey of the endogenous growth theories in Chapter2 will introduce the possibility of the "S-shaped path" of technology transfers: accelerating and then decelerating.

To attain these goals, Chapter2 first surveys the several strands of the endogenous growth theories spotlighting the main differences between them. The orthodox neoclassical growth theory will be reviewed as a starting point to help the understanding of background of the new growth theory. Several modified endogenous growth theories applied to the developing countries will be introduced. Also, it will be indicated that, as an entailed conclusion of the new growth theories, the developing countries with export-oriented strategy will face the growth slowing-down as knowledge gap narrows down.

Chapter3 introduces several econometric techniques for cointegration test such as Engle-Granger(1987) test and Johansen(1988) test. As a preliminary step, the technique of unit-root tests such as Dickey-Fuller(1979,1981) and Phillips-Perron(1988) will be described, which is to examine if the variables in the production function are integrated of order one in common, i.e. nonstationary I(1).

Chapter4 sets up a special production function including export and import as a kind of production factor, which is going to be used as a model for testing the role of trade,i.e. the efficacy of the endogenous growth theories extended to the economic development of developing countries. Then, the result of unit-root test and cointegration test will follow the model set-up. Analysis of TFP(Total Factor Productivity) using growth accounting technique will be performed to reveal the contribution of trade(export and import) to productivity growth, which justifies the special form of production function used in the cointegration tests. Finally, re-interpretation of the existing studies will be tried to support the hypothesis of growth slowing-down.

Chapter5 summarizes the implication of the several tests and indicates the limitation of the research.

<Table 1.1>

Annual Growth Rate of Real GDP and Export

of the Asian NICs and Japan (Average,%)

Country & Variables	1963-72	1973-80	1981-91
Hong Kong			
GDP	11.74	10.13	6.68
Export	14.04	9.79	13.62
Japan			
GDP	9.39	4.08	4.25
Export	15.84	6.16	4.34
S. Korea			
GDP	**9.14**	**8.34**	**9.31**
Export	**30.32**	**17.57**	**11.60**
Singapore			
GDP	10.30	8.08	7.07
Export	6.05	29.13	9.47
Taiwan			
GDP	10.95	8.38	7.83
Export	27.65	22.64	9.42

Sources: IMF,IFS for Japan, Korea and Singapore. United Nations for Hong Kong. Chung-Hua Institution for Economic Research for Taiwan. requoted from Krueger(1995).

<Table 1.2>

Share of Export and Import in GDP

of the Asian NICs and Japan (%)

Country & Variables	1963	1973	1980	1990
Hong Kong				
Export	67.14	89.26	95.71	135.15
Import	99.74	85.53	100.61	129.72
Japan				
Export	7.82	8.92	12.23	9.77
Import	9.66	9.25	13.32	7.97
S. Korea				
Export	**4.76**	**29.13**	**34.03**	**30.96**
Import	**15.91**	**32.12**	**41.47**	**31.52**
Singapore				
Export	124.55	87.28	165.21	149.52
Import	153.41	122.62	204.67	172.81
Taiwan				
Export	15.22	41.60	47.76	42.70
Import	16.60	35.35	47.71	34.86

Sources: IMF,IFS for Japan, Korea and Singapore. United Nations for Hong Kong. Chung-Hua Institution for Economic Research for Taiwan. requoted from Krueger(1995).

<Table 1.3>

Sources of Technology Transfer to Korea

Sources & Countries	1962-66	1967-71	1972-76	1977-81	1982-86	1987-91	Total
Direct Foreign Investment							
Japan	8.3	89.7	627.1	300.9	875.2	2113.6	4014.8
U.S.A.	25.0	95.3	135.0	235.7	581.6	1482.1	2254.7
Etc.	12.1	33.6	117.3	184.0	309.7	2036.1	2694.8
Sub-total	45.4	218.6	879.4	720.6	1766.5	5631.8	9264.3
Foreign Licensing							
Japan	-	5.0	58.7	139.8	323.7	1483.9	1911.1
U.S.A.	0.6	7.8	21.3	159.2	602.7	2121.9	2913.5
Etc.	0.2	3.5	16.6	152.4	258.5	853.6	1284.7
Sub-total	0.8	16.3	96.6	451.4	1184.9	4359.4	6109.3
Technical Consultancy							
Japan	-	12.1	7.7	20.8	89.2	217.6	347.4
U.S.A.	-	3.1	6.0	16.7	159.1	619.8	804.7
Etc.	-	1.6	4.8	17.2	84.0	413.5	521.1
Sub-total	-	16.8	18.5	54.7	332.3	1250.9	1673.2
Import of Capital Goods							
Japan	148.0	1292.0	4423.0	14269.0	20986.0	54643.0	95761.0
U.S.A.	75.0	72.0	973.0	6219.0	12394.0	33099.0	54232.0
Etc.	93.0	77.0	445.0	7490.0	17205.0	33197.0	61207.0
Sub-total	316.0	541.0	841.0	27978.0	50585.0	120939.	211200.0

Unit: US$(Million), Sources: Cha and Kim(1995, p433) and Kim,Linsu(1995,p275)

Chapter 2. Survey of the Endogenous Growth Theories

The neoclassical growth theories have many significant predecessors. These include the "classical" growth theories of Smith, Ricardo and Malthus. The largely neoclassical growth theoretic literature of 1960s and earlier can be categorized in three strands.[1]

(1)Positive or descriptive theory, which is aimed at explaining the stylized facts of long-run growth in industrialized countries, had been established by the works of empirically oriented economists such as Abramovitz(1956), Solow(1956,1957), Denison(1962), Kuznets(1966), Jorgenson and Griliches(1966), and Uzawa(1961,1963).

(2) Normative theory- Inspired by the pioneering work of Ramsey(1928)'s classic paper on optimal saving, several studies had followed such as Koopmans(1965), Cass(1965), Srinivasan(1962), Uzawa(1964), Phelps(1961). While the descriptive models specified the aggregate savings rate as exogenous, the normative models derived time-varying savings rates from the optimization of an intertemporal social welfare function.

(3) Neither descriptive nor normative, though it is related to both- One example is von Neumann (1945) on balanced growth at a maximal rate, the other is the dynamic extension of the Keynesian model by Harrod(1939), Domar(1947) and Tobin(1955).

Especially, the knife-edge property resulting from Harrod's assumption that capital and labor are used in fixed proportions, had provided such a strong motif that Solow(1956) led the orthodox neoclassical growth theory by looking for growth paths

[1] Srinivasan(1995.p39-40)

converging to a steady state. This was possible by replacing Harrod's technology with a neoclassical technology of positive elasticity of substitution between labor and capital.

In its purest form, the orthodox neoclassical model of growth with no exogenous technological progress says that the economy will reach a steady state in the long-run with zero growth in per capita income. Long-run growth rates could not be affected at all by economic policy. In this sense, the engine of growth such as technological progress and population growth was seen as entirely exogenous.

For many economists, however, the neoclassical theories had seemed unsatisfactory[2] in that it predicted only a slowing down of growth rates due to diminishing returns to additional factor accumulation. Sustained high growth rates in Japan(in 1950s and 1960s) and in the four Asian NICs seem to contradict this prediction.

Challenges to the orthodox neoclassical model have been already mounted partially from the earlier work on growth theory by Stigler(1951), Haavelmo(1954), Myrdal(1957), Schultz (1961, 1962) and Arrow(1962). But, it is not until the endogenous growth theories in the 1980s by Romer(1986,1990a,b), Lucas(1988), Grossman and Helpman(1990,1991a-e) and others[3] that set off a revolution changing the paradigm in growth theories.

These endogenous growth studies have developed several models in which long-run growth rate could be determined by the same kind of factors that had previously been

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[2] Ito and Krueger(1995,p2-3)

[3] Jones and Manuelli(1990) and Rebelo(1991) etc.

regarded as affecting only short-run or medium-term growth. In the endogenous growth theories, the engine of growth has become part of the model itself: it results from the maximizing behavior of individual economic agents. Also, starting with the observation that growth rates of individual countries are highly correlated for long periods of time and do not show the tendency of deceleration, one strand of the endogenous growth theories has developed models in which knowledge spillovers between countries play significant roles in realizing increasing returns to a factor and spreading growth among trading countries.

2.1 The Neoclassical Growth Theories

The implication of the neoclassical theory of growth[4] can be well understood through Solow(1956)'s equilibrium growth model. In its purest form, it predicts that the capital-labor ratio converges to some long-run equilibrium value, as do the real wage, the rate of return to capital, and the level of income per capita. But, the long-run rate of growth of output is exogenous, being equal to the rate of population growth and technological progress. Consumption per capita also converges to a stationary equilibrium value. Policies to enhance growth can only influence the short-run paths.

The orthodox neoclassical growth model[5] postulates a production function which is constant returns to scale(CRS) and concave:

[4] See also Swan(1956) and collections of articles by Newman(1968), Stiglitz and Uzawa(1969), Sen(1970), Hahn and Matthews(1964).

[5] The description here follows the simple function form by Hammond and Rodriguez(1994.p5-6) to clarify the meaning of Inada(1963) condition.

$$Y = F(K, L) \quad \ldots\ldots\ldots\ldots <2.1>$$

Net investment is given by

$$\dot{K} = F(K, L) - C \quad \ldots\ldots\ldots\ldots <2.2>$$

,where C denotes consumption and $\dot{K}$(=dK/dt), is the time derivative of capital.

Taking total differentials of equation<2.1> with respect to time, we can get

$$\dot{Y} = F_k \dot{K} \ldots\ldots\ldots\ldots <2.3>$$

,where F_i (i = K,L) denotes the partial derivative of F with respect to K or L.

Suppose that net investment $\dot{K}$ is a positive constant proportion (i.e. s) of net output(i.e. Y).

Equilibrium condition of the whole economy requires that investment(i.e. I or $\dot{K}$) is equal to savings(i.e. S):

$$I = S$$

or $\dot{K} = s Y \ldots\ldots\ldots\ldots <2.4>$

,where S = s Y.

From equation<2.4>, we get

$$\dot{K}/Y = s \ldots\ldots\ldots\ldots <2.5>$$

Dividing equation<2.3> with Y and plugging equation<2.5> yields

$$\dot{Y}/Y = F_k \dot{K}/Y$$

--> $\dot{Y}/Y = F_k s$

--> $\hat{Y} = s F_k(K,L) \ldots\ldots\ldots\ldots <2.6>$

,where a hat ($\wedge$) over Y denotes the proportional growth of output.

In order to ensure existence of a steady state with a positive level of output, the neoclassical growth theory has generally assumed the "**Inada(1963) conditions**". There are two of those: The first lower condition requires that

$F_k \to \infty$, as $K \to 0$ ....<2.7>

and the second upper condition assumes

$F_k \to 0$, as $K \to \infty$ ....<2.7'>

Given the upper Inada condition <2.7'>, i.e. the law of diminishing returns, equation <2.6> implies that the growth rate of output converges to zero. This is true no matter what the value of savings rate(i.e. s) may be, and it remains true even when s(t) varies with t in a finite range.[6]

2.2 The Endogenous Growth Theories

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[6] To see what happens specifically to capital-labor ratio(i.e. K/L), Srinivasan(1995) uses more general functional form by Solow(1956): $Y=A_t F(K_t, b_t L_t)$ ....<2.1>

,where A_t ($A_0 \equiv 0$) is the disembodied technology factor (i.e. index of total factor productivity), and b_t is the labor augmenting efficiency level. Technical progresses through A_t is "**Hicks neutral**" .and those through b_t is "**Harrod neutral**".

Let $k_t \equiv K_t / b_t L_t$ and $y_t \equiv Y_t / b_t L_t$. Under the assumption of CRS and concavity, equation<2.8> can be transformed into $y_t = A_t F(k_t, 1) = A_t f(k_t)$ ....<2.9>

Inada condition(1963) means that $f'_k \to \infty$,as $k \to 0$ and $f'_k \to 0$, as $k \to \infty$. Assuming that labor is growing exogenously as $L_t=(1+n)^t L_0$, and labor skill is growing exogenously as $b_t=(1+b)^t$, we have

$k_{t+1} = [A_t f(k_t) + (1-\delta)k_t - c_t] / (1+n)(1+b)$ ....<2.10>

,where δ is depreciation rate of capital and c_t is the consumption per augmented labor unit (i.e. $b_t L_t$). Under the assumption of a fixed saving ratio, $c_t = (1-s)\, y_t$,and then equation<2.10> becomes

$k_{t+1} = [s A_t f(k_t) + (1-\delta)k_t] / (1+n)(1+b)$

$\equiv g(k_t)$ ....<2.11>

Equation<2.11> implies that, under the Inada condition of diminishing marginal condition of k, there exists a steady state $k_{t+1}^* = k_t^*$ such that $k_{t+1}^* = g(k_t^*)$, in which all the per capita variables will grow at the rate b. Thus if b=0, the growth rate of per capita income, consumption and savings deteriorate and become zero. Policies that affect savings rate(i.e. s) and population growth rate(i.e. n) permanently, will not affect growth rate in the long-run. However, in the short-run, the average growth rate of per capita income is higher than b, the exogenously given rate of labor-augmenting technical progress until the initial capital-labor ratio(i.e. k) tends to k*. Then, average growth rate decreases as k increases, which means the "convergence hypothesis".

The endogenous growth theories initially started from building a general equilibrium model, but modifying the basic assumption of the neoclassical models to make the long-run growth possible. A primary goal of these theories was to build models that can generate sustained long-run growth in per capita income. A related object is to ensure that the long-run growth rate of income depends not only on the parameters of the production and utility function, but also on fiscal policies, foreign trade policies and population policies. In most of the new theories, the goal has been accomplished through **increasing returns to scale** in aggregate production. The resulting **non-convexities** lead to the possibility of **multiple equilibrium** and **hysteresis** so that **history(i.e. initial conditions)** and **policies** may have long-run effects.

They have made progresses in three strands.[7]

(1) Model of essential reproducible factors (or Linear model)- They started from dropping the crucial upper Inada condition<2.7’>.

(2) Model of externality from capital accumulation- They assert that, as by-products of capital accumulation, the productivity of labor or other non-reproducible factors may increase through the process of "learning by doing","division of labor" and "government provision of public services" financed out of taxation.

(3) Model of externality from R&D or innovation- They also rely on an accumulation process having a by-product, but emphasize how increased knowledge or human capital make innovation and/or education less costly.

2.2.1 Model of Reproducible Factor such as Human Capital (Linear Model)

[7] The description here follows those provided by Hammond and Rodriguez(1994,p6)

2.2.1.1 Dropping the Inada condition

One strand of the endogenous growth theories starts from relaxing the upper Inada condition <2.7'>, so that the marginal productivity of capital does not tend to zero, as the capital-labor ratio goes to infinity. This assumption means that only reproducible factor such as capital are essential in the sense that, as their input levels approach zero, the marginal products of other factors also converge to zero.

Jones and Manuelli(1990) explicitly assume that

$F_k(K,L) \rightarrow \mu > 0$, as $K \rightarrow \infty$ ....<2.12>

Since $\hat{Y}$= s F_k(K,L) from equation<2.6>, the assumption<2.12> yields

$\hat{Y} = s\,\mu > 0$ ....<2.13>

Equation<2.13> implies that the growth rate of Y is bounded away from zero in the limit. The long-run output growth and consumption is endogenous, which is determined by the rate of capital accumulation and the savings rate(s).

2.2.1.2 Production Function with Constant Elasticity of Substitution (C.E.S.)

One example of the relaxing condition<2.12> is the well known C.E.S. production function:

$F(K,L) = [\alpha K^{\rho} + (1-\alpha)\, L^{\rho}]^{1/\rho}$, $0 < \rho \leq 1$ ....<2.14>

When ρ=0, equation<2.14> deteriorates to the Cobb-Douglas function: $F(K,L) = K^{\alpha} L^{1-\alpha}$.

The condition $\rho \leq 1$ is necessary for F to be concave.

What ρ>0 implies is that, as $K \rightarrow \infty$,

$$F_K(K,L) = \alpha K^{\rho-1} [\alpha K^\rho + (1-\alpha) L^\rho]^{(1/\rho)-1}, \quad 0< \rho \leq 1 \text{ ....} <2.14>$$

$$= \alpha [\alpha + (1-\alpha) (L/K)^\rho]^{(1/\rho)-1}$$

$$\rightarrow \alpha^{1/\rho} > 0$$

Thus, $F_K(K,L) \rightarrow \alpha^{1/\rho} > 0$, as $K \rightarrow \infty$ ....<2.12'>

$\rho>0$ ensures that the elasticity of substitution (i.e. $\sigma = (1-\rho)^{-1}$) is larger than unity. Hence, high elasticity condition(i.e. $\rho>0$ or $\sigma>1$) is necessary for the share of capital in output or the output growth rate to be positive, as the capital-labor ratio goes to infinity.

2.2.1.3 Linear Model (AK Model)

Another example of relaxing the condition<2.12> is the "linear model" or "AK model" provided by Rebelo(1991), Barro and Sala-i-Martin(1992):

$F(K,L) = \mu K + B K^\alpha L^{1-\alpha}, \quad 0<\alpha<1, \mu>0$ ....<2.15>

Then, $F_K = \mu + \alpha B (L/K)^{1-\alpha}$, so that

$F_K \rightarrow \mu$, as $K \rightarrow \infty$ ....<2.12''>

They posit a model in which the production function is in the form of equation<2.15>, but with B=0. Thus, only reproducible resources(i.e. K) are used as inputs in the long-run, in other words, per capita capital is infinitely large. This model is referred to as the "AK model" or "Linear model", because the production function can be expressed as F(K,L) = AK.

Even when B>0, the production function provides the same asymptotic properties because the second term becomes relatively unimportant as $K \rightarrow \infty$.

2.2.1.4 Model with Essential Reproducible Factors

The important implication of the linear models is that long-run growth is still possible as long as there is at least one capital good(i.e. physical or human capital) whose production uses only reproducible resources. For example, current production of capital good increases not only current output, but also production capacity in the next period. Human capital suggested by Lucas(1988) may also play the role as a reproducible factor of increasing future production capacity.

Rebelo(1991) shows that even when non-reproducible factor such as labor is essential in production as they are in the Cobb-Douglas function, long-run growth is still possible only if there exists a reproducible capital good in the production process.

In a two sector model with output C of the consumption good being produced according to a Cobb-Douglas function using capital(i.e. K_C) and labor (i.e. L),

$$C = K_C^{\alpha} L^{1-\alpha}, \quad 0<\alpha<1 \quad \ldots\ldots\ldots\ldots <2.16>$$

While investment sector uses only capital and exhibits CRS, so that

$$\dot{K} = a K_I, \quad a>0 \quad \ldots\ldots\ldots\ldots <2.17>$$

,where $K_C + K_I = K$.

If a constant fraction ϕ of the capital stock goes to produce investment goods, then

$K_I = \phi K$, and $K_C = (1-\phi) K$.

Thus, equation <2.16> and <2.17> yields the constant growth rate in the long-run

$$\hat{C} = \alpha \hat{K}_C = \alpha \hat{K} = \alpha a \phi > 0 \quad \ldots\ldots\ldots\ldots <2.18>$$

Lucas(1988) points out the role of human capital as a reproducible factor: individual skill acquisition and social spillover of the skill. His model assumes that skill augments the efficiency of labor, which is based on the work carried out by Uzawa(1965).

Moreover, skill is passed from generation to overlapping generation. Also, individuals spend fractions u of their time in producing output and (1-u) in increasing their human capital(i.e. H) through education etc.. The model is described as

$$\dot{K} + C = Y = F(K, uLH),\ \ 0<u<1 \ \ldots\ldots\ldots\ldots\ldots\ldots <2.19>$$

$$\dot{H} = \xi(1-u)\ LH,\ \ \xi>0 \ \ldots\ldots\ldots\ldots\ldots\ldots <2.20>$$

,where H as well as K is another reproducible factor that is accumulated through time.

Long-run balanced growth is possible, for any u<1,at a rate g given by

$$g = \hat{C} = \hat{K} = \hat{H} = \xi(1-u)\ L \ \ldots\ldots\ldots\ldots\ldots\ldots <2.21>$$

provided that u and the savings ratio (i.e. s= /Y) can be chosen to satisfy $\dot{K}$= g K = s Y = s F(K, uLH).

Equation <2.21> implies that the long-run growth rate is determined by

(1) the exogenous labor supply(L)

(2) proportion (1-u) of labor effort that is made to accumulate human capital through education or acquiring skill.

(3) efficiency of learning process(ξ).

2.2.2 Model of Externality Effect from Capital Accumulation

One strand of the endogenous growth theories has recognized that accumulation of capital may increase the labor productivity mainly through learning-by-doing process or division-of-labor efficiency, and that capital accumulation can provide ways for long-run growth.

Assume that the production function of each identical agents has the form of constant returns to scale:

$y = F(k, El)$ ....<2.22>

,where k is the stock of available capital and l is the labor. E represents the **efficiency of labor** and has the form:

$E = A(K)$, $A' > 0$ ....<2.23>

,where K is the aggregate capital stock. This assumption means that labor or non-reproducible factor becomes more productive as a direct external effect of capital accumulation.

Aggregation over all identical agents yields

$Y = F(K, A(K)L)$ ....<2.22'>

When investment is a constant fraction s of output (i.e. $\dot{K}$=sY), equation <2.22'> implies that the growth rate of aggregate output is

$\hat{Y} = \dot{Y}/Y = [F_K + F_{AL} A'(K)L] (\dot{K}/Y)$

$= s F_K + s F_{AL} A'(K) L$ ....<2.24>

Suppose that under the upper Inada condition<2.7'>, the term sF_K in equation<2.24> converges to zero, as $K \to \infty$. Even in this case, the long-run growth is possible provided that the second term of equation<2.24> (i.e. sF_{AL} A'(K) L) does not converges to zero.

Since F is CRS, its partial derivatives are homogeneous of degree zero, and so

$F_{AL}\,[K, A(K)L]\,A'(K)\,L = F_{AL}\,[1,\, A(K)L/K]\,A'(K)\,L$

If A'(K)L converges to b(>0) as $K \rightarrow \infty$, then

$A(K)L/K\; K \rightarrow b$ ....<2.25>

and $F_{AL}\,[1,\, A(K)L/K]\,A'(K)\,L \;\rightarrow F_{AL}(1,b)\; b$. ....<2.25'>

Therefore, the asymptotic growth rate of output in the long-run is

$\hat{Y} = s\, F_{AL}(1,b)\; b > 0$.................... ....<2.26>

Equation<2.26> implies that the long-run growth rate depends on the savings rate(i.e. s) and the parameter b under the assumption that labor becomes more productive as a direct external effect of capital accumulation. It needs to be noted that asymptotic marginal product of aggregate capital should be positive as in equation<2.25> in order to generate endogenous growth.

2.2.2.1 Learning by Doing or Knowledge Spillovers

Haavelmo(1954)and Arrow(1962) postulate that aggregate learning by doing results from the investment process so that the knowledge stock of the workforce is a function of capital stock.

Romer(1986) regards K, the aggregate stock of knowledge as a public good from which individual producers could benefit directly. Each agent of n identical firms has a production function of the form:

$y_i = G(k_i,\, l_i,\, K)$.................................<2.27>

,where k_i is the stock of knowledge capital or R&D capital employed by firm i , and l_i is the labor or other non-reproducible inputs.

$K=\sum_{i=1}^{n} k_i$ is the aggregate stock of knowledge. In equation<2.26>, K is assumed to have a positive spillover effect on the output of each firm, although the choice of K is external to the firm. Romer assumes that, for fixed K, the production function G is homogeneous of degree one in other inputs. Under identical firms, equation<2.27> becomes

$$y_i = G(k_i, l_i, nk_i) = F(k_i, l_i) \qquad \text{<2.28>}$$

Then, it is obvious that F exhibits increasing returns to scale with respect to the inputs, k_i and l_i.

Note that even though there may be increasing returns to scale in the aggregate level, each agent behaves with a production function that is concave and has constant returns to scale in the variables under agent's control.

Therefore, as Chipman(1970) and Romer(1986) point out, perfect competition remains possible with each producer taking both prices and the aggregate capital stock (or labor productivity) as fixed. In this sense, capital accumualtion is a kind of public good to which each agent contributes privately by investment.

2.2.2.2 Division of Labor

It has long been observed that a deeper division of labor between different specialized tasks increases the productivity of non-reproducible factor such as labor. Since division of labor is limited by the size of the market, capital accumulation and the accompanying increase in the market size may deepen division of labor, and so increase labor productivity.[8]

A simple formulation of this idea postulates a CRS production function of final output Y:

$$Y = F(K_Y, Z) \text{ ....} \langle 2.29\rangle$$

,where K_Y is the capital employed in Y sector and Z is the intermediate input.

Following Dixit and Stiglitz(1977), Hammond and Rodriguez(1994) assumes that Z is produced using quantities z(j) (0≤j≤∞) of a continuum of varieties of an intermediate good according to a strictly concave function with constant elasticity of substitution(CES) exceeding unity:

$$Z = [\int_0^{\infty} z(j)^{\alpha}\, dj\,]^{1/\alpha}, \quad 0<\alpha<1 \text{ ....} \langle 2.30\rangle$$

Assume also that each variety of intermediate good z(j) is produced from K(j) units of capital and L(j) units of labor according to

$$z(j) = \begin{cases} 0, & \text{if } K(J) < 1 \\ L(j), & \text{if } K(j) \geq 1 \end{cases} \text{ ....} \langle 2.31\rangle$$

Since producing z(j) involves set-up costs, perfect competition is no longer possible and there will be a monopolistically competitive equilibrium. Equation<2.31> implies that ,because of the set-up cost, not all varieties of the intermediate good are not made.

[8] The model here is quoted from Hammond and Rodriguez(1994), Becker and Murphy(1992), and Yang and Borland(1991)

If we represent the set of available varieties by the interval [0, n] of the real line, n must be equal to K_Z, the quantity of capital used in the intermediate good sector.

Then, the specification of production functions <2.30> and <2.31> implies that there are returns from the division of labor in the production of intermediate goods.

To see this, suppose that efficiency requires all firms producing final goods to use the same quantity of all available varieties: $z(j)=z$ for all $j \leq n$. Then, equation<2.31> means that $L(j)=z$ for all such j. The total amount of labor devoted to the production of intermediate goods must be $L_Z = nz$. Since $L_Z = L$, thus $z(j) = z = L/n$ for all $j \leq n$. Then equation <2.30> implies that

$$Z = [\int_0^n z^{\alpha}\, dj\,]^{1/\alpha} = [\, n\, z^{\alpha}\,]^{1/\alpha} = n^{1/\alpha} z = n^{1/\alpha} (L/n) = n^{\phi} L$$

That is,

$$Z = n^{\phi} L, \text{ where } \phi = (1-\alpha)/\alpha \quad \ldots\ldots\ldots\ldots\langle 2.32\rangle$$

Plugging equation<2.32> into equation<2.29> yields

$$Y = F(K_Y, n^{\phi}L) = F(K_Y, K_Z{}^{\phi}L), \quad 0<\phi<\infty \quad \ldots\ldots\ldots\ldots\langle 2.33\rangle$$

Note that K_Y is the quantity of capital used in the final good sector and K_Z is the quantity of capital used in the intermediate good sector.

Equation<2.33> clearly shows that an increase in the varieties of available intermediate goods(i.e. $n= K_Z$) increases the efficiency of labor or labor productivity in producing final goods. This property is usually called as "**love of more variety for inputs**" It results from the fact that different inputs are imperfect substitutes for each other: If fewer varieties of intermediate goods are available, then the firm will have to use those that are available more intensively. If a wanted input is not available in the market, the firm will buy the closest one and transform it into the desired input at some cost. This means that there will be a loss of output due to imperfect competition and more varieties will reduce the production cost.

2.2.3 Model of Externality Effect by R&D or Innovation (Innovation-based-growth of the Neo-Schumpeterian)

One strand of the endogenous growth theories postulates that private R&D or innovation have a strong externality effect in reducing the cost of other R&D or innovation by the other agents. The spillover effect of R&D by each agent works as a source of realizing increasing returns to scale (IRS) in the whole economy and long-run growth. Firms have profit incentives to invest in new R&D or innovation under monopolistic competition all along.

Romer(1993) named these models of innovation-based-growth as the "Neo-Schumpeterian", since their idea about innovation and private incentive are very similar to those of Schumpeter.

Hammond and Rodriguez(1994,p13-4) interpret the implication in a simple way:[9] the higher is the knowledge stock(K), the lower is the cost of accumulating more knowledge.

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[9] The innovation-based-growth postulates that the higher is the knowledge stock(K), the lower is the cost of accumulating more knowledge:

$Y = F(K, L, H_Y)$ ....<2.34>

$\dot{K} = G(H_I)\, h(K)$ ....<2.35>

,where K is the stock of knowledge, L is the size of the labor force. H_Y denotes the amount of human capital devoted to producing output, while H_I denotes the level of human capital devoted to the accumulation sector. Thus, $H_Y + H_I = H$, where H is the total stock of human capital in the economy. It is assumed that F and G are both concave CRS function, while the function h is a just increasing function. Note that the current knowledge stock(K) is the essential reproducible input which increases the future production capacity.

If the income share of knowledge capital in output is bounded away from zero in the limit as $K \to \infty$, then the growth rate of output will converge to a positive constant even in the long-run.

The idea of the innovation-based-growth has made its progress in two ways:[10] The first has been built on the Dixit and Stiglitz(1977) formulation of **horizontal product differentiation**(i.e. **expanding product variety**)[11], and the second is about **vertical product differentiation**(i.e. **product quality improvement** or **quality ladder model**).[12]

2.2.3.1 Model of Expanding Product Variety

(Horizontal Product Differentiation)

These models start from the definition of an index Z by means of the following C.E.S. function[13] similar to equation <2.30>:

$$Z = [\int_0^n z(j)^{\alpha}\, dj\,]^{1/\alpha}, \quad 0<\alpha<1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots <2.30'>$$

If $h(K)/K$ is bounded away from zero and $G(H_I) > 0$, then

$\hat{K} = \dot{K}/K = G(H_I)\, h(K)/K$ will be positive as $K \to \infty$. Then, equation<2.34> implies that

$$\hat{Y} = \dot{Y}/Y = F_K \dot{K}/Y = [K F_K/Y]\ \hat{K} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots <2.36>$$

Equation <2.36> represents the implication of the innovation-based-growth that, if the income share of knowledge capital in output(i.e. KF_K/Y) is bounded away from zero in the limit as $K \to \infty$, then the growth rate of output will converges to a positive constant in the long-run.

[10] Helpman(1992) and Grossman and Helpman(1991a) provide good reviews about the innovation-based-growth.

[11] Judd(1985) extends Dixit and Stiglitz(1977) to a dynamic framework, while Romer(1990a) applies the model in terms of the endogenous growth theory.

[12] Aghion and Howitt(1990), Grossman and Helpman(1991c,d)

[13] The constant elasticity of substitution between inputs equals $\sigma = 1/(1-\alpha)$. The restriction of positivity on α (>0) implies that an elasticity of substitution exceeds unity, which means that varieties substitute well for each other.

,where z(j) represents the quality of variety j of differentiated products(or high tech products)[14]

In the dynamic version of monopolistic competition with a dynamic free entry condition, the value of a firm equals the present value(i.e. V(t)) of its profits(i.e. $\pi(t)$). This implies the "**no arbitrage condition**" or market equilibrium condition.

$\pi/V + \dot{V}/V = r$ ....<2.37>

,which states that the rate of return on the ownership of a firm(i.e. π/V) and the rate of capital gain(i.e. $\dot{V}/V$) has to be equal to the nominal interest rate(i.e. r).

Now, suppose that the productivity of research labs rises with the stock of available knowledge capital(i.e. K_n), which plays a central role in bringing about endogenous long-run growth. Then the dynamic free entry condition implies that the value of a firm does not exceed product development cost(i.e. wa/K_n) at each point in time, where "w" is wage rate and "a" represents a parameter. That is,

$V \leq wa/K_n$, with equality holding whenever $\dot{n} > 0$.

Now, "**labor market clearing condition**" requires employment in R&D (i.e. $a\dot{n}/K_n$) plus employment in manufacturing(i.e. X) is equal to the available labor supply:

$a\dot{n}/K_n + X = L$ ....<2.38>

In this economy, investment consists of developing new products and this investment has to be financed by household savings, which arouse the necessity of borrowing the solution from the intertemporal utility(i.e. U_t) maximization problem of consumers:

[14] In a model that contains labor, intermediate goods and physical capital as inputs to produce final goods(Y), Z represents intermediate goods. However, in a simple model that does not distinguish between intermediate goods and final goods like the case here, Z represents a king of high tech products which may be used either as production factor or as final consumption.

$$U_t = \int_t^{\infty} e^{-\rho(\tau - t)}\, u(\tau)\, d\tau \ldots\ldots\ldots\ldots \langle 2.39 \rangle$$

,where ρ is the subjective rate of time preference, and $u(\tau)$ describes the flow of utility such that

$$u = (C_Z^{1-v} - 1)/(1 - v), \quad for\ v>0 \ldots\ldots\ldots\ldots \langle 2.40 \rangle$$

The parameter v represents the elasticity of the marginal utility of consumption, while C_Z stands for the consumption level of high tech product Z. In equilibrium, $C_Z = Z$.

A consumer that maximizes equation <2.39> and <2.40> subject to an intertemporal budget constraint allocates consumption according to the path of consumption growth rate:

$$\dot{C}_Z/C_Z = (1/v)\ [\, r - \rho - \dot{P}_Z/P_Z \,] \ldots\ldots\ldots\ldots \langle 2.41 \rangle$$

,where P_Z is the price index of Z, given by

$$P_Z = \left[\int_0^n p(j)^{-\alpha/(1-\alpha)}\, dj \right]^{(1-\alpha)/\alpha}$$

Equation <2.41> shows that this type of economy in which investment consists of developing new high-tech products(i.e. z(i)) sustains long-run growth, only if the real interest rate(i.e. $r - \dot{P}_Z/P_Z$) remains above the subjective discount rate(ρ), or only if the marginal product of capital remains higher than the subjective rate of time preference.

In reality, the stock of knowledge capital(K_n) which is measured by the number of blueprints, rises over time in an innovation economy, and this knowledge stock raises the productivity of resources in manufacturing and research labs. Cumulative experience in R&D raises the productivity of labs by raising the stock of knowledge capital available to researchers. To capture these features, Romer(1990a) assumes that the stock of knowledge capital equals cumulative experience in R&D as measured by the number of brands that have been developed:[15]

$$K_n = n \ldots\ldots\ldots\ldots\ldots\ldots <2.42>$$

Then, the steady state is characterized by the following two equations:

$$ag + X = L \ldots\ldots\ldots\ldots \quad <2.43>$$

$$(1\text{-}\alpha)X / \alpha a = \rho + \beta_Z g \quad ,where\ \beta_Z = 1 + (v\text{-}1)(1+\alpha)/\alpha > 0 \ldots\ldots\ldots\ldots <2.44>$$

Equation<2.43> represents the resource(i.e. labor) constraint, while g(= $\dot{n}$ /n) is the rate of innovation. Equation<2.44> describes the no-arbitrage condition in which the left side represents the inverse of the price earning ratio and the right side represents the effective cost of capital.

<Figure 2.1> shows the fundamental trade-off between resource allocation in innovation(i.e. g) and manufacturing(i.e. X), as "g" denotes the rate of innovation and "X" denotes the resource(labor) employed in manufacturing. The line LL(i.e. equation<2.43>) represents the **resource(labor) constraint**, while NN(i.e. equation<2.44>) represents the **no-arbitrage condition**, which is often called the **"Schumpeterian line"**.[16]

The intersection A describes a long-run equilibrium. Growth is constrained by resource availability and by market incentive.

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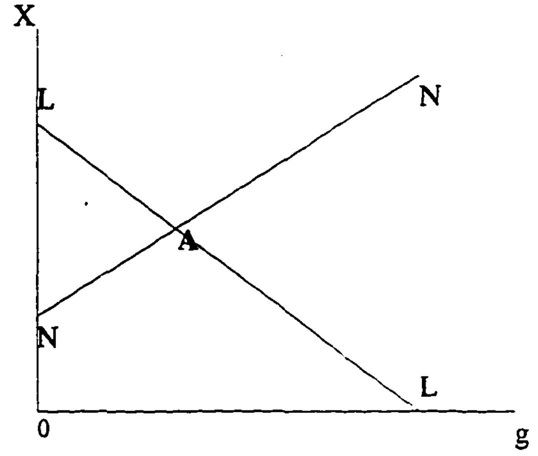
[15] This means that every developer of a new brand contributes equally to the future stock of knowledge.
[16] This is so because the line NN embodies the notion that innovation is driven by the quest for profit opportunities.

< **Figure 2.1**>

Equilibrium of Resource Allocation

between Manufacturing(X) and Innovation(g)



The conclusion is that a country innovates faster (and so the long-run growth rate is higher), when it has

(1) a larger resource base(i.e. an expansion of L shifts out the LL line)

(2) a lower rate of time preference(i.e. a reduction of ρ shifts down the Schumpeterian line NN)

(3) a higher degree of monopoly power, $1/\alpha$ (i.e. a reduction of α shifts down the Schumpeterian line)

(4) a higher intertemporal elasticity of substitution, $1/\nu$(i.e. a reduction of ν shifts down the Schumpeterian line).

Evidently, the rate of growth is endogenous. More directly, the rate of innovation in the steady state can be obtained by solving the equation<2.43> and <2.44>:

$$g^* = [\ L(1-\alpha)/a\ - \alpha\rho\ ] / [\alpha + (1-\alpha)\nu\ ] \qquad \text{<2.45>}$$

If we consider physical capital such as plant and equipment (i.e. K) additionally, then the Cobb-Douglas production function of final good(i.e. Y) has the form:

$Y = A\, Z_Y^{\eta}\, K^{\beta}\, L_Y^{\,1-\beta-\eta}$, $\eta, \beta > 0$, $1 > 1-\eta-\beta > 0$ ....<2.46>

Note that K is the stock of physical capital and Z represents a Dixit-Stiglitz index of differentiated products(i.e. intermediate inputs) and L_Y is the labor employed in the production of Y. In this economy, unlike the former model, demand for labor derives from three sources: R&D, production of the final output and manufacturing of differentiated intermediate inputs. Thus, labor clearing condition requires, instead of equation <2.43>,

$ag + X + L_Y = L$ ....<2.43'>

Grossman and Helpman(1991b,Ch5) shows that in this type of an economy with non-depreciating capital, the steady state growth rate of output Y is

$g_Y = [\, \eta(1-\alpha)/\alpha(1-\beta)]\, g$ ....<2.47>

and the rate of investment is

$\dot{K}/Y = \beta g_Y / (\rho + v\, g_Y)$ ....<2.48>

Equation <2.47> and <2.48> evidently shows that the rate of investment in plant and equipment(i.e. $\dot{K}/Y$) increases with the rate of output growth(i.e. g_Y), while the latter(g_Y) increases with the rate of innovation(i.e. g).

Note that investment in plant and equipment is not a primary source of growth in this endogenous growth model, which is the big difference in implication from those of the neoclassical models. The rate of investment only adjusts so as to keep the rate of expansion of conventional capital in line with the growth rate of output.[17]

Rather, the primary sources of growth are a variety of factors that affect the incentive for industrial research and innovation rate such as the rate of time preference(ρ), the degree of monopoly power($1/\alpha$), the intertemporal elasticity of substitution($1/\nu$) and the size of resource base(L).

2.2.3.2 Growth Model with Quality Ladders (Vertical Product Differentiation)

The growth model with quality ladders has emerged to overcome the weakness of the growth model with expanding product varieties by adopting different assumptions[18]: innovation improves the quality of a fixed number of goods. New products drive out old products from the market, and R&D is risky.

However, despite these difference in assumption, the same mechanism of economic growth also works in the model with quality ladders. Moreover, both models have a similar reduced form about the rate of innovation, and the growth rate of output in the steady state. Main implication of the model is

(1) Profit-seeking drives innovation.

(2) Innovation contributes to the society's stock of knowledge.

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[17] In terms of causality, the investment rate and the growth rate of income are simultaneously determined by technological progress that affects them in the same direction, while the pace of technological progress(i.e. g) is endogenously determined by more primitive factors.

[18] The weakness of growth model with horizontal product differentiation is that it assumes new goods are no better than old, that is, society uses old brands side by side with new ones without ever dropping a product. Besides, whereas innovation involves risk taking, the model employs a deterministic R&D technology.

(3) An expansion of knowledge capital reduces future innovation costs. This cost reduction mitigates the decline in the profitability of incentive activity that would have taken place in its absence. As a result, the profitability of innovation can be sustained and so can the output growth rate.

The growth model of quality ladder assumes that a consumer enjoys a unit of good j which was improved m(j) times, $j \in [0,1]$, as much as he would enjoy $\lambda^{m(j)}$ unit of the good.

Then, we can still use intertemporal preferences by means of equation<2.39> and the flow of utility by means of equation<2.40>. But, the real consumption index C_Q, that replaces C_Z, takes the Cobb-Douglas form:

$$C_Q = exp\ [\ \int_0^1 log\, q(j)\, dj\ ] \ldots\ldots\ldots\ldots <2.30''>$$

,where q(j) represents the quality weighted consumption level of good j. The price index of real consumption C_Q is

$$P_Q = exp\ \{ \int_0^1 log\, [\, \tilde{P}\, (j)\, \lambda^{-\tilde{m}(j)}\,]\, dj\, \}$$

,where $\tilde{P}$ (j) is the lowest quality-adjusted-price and $\tilde{m}$ (j) is the number of improvements of the brand of good j that provides the lowest quality-adjusted-price. Then the optimal intertemporal allocation of real consumption is

$$\dot{C}_Q/C_Q = (1\,/\,v)\ [\, r - \rho - \dot{P}_Q/P_Q\,] \ldots\ldots\ldots\ldots <2.41'>$$

Now, a firm does not maintain monopoly power forever, but shuts down when a better variety of its good appears on the market. This means that experience in the improvement of a particular good does not provide a lab with future advantage in the improvement of this good. This implies in turn that whatever learning has taken place during the innovation process becomes public, which results in a "spillover effect" from private R&D to the society's stock of knowledge capital.

Assume that a firm employs "$\iota(l, j) \bullet a$" workers in lab "l" that targets good j to attain a flow density of $\iota(l, j)$ of product improvement. Then, the firm that owns technology to manufacture the top quality brand of good j faces the **hazard rate** "$\iota(j)$" of losing the monopoly profit stream.

The **no-arbitrage condition** is slightly different from equation<2.37>:

$$\pi/V + \dot{V}/V = r + \iota \quad \text{......} \langle 2.37' \rangle$$

In equilibrium, the value of a firm can't exceed "wa" and it has to be equal to "wa" for innovation to take place. Thus,

$V \leq wa$, with equality holding whenever $\iota > 0$.

The **resource constraint** is determined by full employment condition.

$$a\iota + X = L \quad \text{......} \langle 2.43' \rangle$$

$$(1-\lambda^{-1})X / \lambda^{-1}a = \rho + \beta_Q \iota \quad , where\ \beta_Q = 1 + (v-1) \log\lambda \quad \text{......} \langle 2.44' \rangle$$

Equation<2.43'> and <2.44'> complete the full model. The equilibrium rate of innovation(ι^*) is

$$\iota^* = [\, L(1-\lambda^{-1})/a - \lambda^{-1}\rho \,]\, \lambda / [\lambda + (v-1) \log\lambda \,] \quad \text{......} \langle 2.45' \rangle$$

$$g^* = [\, L(1-\alpha)/a - \alpha\rho \,] / [\alpha + (1-\alpha) v \,] \quad \text{......} \langle 2.45 \rangle$$

Comparing equation<2.45'> for quality ladders with equation<2.45> which describes the rate of innovation for horizontal product differentiation, we see that the same logic is working for innovation only with λ playing the role of $1/\alpha$. λ in quality ladder model and $1/\alpha$ in horizontal product differentiation model represent the degree of monopoly power.

In the endogenous growth model with Dixit-Stiglitz type horizontal product differentiation, a market economy always innovates too slowly, while with quality ladders, it may innovate too slowly or too fast. Thus, whenever economies feature endogenous long-run growth, we can expect the growth rate to depend on economic policy. This is more so for economies with innovation-based-growth in which free markets may lead to growth that is either too slow or too fast.

2.3 Endogenous Growth with Int'l Trade in Developing Countries

The rapid growth of the Asian NICs(i.e. newly industrialized countries) such as Hong Kong, Korea, Singapore and Taiwan can't be easily explained in the context of the neoclassical model which mainly cares about the accumulation of physical capital.

Besides, by 1960, most of the NICs already had a higher level of education. But many other poor countries that didn't grow, had also similarly high level of education.[19] This means that the human capital theory is not sufficient to explain the past experience of economic development.

[19] Pack and Page(1994) mentions India as one of the examples.

In the innovation-based-growth models of the endogenous growth theories, externalities arise from improved designs or variety in the production sector of domestic intermediate goods. However, since the Asian NICs have imported a very large percentage of their machinery for much of the period, there is little theoretical basis for arguing that those externalities have been generated by the innovation of domestically produced intermediate goods. Also, there was relatively little formal R&D in the Asian NICs until the mid-1980s.

If the extent of international trade and the resulting transfer of knowledge and the variety of intermediate inputs affect the rate of productivity growth, then the pure production function approach as captured in either neoclassical or early version[20] of the endogenous growth theory loses its persuasive power.[21] The endogenous growth theories that stress the role of externalities from R&D spillover and/or capital accumulation have provided a clue to consistently explain the rapid growth through international knowledge spillover or more efficient capital accumulation by trade.

They postulate that the expanded international trade ,especially imports, increase the variety of differentiated intermediate inputs, increasing growth rates as economies become open to international trade.[22] Besides, it should be noticed that there are many

[20] Linear model or human capital model of the endogenous growth theories.

[21] However, part of this growth in productivity stemming from increasing international trade is undoubtedly facilitated by improved "domestic absorption capacity" made possible by higher levels of human capital as suggested by Lucas(1988) and Rebelo(1991). This would suggest the Asian NICs have benefited from the interaction of rapid transfers of technology and a highly skilled labor force which can adapt it to local needs.(quoted in Pack(1994))

[22] Romer(1990a) and Grossman and Helpman(1991a,Ch6; 1991e) study the growth performance of a small country in which knowledge flows from abroad are related to its extent of foreign trade, which generate externality that coexists with the externality of domestic innovation, while Rivera-Batiz and

types of useful knowledge which are not embodied in material inputs such as production engineering and information about changing product patterns. They are likely to be transferred as a result of expanded international trade.[23] Suggestive firm-level empirical evidence of the importance of transfers of knowledge rather than machinery had been partially identified for Korea.[24] Pack and Page(1994) provides evidence that exports are also important in explaining international difference in productivity growth.

2.3.1 Knowledge Spillover of Innovation-Based-Growth to Developing Countries

Grossman and Helpman(1991a,e) extend the innovation-based-growth model to a small developing country[25] in which technological knowledge spillover from abroad and the resulting increase in the variety of intermediate inputs are related to its extent of foreign trade.

They start from modeling endogenous technical progress that results from the profit maximizing behavior of entrepreneurs who invest in R&D in order to capture monopoly rents from innovative products. They assume that the productivity of their employers in

Romer (1991) provide a model in which integration between developed countries can increase long-run growth rate if it encourages the worldwide exploitation of increasing returns to scale in the R&D sector.

[23] Pack(1992)

[24] Westphal and Rhee(1981)

[25] Edwards(1992) suggests a test model and an empirical test results for developing countries in which knowledge spillovers from developed countries through trade work as a main source of technological development and economic growth of developing countries. Brecher,Choudhri and Schembri(1996) suggest a two-country model of a monopolistically competitive industry in which the production function or technology shifts endogenously via national and international knowledge spillover, implying that in the long-run the growth rate of sectoral productivity is the same in each country. For a number of matched Canadian and US manufacturing industries, the paper finds that these two countries' rate of sectoral productivity growth tend to converges despite marked international differences in R&D.

the research lab depends on the general knowledge level of the country stock of knowledge capital. This knowledge capital may increase with the number of contacts that local agents have with their counterparts in the international R&D communities. More generally speaking, it increases with the volume of international trade.[26]

Consider a small economy which is endowed with a single primary factor, labor(L). Households consume two final products(i.e. Y and M), but the country specializes in the product of Y and imports M. Firms produce the good Y using labor(L) and a set of horizontally differentiated intermediate products(χ). Assume that the production function for good Y takes the Cobb-Douglas form, while the production function of intermediate goods χ has the form of constant elasticity of substitution(C.E.S.):

$$Y = A\,L_Y^{\,1-\beta}\,[\int_0^n \chi(\omega)^\alpha\, d\omega]^{\beta/\alpha}, \quad 0< \alpha,\beta<1 \quad \text{.................................} \langle 2.49\rangle$$

Note that β represents the income share of whole intermediate goods used in the production of good Y, and that $1/\alpha$ means an index of monopoly power of a firm which innovates and produces the intermediate good $\chi(\omega)$. n(t) represents the number of variety available on the market at time t.

With C.E.S. between varieties, each monopolist sets a price that is a constant mark-up over its marginal costs:

$P_\chi = w/\alpha$,where w is the wage rate.[27]

Then, equation<2.49> can be simplified as

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[26] This argument hinges on the public good characteristics of many forms of knowledge: knowledge is not only non-rival, but also non-excludable, which means that the same idea can be used by different users at the same time, and that spillover benefits may be created in the process of innovation.

[27] Under the assumption that each unit of any intermediate is produced with one unit of labor, marginal cost of producing each intermediate is equal to the wage rate(w).

$$Y = A L_Y^{1-\beta} X^{\beta} n^{\beta(1-\alpha)/\alpha}, \quad 0< \alpha,\beta<1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots<2.50>$$

,where $X \equiv n\chi$[28] is the aggregate quantity of intermediate inputs used, and also the amount of labor embodied in these intermediate inputs.

In the steady state without trade and international spillover, output Y grows at the rate

$$g_Y = g\,\beta(1-\alpha)/\alpha$$

$$= g\,\beta(1/\alpha\ -1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots<2.51>$$

. ,where g ($=\dot{n}/n$) is the innovation rate at which new varieties of intermediate inputs are being introduced to the economy.

Now, let's assume that an entrepreneur can invest a measure "dn" of new variety of intermediate goods by applying (a/K)dn units of labor per unit time to research, where "a" is a constant and "K" denotes the economy's knowledge capital stock. Knowledge capital may accumulate through local R&D or international knowledge spillover.

Suppose that the extent of the spillovers between two countries will increase with the volume of trade. Then, the knowledge capital equation<2.42> in the domestic innovation-based-growth model can be modified as

$$K(t) = F[\,n(t),\ T(t)\,] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots<2.52>$$

,where T(t) denotes the cumulative volume of trade(exports and imports) up to time t and n(t) is the number of available varieties.

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[28] It is assumed that each intermediate is demanded to the same extent. $\chi=\chi(\omega)$.

If we take F(•) to be increasing in both arguments and homogeneous of degree one, then equation<2.52> can be rewritten as

$$K = n\ \varphi(T/n) \quad , \varphi' > 0 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots <2.53>$$

,where $\varphi(\bullet) \equiv F[1, T(t)/n(t)]$.

Like equation<2.37>, no-arbitrage condition is

$$\pi/V + \dot{V}/V = r \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots <2.54>$$

Plugging the free entry condition (i.e. V= wa/K) into equation<2.54> modifies the no-arbitrage condition as

$$(1-\alpha)X\varphi/\alpha a \ + \ \dot{w}/w \ - \ \dot{K}/K = r \ \ldots\ldots\ldots\ldots\ldots\ldots <2.55>$$

,where π is an infinite stream of profit from sales of $\chi(t)$ ($=X(t)/n(t)$) units at the price P_χ ,and V is the value of a innovative firm. r denotes the normal rate of return or market interest rate.

Similarly to equation<2.39>, intertemporal utility function of a representative household is

$$U_t = \int_t^{\infty} e^{-\rho(\tau - t)} \ \log u[C_Y(\tau), C_M(\tau)] \ d\tau \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots <2.56>$$

,where $C_i(\tau)$ is the consumption of final good i(=Y,M).

Dynamic optimization requires that spending E evolves according to

$$\dot{E}/E = r - \rho \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots <2.57>$$

If we suppose for a moment that $\varphi(T/n)$ converges to a finite value $\tilde{\varphi}$, then the small economy approaches a steady state and the rate of growth of knowledge capital converges on g such that

$\dot{K}/K = g$ ....<2.58>

The aggregate budget constraint limits the spending growth to the growth rate of final output, and wages grows at the same rate:

$\dot{E}/E = g\,\beta(1-\alpha)/\alpha = \dot{w}/w$ ....<2.59>

Plugging equation<2.57>~ <2.59> into <2.55> yields the no-arbitrage condition in the steady state as

$(1-\alpha)X\tilde{\varphi}\;/\alpha a = g + \rho$ ....<2.60>

The labor market clearing condition is similar to equation<2.43'>:

$ag/\tilde{\varphi}\;+ X + L_Y\; = L$ ....<2.61>

,where the three terms represent employment in R&D($ag/\tilde{\varphi}$), intermediate good manufacturing(X) and final good manufacturing(L_Y), respectively.

Through the cost minimization,[29] equation<2.61> yields the resource constraint

$ag/\tilde{\varphi}\;+ b_L X\; = L$, for constant $b_L > 1$ ....<2.61'>

Equation <2.60> and <2.61'> show how the economy will assign total resources(L) between manufacturing(X) and R&D(g) in the steady state when there are knowledge spillovers by trade from abroad.

Comparison of the innovation-based-growth model without international spillover and that with international spillover through trade, provide a clear insight of the difference:

Model without international spillover consists of resource constraint equation<2.43> and no-arbitrage condition equation<2.44>

[29] Cost minimization of good Y makes L_Y/X a function of P_χ/w.

$ag + X = L$ .... <2.43>

$(1-\alpha)X / \alpha a = \rho + \beta_Z g$,where $\beta_Z = 1 + (v-1)(1+\alpha)/\alpha > 0$ ....<2.44>

Model with international spillover consists of resource constraint equation<2.61'> and no-arbitrage condition equation<2.60>.

In the steady state, consumption of each good grows at the same rate(i.e. $\dot{C}_Y / C_Y$ and $\dot{C}_M / C_M$) as final output(i.e. g_Y). Thus, the volume of trade grows at the same rate:(i.e. $\dot{T}/T$):

$g_Y = \dot{C}_Y / C_Y = g\,\beta(1-\alpha)/\alpha = \dot{E}/E = \dot{w}/w = \dot{C}_M / C_M = \dot{T}/T$ ....<2.59>

That is,

$\dot{T}/T = g\,\beta(1-\alpha)/\alpha$

$= [\dot{n}/n]\,[\beta(1-\alpha)/\alpha]$.................................<2.62>

or $(\dot{T}/T) / (\dot{n}/n) = \beta(1-\alpha)/\alpha$.................................<2.62'>

It follows from equation<2.62'> that T/n will either shrink to zero, grow without bound, or tend to a constant in the long-run, depending on whether α is larger than, smaller than, or equal to $\beta(1-\alpha)$.

(Case1) If $\alpha > \beta(1-\alpha)$, then $(\dot{T}/T) / (\dot{n}/n) < 1$. Thus, the growth rate of trade volume is smaller than that of varieties of intermediate goods. Since $1 > \beta(1/\alpha - 1)$, this is the case in which income share(β) of intermediate inputs in the production of final good Y is small and the monopoly power($1/\alpha$) of firms producing intermediate inputs is small.

Then, the relative importance of international knowledge spillovers as a source for the accumulation of domestic knowledge capital declines over time. Thus, the economy tends to a steady state with the knowledge capital $\dot{K} = n\tilde{\varphi}$, where $\tilde{\varphi}$ (≡F(0)) is a just a positive constant.

Growth in the long-run is determined entirely by the available resources and by parameters describing tastes and technologies.[30] Trade policy will affect the economy along the transition path only before the steady state. Policies that serve to to expand the "level" of trade[31] promote contacts between local and foreign residents. Trade promotion policies accelerate the rate of knowledge accumulation and growth before the economy reaches the steady state.

In this case, the steady state innovation rate is

$$g^* = [\, L\tilde{\varphi}(1-\alpha)/a \; - \alpha\, b_L\, \rho] \,/\, [\, \alpha\, b_L + (1-\alpha)\,] \quad \text{.........<2.63>}$$

(Case2) If $\alpha < \beta(1-\alpha)$, then the ratio of trade volume to the number of varieties tends to infinity. Two possibilities exists:

(1) It may converge to a finite constant, if F(•) had a C.E.S. form with elasticity of substitution between domestic and foreign sources in excess of one. Then, the long-run equilibrium is the same as for an economy that does not learn from abroad.

[30] See Grossman and Helpman(1991a) for the details.

[31] However, trade policies that serves to change the "structure of trade" by changing "industrial structure" may lead to different conclusion even for the long-run.

(2) However, if $\varphi(=K/n)$ has no bound , then productivity in the research lab also increases without bound. This causes the rate of innovation and utility growth to become unbounded.

(Case3) If $\alpha = \beta(1-\alpha)$, then the volume of trade and the number of varieties grow at the common rate(g) in the long-run. The ratio of trade volume and varieties approaches an endogenously determined finite value (i.e. $\tau \equiv \lim T(t)/n(t)$ as $t \to \infty$).

In this case, long-run equilibrium is determined by the two equation system <2.60> and <2.61'>.

Trade promotion policy such as a reduction in the tariff rate causes consumer to increase the consumption of imported good(M) by reducing that of domestically produced good(Y) at the first time. But, the long-run ratio of the cumulative trade volume to the number of varieties must rise. This in turn causes $\varphi(=K/n)$ to rise even in a steady state, which acts like a boost to productivity in the research lab. Hence technical progress accelerates and the economy grows more quickly.

The steady state rate of innovation is

$$g^* = [\, L\, \varphi(\tau)\, (1-\alpha) / a \; - \alpha\, b_L\, \rho] \, / \, [\, \alpha\, b_L + (1-\alpha)\,] \, , \; b_L > 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \langle 2.64 \rangle$$

Comparison of equation<2.64> with equation<2.45> of no international spillover , will provide a clear insight into the role of international knowledge spillover by trade.

Besides, a developing country that imports human capital intensive goods finds that international integration reduces derived demand for human capital and so lowers the cost of innovation. In such a country, the indirect effect of trade is also to encourage growth.

Growth may be too fast or too slow in a small country that generates endogenous productivity gains from knowledge spillovers. In any event, a technology policy(i.e. R&D tax or subsidy) can always be used to raise the social welfare and an appropriate intervention of this sort coupled with a subsidy to intermediate input production can achieve the first best.[32]

2.3.2 Model of Southern Imitation and the Product Cycle[33]

Most firms in the developing countries(South) confine their technological effort to imitating products developed abroad, while many firms in the developed countries(North) race to bring out the latest innovative products. This pattern of invention in the North and imitation in the South gives rise to a "**product life cycle**" in international trade: Northern firms produce and export many goods early in their technological lives, then manufacturing shifts to the South as production methods become more widely known.

At a first glance, it may seem that such product cycle trade must be detrimental to the incentive to invest in new technologies. However, the endogenous growth literatures[34] show that this is not necessarily so.

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[32] Grossman and Helpman(1991a, p170-1)
[33] Grossman and Helpman(1994)
[34] Krugman(1979) made the first attempt to formalize some of the idea contained in Vernon(1966)'s product life cycle theory, but without endogenous innovation and imitation. Jensen and Thursby(1986,1987) introduced a decision theoretic framework into Krugman model, but only with a single agent in North and South. Grossman and Helpman(1989a) developed a model of endogenous product cycle. Studies in this area have been followed by Grossman and Helpman(1989b;1991b,c,d) and Segerstrom et al(1990).

The endogenous growth models identify two contradictory effect of product cycle trade on the incentives to innovate:

The pro is the argument to which the unlucky Northern firms point: Imitators reduce the rewards that accrue to the originators of new ideas.

However, the con argues that whereas no Northern innovator wants to see its own technology copied, every such firm is happy to see foreign companies master the technologies of its domestic rivals.[35] When this happens, production factories move abroad and resources are related by the targeted producers. Some of these resources may find their way into the factories of the surviving Northern manufactures of innovative products. Then, sales for these firms will expand and profits rise.

In short, while a faster rate of Southern imitation means a shorter duration of monopoly profits for the typical Northern innovator, it may also mean a higher level of profits while that monopoly position lasts.

Grossman and Helpman(1991a, Ch11 and Ch12) offer models which illustrate that product cycle trade-by easing Northern manufacturer's demands for scarce resources-actually can accelerate innovation and growth in the global economy.

Helpman(1993) takes the argument one step further by showing that the Northern countries can actually benefit in welfare terms from a relaxation of Southern enforcement of intellectual property rights, that is, increased Southern imitation.

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[35] Grossman and Helpman(1994,p41-2)

2.3.3 Model of Efficiency in Capital Accumulation

In the model of innovation-based-growth, imports of foreign inputs are an important determinant of the link between trade and growth by increasing the knowledge capital or knowledge spillover.

Lee(1994), however, emphasizes another link between foreign intermediate goods and growth- the efficiency of capital accumulation. The price of capital goods has been relatively cheaper in developed countries. Thus, developing countries can increase the speed of capital accumulation by importing the relatively cheaper capital goods, which will in turn accelerate the output growth according to the model of externalities from capital accumulation such as learning by doing and division of labor.

To show this connection, Lee(1994) extends a recent endogenous growth model of Rebelo(1991)[36] in which two final goods- one consumption and one capital good-are produced and the capital good sector determines the long-run growth rate of per capita income. Developing countries imports capital goods from developed countries and combines them with domestic capital goods for the production of its core capital goods sector. The cheaper foreign capital goods then make the less developed country grow faster. Hence, the growth rate is higher in a country that uses imported inputs relatively more than domestically produced intermediate goods for investment.

[36] As is introduced in the earlier section, Rebelo(1991) is of the Linear model(AK type) of the endogenous growth theories. Rebelo(1991) implies that the relative price of the capital good decreases over time along the balanced growth path, and so the price of the capital good relative to the consumption good is cheaper in a higher income country which has a larger capital stock.

As described in the earlier section, Rebelo(1991) assumes that final consumption good(C) is produced by a Cobb-Douglas combination of capital and labor:

$C = (\phi K)^{\alpha} L^{1-\alpha} \quad , 0<\alpha,\phi<1$ .... <2.16'>

,where ϕ is a fraction of the capital stock employed in the consumption good sector.

Capital good is produced using only capital stock:

$I = \dot{K} = a\,(1 - \phi)\,K$ .... <2.17'>

Profit maximization condition requires that marginal productivity of capital will be the same in both sectors:[37]

$pa = C = \alpha(\phi K)^{\alpha-1}$ .... <2.65>

,where p is the relative price of capital good in terms of consumption good. Since α-1<0, equation<2.65> implies that the relative price of the capital good is cheaper in a country with a higher per capita capital stock.

National income which is measured in terms of the consumption good is

$Y = C + pI = [\,1 + \alpha(1-\phi)/\phi\,]\,C$ .... <2.66>

Then, Rebelo(1991) draws the steady state growth rate of income as

$g_Y = \alpha\,(A - \rho)$ .... <2.70>

Equation<2.70> implies that the lower the time preference(ρ) and the more productive(A), the economy grow faster.

Lee(1994) assumes that the developing country's capital good is produced by a Cobb-Douglas combination of a domestic capital good(I_D) and an imported capital good(I_M):

[37] To simplify, the total size of labor L is normalized to one.

$$I = I_D^{1-\gamma} I_M^{\gamma} \quad , \; 0< \gamma <1 \; \ldots\ldots\ldots\ldots <2.71>$$

If we denote "m" for the ratio of imported to domestic capital good in the production of capital good, that is,

$$m = I_M / I_D \ldots\ldots\ldots\ldots\ldots\ldots <2.72>$$

,then equation<2.71> can be rewritten as

$$I = [A(1-\phi)K]\, m^{\gamma} \quad ,where\ I_D = A(1-\phi)K \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots <2.73>$$

Profit maximization condition gives

$$pA(1-\gamma)m^{\gamma} = \alpha\, \phi^{\alpha-1} K^{\alpha-1} \; \ldots\ldots\ldots\ldots\ldots\ldots <2.74>$$

$$P_M = p\gamma m^{\gamma-1} \; \ldots\ldots\ldots\ldots\ldots\ldots <2.75>$$

,where P_M denotes the price of the imported capital good.

Equation<2.74> and <2.75> yields the equilibrium m:

$$m^* = \gamma / [A\ \alpha\, (1-\gamma)\, P_M\ (\phi K)^{1-\alpha}] \ldots\ldots\ldots\ldots\ldots\ldots <2.76>$$

Equation<2.76> shows that, given capital stock(K) and other parameters, a cheaper imported capital good leads to a higher value of m, the ratio of imported capital in investment.

From equation<2.73>, the growth rate of capital stock is given by

$$\dot{K}/K = A(1-\phi)\, m^{\gamma} \; \ldots\ldots\ldots\ldots\ldots\ldots <2.77>$$

National income is given by

$$Y = C + (1-\gamma)pI = [\, 1 + \alpha(1-\phi)/\phi\,]\, C \ldots\ldots\ldots\ldots\ldots\ldots <2.78>$$

The balanced growth rate of income is given by

$$g_Y = \alpha\, [A(1-\gamma)m^{\gamma} - \rho\,] \ldots\ldots\ldots\ldots\ldots\ldots <2.79>$$

Equation<2.77> and <2.79> show that the growth rates of capital and income are higher in an economy with a higher ratio of imported capital in investment(i.e. m).

Now, by replacing P_M with equation<2.65>, equation<2.76> can be rewritten as

$$m = [\gamma/(1-\gamma)]\ (\phi^* K^* / \phi K)^{(1-\alpha)/\alpha}$$

$$= [\gamma/(1-\gamma)]\ (y^*/y)^{(1-\alpha)/\alpha}\ J \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots <2.80>$$

,where $J \equiv \{ [(1-\alpha) + \phi^{-1}] / [(1-\alpha) + \phi^{*-1}] \}^{(1-\alpha)/\alpha}$. * denotes the developed countries and y is the per capita income.

Equation<2.80> implies that, given other parameters, the ratio of imported capital goods in investment(m)decreases as income gap(y*/y) between developing and developed countries decreases. Thus, as developing countries approach the steady state, the ratio of imported capital goods(m) and thereby the growth rates of income and capital decrease.

This prediction implies a "**growth slowing-down** or **convergence of income**": The growth rate of income is higher in lower income countries. It needs to be noted that although the model is built on the endogenous growth model, the conclusion leads to the convergence of income through trade among countries.

2.3.4 Model of Externalities from Export

Studies about the linkage between exports and economic growth in developing countries began to attract new attention from late 1970s when the Asian NICs had recorded remarkable growth rates based on export-oriented-strategies.[38] The poor

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[38] Balassa(1978),Krueger(1980),Tyler(1981),Feder(1982),Kavoussi(1984),Ram(1985,1987), Kohli and Singh(1989)

performance of the Latin American countries that had pursued the import-substitution-strategies provided a good example of comparison and gave rise to a strong interest in the export-oriented-strategies as an engine of economic development.

However, it was not until late 1980s that the description of the role of exports in growth began to have a close connection with the framework of the newly emerging endogenous growth theories.[39] Even though these new studies try to be basically in the category of the endogenous growth theories, their models have inherited so much from the earlier studies about the role of exports: They treat exports as a kind of production input, which raises national output through externalities. The increase of exports is supposed to bring about more externalities, and so raises the output. Some endogenous growth models such as Sengupta(1991,1993) have considered the role of human capital in the production function, which can also increase by international knowledge spillover or externalities from exports.

Studies on the export-economic growth nexus have been conducted along a number of divergent lines.[40]

(1) The initial tests were done on a "bivariate level" to study the **correlation coefficient** between exports and economic growth in levels and then in terms of growth rate.[41]

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[39] Sengupta(1991,1993), Edward(1992), Chou(1995)

[40] Refer to Dutt and Ghosh(1996,p167-9)

[41] See Jung and Marshall(1985) to review previous empirical studies.

(2) There have been relatively recent studies on the **bivariate causality** between exports and economic growth,[42] using Granger(1969), Sims(1972) and Hsiao(1981,1987) causality test or

Error Correction Model by Engle and Granger(1987).

(3) Different kind of effort has been made on finding the **transmission mechanism between export growth** via other economic growth-determining fundamentals such as labor and capital in a **production-type function**.[43] **Growth accounting analysis** to decompose the contribution of factor growth and the growth of total factor productivity has diversified the studies which aim at figuring out the role of exports.[44]

Several papers using the production function approach have highlighted various beneficial aspects of exports. Ram(1985, 1987) describe the role of exports as following: Exports have a significant indirect effect (externality effect) [45] as well as direct effect of increasing production to meet the increased demand from abroad. High level of exports leads to a better allocation of resources by realizing comparative advantage and reducing X-inefficiency in production. Expansion of exports may also facilitate exploitation of economies of scale, and make for increased capacity utilization.

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[42] Jung and Marshall(1985),Chow(1987),Bahmani-Oskooee,Mohtadi and Shabsigh(1991), ,Dodaro(1993), Bahmani-Oskooee and Alse(1993),Dutt and Ghosh(1996). The last two papers apply cointegration and Granger ECM model considering the nonstationarity of variables.

[43] Balassa(1978),Krueger(1980),Tyler(1981),Feder(1982),Kavoussi(1984),Ram(1985,1987), Kohli and Singh(1989), Kwak(1994).

[44] Kawai(1994),Kwak(1994)

[45] The specific researches of externalities from international trade include Bhagwati(1978) which considers "scale economies" the largest benefit of the export promotion trade strategy, Feder(1982) which take into account the "reallocation of existing resources" from less efficient nonexport sector to higher productivity export sector, and Grossman and Helpman(1991a-e) which sees the "international knowledge spillover" generated by trade coexisting with the externality of domestic innovation.

Moreover, expansion of exports relaxes the foreign exchange constraint and may raise the productivity of labor and capital by enabling the economy to import advanced capital goods within the framework of two-gap models of development. Especially, as is emphasized by the endogenous growth theories, exports work as a conduit of knowledge spillover from advanced economies, and strengthen inducement for technological change. This knowledge spillover works again as a conduit that enables the economy to realize increasing returns.

To specify these ideas, Balassa(1978) and Tyler(1981) adopted the specification of a straightforward production function model that treats exports as similar to a production input:

$$Y = f(K, L, X) \ldots\ldots\ldots\ldots\ldots\ldots <2.81>$$

,where Y is the aggregate real output, K is the capital stock. X denotes exports and it is included as a kind of production input like labor(L) and capital(K), because exports are assumed to create externality effect affecting the total factor productivity.

Inheriting the idea, Feder(1982) develops a model to show how exports exert their externalities on the non-export sector and the whole economy to increase the aggregate real output. These externalities are incorporated in the two sector general equilibrium model as:

$$N = F(K_N, L_N, X) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots <2.82>$$

$$X = G(K_X, L_X) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots <2.83>$$

,where N and X are the output of non-export sector and export sector, respectively. F and G are their respective production functions, so that there is an externality from the export sector to the non-export sector. K_j and L_j denote capital and labor force respectively of sector j (j = N,X) .

Marginal products in two sectors may deviate from unity by a margin(δ): i.e.

$$G_K/F_K = G_L/F_L = 1 + \delta \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{<2.84>}$$

,where the subscripts denote partial derivatives. The positive effects of export is the result of positive externalities: That is,

$$F_X > 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{<2.85>}$$

Also, marginal products are likely to be higher in the export sector[46]: i.e.

$$\delta > 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{<2.86>}$$

Differentiating equation <2.82> and <2.83>, and using the relation Y= N+X, we can get

$$\begin{aligned}\dot{Y} &= \dot{N} + \dot{X} \\ &= F_K I_N + F_L \dot{L}_N + F_X \dot{X} + (1+\delta)F_K I_X + (1+\delta)F_L \dot{L}_X \\ &= F_K (I_N + I_X) + F_L(\dot{L}_N + \dot{L}_X) + F_X \dot{X} + \delta(F_K I_X + F_L \dot{L}_X) \\ &= F_K I + F_L \dot{L} + F_X \dot{X} + \delta(F_K I_X + F_L \dot{L}_X) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{<2.87>}\end{aligned}$$

Since $\dot{X} = G_K I_X + G_L \dot{L}_X$, $F_K = G_K/(1 + \delta)$ and $F_L = G_L/(1 + \delta)$,

thus equation<2.87> can be modified as

$$\dot{Y} = F_K I + F_L \dot{L} + [\delta/(1+\delta) + F_X]\dot{X} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{<2.88>}$$

46 One important reason is the more competitive environment in which export-oriented firms operate. Competition induces innovativeness, adaptability and efficient management. Higher uncertainty and various constraints such as credit and foreign exchange rationing may be another reason(Balassa(1977)).

Assuming that the marginal product of labor is proportional to its average product, i.e. $F_L = \beta \bullet (Y/L)$, Feder was able to derive the following "**sources-of-growth equation**" from equation<2.88>:

$$\dot{Y}/Y = \alpha \bullet (I/Y) + \beta \bullet (\dot{L}/L) + [\delta/(1+\delta) + F_X](\dot{X}/X)(X/Y)$$

or $$g_Y = \alpha S_i + \beta g_L + \gamma g_X S_X \quad \text{................}<2.89>$$

,where $g_Y(=\dot{Y}/Y)$ is the growth rate of GDP, S_i (=I/Y) is the share of investment in GDP, $g_L(=\dot{L}/L)$ is the growth rate of labor, $g_X(=\dot{X}/X)$ is the growth rate of exports and S_X (= X/Y) is the share of exports in GDP.

Note that the parameter $\alpha(\equiv F_K)$ represents marginal productivity of capital in the non-export sector, and the parameter $\beta(\equiv F_L/(Y/L) = (dF/dL)/(Y/L))$ represents elasticity of output with respect to labor in the non-export sector.

The parameter γ $(\equiv \delta/(1+\delta) + F_X)$ measures the difference between the marginal contribution to GDP of production factors relative to the marginal contributions of these factors to export sector's output, which is the combination of externality effect(F_X) and higher marginal productivity($\delta/(1+\delta)$) of export sector. It is expected that γ is positive and significantly different from zero.[47]

Feder(1982) also developed a method to decompose the factor productivity differential γ into its components for empirical test. Suppose that exports affect the production function of non-export with constant elasticity(θ):i.e.

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[47] Feder(1982) found in a regression for semi-industrialized LDCs(less developed countries) of the period 1964 - 73 that γ is positive and significantly different from zero.

$N = F(K_N, L_N, X) = X^{\theta}\,\Psi(K_N, L_N)$ ....<2.90>

Then, equation<2.89> takes the form

$g_Y = \alpha S_i + \beta g_L + [\delta/(1+\delta) - \theta]\, g_X S_X + \theta g_X$

$= \alpha S_i + \beta g_L + [\delta/(1+\delta)]\, g_X S_X + \theta g_X (1-S_X)$.............<2.91>

In equation<2.91>, the effects of higher marginal productivity($\delta/(1+\delta)$) and externality(θ) are separated out. In addition, Feder assumes that

$\delta/(1+\delta) = \theta$

,then equation<2.91> yields the simple growth rate of output in the long-run:

$g_Y = \alpha S_i + \beta g_L + \theta g_X$ ....<2.91>[48]

If $\theta < 1$ in equation<2.91> or<2.92> as Feder(1982) found empirically, there are diminishing returns to the externality effect of export sector's growth.[49]

The model <2.89> or <2.91> in Feder(1982) have been adopted by many empirical studies afterwards to study the impact of export on total factor productivity.

However, it is difficult to apply such a Feder-type two sector framework to a situation in which one wishes to study the impact of other unconventional inputs such as imports, foreign direct investment and government expenditure along with that of exports.[50]

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[48] If we differentiate equation<2.81>, Y=f(K,L,X), then we can get equation<2.92> directly. Note in this case that we are assuming that the difference in productivity between export and non-export sector is equal to the externalities from exports.

[49] Kohli and Singh(1989) indicate that there are no diminishing returns in the Feder(1982) model such as equation<2.91> and <2.92>, since the relation is linear. Instead, they adopt a quadratic term to specify the diminishing returns to the externality effect of exports as

$g_Y = \alpha S_i + \beta g_L + \gamma g_X S_X + \mu (g_X S_X)^2$.............<2.93>

Now, $\mu < 0$ implies diminishing returns to the effect of exports on GDP growth, since then $d^2 g_Y / d g_X^2 = 2\mu S_X^2 < 0$, and $d^2 g_Y / d S_X^2 = 2\mu g_X^2 < 0$.

[50] Ram(1987,p53-4)

Thus, many studies[51] after Feder(1982) have directly adopted the aggregate production function like equation<2.81> instead of two sector model, considering the broad range of externality effect by exports and imports etc..[52]

The endogenous growth models such as Sengupta(1991,1993) address the similar idea to analyze the broad externality effect of exports in the aggregate production function-type models.

Inheriting the same idea, but enlarging it to address the role of imports as suggested in the endogenous growth literature, this dissertation adopts the aggregate production function which includes exports and imports as a kind of production factor exerting much broader range of externalities: externality from more efficient capital accumulation and externality from knowledge spillover in the innovation-based-growth models.

2.4 Growth Slow-down of Developing Countries

2.4.1 Misunderstandings of the Convergence Hypothesis for Developing Countries

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[51] Refer to Ram(1985,1987)

[52] Ram(1987,p70) notes that other kinds of linkage between exports and economic growth can be plausibly proposed. For example, it is possible that imported intermediate inputs constitute the main export-related source of growth, and exports might serve only as a proxy for such inputs or for foreign exchange availability for importing such inputs.
Kavoussi(1984,p248-9) also notes that there are indications that growth of exports tends to accelerate the rate of capital formation by raising the savings and/or imports. This kind of theory provides a motive to adopt the production function like equation<2.81> to make it possible to analyze the broad effect of exports for more imports and the resulting knowledge spillover effects as suggested in the endogenous growth models.

The neoclassical theories have been interpreted as implying "convergence" across countries in either growth rates or income levels: The growth rates of the poorer countries should be greater.

Poorer nations will initially exhibit lower capital-labor ratios, which implies a higher marginal product of capital.

Given equal rates of exogenous technical progress, savings and labor force growth between countries, the capital stock growth of poorer countries will exceed those in developed countries[53] and they should converge to the capital-labor and capital-output ratio of developed countries.

However, since the basic assumption of equal technical savings and population growth is unrealistic, it is thus necessary to test for "**conditional convergence**", which simply means examining whether per capita income levels converge after adjusting for differences in investment/GDP ratios and population growth ratios. If conditional convergence is found, it has been interpreted as confirming the existence of diminishing returns to capital.[54]

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[53] Poorer countries that begin with a lower capital-labor and capital-output ratio will have a faster rate of growth of the capital stock, which means in turn a faster growth rate of income. Note that the growth rate of the capital stock is $\dot{K}/K \equiv I/K = (I/Y)(K/Y)$. If the rate(I/Y) in numerator is fixed, then a lower capital stock in the denominator implies faster growth.

[54] Convergence or conditional convergence have been proved to occur among the OECD countries by Barro(1991), Mankiw, D.Romer and Weil(1992) and Ben-David(1996). Dollar(1992) tries the empirical test of the convergence between Korea and West Germany for the period 1966-78.

In contrast, the endogenous growth theories have been interpreted, at least in the earlier stage,[55] to imply non-convergence or the possibility of sustained differences in both levels and growth rates of national income. Because of the externalities or the productivity gains obtained from the availability of differentiated inputs made possible by capital accumulation and/or R&D, diminishing returns to human and physical capital do not occur. Also, absence of conditional convergence often adjusting for differences in investment/GDP ratio etc., has been interpreted to support the endogenous growth theories.

The initial strand of the endogenous growth theory has paradoxically focused on tests of convergence implied by the neoclassical theories rather than effort to directly test endogenous growth theory itself. They tried to show that the growth rates of developed countries don't need to be lower than those of developing countries, which means in turn that developing countries may keep lower growth rates than developed countries.

However, considering the advantage of late-comers, the endogenous growth theoretic approach may also agree with the possibility of convergence in which developing countries may grow faster than developed countries.

Therefore, according to both the neoclassical theory and the endogenous growth theory, the convergence hypothesis has a room to work for developing countries: Developing countries may grow faster than developed countries in a cross-sectional analysis, which means in turn in a time- series analysis that the growth rates of developing

[55] Romer(1994), whose work Romer(1986) initiated the endogenous growth theories, indicates that the essence of the endogenous growth theories had been misled for a while by excessive emphasis on convergence controversy and empirical tests.

countries may become lower, as per capita income grows. This phenomenon of growth slowing-down may be due to both diminishing returns of capital accumulation(neoclassical theory) and diminishing knowledge gap between developing and developed countries(endogenous growth theory).

Various endogenous growth models implicitly or explicitly entail in the result of growth slowing-down of developing countries when the models are extended to the global economy and the economic development of developing countries.

This dissertation will try to survey these literatures about growth slowing-down and interpret their implication in a linkage.

2.4.2 Growth Slow-down in the Model of Knowledge Spillover (Diminishing Knowledge Spillover)

The innovation-based-growth theory about developing countries may entail in the "**S-shaped" path of technology transfers**: accelerating and then decelerating of knowledge spillovers. As the general knowledge gap between developing and developed countries narrows down, the growth of the small developing countries has the possibility to be slowed down.

As Grossman and Helpman(1991a,Ch6) indicates, if monopoly power of domestic firms producing intermediate inputs is small and so the growth rate of trade volume is smaller than that of variety of intermediate inputs,[56] which is the more usual case for developing countries, then the relative importance of international knowledge spillovers as a source for the accumulation of domestic knowledge capital declines over time and the economy tends to a steady state with the knowledge capital converging to a steady state level, $n\tilde{\varphi}$.[57]

However, in the rarer cases in which the volume of trade and the variety grow at the common rate g in the long-run,[58] trade promotion policy such as a reduction in the tariff rate can increase the ratio of knowledge capital over the variety(i.e. φ = K/n) in the steady state, which will boost the productivity in the research lab and so boost the innovation rate and economic growth rate.

2.4.3 Growth Slow-down in the Model of Imitation and Product Cycle

Jensen and Thursby(1986) argue[59] that technology gap between developed country(i.e. North) and developing country(i.e. South) does not die out permanently, even though developing countries may catch up to some point.

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[56] This is the case, $\alpha>\beta(1-\alpha)$ or $1>\beta(1/\alpha-1)$ in equation<2.61'> and <2.60> in the earlier section, where $1/\alpha$ means the monopoly power and β represents the income share of intermediate inputs in the production of final goods.

[57] n is the variety of intermediate inputs and $\tilde{\varphi} \equiv F(T/n)$ is the positive constant for a steady state.

[58] This is the case of $\alpha = \beta(1-\alpha)$ or $1= \beta(1/\alpha-1)$ in equation<2.61'> and <2.60>. See Grossman and Helpman(1991a) for the details.

[59] This argument inherits from Posner(1961) and Hafbauer(1966) which posited not only that advanced countries would be the first exporters of high technology goods, but also that they would extend their leadership from one decade to the next. (quoted in Hafbauer1966,p86). Vernon(1966) modified the theory in dynamics and hypothesized a trade pattern(i.e. product life cycle) in which advanced countries would develop and initially export goods, and less developed countries would produce and export goods in the later stages of their life cycle.

They show that there exists a steady state open-loop Nash equilibrium of a game in which a Northern monopolist devotes resources to new product development and a Southern planner(firm or government) devotes resources into reverse engineering to learn the technology to produce these. Then, a steady state equilibrium technology gap exists, implying that a constant technology gap over time may be explained by optimal strategic behavior of decision makers in a product life cycle model. Given resource costs, neither the Northern monopolists nor the Southern planner wants to alter the gap.

2.4.4 Growth Slow-down in the Model of Efficient Capital Accumulation

Lee(1994) suggests, by modifying Rebelo(1991), that developing countries can increase the efficiency of capital accumulation by importing cheaper foreign capital goods, which will in turn accelerate the output growth according to the model of externalities from capital accumulation such as learning by doing or division of labor.

Lee's argument is based on the Rebelo(1991)'s study that the relative price of the capital goods decreases over time along the balanced growth path and so the price of the capital goods relative to the consumption goods is cheaper in a higher income country, which has a larger capital stock.

However, as a developing country achieves higher income and higher capital accumulation, the relative price of domestic capital goods decreases and the imports of foreign capital goods also decrease. This implies that the efficiency of capital accumulation and the accompanying externalities from faster capital accumulation will diminish, as developing countries achieve higher income.

As we can see in equation<2.79> and <2.80>, the ratio of imported capital goods in total investment(i.e. m) decreases as income gap between developing and developed countries decreases. Thus, as developing countries approach the steady state, the growth rates of income and capital accumulation decrease.

2.4.5 Growth Slow-down in the Model of Externalities from Export (Diminishing Externalities of Export)

Feder(1982) argues that exports may have externalities with which exports sector increases the productivity of non-export sector. There may be several reasons for why the productivity of export sector is higher than that of non-export sector: Higher competition in the international market, principle of comparative advantage, economies of scale and the knowledge spillovers in the process of marketing and production.

However, as developing countries achieve higher income by expanding exports, the productivity gap between export and non-export sector decreases. Then, the externality effect from export to non-export sector will decrease. The original source of externalities such as knowledge spillovers or comparative advantage tends to be depleted, as exports increase.

Feder(1982) recognizes the possibility of those diminishing returns in the externalities of exports. Kohli and Singh(1989) set up a detailed model as shown in equation<2.93> to prove the diminishing returns of exports empirically for the period 1960-81 of developing countries. They provide some convincing evidence for non-linearity in the relationship between GDP growth rate and export growth rates, and in the relationship between GDP growth rate and export shares. These non-linearity are interpreted to imply that export-led growth may be subject both to a form of dynamic diminishing returns and to a critical minimum effort requirement.

2.4.6 Growth Slow-down in the Model of Human Capital

Getting a motif from the empirical analysis[60] of "S-shaped" technology transfer, Takii(1995) directly sets up a endogenous growth model to show that the **S-shaped path of human capital accumulation and knowledge spillover** can result in growth slowing-down in developing countries.[61]

The main conclusion of Takii(1995) is as following:

(1) There exists a **critical minimum point** of income level below which the lowest income country is trapped in the **vicious circle of underdevelopment**. But, **over the critical minimum point**, higher growth in the middle income countries and lower

[60] Griliches(1957), Gort and Klepper(1982)

[61] Similar models have been provided by Nelson and Phelps(1966) and Findlay(1978) in which the speed of technology transfer depends on the degree of technology gap and human capital in a following country. Since, however, these models don't consider the effect that technology transfer pushes up human capital and social capability in a following country, Takii(1995) modifies their models on a Lucas(1988) type model.

economic growth in high income countries are possible, which depend on the combination of the degree of **relative backwardness** and **social capability**.

(2) **S-shaped transfer of knowledge** may occur, because of the relation between **relative backwardness** and **social capability**.

(3) At the beginning of industrialization, people in the following country may reduce their consumption level initially to spend time on learning new knowledge from a leading country.

(4) Permanent knowledge gap may exist.The level and growth rate of income in the following country converge to that of a leading country only to some extent[62], and the growth rate of income in the following country may fluctuate near the leading country.

To prove these hypotheses, Takii adopts a model similar to Lucas(1988): People in a following country accumulate human capital in a way[63] such that

$$\dot{Q}_t = H(Q_t^* - Q_t,\ Q_t)\,(1 - L_t),\quad 0 \le L_t \le 1 \ \ldots\ldots\ldots\ldots\ldots\ldots <2.94>$$

,where L_t and $(1- L_t)$ are proportion of hours for work and for learning new knowledge, respectively. Q and Q* denote the level of human capital in a following country and a leading country, respectively. Assume

$$H_1 > 0 \ \text{and}\ H(0, \bullet) = 0 \ \ldots\ldots\ldots <2.95>$$

[62] This means that permanent knowledge gap can exist between developing and developed countries.
[63] The same logic can hold in the firm level instead of a person level .by replacing personal learning effort with imitation by firms(or R&D expenditure for imitation), and by replacing personal work hours with resource which will be assigned to manufacturing final goods.

Equation<2.95> means the benefits of relative backwardness such that people in the following country can get knowledge or skill by learning from the leading country. Assume also

$$H_2 > 0 \; and \; H(\bullet, 0) = 0 \text{ ....<2.96>}$$

Equation<2.96> means that to learn any knowledge, we need a foundation to learn it. For simplicity, assume that

$$H(Q_t^* - Q_t, Q_t) / Q_t = G(Q_t^* - Q_t, Q_t) \text{ ....<2.97>}$$

,where G_1 and G_2,>0 , G_{11} and G_{22}, ≤0 , G_{12} ≥0 , and G(0,•)= G(•,0)=0.

The assumption G_{11} and G_{22}, ≤0 means that the larger the knowledge gap or the higher the human capital level of the following country, then the smaller the knowledge spillover becomes. The assumption G_{12} ≥0 means that the increase in the human capital level makes the benefit of the relative backwardness larger.

From equation<2.94> and <2.97>, we can get

$$\dot{Q}_t = G(Q_t^* - Q_t, Q_t) \bullet Q_t \bullet (1 - L_t) \quad , \; 0 \leq L_t \leq 1 \text{ ....<2.98>}$$

The budget constraint of a consumer in the following country requires that consumption per capita(C_t) is equal to his/her income:

$$C_t = w_t \, Q_t \, L_t \text{ ....<2.99>}$$

,where w is a wage rate.

The object of the representative consumer is to maximize the following intertemporal utility function(u) subject to the budget constraint, equation<2.99>:

$$\int_0^{\infty} u(C_t) \, e^{-\rho t} \, dt \text{ ....<2.100>}$$

,where u'>0, u''≤0, u'(0)= ∞, u(∞)= 0.

Suppose a production function is $AQ_t L_t$, so that

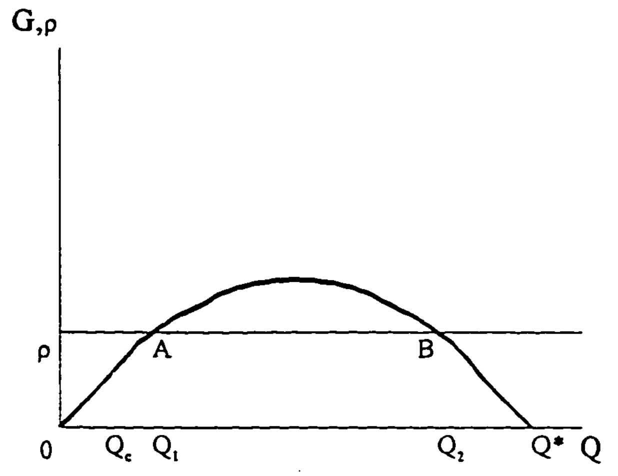
$w = A.$

Then, from the equilibrium condition, we can get the growth rate of consumption in the steady state as

$$\dot{C}/C = -(u'/u''C_t)\,[G(Q_t^*-Q_t, Q_t) - \rho] \quad \text{.......................... <2.101>}$$

<Figure 2.2>

<u>Human Capital(Q) and its Accumulation Function(G)</u>

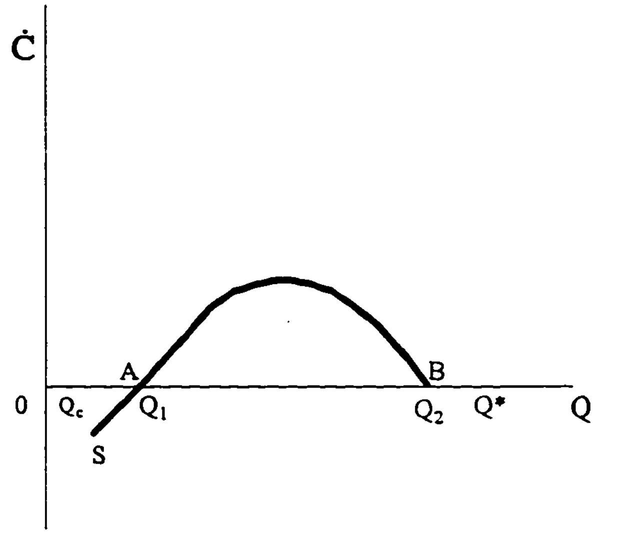


As we can see in equation<2.101> and so <Fig 2.2>, there are two level of human capital (i.e. Q_1 and Q_2) that bring about $G = \rho$ and so $\dot{C}/C = 0$(i.e. no growth in consumption).

From equation<2.98>,<2.99> and <2.101>, we can derive the following condition and <Fig 2.3> for the growth rate of consumption($\dot{C}$):

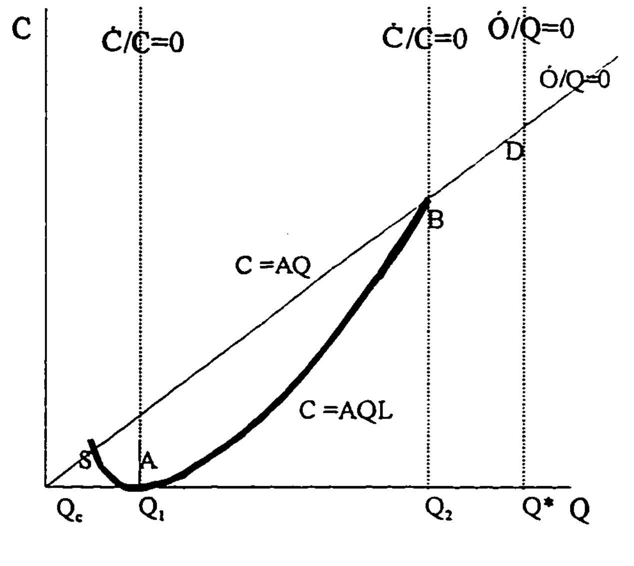
<Figure 2.3>

Optimal Path of the Growth Rate of Consumption, $\dot{C}$(SAB)



<Figure 2.4>

Optimal Path of Consumption (SAB)



If Q_c[64] $< Q < Q_1$, then $\dot{C} < 0$ and $\dot{Q} > 0$.

If $Q_1 < Q < Q_2$, then $\dot{C} > 0$ and $\dot{Q} > 0$.

If $Q_2 < Q < Q^*$, then $\dot{C} < 0$ and $\dot{Q} > 0$

If $Q > Q^*$, then $\dot{C} < 0$ and $\dot{Q} < 0$.

<Fig 2.4> shows the optimal path of consumption. The straight line from the origin(OD) represents the locus of consumption path for "all-work and no-learning"(i.e. $L_t=1$) :$C= AQ$ or $\dot{Q}/Q = 0$(no increase in human capital) or $\dot{C}/C= 0$(no growth in consumption). This is so because, if $L_t=1$(all work and no learning), then $\dot{Q}=\dot{C}=0$ by equation<2.98>, and $C = wQL = AQ$ from equation <2.99>.

Let's Q_c in <Fig 2.4> represent a critical minimum point of income or human capital. Then, the locus, SAB, in <Fig 2.4> represents the optimal consumption path for the usual case, $L_t \in (0,1)$. A person in the human capital level of $Q \in (Q_c, Q_2)$ will optimally work for L_t hours and spend time for $(1- L_t)$ hours in learning. Then, he/she can consume the amount($C=AQL$) in current period and increase human capital by $\dot{Q}_t = G\, Q_t\, (1-L_t)$ and so increase the consumption for the next period by $\dot{C}_t = A\,(1-L_t)\,\dot{Q}_t$.

Since the straight line(OBD) means $C= AQ$, and $C= AQL$ on the optimal path SAB, thus vertical difference between the two lines is $AQ(1-L)$, which represents the effort invested in increasing the human capital.

[64] If initial human capital is lower than Q_c, which denotes the critical minimum point. then no one will spend time to raise his/her human capital because they think that it is most profitable to work all day long. Hence, an underdevelopment trap will take place with little advantage in knowledge accumulation.

From <Fig 2.4>, AQ(1-L) describes one peak on the optimal path. Then, Q(1-L) also describes one peak. Since G function has one peak, it is possible for GQ(1-L) = $\dot{Q}$ to describe one peak on the optimal path. Therefore, the path of human capital accumulation($\dot{Q}$) may have one peak on the optimal path, which implies **S-shaped path of human capital or knowledge capital stock** with respect to time.

Besides, as the optimal path converges to the point B, the level of human capital and the income level of the following country can't converge to that of a leading country any more. Permanent knowledge gap($Q^* - Q_2$) and income gap do not narrow down any more.

The reason is that the knowledge spillover decreases as the human capital level of the following country converges to that of leading country. Since people discount future gains that can be obtained by reducing current consumption and by increasing learning effort, they will cease to spend time on learning some knowledge from a leading country before their human capital converges to that of a leading one.

Takii(1995) also analyze the another case in which a leading country accumulates its human capital by a constant ratio: $\dot{Q}^*/Q^* = n$. Then, it can be shown that $\dot{Q}/Q$ does not have a steady state with $\dot{Q}/Q = n$, and so that $\dot{Q}/Q < n$.

This result means that the growth rates of human capital and income of a following country do not necessarily converge to those of a leading country. Two cases are possible: (1) The growth rate of consumption and human capital of a following country may be stable near the growth rate of human capital of a leading country after high growth (Japanese case).

(2) The growth rate of consumption and human capital of a following country may fluctuate.[65]

[65] When the growth rate of human capital of a following country is larger than that of a leading one, the level of human capital of the following one will become close to that of the leading one. This, however, means that the amount of knowledge learned from the leading country decreases and so people in the following country will decide to reduce time to learn from the leading country. Then, the growth rate of human capital in the following country decreases, while that of the leading country is constant. The gap begins to increase and then people in the following country decide to increase time to learn from a leading country again. This relationship will be repeated, creating a fluctuation.

Chapter 3. Methodology for Empirical Test

3.1 Introduction

A random walk process (that is, one unit root process) is one of nonstationary stochastic time series and can be defined as a stochastic process where random shocks are accumulated or integrated over time. Since the variance of error terms in the nonstationary process becomes larger with respect to time, the forecast of random walk process is meaningless and regressing one random walk against another random walk can lead to spurious results, in that conventional significance tests will tend to indicate a relationship between the variables when in fact none exists.

That is one reason why it is important to test for random walks. If a test fails to reject the hypothesis of random walk(that is, one unit root process), one can difference the series in question before using it in a regression. While this is acceptable, differencing may result in a loss of information about the long-run relationship between two variables.

However, the source of the non-stationarity in these variables is worthy of further consideration. For example, CPI(Consumer Price Index) inflation rate may be nonstationary because the money growth rate is nonstationary. Such a conjecture can be the basis for the test of 'Co-integration', which is a test for a common unit root in two time series such that a regression of one nonstationary series on another nonstationary series, yields stationary errors.

In this case, the pair may be expected to move so that they don't drift too far apart, even though each series can wander extensively. Economic theory will propose forces which tend to keep such series together. (Engle and Granger(1987),pp251-63)

3.2 Definition of Cointegration

Co-integration is said to exist between two time series which are independently nonstationary, if there exists a linear combination which is stationary.

. Engle and Granger(1987) defines co-integration as following:

"If each element of time series Y_t and X_t first achieves stationarity after differencing (that is, X_t and Y_t are integrated of order one in common), but a linear combination Y_t- βX_t is already stationary, then the time series Y_t and X_t are defined to be cointegrated with cointegrating parameter β ,where X_t and can be vectors.

Interpreting $Y_t - \beta X_t = 0$ as a long-run equilibrium, cointegration implies that deviations from equilibrium are stationary with finite variance, even though the series themselves are nonstationary and have infinite variances".

In more general terms, the component of the vector $Z_t = (z_{1t}, z_{2t}, \ldots, z_{nt})'$ are said to be cointegrated of order d,b denoted by $Z_t \sim CI(d,b)$, if

1. All components of Z_t are integrated of order d

2. There exists a vector $\beta = (\beta_1, \beta_2, \ldots, \beta_n)$ such that linear combination $\beta Z_t = \beta_1 z_{1t} + \beta_2 z_{2t} +$.+ $\beta_n z_{nt}$ is integrated of order (d-b), where b>0. The vector β is called the cointegrating vector.

3.3 Test of Nonstationarity : Unit-Root Test

Unit-root test must be done before we proceed to the cointegration test, in which we have to check if all the time series under consideration are random walk process and nonstationary.

After Dickey and Fuller(1979,1981) pioneered the unit root test of an AR(Auto-regressive) time series, Phillips and Perron(1988) developed a generalization of the test by allowing auto-correlation and heteroscedasticity of error terms of the AR model.

3.3.1 Dickey and Fuller(1979,1981) Unit-Root Test

The Pth order autoregressive process AR(p) with a time trend is expressed as

$$Y_t = \alpha_0 + \alpha_1 t + \sum_{j=1}^{p} \phi_j Y_{t-j} + u_t \qquad \text{<3.1>}$$

or $(1 - \phi_1 L - \phi_2 L^2 - \ldots - \phi_p L^p)\, Y_t = \alpha_0 + \alpha_1 t + u_t$

or $\varphi(L)\, Y_t = \alpha_0 + \alpha_1 t + u_t$, where $\varphi(L) = 1 - \phi_1 L - \phi_2 L^2 - \ldots - \phi_p L^p$

The process Y_t is stationary, if ,for all the inverse characteristic roots L^* of the inverse characteristic equation $\varphi(L)=0$, all the absolute value of L^* is strictly larger than unity, which is the same condition as $\sum_{j=1}^{p} \phi_j < 1$ (Judge and et all(1988),p681). In other terms, If all the characteristic roots λ^* of the characteristic equation $\varphi(\lambda)=0$ is smaller than unity in absolute value, then the time series is stationary. This relationship holds because $1/L^* = \lambda^*$. In this case, Y_t is called the "trend stationary series" I(0), where stationarity is assumed around a linear deterministic time trend.

The process Y_t is a random walk process, if the AR process contains one real positive unit root(that is one $L^*=1$) so that the sum of the autoregressive coefficients in the equation <3.1> equals unity (that is, $\sum_{j=1}^{p} \phi_j = 1$). This case is called the "difference stationary series" I(1), since Y_t is not stationary and ΔY_t is stationary.

The equation<1> can be rearranged as

$$Y_t = \alpha_0 + \alpha_1 t + (\sum_{j=1}^{p} \phi_j) Y_{t-1} + \sum_{i=1}^{p-1} (-\sum_{j=i+1}^{p} \phi_j) \Delta Y_{t-i} + u_t$$

,where $\Delta Y_{t-i} = Y_{t-i} - Y_{t-i-1}$

or $Y_t = \alpha_0 + \alpha_1 t + BY_{t-1} + \sum_{i=1}^{p-1} \phi_i' \Delta Y_{t-i} + u_t$

,where $B = \sum_{j=1}^{p} \phi_j$ and $\phi_i' \equiv -\sum_{j=i+1}^{p} \phi_j$

Therefore, the Dickey and Fuller test involves estimating the following models:

<No trend> $\Delta Y_t = \alpha_0 + \beta Y_{t-1} + \sum_{i=1}^{p-1} \phi_i \Delta Y_{t-i} + u_t$ ....<3.2>

<Trend> $\Delta Y_t = \alpha_0 + \alpha_1 t + \beta Y_{t-1} + \sum_{i=1}^{p-1} \phi_i \Delta Y_{t-i} + u_t$ ....<3.2'>

,where $\beta \equiv B - 1$

Under the null hypothesis of a unit root, the coefficient β should be equal to zero. A natural test statistic for this hypothesis is the t-test, defined as $\tau_\beta = \hat{\beta} / s(\hat{\beta})$, where $\hat{\beta}$ is an OLS estimator. However, Dickey and Fuller showed that this statistic does not have the usual Student- t distribution, but has a distribution that is skewed toward negative values. Dickey and Fuller used Monte Carlo experiments to tabulate the new critical values. They also generated F-distribution to test whether the joint restrictions (H_0: α_1=0 and β=0) in the equation with time trend hold.

Therefore, if the t- or F-statistics is smaller than the critical value, then it is concluded that the null hypothesis is not rejected and so Y_t is a random walk process.

3.3.2 Phillips and Perron(1988) Unit-Root Test

Instead of the Dickey-Fuller assumptions of independence and homogeneity, the Phillips-Perron test allows the disturbances of the AR model not to be white noise and so to be weakly dependent and heterogeneously distributed. Thus P-P test results are much more robust to serial correlation and various forms of time-dependent heteroscedasticity.

The test involves estimation of the modified Dickey-Fuller OLS regressions:

<No trend> $Y_t = \alpha_0^* + \alpha_1^* Y_{t-1} + \sum_{i=1}^{p-1} \phi_i' \Delta Y_{t-i} + u_t$ ....<3.3>

<Trend> $Y_t = \alpha_0' + \alpha_1' Y_{t-1} + \alpha_2 (t - T/2) + \sum_{i=1}^{p-1} \phi_i' \Delta Y_{t-i} + u_t$ ....<3.3'>

The Phillips-Perron test statistics are modifications of the Dickey-Fuller t-statistics that take into account the less restrictive nature of the error process. The most useful of the Phillips-Perron test statistics are as follows:

<t statistics for No-trend case>

$Z(t_{\alpha 1^*})$: used to test the null hypothesis of unit root, $\alpha_1^*=1$

<t statistics for Trend case>

$Z(t_{\alpha 1'})$: used to test the null hypothesis of unit root, $\alpha_1'=1$

The critical values for the Phillips-Perron statistics are precisely those given for the Dickey-Fuller tests.

3.4 Techniques of Cointegration Test

The basic concept and technique of cointegration test were provided by Engle and Granger(1987). Complementing the possible defect of the Engle-Granger test, Johansen(1988) and Stock-Watson (1988) provided the new kind of techniques of examining the rank of the cointegrating vectors.

3.4.1. Engle and Granger(1987) Test

The Engle-Granger test is based on the Error Correction Model.

A principal feature of cointegrated variables is that their time paths are influenced by the extent of any deviation from long-run equilibrium. If the system is to return to the long-run equilibrium, the movements of at least some of the variables must respond to the magnitude of the disequilibrium, which means a error correction or partial adjustment of short-run movement to the long-run path.

The Granger **ECM(Error Correction Model)** is expressed in the form:

$$\Delta Z_t = \pi_0 + \pi Z_{t-1} + \pi_1 \Delta Z_{t-1} + \pi_2 \Delta Z_{t-2} + \ldots + \pi_{p-1} \Delta Z_{t-p+1} + \varepsilon_t \quad \ldots\ldots <3.4>$$

, where the vector with n-variables $Z_t = (z_{1t}, z_{2t}, \ldots, z_{nt})'$

Let all variables in Z_t be I(1). Then all of the ΔZ_{t-i} (i=0,1,2,...) are stationary.

Since $\pi Z_{t-1} = \Delta Z_t - \pi_0 - \pi_1 \Delta Z_{t-1} - ... - \pi_{p-1} \Delta Z_{t-p+1} - \varepsilon_t$ from the ECM and each expression on the right-hand side is stationary, πZ_{t-1} must also be stationary even though Z_{t-1} is nonstationary. Since π contains only constants, each row of π is a cointegrating vector of Z_t. If one or more of the cointegrating vectors differs from zero, ΔZ_t responds to the previous period's deviation from long-run equilibrium. Hence, estimating Z_t as a VAR(Vector Auto-Regression) in first differences is inappropriate if Zt has an error-correction representation, in which the omission of the expression πZ_{t-1} entails a misspecification error.

Therefore, the restrictions necessary to ensure that the variables are CI(1,1) guarantee that an error-correction model exists. *"Granger Representation Theorem" states that for any set of I(1) variables, error correction and cointegration are equivalent representations.*

Engle and Granger(1987) test consists of two step procedure, in which the concept of the Dickey-Fuller nonstationarity test is applied.

<Step1> Estimate the cointegrating equation, the long-run equilibrium relationship for two series. If the variables are cointegrated, then an OLS regression yields a "super-consistent" estimator of the cointegrating parameters.

<No trend> $Y_t = \beta_0 + \beta_1 X_t + u_t$ ....<3.5>

<Trend> $Y_t = \beta_0 + \beta_1 t + \beta_2 X_t + u_t$ ....<3.5'>

<Step2> Denote the residual sequence from the above cointegrating equation by $\{\hat{u}_t\}$. Then, estimate the autoregression of the residuals with no-constant and no-trend:

$$\Delta \hat{u}_t = \alpha_1 \hat{u}_{t-1} + \sum_{i=1}^{p-1} \alpha_{i+1} \Delta \hat{u}_{t-i} + \varepsilon_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots <3.6>$$

If we can reject the null hypothesis H_0: $\alpha_1=0$, then we can conclude that the residual series do not contain a unit root and so they are stationary. Hence we conclude that the $\{Y_t\}$ and $\{X_t\}$ sequences are cointegrated of order (1,1).

In most applied studies, it is not possible to use the Dickey-Fuller tables since the residual variance is made as small as possible by using the OLS in the cointegrating equation and so the procedure is prejudiced toward finding a stationary error process in the residual equation. Thus Engle and Granger(1987) provided test statistics that can be used to test the hypothesis H_0: $\alpha_1=0$. When more than two variables appear in the equilibrium relationship, the appropriate tables are provided by Engle and Yoo(1987).

3.4.2 Johansen(1988), Johansen and Juselius(1990) Test

The Engle-Granger methodology,however, possesses certain potential defects. First, finite sample biases can arise in static single equation OLS estimates of cointegrating vectors, even if the OLS estimators are super-consistent under large sample. Second, it is also possible to find that under finite samples one regression indicates the variables are cointegrated, whereas reversing the order indicates no cointegration.

Third, in tests using three or more variables, we know that there may be more than one cointegrating vector. However, the Engle-Granger method has no systematic procedure for the separate estimation of the multiple cointegrating vectors. Fourth, since the Engle-Granger method relies on a two step estimator, any error introduced by the researcher in step1 is carried into step2 (Enders(1995),p385).

The tests using maximum likelihood estimators by Johansen(1988), Stock and Watson(1988) and Johansen and Juselius(1990) circumvent the use of two step estimators and can estimate and test for the presence of multiple cointegrating vectors. Moreover, these tests allow the researcher to test restricted versions of the cointegrating vectors and speed of adjustment parameters. These test procedure rely heavily on relationship between the rank of a matrix and its characteristic roots.

The vector autoregressive representation(VAR) of Z_t is:

$$Z_t = \pi_0 + \pi_1 Z_{t-1} + \pi_2 Z_{t-1} + \ldots + \pi_p Z_{t-p} + \varepsilon_t \quad \ldots\ldots\ldots\ldots$$ <3.7>

, where the vector $Z_t = (z_{1t}, z_{2t}, \ldots, z_{nt})'$ and the error term $\varepsilon_t \sim N_n(0,\Omega)$ and n is the number of variables contained in Z_t.

If the variables in Z_t are nonstationary and integrated of order one in common, it is natural to express the above equation in first difference form. It is necessary to apply the difference operator to the error process, otherwise differencing implies a loss of information in the data. Defining L as the lag operator and $\Delta=(1-L)$, the above equation can be rewritten in the following **ECM(Error Correction Model)** by Johansen:

$$\Delta Z_t = \pi_0 + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \ldots + \Gamma_{p-1} \Delta Z_{t-p+1} + \Pi Z_{t-p} + \varepsilon_t \quad \ldots\ldots\ldots\ldots$$ <3.8>

,where $\Gamma_i = -(I - \pi_1 - \ldots - \pi_i)$, $i=1,2,\ldots,p-1$ and $\Pi = -(I - \pi_1 - \ldots - \pi_p)$

The rank of the coefficient matrix Π, the matrix which contains information concerning the long-run relationships between the variables in Z_t is equal to the number of cointegrating relationships denoted by r. Three cases are possible for the rank of Π.

If rank(Π) = n (that is, full rank case), then the vector process Z_t is stationary, implying the absence of stochastic trends in the data. In this case all variables are stationary and we can use the regular regression estimation without adopting the concept of cointegration.

. If rank(Π)=0, the matrix Π is the null matrix and the above ECM model <3.8> corresponds to a traditional VAR in first differences. In this case, there is no cointegration and no stationary long-run equilibrium relationship among the variables in Z_t.

If rank(Π)=1, there is a single cointegration vector and the expression ΠZ_{t-p} is a error correction term.

If 1< rank(Π)=r < n , there are multiple cointegrating vectors(β). That is, there are n $_x$ r matrices α and β such that Π can be factored as $\Pi= \alpha\beta'$. It is those third and fourth cases which are of interests in this study. Since ε_t and ΔZ_t are assumed to be stationary in the above ECM model, ΠZ_{t-p} must also be stationary. Using the factorization $\Pi= \alpha\beta'$, the r columns of β can be defined as the **cointegrating vectors** and they have the property that the cointegrating relationships given by

$$\beta_i{}'Z_t = \eta_{it} \quad , \; i=1,2,\ldots,r \quad \ldots\ldots\ldots\ldots\ldots\ldots <3.9>$$

are stationary process, where the error term η_{it} is I(0) even though the elements of Z_t are nonstationary. The long-run relationships among level variables are given by the equation

<3.9> and, considering that η_{it} is stationary process, the long-run behavior of the n variables in Z_t is determined by the n - r common trends.

Under the Johansen (1988) approach, the maximum likelihood estimation of the equation <3.8> permits the testing of hypotheses concerning the number of cointegrating vectors, as well as specific linear restrictions on these vectors.

Chapter 4. Model Specification and Test Result

Dynamic link between openness of an economy and growth will be tested through the "co-integration test" of production factors in a production function at the aggregate level. For this purpose, special form of aggregate production function that treats trade as a kind of production input will be used to investigate the externality effect of international trade.

Besides, analysis of TFP(Total Factor Productivity) will be performed to justify the special form of production function specified in this dissertation for the cointegration test.

4.1 Model Specification

4.1.1 Test Model : Production Function Augmented with Trade

The role of export in economic growth can be analyzed in the framework of a straightforward production function model that treats export as similar to a production input.[1] Specification of this idea defines the national production function as

$Y = f(K, L, X)$ .... <4.1>

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[1] Similar specification has been developed and used by Balassa(1978), Tyler(1981), Feder(1982), Ram(1985, 1987), Kohli and Singh(1989), Edward(1993), Sengupta(1990,1993), Chou(1995) to decompose the contribution of exports in the production function.

In contrast, Michaely(1977) objects to the use of this method based on the argument that since export is themselves part of the national output, a positive correlation of the two variables is almost enevitable, whatever their true relationship to each other.

However, this argument has been contradicted by Kavoussi(1984, P.243): Growth of GDP can only be caused by the growth of factors of production and technical progress. In a country where resources have not been growing rapidly and technical progress has been slow, growth rate of output can't be very high, regardless of high growth of export. In such a situation, a high growth of export can be accompanied only through a slowdown of import competing sectors. A positive correlation between growth rates of exports and output will occur, if and only if export expansion is accompanied with a rapid growth of resources and/or major gains in factor productivity.

Most researches which study the role of export in economic development follow the same argument as Kavoussi (1984) that the correlation between export growth and economic performance is by no means automatic simply because export is themselves part of the output.

where Y is the aggregate real output, K is the input of total physical capital stock , L is the labor input, X denotes the level of export.

Equation <4.1> is specified in such a way that export is a production input in the sense that level of export affects aggregate output for given level of labor and capital stock in the long-run relationship.

Equation <4.1> can be justified as follows as Ram(1985,1987) and several other studies have done.[2] Export has a significant indirect effect (externality effect) as well as direct effect of increasing production to meet the increased aggregate demand from abroad. High level of export leads to a better allocation of resources by realizing comparative advantage and reducing X-inefficiency in production. Expansion of export may also facilitate exploitation of economies of scale, and make for increased capacity utilization.

Moreover, expansion of export relaxes the foreign exchange constraint and may raise the productivity of labor and capital by enabling the economy to import advanced capital goods within the framework of two-gap models of development.

Especially, as is emphasized by the endogenous growth theories, export works as a conduit of knowledge spillover from advanced economies, and strengthens inducement for

[2] The specific researches of externalities from international trade include Bhagwati(1978) which considers "scale economies" the largest benefit of the export promotion trade strategy, Feder(1982) which take into account the "reallocation of existing resources" from less efficient nonexport sector to higher prodictivity export sector, and Grossman and Helpman(1991) which sees the "international knowledge spillover" generated by trade coexisting with the externality of domestic innovation.

technological change. This knowledge spillover works again as a conduit that enables the economy to realize increasing returns.[3]

While most of the existing studies in this area have addressed the role of export only, the idea of the endogenous growth theories as surveyed in the earlier chapter enables it possible to address the role of import in the same context. Treating imports as a kind of production input like export, this dissertation will augment the production function <4.1> with import such that

$$Y = f(K, L, X, M) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \langle 4.2 \rangle$$

where Y is the aggregate real output, K is the input of total physical capital stock, L is the labor input or employment, X and M denote the level of export and import respectively.

The externality effect or knowledge spillover effect can be addressed into the Cobb-Douglas production function as following:

$$Y = A\, K^{\alpha} L^{\beta} X^{\delta} \quad \ldots\ldots\ldots\ldots\ldots \quad \langle 4.3 \rangle$$

or $$Y = A\, K^{\alpha} L^{\beta} X^{\delta 1} M^{\delta 2} \quad \ldots\ldots\ldots\ldots\ldots \langle 4.3 \rangle'$$

Taking the natural logarism, the test model for the new growth theory can be set up as

[3] The "increasing returns effect" induced by the non-rival inputs for which technology or various kind of knowledge can be provided as examples. A non-rival good is one for which subsequent units have a lower unit-cost of production than the first. In terms of production function, this implies that, with non-rival inputs, the output will more than double by doubling all non-rival inputs, which can be used again and again in a replication process like a computer software or production experience of a product. With rival inputs, however, it is possible to double the output only by doubling all of the rival inputs. (Sengupta (1993)) The increasing returns by the non-rival inputs is described as $F(\pi R, \pi N) > F(\pi R, N) = \pi F(R, N)$ for the production function F(.), where R is the set of rival inputs, N the set of non-rival inputs and $\pi > 0$. The above production function is not concave and it shows that the elasticity of output with respect to inputs comprising both rival and non-rival inputs is greater than unity.

$$lnY_t = C + \alpha \, lnK_t + \beta \, lnL_t + \delta \, ln X_t + u_t \text{.......................} \langle 4.4 \rangle$$

or

$$lnY_t = C + \alpha \, lnK_t + \beta \, lnL_t + \delta_1 \, lnX_t + \delta_2 \, lnM_t + u_t \text{ ....} \langle 4.4 \rangle'$$

Note that each coefficient in the above equation implies the aggregate output elasticity with respect to the input(that is, size of output increase in percentage induced by a percentage increase of an input).

The production function <4.3> and <4.3>' by the new growth theory are different from those by the neo-classical production function of Solow style:

$$Y = A \, e^{\mu t} K^{\alpha} L^{\beta} \text{ ....} \langle 4.5 \rangle$$

This neoclassical production function assumes that technology is given exogenously and that the contribution of technological change to total output is constant as μ. The autonomous factor A reflects all the remaining factors that is not explained by K,L and exogenous technical change.

In contrast, the production function<4.4> or <4.4>' set up in this dissertation for the new growth theory assume that technological change due to international trade can be decomposed in the form of separate factors. The contribution of technical change to output through international trade will be explicitly disaggregated into δ. In this case, the technical change and the productivity growth are not totally exogenous, because they are affected by international trade, which will be in turn dependent on the national income and policy.

Note that in the new growth model, any policy affecting export and import may influence on the technical change and so on the long-run growth path. Especially, this is more effective for developing countries that have a technology gap with developed countries and so may benefit from the knowledge spillover from developed countries.

It is expected that the signs of trade are positive if international trade is exerting positive externality effect or knowledge spillover effect as suggested by the endogenous growth theories for developing countries.

In the mean time, if some of the variables in the equation <4.4> are not stationary, then coefficients estimated using regular regression techniques are spurious and useless. To avoid these nonstationarity problem, most of the existing studies which tried to figure out the role of trade, have used growth rate or first differences of all the variables in the equation <4.4>.

Even if differencing can be one way of avoiding the nonstationarity problem, it can lead to the loss of some useful information included in the original variables. In this nonstationary case, if all the original variables in the equation <4.4> are integrated of order one in common, then cointegration test can be used to find whether all the level variables in the production function have the same stochastic trends. If they are cointegrated, it means they have showed co-movement, where a basic economic force causes the other variables(Y,K,L) to move in the similar stochastic patterns.[4]

If output and the other production factors are not cointegrated after excluding export and import, but well cointegrated after including international trade, then it means that trade is a required factor to explain the co-movement of output, capital and labor.

Estimation of the cointegrated equations provides the cointegrating vectors, which enables us to judge whether the sign of trade is positive and significant in the long-run equilibrium relationship.

4.1.2 Steady State Equilibrium in a Simple Macro Model

In the traditional Neoclassical or Keynesian macroeconomic theory, export and import have been regarded only as an injection and a leakage respectively in the flow of national income. Thus, the contribution of current export is only to increase the aggregate effective demand and so increase the current income or future income as a multiplier effect. The import working as a leakage only reduces the aggregate demand and income. Equilibrium is attained when aggregate supply(Y) equals aggregate demand or when injection equals leakage:

$$Y = C + I + G + X - M \quad \text{..............................} \langle 4.6 \rangle$$

or $C + I + G + X = C + S + T + M$ ....<4.7>

where C(Consumption), I(Investment), G(Government expenditure), S(Savings), T(Tax revenue).

---

[4] The Granger causality can help clarify the direction of causality. The causality test here does not imply the simple Granger(1969) test, but those from the cointegration test and the relevant Error Correction Model, which will be shown in the later section.

It has been assumed that export is exogenously determined, i.e. $X=\overline{X}$, and import is determined by income, i.e. M= mY.

In this system, if export and import increase by the same amount, then there is no change in the equilibrium income in the long-run.

However, even in this system, investment has been recognized to have the two effect. The first is to increase the aggregate demand and income as an increase in injection of the income flow, and the second is to increase the production capacity in the next period. Harrod(1939), Domar(1947) and Solow(1956) have ever addressed the double role of investment into the system to extend the statics into the long-run equilibrium dynamics. Their idea about the existence of a reproducible factor, which means a production factor playing the double role in the system, provided the human capital theory with a clue to address the double role of human capital or knowledge stock.

Since the existing endogenous growth theories have rarely tried to model export and import in the context of macro equilibrium model of Solow style, this dissertation tries to address the double role of export and import into a simple macro-economic system of Solow type. This implies that the Solow growth model will be extended to the open economy case of developing countries, which can take advantage of the benefit of late-comers through knowledge spillover, etc..

In this case, the steady state analysis in the following mathematically shows that the developing country with export-oriented strategy will enjoy a rapid growth in the early stage, but face growth slowing-down as the externality effect of trade diminishes.

Trade of developing countries may play the double role. It changes not only the current aggregate effective demand, but also the production capacity, which is due to the externality effect coming from international knowledge spillover, economies of scale and the other effect postulated by the endogenous growth theories.

Now, define

aggregate demand : $Y^d = C + I + G + X - M$ ....<4.8>

aggregate supply(production function): $Y^s = A(X,M) \bullet F(K,L)$ ....<4.9>

Note that the disembodied technology factor(A) is assumed to be positively affected by trade. It is also assumed that the effect diminishes as trade volume(or income) increases. That is, partial derivatives

A_x and A_m>0 , A_{xx} and A_{mm}<0 , A_{xm} and A_{mx}<0 ....<4.10>

Assume that Government keeps the budget in balance (i.e. G=T) and there is no unbalance in current account(i.e. X=M and $\dot{X}=\dot{M}$,where "•" over a letter denotes time derivative or growth rates). Then, the aggregate equilibrium condition <4.7> implies

$I = S\ (= sY) \;\; => \;\; \dot{K} = sY \;\; => \;\; s = \dot{K}/Y$ ....<4.11>

Differentiating the production function <4.9> with respect to time yields

$dY = A_x F(K,L)\ dX \ + \ A_m F(K,L)\ dM \ + \ A\ F_k(K,L)\ dK$

$=> \;\; \dot{Y} = A_x F(K,L)\ \dot{X} \ + \ A_m F(K,L)\ \dot{M} \ + \ A\ F_k(K,L)\ \dot{K}$...............<4.12>

Dividing equation<4.12> by Y and plugging <4.11> gives

$\dot{Y}/Y = (A_x + A_m)\ F(K,L)\ \dot{X}/Y \ + \ A\ F_k(K,L)\ \dot{K}/Y$

=> $\hat{Y} = (A_x + A_m)\, F(K,L)\ \dot{X}/Y\ +\ A\, F_k(K,L)\, s$ ....<4.13>

where "^" over a letter denotes growth rate of the variable.

Since F(K,L) / Y = 1 / A(X,M) from the production function <4.9>, equation<4.13>, i.e. the growth rate equation can be expressed as:

$\hat{Y} = (A_x + A_m)\ \dot{X}/A\ +\ A\, F_k(K,L)\, s$ ....<4.14>

Equation <4.14> implies that growth rate of output($\hat{Y}$) will be higher, (1)when the externality effect of both export and import(i.e. A_x, A_m) is larger, (2) when the growth rate of export($\dot{X}$) is higher.

However, the role of technology level(A) is offsetting in the first term and in the second term of the right side of equation <4.14>. The low level of technology enables the total externality effect from trade to increase(i.e. (A_x+A_m) $\dot{X}$/A), while it reduces the marginal productivity of capital(i.e. A F_k s). When the developing country enters into a trade, the country also gets a possibility to turn the handicap of low level of technology and low marginal productivity of capital into an advantage of large externality effect. How much the country can turn the handicap into an advantage, depends on the size of A_x and A_m ,which in turn depends on the social capability of the developing country such as human capital, active government policy and the other social institution.

Note that if we don't consider knowledge gap or externality effect from trade, then the growth of developing country follows the similar path as those of developed countries:

$\hat{Y}$= A F_k(K,L) s. In this case, low level of technology(A) will only offset the advantage of high marginal productivity of capital in the developing country, and will be a main cause of low growth rate.

Therefore, as the technology level becomes higher with economic development, then the first term of the right side of equation<4.14> gets smaller, which implies that the contribution of the externality effect can diminish.

To make it clear, suppose that $\dot{X}=\dot{M}=\mu$(constant) >0. Then, equation<4.14> becomes

$$\hat{Y}=(A_x+A_m)\,\mu/A \;+\; A\,F_k(K,L)\,s \quad \ldots\ldots\ldots\ldots\ldots\ldots \langle 4.15\rangle$$

Differentiation of equation<4.15> with respect to export(X) yields:

$$d\hat{Y}/dX=\;(\mu/A^2)\,[\,A(A_{xx}+A_{mx})-(A_x^2+A_mA_x)]\;+\;A_x\,F_k(K,L)\,s \quad \ldots\ldots\ldots \langle 4.16\rangle$$

Since the first derivatives are positive(A_x, A_m>0) and the second derivatives are negative (A_{xx},A_{mm}, A_{xm},A_{mx}<0), the first term of the right side of equation<4.16> is negative, while the second term is positive. Equation <4.16> therefore implies that the growth rate of developing countries with export oriented strategy may be higher than those of developing countries with no export, or higher than those of developed countries with no knowledge gap.[5] Three cases are possible.

---

[5] Structural change of export or industry is not considered here. However, to keep the high growth rate of export, it is inevitable to change the structure of domestic industry and export pursuing dynamic comparative advantage. The fact that the knowledge gap is narrowed down by economic development, implies that the comparative advantage has relatively shifted to the technology intensive goods.

(1) The growth rate of export and import can be relatively higher at the early stage of export oriented development than the later stage. In this case, the developing country is using relatively low level of technology(i.e. $A \to 0^+$). Then, $A_x \to \infty^+$, $A_{xx} \to \infty^-$.

Thus, the negative first term of the right side of equation<4.16> possibly dominates the positive second term. Therefore,

$d\hat{Y}/dX < 0$ ....<4.17>

(2) However, as the developing country achieves economic development and higher income, the country uses relatively higher level of technology(i.e. $A \to \infty^+$). Then, $A_x \to 0^+$, $A_{xx} \to 0^-$.

Thus, both the first term and the second term of the right side in equation<4.16> converge zero. Therefore,

$d\hat{Y}/dX \to 0^-$ ....<4.18>

(3) If there is no knowledge spillover($A_x = A_m = 0$) as in the case of most developed countries,[6] then, A(X,M) = a (constant level of technology). Thus, from equation<4.14> we get

$\hat{Y} = a F_k(K,L)\, s > 0$

and $d\hat{Y}/dX = 0$ ....<4.19>

The above results imply that a developing country can achieve rapid growth($d\hat{Y}/dX<0$ or $\hat{Y} > aF_k s \equiv c$: constant) by adopting export-drive-development strategy, which is mainly due to the larger externality effect from export and import at the early stage of export. The

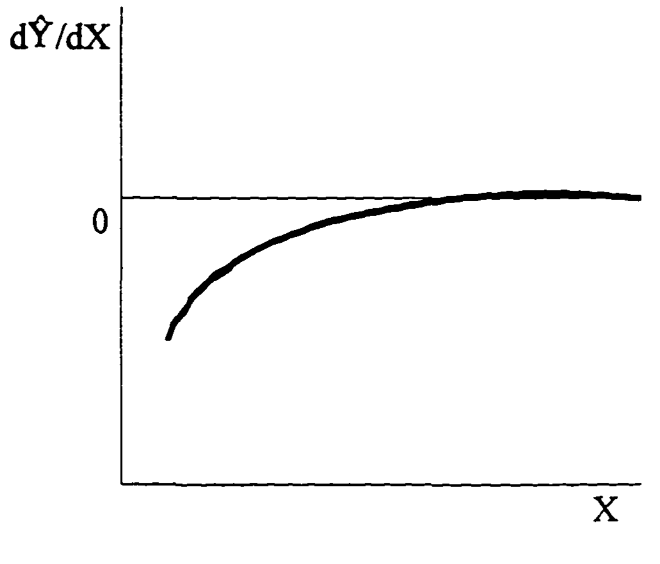
[6] Even if $\dot{X} = \dot{M} = 0$, it can be X=M>0.

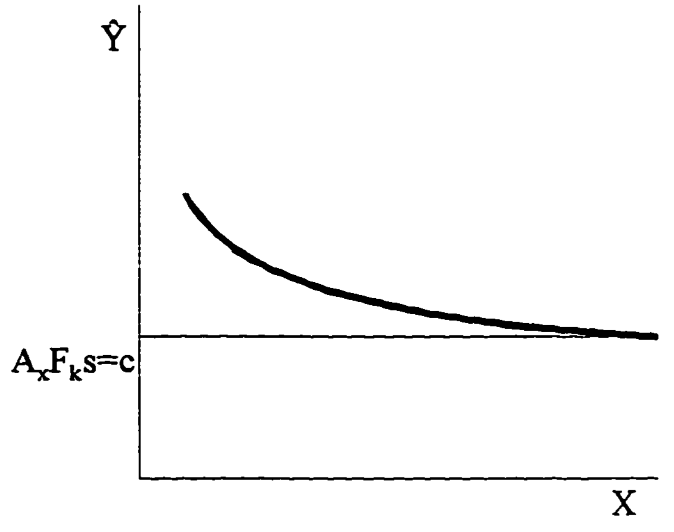
higher the knowledge gap between developing countries and developed countries is, the larger the externality effect and the growth rate becomes.

However, as the income grows up, the externality effect also gets smaller since the knowledge gap becomes smaller. Then, the developing country follows the same dynamics as those of developed countries(d $\hat{Y}$/dX = 0 or $\hat{Y} = aF_k s \equiv c$). In this case, the country can hardly benefit from the knowledge spillover, but depend its growth more on its own R&D and innovation.

<Figure 4.1>

Long-run Growth Rate($\hat{Y}$) of the Developing Country with Export(X)-Oriented Development Strategy





4.2 Data

The data about Y(real GDP), L(total employment), X(total export of goods and services) and M(total import of goods and services) for the above production function have been collected from "The Statistics of the Korean Economy" issued by the Bank of Korea(1995).

The data for physical capital stock(K), which excludes land and inventory stocks ,but includes 5 types of capital from all industries: houses, nonresident buildings, plant and equipment, transportation facilities, and the other production facilities, are from Pyo (1996).[7] The capital stock here uses the net concept which measures fixed physical capital stocks net of depreciation, since GDP, not gross output, is used as output and income. The estimation of physical capital stocks combines the polynomial benchmark method and

[7] The data set have been obtained from the author directly. I appreciate Dr.Pyo for his invaluable data set. The data have been calculated for the period 1953-1994 for the paper, Pyo(1996), "Sources of Growth and Productivity Trends in Korea", for which publishers are not determined yet. Pyo(1992,1995) have also used the similar technique to calculate the physical capital stock for the period 1955-1990.

the perpetual inventory method utilizing Korea's three time national wealth survey in 1968, 1977 and 1987.[8]

The data for X(export) and M(import) include not only goods but also services to reflect the significant increase in oversea construction and services of Korean construction & Engineering companies.

The data for Y, K, X and M are in Korean currency unit(billion Won) in real value which is evaluated in 1990 constant price. However, the data for L is the total number of employment denoted in unit of one thousand men.

All the data are annual data for 32 years of the period 1963-1994, for which the first 5-year economic development plan and the export-oriented policy were first launched in 1963. All the data are used in the natural log form.

The econometric softwares, SHAZAM v7.0 and RATS (CATS) v4.2 have been mainly used to perform the Engle-Granger(1987) cointegration test and the Johansen(1988) cointegration test, respectively.

<Table 4.1>

Annual Growth Rate of the Variables

in the Production Function of Korea (Average,%)

Variables	1963-72	1973-82	1982-94	1963-94
Y (GDP;output)	8.97	7.72	8.79	8.50
K (Physical Capital)	7.68	13.52	11.42	11.01
L (Employment)	3.59	3.33	2.73	3.17
X (Export)	30.79	17.57	11.91	19.22
M (Import)	21.49	14.45	12.72	15.82

[8] For the details, refer to Pyo(1992).

4.3 Result of Unit-Root Test

<Table 4.2> and <4.3> show the unit root test result of the level variables in log transformation and their first differences respectively. If a negative t-statistics in two tailed test is smaller than the negative critical value in absolute term[9], then we can conclude that the null hypothesis of unit-root process can not be rejected, and that the process is nonstationary.

As to the level variables, Dickey-Fuller(D-F) test shows that all the variables(lnY, lnK, lnL, lnX, lnM) are unit-root processes and so nonstationary time series.

In contrast, the Phillips-Perron(P-P) test rejects the null hypothesis of unit-root in the case of lnX (no trend case). However, extension of sample period to 1953-94 enables the P-P test not to reject the null hypothesis of unit-root about export.

As to the first differences, the D-F test shows that all the first differences are not unit-root processes, and that they are stationary.

In contrast, the P-P test does not reject the null of unit-root about ΔlnK(trend case), while ΔlnK(no trend case) is shown to be stationary at 10% significance level.

Even though the Phillips-Perron test partially shows an inconsistent result about capital stock for trend and no trend cases, it also arrives at the same conclusion about the

[9] Since the distribution is skewed toward negative value, the negative critical value is larger than the positive critical value in absolute term.

other variables as those of the Dickey-Fuller test. Therefore, it can be concluded[10] that all the first differences in the production function are stationary, while all the level variables are unit-root processes and so nonstationary.

In summary, all of the variables(Y,K,L,X,M) are integrated of order one: I(1).

<Table 4.2>

Summary of Unit Root Test

: Level Variables

<No trend> $\Delta Z_t = \alpha_0 + \beta Z_{t-1} + \sum_{i=1}^{p} \phi_i \Delta Z_{t-i} + u_t$

<Trend> $\Delta Z_t = \alpha_0 + \alpha_1 t + \beta Z_{t-1} + \sum_{i=1}^{p} \phi_i \Delta Z_{t-i} + u_t$

The null hypothesis is H_0: $\beta=0$ (unit-root process), $XM_t \equiv X_t + M_t$

Z_t	Lag (p)[2] in D-F (or P-P) eq.	Time Trend	t-statistics (Dickey-Fuller test)	t-statistics (Phillips-Perron test)
lnY	0(1)		-0.8214	-0.8058
	0(1)	x	-2.1213	-2.2382
lnK	2(1)		0.4879	1.6420
	2(1)	x	-2.4965	-3.3948*
lnL	0(1)		-1.5775	-1.5162
	0(1)	x	-1.2271	-1.3072
lnX	5(1)		-2.6283(-0.54)[1]	-3.55***(-0.54)
	5(1)	x	-3.1300(-0.84)	-1.0083(-1.04)
lnM	0(1)		-1.2885	-1.2561
	0(1)	x	-1.5021	-1.5952
lnXM	0(1)		-2.2117	-2.1038
	0(1)	x	-1.0777	-1.1470

The critical values for the Dickey-Fuller and the Phillips-Perron test are -3.43(1%), -2.86(5%),-2.57(10%) for no trend model, and -3.96(1%),-3.41(5%),-3.13(10%) for trend model.

* significant (not unit-root or stationary) at α=10% , ** significant at 5% , ***significant at 1%

Data:Y,K,L,X and M(1963-1994)

1 t-statistic in parenthesis is for the period 1953-94.

2 Lag length(p) is set to the highest significant lag order (using an approximate 95% confidence interval) from either the autocorrelation function or the partial autocorrelation function to ensure that the residuals from the estimated model(i.e. augmented D-F equation) are white noise.

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[10] Since there is a little possibility, even if small, that K is not I(1), it is desirable to interpret and apply the result of the cointegration test in a careful manner.

<Table 4.3>

Summary of Unit Root Test

: First Differences of the Variables

<No trend> $\Delta Z_t = \alpha_0 + \beta Z_{t-1} + \sum_{i=1}^{p} \phi_i \Delta Z_{t-i} + u_t$

<Trend> $\Delta Z_t = \alpha_0 + \alpha_1 t + \beta Z_{t-1} + \sum_{i=1}^{p} \phi_i \Delta Z_{t-i} + u_t$

The null hypothesis is H_0: β=0 (unit-root process)

Z_t	Lag (p)[2] in D-F (or P-P) eq.	Time Trend	t-statistics (Dickey-Fuller test)	t-statistics (Phillips-Perron test)
ΔlnY	1(1)		-3.7168***	-4.9497***
	1(1)	x	-3.7887**	-4.9162***
ΔlnK	1(1)		-3.5229***	-2.6670*
	1(1)	x	-3.4219**	-2.3797
ΔlnL	0(1)		-4.4605***	-4.9497***
	0(1)	x	-4.8466***	-4.9162***
ΔlnX	1(1)		-2.7198*	-3.4577***
	1(1)	x	-4.7501***	-5.0050***
ΔlnM	1(1)		-4.5573***	-4.7307***
	1(1)	x	-5.4556***	-4.7081***
ΔlnXM	1(1)		-3.6269***	-4.1712***
	1(1)	x	-5.4163***	-4.4918***

The critical values for the Dickey-Fuller and the Phillips-Perron test are -3.43(1%), -2.86(5%),-2.57(10%) for no trend model, and -3.96(1%),-3.41(5%),-3.13(10%) for trend model.

* significant (not unit-root or stationary) at α=10%, ** significant at 5%, ***significant at 1%

Data:Y,K,L,X and M(1963-1994)

[1] t-statistic in parenthesis is for the period 1953-94.

[2] Lag length(p) is set to the highest significant lag order (using an approximate 95% confidence interval) from either the autocorrelation function or the partial autocorrelation function to ensure that the residuals from the estimated model(i.e. augmented D-F equation) are white noise.

4.4 Result of Cointegration Test : Engle and Granger(1987) Test

The fact that all the variables in the production function are I(1) enables us to try the cointegration test. The purpose of the test is to check if national output and the production inputs such as capital and labor can be cointegrated with export and/or import in the same production function, and to check the signs of trade.

In the meantime, several studies such as Bahmani-Oskooee and Alse(1993), Dutt and Ghosh(1996) have applied the bi-variate Engle-Granger cointegration test[11] to find the causality between GDP and export in Asian countries including Korea. Since these bi-variate causality tests have been criticized to lack a theoretical foundation leading to a omitted variable bias, this dissertation starts from the Engle-Granger cointegration test of the production function type model to compare the results with those by the bi-variate cointegration tests.

4.4.1 Engle and Granger Cointegration Test

<Table 4.4> is a summary of Engle and Granger(1987) cointegration test using Dickey-Fuller method for cases where only current variables are included in cointegration equations. <Table 4.4> can be summarized as following.

If only the current variables are included, then the variables in the production function are not easily cointegrated in the Engle and Granger cointegration test. Especially,

(1) when both export and import are excluded in the production,

(3) when only current import is included,

(4) when import and export are separately included,

[11] Their cointegration tests are performed after the preliminary unit-root tests(Dickey-Fuller test, Phillip-Perron test, KPSS test) in which export and output are confirmed to be nonstationary unit root processes.

(5) when sum of only current export and import is included, then cointegration is denied at 5% or 10% singnificance level. The residuals from the above cointegrating equations are nonstationary unit root processes.

<Table 4.4>

Summary of the Engle-Granger Cointegration Test

Cointegrating Equation : $lnY_t = a\ (+ b\ t) + \alpha\, lnK_t + \beta\, lnL_t\ (+ \delta_1\, lnX_t + \delta_2\, lnM_t) + u_t$

Residual equation(i.e. Augmented D-F equation) : $\Delta\hat{u}_t = \alpha_1\hat{u}_{t-1} + \sum_{i=1}^{p} \alpha_{i+1}\Delta\hat{u}_{t-i} + \varepsilon_t$

$XM_t \equiv X_t + M_t$

Right-Side Variables (log form)	Trend	t-statistics for Ho: no-cointegration	Lag length(p)[1] for the minimum AIC
(1)Kt, Lt		-1.91	3
	x	-3.58	1
(2)Kt, Lt, Xt		-2.00	3
	x	-4.16*	2
(3)Kt, Lt, Mt		-2.01	3
	x	-3.56	1
(4)Kt, Lt, Xt, Mt		-2.34	3
	x	-3.63	1
(5)Kt, Lt, XMt		-1.91	3
	x	-3.79	1

The null hypothesis is H_0: no-cointegration (unit-root of the residuals of cointegrating equation)

* significant (cointegration) at α=10%

For the model (1), the critical values for the Dickey-Fuller test are -4.29(1%),-3.74(5%),-3.45 (10%) for no trend case, and -4.66 (1%), -4.12(5%),-3.84 (10%) for trend case.

For the model (2),(3) and (5), the critical values are -4.64(1%),-4.10(5%),-3.81 (10%) for no trend case, and -4.97(1%),-4.43(5%),-4.15 (10%) for trend case.

For the model (4), the critical values are -4.96(1%),-4.42(5%),-4.13 (10%) for no trend case, and -5.25 (1%), -4.72(5%), -4.43(10%) for trend case.

Data: All the variables are in the natural logarism for the period 1966-94.

[1] Lag length is set to ensure the minimum AIC (Akaike Information Criteria) in each model.

However, <Table 4.4> shows the possibility that if only export is included excluding import, then the variables in the production function with a linear trend can be cointegrated at 10% significance level. Since the t-value(-4.16) of the coefficient $\hat{\alpha}_1$ in the residual equation(i.e. augmented Dickey-Fuller equation with lag p=2) exceeds the critical value(-4.15), the null hypothesis of α_1 =0(or no cointegration) is rejected at 10% significance level. This result means that export is a required factor for the cointegration of the production function and has worked as a kind of production factor exerting externalities.

4.4.2 Estimation and Interpretation of the Cointegrating Relationship

4.4.2.1 Estimation of the Cointegrating Equation

Estimation of ECM in the Engle-Granger cointegration test uses the cointegrating equation only with the current export, since this is is the only case in which all the current variables in the production function are cointegrated as shown in <Table 4.4>.[12]

According to the Engle and Granger(1987), the OLS estimators of the cointegrating equation are "super-consistent" estimators which converge much faster on the population parameters than any other estimators. The iteration technique such as Cochrane-Orcutt estimation can result in a biased estimator. The OLS estimators of cointegrating equation represent long-run equilibrium relationship among variables, if they are cointegrated.

<Table 4.5> shows the cointegrating relationship in the long-run between the variables which contain only current export and excludes import.

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[12] Note that in this case the externality effect of export can be evaluated as smaller than the real size, since the cumulative lagged effect is not being addressed.

<Table 4.5>

Engle and Granger Cointegration Test

: Long-run Equilibrium Relationship between Cointegrated Variables

Model : $lnY_t = a + b\,t + \alpha\, lnK_t + \beta\, lnL_t + \delta\, lnX_t + u_t$

	lnK	lnL	lnX	constant	trend
Coefficient	0.3344***	1.0469***	0.0408*	3.0452	0.0922***
[p - value]	[0.008]	[0.002]	[0.088]	[0.243]	[0.000]

p-values,i.e., the marginal significance level of a two-tailed test of the hypothesis that the coefficient is zero are given in square brackets.
* significant at α=10% , ** significant at α=5%, *** significant at α=1%
Data: All the variables are in the natural logarism for the period 1966-94.

$\bar{R}^2 = 0.9983$, D.W.=1.2053

The coefficients of physical capital(lnK) and employment(lnL) are significant at 1% significance level, while that of export(lnX) is significant at 10% significance level.

This result implies that, since the coefficient of export is positive, export has exerted positive externalities that is not explained by the other production factors in the long-run equilibrium relationship. However, the role of export in the Engle-Granger cointegration equation is only marginally admitted at 10% significance level.

4.4.2.2 Macro-economic Interpretation of the Error Correction Term

The stationary cointegrating equation (i.e. error correction term $\beta' Z_t$) represents any deviation from the long-run equilibrium relationship. From the above estimation, the short-run deviation is expressed as

$$\beta' Z_t \equiv lnY_t - a - b\,t - \alpha\, lnK_t - \beta\, lnL_t - \delta\, lnX_t$$

The above equation implies excess demand in the aggregate economy. Now that

aggregate demand : $Y^d \equiv C + I + G + X - M$

aggregate supply (i.e. production function): $Y^s \equiv f(K,L,H,X) \equiv a\text{-}\alpha\ lnK_t - \beta\ lnL_t - \delta\ lnX_t$,

then equilibrium condition requires

$$Y^d - Y^s = 0$$

where C(Consumption), I(Investment), G(Governmental expenditure), X(Export), M(Import).

Thus, the error correction term ($\beta' Z_t$) can be interpreted as excess demand by which the aggregate demand exceeds the aggregate supply or production capacity :i.e.

$$\beta' Z_t = Y^d - f(K, L, X).$$

In the mean time, export has been assumed to work as a production factor exerting externalities through knowledge spillovers, etc. Export plays the two role like investment. Export increases not only current aggregate demand and income, but also production capacity in the next period. This means that an increase in export improves potential production capacity, and so reslts in the excess supply in terms of potential GDP.

The excess supply due to an increase in current export can be released by an increase in aggregate demand in the next period. It will result in the output increase in the next period.

If an increase in aggregate demand is met by the new increase in foreign demand, then the new export will again increase the production capacity after two periods from now. Therefore, export promotion policy will help increase not only the current output, but also future production capacity.

Besides, import works not merely as a leakage in the flow of aggregate income, but as a production factor like export exerting externalities of knowledge spillover. Thus, even if export increases in the same speed as import so that net export(i.e. export minus import) is zero, the externalities from export and import may increase the potential production capacity in the long-run, which will cause a deviation in the cointegrating equation.

4.4.3 Estimation of ECM and Granger Causality

<Table 4.6> and <4.7> shows the estimated coefficients of ECM(Error Correction Model), which implies the short-run adjustment coefficients of each endogenous variables. To consider the deviation in the long-run equilibrium relationship, estimation of ECM by Engle-Granger uses the residuals obtained from the cointegrating relationship, which were already obtained in <Table 4.5>.

<Table 4.6> and <4.7> show the two different cases in which different lag length (i.e. p=2 and 3) are used in ECM. <Table 4.6> represents the ECM of lag length P=2 and <Table 4.7> represents the ECM of lag length p=3.

The model selection criteria, SBC(Schwarz Bayesian Criteria) indices[13] are shown in the two tables. The smaller the SBC index is, the better the model is.

The SBC indices for the equation $\Delta \ln K_t$, , $\Delta \ln L_t$ and $\Delta \ln X_t$ are smaller in the ECM with lag length p=2 (i.e. -7.9905, -8.0029, -4.0900) than those in the ECM with lag p=3 (i.e. -7.7898, -7.6993, -3.3742). But, the SBC index for the equation $\Delta \ln Y_t$ is smaller in

[13] SBC index is defined as $SBC = T \log(RSS) + n \log(T)$, where RSS is the squared sum of the residuals and n denotes total number of parameters estimated in each equation. The principle is to select the model having the lowest SBC value.

the ECM with lag length p=3 (i.e. -7.2560) than that in the ECM with lag p=2 (i.e. -7.1854).

This result shows that, for the equation ΔlnK_t, ΔlnL_t and ΔlnX_t, the ECM with lag length p=2 (i.e. <Table 4.6>) is better as a parsimonious model. However, for the equation ΔlnY_t, the ECM with lag p=3 (i.e. <Table 4.7>) is needed to ensure the smaller prediction error.

The common result of <Table 4.6> and <4.7> can be summarized as following. Only output(ΔlnY_t) and capital(ΔlnK_t) respond to the error correction term($\beta' Z_{t-1}$) i.e. to the deviation in the long-run equilibrium relationship, while the other variables such as employment (ΔlnL_t) and export(ΔlnX_t) don't respond.

As to the response to lagged values, aggregate output(ΔlnY_t) is positively affected only by one or two period lagged values of export (i.e. ΔlnX_{t-1} and ΔlnX_{t-2}) at 10% significance level as shown in <Table 4.7>.

In contrast, physical capital isn't affected by lagged values of the other variables in <Table 4.7>. However, since the coefficients(0.3616 or 0.4258) of the error correction term of the capital equation are significant at 1% significance level, it can be said that physical capital is affected by export and national output by way of the long-run equilibrium relationship.

It is interesting to see that export is positively affected by the change of the lagged physical capital (or investment) at 5% significance level in the model with 2 lags as shown in <Table 4.6>. This result can reflect the fact that the increase in export has followed huge investment in physical capital.[14]

However, in the model with 3 lags as shown in <Table 4.7>, F-test doesn't reject the null of insignificance for the coefficients of physical capital. Since the test result is varying up to the models with different lags, the conclusion about the causality from physical capital to export is not so robust.

In summary, <Table 4.6> and <4.7> about the Engle-Granger ECM reveal that aggregate output and physical capital have clearly adjusted to any short-run shift of the other variables in the production system, which especially include export. Also, export has responded to the change of physical capital or investment, but this latter causality is not so robust.[15]

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[14] Since major portion of the investment in physical capital in Korea is achieved through import of foreign capital goods, it can be concluded that huge investment and import of capital goods and the relevant knowledge spillover have jointly enabled export to increase in the later periods.

[15] The other study which is not introduced here also shows that total trade(i.e. imports plus exports) have had an significant externality or knowledge spillover effect which can be realized more completely in the long-run, and that they have worked as an important source of economies of scale(i.e. increasing returns) in the Korean economy. This externality effect tends to increase as the longer lags of import and export are included.

In a cointegrated system, "**Granger causality**"[16] is defined in a slightly different way from those in a regular VAR(Vector Autoregression) model.[17] For example, the variable $\{Y_t\}$ does not Granger cause $\{X_t\}$, (1)if all the coefficients of lagged values ΔY_{t-i} in ΔX_t equation are zero, and (2)if ΔX_t does not respond to the deviation in the long-run equilibrium(i.e. $\alpha_x = 0$).

In this case, restrictions that all the coefficients of lagged values of the same explanatory variable can be checked using a F-test. Also, if there is a single cointegrating vector, restriction concerning coefficients of adjustment speed can be conducted using a t-test.[18]

Therefore, significance of all the estimated coefficients in the ECM with 2 lags (i.e. <Table 4.6>) can be tested by t-test, because t-test has the same result as F-test. However, in the ECM over 2 lags(i.e. <Table 4.7>), significance of the estimated coefficients of lagged values can be tested by F-test, while the estimated adjustment speed of error correction term($\beta' Z_{t-1}$) is tested by t-value.

In terms of the Granger causality, the above Engle-Granger cointegration analysis shows not only that export Granger-causes output and physical capital, but also that physical capital (and so indirectly output) Granger-causes export, although in a less robust way, in cointegration test of the production function. The causality between output(or

[16] Granger causality is a weaker condition than the condition for exogeneity. A necessary condition for the exogeneity of $\{X_t\}$ is for both current and past values of $\{Y_t\}$ not to affect $\{X_t\}$. In this sense, Granger causality condition is called as one for weak exogeneity.[Enders(1995,p315)]
[17] Enders(1995,p371)
[18] Ibid (p376)

physical capital) and export is bi-directional between export and output and/or physical capital.

These results are consistent with the widely held consensus in Korea that export has been a main engine of growth. Also, the result implies that export has played important roles in the production function as a kind of production factor.

<Table 4.6>

Engle and Granger Cointegration Test

: Estimation of ECM with 2 Lags

Model : $\Delta Z_t = \pi_0 + \alpha(\beta' Z_{t-1}) + \Gamma_1 \Delta Z_{t-1} + \varepsilon_t$, where $Z_t = [\ln Y_t, \ln K_t, \ln L_t, \ln X_t]'$

Explanatory (Right-side) Variables	Dependent	(Left-side)	Variables	(ΔZ_t)
	$\Delta \ln Y_t$	$\Delta \ln K_t$	$\Delta \ln L_t$	$\Delta \ln X_t$
$\beta' Z_{t-1}$	-0.6009***	0.3616***	0.0801	0.2528
	[0.003]	[0.007]	[0.502]	[0.771]
$\Delta \ln Y_{t-1}$	0.1665	0.1467	-0.0834	-0.8722
	[0.326]	[0.199]	[0.443]	[0.275]
$\Delta \ln K_{t-1}$	-0.1782	0.8795***	-0.1098	1.7553**
	[0.302]	[0.000]	[0.324]	[0.037]
$\Delta \ln L_{t-1}$	0.6134*	0.3654*	0.1302	0.8799
	[0.058]	[0.089]	[0.519]	[0.549]
$\Delta \ln X_{t-1}$	0.0300	0.0190	0.0457	0.3161
	[0.501]	[0.525]	[0.120]	[0.140]
constant	0.0628**	-0.0115	0.0372**	0.3451***
	[0.012]	[0.464]	[0.020]	[0.004]
R^2	0.5922	0.7723	0.2598	0.4113
$(\bar{R}^2)$	[0.5036]	[0.7228]	[0.0989]	[0.2833]
D.W.	2.05	1.83	1.84	2.09
log SBC	-7.1854	-7.9905	-8.0629	-4.0900

Significance of all the estimated coefficients in the table are tested by t-test. The p-values,i.e., the marginal significance level of a two-tailed test of the hypothesis that the coefficient is zero are given in square brackets under each estimate.

Thus, * significant at α=10% , ** significant at α=5%, *** significant at α=1%

Data: All the variables are in the natural logarism for the period 1966-94.

<Table 4.7>

Engle and Granger Cointegration Test

: Estimation of ECM with 3 Lags

Model : $\Delta Z_t = \pi_0 + \alpha(\beta' Z_{t-1}) + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \varepsilon_t$, where Z_t = [$\ln Y_t$, $\ln K_t$, $\ln L_t$, $\ln X_t$]'

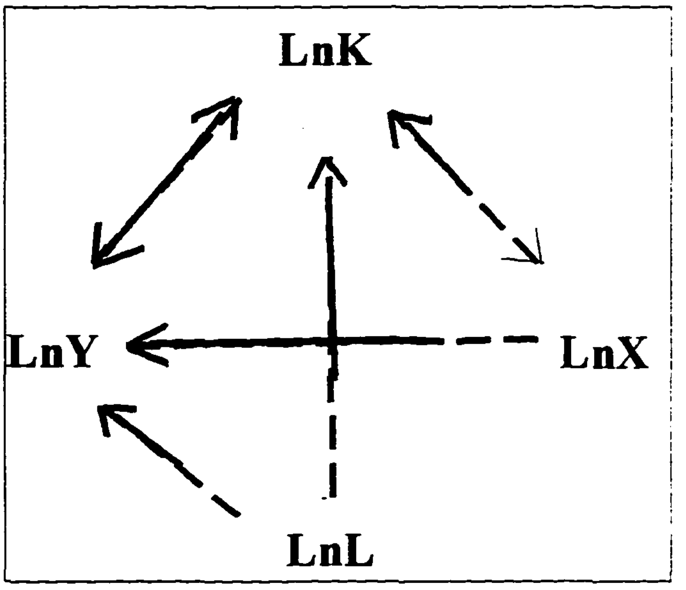
Explanatory (Right-side) Variables	Dependent $\Delta \ln Y_t$	(Left-side) $\Delta \ln K_t$	Variables $\Delta \ln L_t$	(ΔZ_t) $\Delta \ln X_t$
$\beta' Z_{t-1}$	-0.7764***	0.4258**	0.0026	-0.2376
	[0.001]	[0.012]	[0.987]	[0.841]
$\Delta \ln Y_{t-1}$	0.1475**	-0.0040	-0.0951	-1.2984
	[0.039]	[0.525]	[0.596]	[0.371]
$\Delta \ln Y_{t-2}$	0.4393**	0.1295	0.0773	0.5157
	[0.039]	[0.525]	[0.596]	[0.371]
$\Delta \ln K_{t-1}$	0.2340	1.1453***	-0.1516	-1.4145
	[0.438]	[0.000]	[0.568]	[0.121]
$\Delta \ln K_{t-2}$	-0.3868	-0.3167***	0.0296	-0.5110
	[0.438]	[0.000]	[0.568]	[0.121]
$\Delta \ln L_{t-1}$	0.4468	0.2271	0.1198	0.4375
	[0.187]	[0.352]	[0.441]	[0.516]
$\Delta \ln L_{t-2}$	-0.3083	0.2511	0.2862	1.9564
	[0.187]	[0.352]	[0.441]	[0.516]
$\Delta \ln X_{t-1}$	0.0698*	0.0272	0.0518	0.3378
	[0.096]	[0.567]	[0.289]	[0.362]
$\Delta \ln X_{t-2}$	0.0746*	-0.0248	-0.0186	-0.0652
	[0.096]	[0.567]	[0.289]	[0.362]
constant	0.0458	-0.0060	0.0266	0.3138
	[0.214]	[0.828]	[0.363]	[0.147]
R^2	0.7612	0.8251	0.3308	0.4720
$(\bar{R}^2)$	[0.6481]	[0.7422]	[0.0138]	[0.2218]
D.W.	1.93	1.98	1.75	1.91
log SBC	-7.2560	-7.7898	-7.6993	-3.3742

Significance of all the estimated coefficients except $\beta' Z_{t-1}$ in the table are tested by F-test. In this case, the null hypothesis is the joint hypothesis that coefficients of lagged values of the same explanatory variables are zero at the same time, i.e. coefficient of $\Delta \ln Y_{t-1} = \Delta \ln Y_{t-2}$ =0 or coefficient of $\Delta \ln K_{t-1} = \Delta \ln K_{t-2}$ =0 or coefficient of $\Delta \ln X_{t-1} = \Delta \ln X_{t-2}$ =0 etc.. Thus, the number of restriction in each F-test is two.
However, significance of $\beta' Z_{t-1}$ is tested by t-values.
p-values,i.e., the marginal significance level of a two-tailed test of the hypothesis that the coefficient is zero are given in square bracket.
Thus, * significant at α=10%, ** significant at α=5%, *** significant at α=1%
Data: All the variables are in the natural logarism for the period 1966-94.

<Figure 4.2>

Engle-Granger Cointegration Test

: Granger Causality[1] among the Variables in the Production Function



[1] The arrows indicate the direction of Granger causality.

4.5 Result of Cointegration Test: Johansen(1988) Test

As was noted in the earlier chapter, the Engle-Granger cointegration test contains several potential defects. Several methods have been developed that avoid these problems. The Johansen (1988) maximum likelihood estimators circumvent the use of two-step estimators, and can estimate and test for the presence of multiple cointegrating vectors. Besides, since the ECM(Error Correction Model) resembles the VAR(Vector

Autoregressive Model),[19] the Johansen test and its estimators enable us to overcome the problem of simultaneity or endogeneity that the single equation estimation may involve.

4.5.1 Rank Test

4.5.1.1 Test Statistics of Rank Test

From equation<3.8>, Johansen ECM is expressed as

$$\Delta Z_t = \pi_0 + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \ldots + \Gamma_{p-1} \Delta Z_{t-p+1} + \Pi Z_{t-p} + \varepsilon_t$$ ....<3.8>

where the vector $Z_t = (z_{1t}, z_{2t}, \ldots, z_{nt})'$, $\Gamma_i = -(I - \pi_1 - \ldots - \pi_i)$, $i = 1,2,\ldots,p-1$ and $\Pi = -(I - \pi_1 - \ldots - \pi_p)$.

As was described in the earlier section, the number of distinct non-zero cointegrating vectors can be known by checking the rank of the coefficient matrix Π, which is equal to the number of its characteristic roots(λ) that differ from zero.

Let's rearrange the n characteristic roots[20] such that $\lambda_1 > \lambda_2 > \ldots > \lambda_n$. Then, the test for the rank of Π or for the number of characteristic roots that are different from zero can be performed using the following two test statistics:

(1) $\lambda_{trace}(r) = -T \sum_{i=r+1}^{n} \ln(1-\hat{\lambda}_i)$

[19] ECM and VAR share common characteristics in the point that they represent short-run relationship between endogenous variables in the system, and that the coefficients are determined simultaneously in the system. However, **ECM** is different from **VAR** in the sense that ECM additionally includes adjustment terms by the long-run equilibrium(cointegration) relationship between all the endogenous variables in the system.

[20] The n characteristic roots can be obtained by solving the **characteristic equation** of n dimensional polynomial, $|\hat{\Pi} - \lambda I| = 0$, where $\hat{\Pi}$ is the estimates of the $n \times n$ coefficient matrix, λ is a scalar and I is the $n \times n$ identity matrix.

H_0 : rank(Π) $\le$ r, H_A : rank(Π) > r.

(2) $\lambda_{max}(r, r+1) = -T \ln(1-\hat{\lambda}_{r+1})$

H_0 : rank(Π) = r, H_A : rank(Π) = r+1.

where $\hat{\lambda}_i$ is the **characteristic roots**(or **eigenvalues**) obtained from the estimated Π matrix ,and T is the number of usable observations.

The first statistic(λ_{trace}) tests the null hypothesis that the number of distinct cointegrating vectors is less than or equal to r against a general alternative hypothesis. The second statistic(λ_{max}) tests the null that the number of cointegrating vector is r against the alternative hypothesis of r +1 cointegrating vectors.

The further the estimated characteristic roots are from zero, the larger the λ_{trace} and λ_{max} become. Then, the possibility of larger number of cointegrating vectors gets higher.[20] Johansen and Juselius(1990) provide the critical values of the λ_{trace} and λ_{max} statistics from simulation studies, which depend on

(1) the number of nonstationary components under the null hypothesis(i.e. n-r)

(2) inclusion of the drift term π_0 in the ECM model, or a constant in the cointegrating vector, which will reflect any potential deterministic linear trends.

The rank test which involves the Korean production function reveals that there exist at least one cointegrating vector among the variables in the production function under consideration. The test result will be introduced in the next section.

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[20] If the variables in Z_t are not cointegrated, the rank of Π is zero and all these characteristic roots will be equal to zero, which in turn means $\ln(1-\hat{\lambda}_i)$ will equal zero: $\ln(1-\hat{\lambda}_1) = \ln(1-\hat{\lambda}_2) = ... = \ln(1-\hat{\lambda}_n) = 0$.
If the rank of Π is one, then $0<\hat{\lambda}_1<1$,so that $\ln(1-\hat{\lambda}_1) < 0$ and all the other $\hat{\lambda}_i$ (i=2,3,...n) will equal zero: $\ln(1-\hat{\lambda}_2) = ... = \ln(1-\hat{\lambda}_n) = 0$.

4.5.1.2 Model Selection (Determination of Lag Length)

The first step of Johansen test is to determine the lag length of ECM model. If lag length is too short, then the residuals are autocorrelated. Too long lags may result in a problem of reducing the degree of freedom.

There are two methods to determine the lag length. The first is the LR(Likelihood ratio) test statistic,[21] and the second is the multivariate generalization of the SBC(Schwarz Bayesian Criteria).[22]

Since the sample size is 32 (1963~1994) and the number of endogenous variables is 5, the lag length can't exceed 4.

To estimate the unrestricted ECM, we may use either SBC or LR information criteria in determining the lag length. The SBC criteria provides much simpler way to determine the appropriate lag length.

To make it easy to compare with the estimation result of the Engle-Granger ECM in the earlier section, this dissertation starts first using a model only with current export in the cointegrating equation excluding import. The Johansen test for the model with both export and import will be introduced in the later section.

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[21] Likelihood ratio statistic is defined as LR = (T - c) ($\log|\Sigma_R|$ - $\log|\Sigma_U|$), where T denotes the number of observation, c denotes the number of parameters in the unrestricted system. $\log|\Sigma_i|$ is the natural log of the determinant of Σ_i (i=Restricted or Unrestricted lag length) and Σ is the variance-covariance matrix of the residuals. Under the null that R lag length is right, LR statistic follows the χ^2 distribution with degree of freedom equal to the number of coefficient restriction.

[22] SBC index is defined as SBC = T $\log|\Sigma|$ + N log(T), where $|\Sigma|$ is the determinant of the variance-covariance matrix of the residuals and N denotes total number of parameters estimated in all equations. The principle is to select the model having the lowest SBC value. Since SBC are not based on any distribution theory, it can't be used in testing the type of cross equation restrictions.

<Table 4.8>

Johansen Test for the Model with Export

: SBC Information Criteria for Model Selection

ECM : $\Delta Z_t = \pi_0 + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \ldots + \Gamma_{p-1} \Delta Z_{t-p+1} + \Pi Z_{t-p} + \varepsilon_t$,

where Z_t = [$\ln Y_t$, $\ln K_t$, $\ln L_t$, $\ln X_t$]'

Endogenous Variables	Lag length (p)	SBC	Degree of freedom in each equation	Rank (Π) at 5%
Y, K, L, X	2	-27.20	21	1 ($\hat{\lambda}_{trace}$), 0 ($\hat{\lambda}_{max}$)
	3	-27.92	16	2 ($\hat{\lambda}_{trace}$, $\hat{\lambda}_{max}$)
	4	-27.79	11	3 ($\hat{\lambda}_{trace}$, $\hat{\lambda}_{max}$)

<Table 4.8> shows the SBC index which is related to each ECM model of different lag length. Since the SBC index is the smallest in the model with 3 lags, the ECM with 3 lags can be selected as an optimal model.

4.5.1.3 Rank Test of the ECM with 3 Lags

<Table 4.9> shows the result of λ_{trace} test. For the null hypothesis, H_0: $r \leq 0$, the test statistic (66.36) exceeds the critical value(47.18) and so the null hypothesis is rejected at 5% significance level. For the null, H_0: $r \leq 1$, the test statistic (34.45) exceeds the critical value(29.51) and so the null hypothesis is rejected at 5% significance level.

<Table 4.9>

Johansen Cointegration Test[1] : λ_{trace} Test

4 Eigenvalues: $\hat{\lambda}_1 = 0.6672$, $\hat{\lambda}_2 = 0.5812$, $\hat{\lambda}_3 = 0.2496$, $\hat{\lambda}_4 = 0.0302$

H_0: r ≤	H_A: r >	$\hat{\lambda}_{trace}$ statistic	Critical value[2] at α = 5%	Judge at α = 5%
0	0	66.36	47.18	reject H_0
1	1	34.45	29.51	reject H_0
2	2	9.22	15.20	don't reject H_0
3	3	0.89	3.96	don't reject H_0

[1] Endogenous variables : $Z_t = [\ \ln Y_t, \ln K_t, \ln L_t, \ln X_t\ ]'$

[2] Critical values are from Johansen and Juselius(1990), and requoted from Enders(1995)

Lag length of ECM is set as 3, and drift terms are included in the ECM.

<Table 4.10>

Johansen Cointegration Test[1] : λ_{max} Test

4 Eigenvalues: $\hat{\lambda}_1 = 0.6672$, $\hat{\lambda}_2 = 0.5812$, $\hat{\lambda}_3 = 0.2496$, $\hat{\lambda}_4 = 0.0302$

H_0: r =	H_A: r =	$\hat{\lambda}_{max}$ statistic	Critical value[2] at α = 5%	Judge at α = 5%
0	1	31.91	27.17	reject H_0
1	2	25.24	20.78	reject H_0
2	3	8.33	14.04	don't reject H_0
3	4	0.89	3.96	don't reject H_0

[1] Endogenous variables : $Z_t = [\ \ln Y_t, \ln K_t, \ln L_t, \ln X_t\ ]'$

[2] Critical values are from Johansen and Juselius(1990), and requoted from Enders(1995)

Lag length of ECM is set as 3, and drift terms are included in the ECM.

However, for the null H_0: r ≤ 2 against the alternative H_A: r >2, the test statistic(9.22) is smaller than the critical value(15.20) and the null is not rejected at 5% significance level. This λ_{trace} test means the rank of Π matrix is two: i.e. rank(Π)=2.

<Table 4.10> shows the result of λ_{max} test. For the null hypothesis H_0: r =0, the test statistics(31.91) exceeds the critical value(27.17), and so the null hypothesis is rejected at 5% significance level. For the null H_0: r = 1, the test statistics(25.24) exceeds the critical value(20.78), and so the null hypothesis is rejected at 5% significance level. However, for the null H_0: r = 2 against H_A: r = 3, the test statistic(8.33) is smaller than the critical value(14.04). The null is not rejected at 5% significance level. This λ_{max} test means the rank of Π matrix is two : i.e. rank(Π)=2.

The above tests show that the results of λ_{max} and λ_{trace} test are the same. Therefore, it can be concluded that rank(Π)=2 at 5% significance level.

The fact that rank(Π)=2 implies there exists two cointegrating vectors that can make the nonstationary variables in the production function produce a stationary relationship in the long-run. Total volume of export is well cointegrated into the production function as a kind of input.

Since Johansen test applies the maximum likelihood estimation to ECM model, it does not involve simultaneity bias or endogeneity bias as long as the residuals from the estimation are shown to be white-noise.

4.5.2 Cointegrating Vectors and Restriction Test

4.5.2.1 Unrestricted Cointegrating Vectors

<Table 4.11> and <4.12> show the unrestricted cointegrating vector(β) and the speed of adjustment(α) after normalization with respect to the coefficient of output lnY. Since

the production function means that the coefficient vector has the form $\beta = (1, *, *, *, *, *)$, the cointegrating vector is normalized to ensure the coefficient of output Y to be unity first.

Since the cointegrating vector represents the possible long-run equilibrium relationship between variables, short-run change in any variable in the cointegrating relationship results in a deviation from the long-run equilibrium relationship. This deviation will cause each endogenous variable to adjust partially in the next period. The speed and direction of adjustment is determined by the coefficient vector α. The larger the coefficient α_j (j=1,..,n) is, the larger the future variable changes.

<Table 4.11>

Johansen Cointegration Test[1]

: Unrestricted Cointegrating Vectors

Cointegrating vector	lnY	lnK	lnL	lnX
$\hat{\beta}_1'$	1.000	-0.040	-3.021	0.063
$\hat{\beta}_2'$	1.000	0.038	-4.330	0.337

[1] Endogenous variables : Z_t = [$\ln Y_t$, $\ln K_t$, $\ln L_t$, $\ln X_t$]'
Lag length of ECM is set as 3, and drift terms are included in the ECM.

<Table 4.11> shows that the unrestricted cointegrating relationship in the long-run equilibrium is

$$\beta_1 'Z_t = lnY_t - 0.04*lnK_t - 3.02*lnL_t + 0.06*lnX_t \quad ....<4.20>$$

and $\beta_2 'Z_t = lnY_t + 0.04*lnK_t - 4.33*lnL_t + 0.34*lnX_t$ ....<4.20'>

The way how a unit change in current export affects the other endogenous

<Table 4.12>

Johansen Cointegration Test[1]

: Speed of Adjustment Vectors (α)

Dependent Variables (Equation)	$\hat{\alpha}_1$	t-value for $\hat{\alpha}_1$	$\hat{\alpha}_2$	t-value for $\hat{\alpha}_2$
ΔlnY_t	-0.146	-1.734	0.103**	2.193
ΔlnK_t	-0.141**	-2.592	0.067**	2.223
ΔlnL_t	0.093**	2.389	0.113***	5.190
ΔlnX_t	1.047***	2.966	-0.289	-1.468

Critical values for t-test(d.f=16) are 1.746(α = 10%), 2.120(α = 5%), 2.921(α = 1%).
* significant at α=10%, ** significant at α=5%, *** significant at α=1%
[1] Endogenous variables : $Z_t = [\, lnY_t,\ lnK_t,\ lnL_t,\ lnX_t \,]'$
Lag length of ECM is set as 3, and drift terms are included in the ECM.

variables(including output) in the next period, depends on the adjustment speed(α) as shown in <Table 4.12>.

Therefore, short-run adjustment in national production that is driven by the long-run equilibrium relationship, actually occurs by linear combination of the cointegrating relationship (i.e. equation<4.20>) and the adjustment speed(α). For example,

$$\Delta lnY_t = \hat{\alpha}_1 \hat{\beta}_1' Z_{t-1} + \hat{\alpha}_2 \hat{\beta}_2' Z_{t-1}$$

$$= -0.146*(lnY_{t-1} - 0.04*lnK_{t-1} - 3.02*lnL_{t-1} + 0.06*lnX_{t-1})$$

$$+0.103*(lnY_{t-1} + 0.04*lnK_{t-1} - 4.33*lnL_{t-1} + 0.34*lnX_{t-1}) \text{ ....<4.21>}$$

<Table 4.13> about the matrix $\hat{\Pi}(=\hat{\alpha}\ \hat{\beta}')$ shows all these short-run effects of current change in each endogenous variable on the future adjustment of all the endogenous variables.

<Table 4.13>

Johansen Cointegration Test

: $\hat{\Pi}(=\hat{\alpha}\ \hat{\beta}')$ matrix of Error Correction Terms

ECM : $\Delta Z_t = \pi_0 + \Gamma_1\Delta Z_{t-1} + \Gamma_2\Delta Z_{t-2} + \Pi Z_{t-1} + \varepsilon_t$, where $Z_t = [\ \ln Y_t, \ln K_t, \ln L_t, \ln X_t\ ]'$

Dependent Variable (Equation)	Variables in the Cointegrating Relationship (Error Correction) $\ln Y_{t-1}$	$\ln K_{t-1}$	$\ln L_{t-1}$	$\ln X_{t-1}$
$\Delta\ln Y_t$	-0.043	0.010**	-0.004	0.025
	(-0.448)	(2.559)	(-0.013)	(1.524)
$\Delta\ln K_t$	-0.074	0.008***	0.135	0.014
	(-1.183)	(3.332)	(0.639)	(1.278)
$\Delta\ln L_t$	0.207***	0.001	-0.772***	0.044***
	(4.613)	(0.319)	(-5.105)	(5.682)
$\Delta\ln X_t$	0.759*	-0.053***	-1.914	-0.031
	(1.877)	(-3.308)	(-1.402)	(-0.443)

t-values in parentheses. Critical values for t-test(d.f=16) are 1.746(α = 10%), 2.120(α = 5%), 2.921(α = 1%).
* significant at α=10%, ** significant at α=5%, *** significant at α=1%
Lag length of ECM is set as p=3, and drift terms are included in the ECM.

4.5.3 Testing the Restrictions on β and α Coefficients

The Johansen procedure allows for testing restricted forms of the cointegrating vectors. Test of restrictions on the cointegrating vectors is crucial in the modelling of cointegrated variables, especially if the model contains more than one cointegrating vector. Moreover, since some of the coefficients in the unrestricted cointegrating vectors have the signs that are opposite to our expectation as shown in <Table 4.11>, it is necessary to restrict and test each coefficient in each cointegrating vector.

Let's denote the ordered characteristic roots of unrestricted $\hat{\Pi}$ matrix by $\hat{\lambda}_1, \hat{\lambda}_2, ..., \hat{\lambda}_n$ and the characteristic roots of the restricted model by $\hat{\lambda}_1^r, \hat{\lambda}_2^r, ..., \hat{\lambda}_n^r$. To test restrictions on β and α vectors, form the LR(likelihood ratio) test statistics:

$$LR = T \sum_{i=1}^{r} [\ln(1-\hat{\lambda}_n^r) - \ln(1-\hat{\lambda}_n)]$$

H_0 : restriction is right.

Asymtotically, this statistic has a χ^2-distribution with degree of freedom equal to the number of restrictions placed on β or α.

<Table 4.14> shows the result of the restriction test on β and α coefficients for the model with export. Coefficients $\hat{\beta}$s of most variables except physical capital are significant in the cointegrating relationships. Especially, the likelihood ratio statistic(12.37) for export(lnX) exceeds the critical value(5.99), which means that export can't be excluded from the cointegrating relationship of the production function.

Adjustment speed vector $\hat{\alpha}$ s are also significant for all the variables in the system. Especially, the LR test statistic(8.35) of export(i.e.α_x) is larger than the critical value(5.99) with 2 degree of freedom. This implies that most variables including export respond to the deviation in the long-run equilibrium relationship, which means that all the variables are endogenous in the system.

<Table 4.14>

Restriction Test(LR test) on α and β

for the Model with Export

ECM : $\Delta Z_t = \pi_0 + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \Pi Z_{t-1} + \varepsilon_t$, where Z_t = [$\ln Y_t$, $\ln K_t$, $\ln L_t$, $\ln X_t$]'

Restrictions (Coefficient=0)	χ^2 statistic	Critical Value[1] at α=5%	p-value	
lnK	0.10	$\chi^2(2)$= 5.99	0.95	don't reject the null
lnL	16.77	$\chi^2(2)$= 5.99	0.00	reject the null
lnX	12.37	$\chi^2(2)$= 5.99	0.00	reject the null
α_Y	6.63	$\chi^2(2)$= 5.99	0.04	reject the null
α_K	7.64	$\chi^2(2)$= 5.99	0.02	reject the null
α_L	15.28	$\chi^2(2)$= 5.99	0.00	reject the null
α_X	8.35	$\chi^2(2)$= 5.99	0.02	reject the null
lnX & α_X	20.92	$\chi^2(4)$= 9.49	0.00	reject the null

[1] Parenthesis denotes the degree of freedom.

However, <Table 4.14> shows the LR test results for the restriction that two coefficients of each variable(i.e. lnK or lnL or lnX) of 2 cointegrating vectors are zero at the same time. In this case, rejection of the null hypothesis (i.e. cases of lnL and lnX) only implies that at least one of the two coefficients in 2 cointegrating vectors is significant. In other words, one of the two coefficients of each variable can be insignificant.

To figure out which coefficient is insignificant, it is necessary to restrict each cointegrating vector and test each coefficient in each vector. <Table 4.15> shows the results of restriction test on each cointegrating vector β_i. For the joint null hypotheses(i.e.

joint restrictions) of $\beta_{1K} = \beta_{1L} = \beta_{2K} = \beta_{2X} = 0$, the LR test statistic(0.10) does not exceed the critical value(i.e. $\chi^2(2)$=5.99) at 5% significant level.

In contrast, for the null of β_{1X}=0(i.e. coefficient of export in the first cointegrating vector is zero), the Wald test statistic is $\chi^2 = (-0.824/0.052)^2 = 251$, which exceeds the critical value($\chi^2(2)$=5.99). Also, for the null of β_{2L}=0 (i.e. coefficient of labor in the second cointegrating vector is zero), the Wald test statistic is $\chi^2 = (-2.960/0.046)^2 = 4141$, which reveals that the estimated coefficient is also significant at 5% significant level.

As shown in <Table 4.15>, therefore, the significant coefficients in the two restricted cointegrating vectors have the expected signs. Especially, the coefficient of export(lnX) in the first cointegrating vector $\hat{\beta}_1^r$ has not only an expected sign opposite to that of output, but also a much larger coefficient(0.824) compared to that of unrestricted cointegrating vector(0.063) as shown in <Table 4.11>. These results imply that export has worked to increase the output positively and significantly in the long-run equilibrium relationship.

<Table 4.15>

Restriction Test on Each Cointegrating Vector [1]

& The Restricted Cointegrating Vectors

for the Model with Export

Restricted Cointegrating vector	lnY	lnK	lnL	lnX
$\hat{\beta}_1^r$	1.00***	0.00	0.00	-0.824 (0.052)***
$\hat{\beta}_2^r$	1.00***	0.00	-2.960(0.046)***	0.00

[1] Endogenous variables : Z_t = [$\ln Y_t$, $\ln K_t$, $\ln L_t$, $\ln X_t$]'. Lag length of ECM is set as 3, and drift terms are included in the ECM. LR test statistic for the joint null of $\beta_{1K} = \beta_{1L} = \beta_{2K} = \beta_{2X} = 0$ is 0.10, which does not exceed the critical value(i.e. $\chi^2(2)$=5.99) at 5% significant level. Parenthesis denotes standard error of each coefficient. *** significant at α=1%

4.5.2.3 Estimation of ECM and the Granger Causality

<Table 4.16> summarizes the estimation result of **ECM(Error Correction Model),** which contains not only the vector autoregressive terms in first differences, but also error correction terms driven by the cointegrating (long-run equilibrium) relationship among the variables in the system. OLS estimation is used to apply F-test. Also, the restricted cointegrating vectors in <Table 4.15> from Johansen test are used to compute the error correction terms, $\beta_i' Z_{t-1}$.

As we can see in <Table 4.16>, output($\Delta \ln Y_t$) has responded only to the lagged values of physical capital($\Delta \ln K_{t-1}$) in the short-run adjustment of Error Correction Model. The estimated coefficients of the lagged values of capital in output ($\Delta \ln Y_t$) equation are significant at 1% significance level. But, it was already shown in <Table 4.14> and <4.15> that current export affects output via long-run equilibrium relationship.

In contrast, export($\Delta \ln X_t$) has responded to none of the lagged values in the short-run adjustment mechanism of ECM. But, as was shown in <Table 4.14> and <4.15>, export is affected by output through long-run equilibrium mechanism.

<Table 4.16>

Johansen Cointegration Test

: Estimation of ECM with Export

ECM : $\Delta Z_t = \pi_0 + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \Pi Z_{t-1} + \varepsilon_t$, where $Z_t = [\ \ln Y_t, \ln K_t, \ln L_t, \ln X_t\ ]'$

Explanatory (Right-side) Variables	Dependent	(Left-side)	Variables	(ΔZ_t)
	$\Delta\ln Y_t$	$\Delta\ln K_t$	$\Delta\ln L_t$	$\Delta\ln X_t$
$\beta_1' Z_{t-1}$	-0.029*	-0.015**	-0.053***	0.026*
	[0.100]	[0.037]	[0.001]	[0.065]
$\beta_2' Z_{t-1}$	-0.009*	-0.057**	0.259***	0.682*
	[0.100]	[0.037]	[0.001]	[0.065]
$\Delta\ln Y_{t-1}$	-0.474	-0.337	-0.475***	-1.287
	[0.127]	[0.154]	[0.009]	[0.587]
$\Delta\ln Y_{t-2}$	0.147	0.028	-0.124***	-0.423
	[0.127]	[0.154]	[0.009]	[0.587]
$\Delta\ln K_{t-1}$	0.455***	1.187***	0.300	-0.347
	[0.004]	[0.002]	[0.213]	[0.938]
$\Delta\ln K_{t-2}$	-1.185***	-0.078***	-0.358	0.003
	[0.004]	[0.002]	[0.213]	[0.938]
$\Delta\ln L_{t-1}$	0.512	0.203	0.287**	1.351
	[0.290]	[0.356]	[0.018]	[0.490]
$\Delta\ln L_{t-2}$	-0.261	0.298	0.484**	1.438
	[0.290]	[0.356]	[0.018]	[0.490]
$\Delta\ln X_{t-1}$	0.076	0.050	0.026	0.016
	[0.348]	[0.387]	[0.335]	[0.629]
$\Delta\ln X_{t-2}$	-0.036	-0.005	-0.027	-0.199
	[0.348]	[0.387]	[0.335]	[0.629]
drift(trend)	0.118	-0.841	4.597***	11.677
	[0.962]	[0.600]	[0.001]	[0.278]
R^2	0.6657	0.8298	0.6857	0.6096
($\bar{R}^2$)	(0.4800)	(0.7353)	(0.5111)	(0.3927)
D.W.	1.8722	1.9580	1.9397	2.0296

The restricted cointegrating vectors from Johansen test are used to compute the error correction terms, $\beta_i' Z_{t-1}$.
Significance of all the estimated coefficients in the table are tested by F-test except drift(constant) terms. In this case, the null hypothesis is either the joint hypothesis that coefficients of lagged values of the same explanatory variables are zero at the same time(i.e. coefficient of $\Delta\ln Y_{t-1}=\Delta\ln Y_{t-2}=0$ or coefficient of $\Delta\ln K_{t-1}=\Delta\ln K_{t-2}=0$ or coefficient of $\Delta\ln X_{t-1}=\Delta\ln X_{t-2}=0$ etc.), or the joint hypothesis that coefficients of the 2 error correction terms are zero at the same time(i.e. coefficients of $\beta_1' Z_{t-1}=\beta_2' Z_{t-1}=0$). Thus, the number of restriction in each F-test is two.
p-values,i.e., the marginal significance level of a test of the hypothesis that the coefficient is zero are given in square bracket.
Thus, * significant at α=10%, ** significant at α=5%, *** significant at α=1%
Data: All the variables are in the natural logarism for the period 1963-94.

Thus, the Johansen test concludes that export $\{lnX_t\}$ Granger-causes output $\{lnY_t\}$, while output $\{lnY_t\}$ also Granger-causes export $\{lnX_t\}$.[23] The causality in Johansen cointegration test between output and export is bi-directional in the production function type ECM model. This conclusion in Johansen test is the same as that of Engle-Granger test.

4.5.4 Diagnostic Checking : Residual Analysis

Diagnostic checking is recommended to ensure that the ECM model under consideration is adequate. Usually, the diagnostic checking is tried using the residuals from the estimated model to determine whether the residuals of the near VAR or ECM model approximate white-noise:(1)no-autocorrelation (2)normal distribution.

If the residuals are serially correlated, then lag lengths may be too short. To check serial correlation, Ljung-Box(1978) test is often used, whose test statistics follow χ^2-distribution. In the above estimation of ECM, the lag length has been set p = 3. Ljung-Box test statistic for the joint hypothesis of no-autocorrelation up to 7 lags in the residuals is computed as 88.50, which doesn't exceed the critical value($\chi^2(72)=90.53$) at 5% significance level. Besides, the correlogram of the residuals in <Appendix-A> reveal that, since none of the sample autocorrelation coefficients exceed the critical values,[24] the null hypothesis of no autocorrelation is not rejected.

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[23] In a cointegrated system, "**Granger causality**" is defined in a slightly different way from those in a regular VAR model. For example, the variable $\{Y_t\}$ does not Granger cause $\{X_t\}$, if all the coefficients of lagged values ΔY_{t-i} in ΔX_t equation are zero, and if ΔX_t does not respond to the deviation from long-run equilibrium(i.e. $\alpha_x = 0$).

[24] The critical value for the null of no-autocorrelation($\rho_i=0$; i=1,...,7) is $1.96/\sqrt{T}$ at 5% significance level, where T denotes sample size. Since the sample size in our estimation is 30, the critical value is 0.3578.

Since maximum likelihood estimation assumes normal distribution of sample data, it is required to check the normality of residuals. The test statistic by Doornik and Hansen(1994) is computed as 10.82 for the null of normality, which doesn't exceed the critical value ($\chi^2(8)$=15.52) at 5% significance level.

These results imply that the ECM under consideration(i.e. lag length = 3) may almost produce white-noise residuals, and that the model contains little problem as a parsimonious model.

4.5.5 Model with Export and Import

The above Johansen test can be extended to the model with export and import. <Table 4.17> reveals that there exist multiple cointegrating vectors for every model under consideration. The main conclusion drawn in the above section has not changed.

<Table 4.17>

Rank of the Models with Export and Import

ECM: $\Delta Z_t = \pi_0 + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \ldots + \Gamma_{p-1} \Delta Z_{t-p+1} + \Pi Z_{t-p} + \varepsilon_t$,

where Z_t = [$\ln Y_t$, $\ln K_t$, $\ln L_t$, $\ln X_t$, $\ln M_t$]'

5 Eigenvalues(for p=3): $\hat{\lambda}_1 = 0.9203$, $\hat{\lambda}_2 = 0.7133$, $\hat{\lambda}_3 = 0.5583$, $\hat{\lambda}_4 = 0.3591$, $\hat{\lambda}_5 = 0.0460$

Endogenous Variables	Lag (p)	SBC	Deg. of freedom	Rank (Π) at 5%
Y, K, L, X, M	2	-32.13	19	2 ($\hat{\lambda}_{trace}$), 1 ($\hat{\lambda}_{max}$)
	3	-33.09	13	3 ($\hat{\lambda}_{trace}$, $\hat{\lambda}_{max}$)
	4	-33.03	7	4 ($\hat{\lambda}_{trace}$, $\hat{\lambda}_{max}$)

<Table 4.17> shows that, since the SBC index is the smallest in the model with 3 lags, the ECM with 3 lags can be selected as an optimal model.[26] In the model with 3 lags, $\hat{\lambda}_{trace}$ test and $\hat{\lambda}_{max}$ test show in common that there exist 3 cointegrating vectors at 5% significance level.

<Table 4.18>

Unrestricted Cointegrating Vectors[1]

of the Model with Export and Import

Cointegrating vector	lnY	lnK	lnL	lnX	lnM
$\hat{\beta}_1$'	1.000	-0.154	-1.625	0.022	-0.170
$\hat{\beta}_2$'	1.000	-0.383	-0.476	0.273	-0.494
$\hat{\beta}_3$'	1.000	6.028	-62.906	0.465	7.977

[1] Endogenous variables : Z_t = [$\ln Y_t$, $\ln K_t$, $\ln L_t$, $\ln X_t$, $\ln M_t$]'
Lag length of ECM is set as 3, and drift terms are included in the ECM.

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[26] As a diagnostic checking, the Ljung-Box test statistic for the null hypothesis of no-autocorrelation up to 7 lags in residuals is computed as 126.50, which exceeds the critical value critical value($\chi^2(110)=124.34$) at 5% significance level, but doesn't exceed the critical value($\chi^2(110)=135.81$) at 1% significance level. Besides, the test statistic by Doornik and Hansen(1994) is computed as 14.07 for the null of normality, which doesn't exceed the critical value ($\chi^2(10)=18.31$) at 5% significance level.

These results imply that the residuals behave almost like white-noises, even though there can be a slight auto-correlation at 5% significance level in physical capital as shown in the auto-correlogram of <Appendix-A.2>

<Table 4.18> shows 3 unrestricted cointegrating vectors after normalization with respect to output (lnY). It shows that signs of trade(export and import) and the other inputs are mixed in several cointegrating vectors. However, restriction tests in <Table 4.21> and <4.22> reveal that not only the signs of capital and labor, but also the signs of export and import in restricted cointegrating vectors are opposite to those of output as expected.

<Table 4.19>

Speed of Adjustment Vectors (α)[1]

of the Model with Export and Import

Depend. Variable (Equation)	$\hat{\alpha}_1$	t-value for $\hat{\alpha}_1$		$\hat{\alpha}_2$	t-value for $\hat{\alpha}_2$		$\hat{\alpha}_3$	t-value for $\hat{\alpha}_3$
ΔlnY_t	-0.283***	-4.405		0.271***	3.748		0.001	0.244
ΔlnK_t	-0.159***	-3.656		0.256***	5.219		-0.004*	-1.940
ΔlnL_t	0.046	1.317		0.259***	6.603		0.006***	3.345
ΔlnX_t	0.868**	2.234		-0.222	-0.508		0.019	0.911
ΔlnM_t	0.606*	2.057		0.892**	2.695		-0.034**	-2.181

Critical values for t-test(d.f=13) are 1.771(α = 10%), 2.160(α = 5%), 3.012(α = 1%).

* significant at α=10%, ** significant at α=5%, *** significant at α=1%

[1] Endogenous variables : Z_t = [lnY_t, lnK_t, lnL_t, lnX_t, lnM_t]'

Lag length of ECM is set as 3, and drift terms are included in the ECM.

<Table 4.20>

$\hat{\Pi}(=\hat{\alpha}\ \hat{\beta}')$ **matrix of Error Correction Terms**

of the Model with Export and Import

ECM : $\Delta Z_t = \pi_0 + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \Pi Z_{t-1} + \varepsilon_t$, where Z_t = [$\ln Y_t$, $\ln K_t$, $\ln L_t$, $\ln X_t$, $\ln M_t$]'

Dependent Variable (Equation)	Variables in the Cointegrating Relationship (Error Correction) $\ln Y_{t-1}$	$\ln K_{t-1}$	$\ln L_{t-1}$	$\ln X_{t-1}$	$\ln M_{t-1}$
$\Delta\ln Y_t$	-0.012	-0.055	0.280	0.068***	-0.079
	(-0.122)	(-1.544)	(1.168)	(3.428)	(-1.717)
$\Delta\ln K_t$	0.092	-0.100***	0.417**	0.064***	-0.135***
	(1.396)	(-4.133)	(2.570)	(4.771)	(-4.314)
$\Delta\ln L_t$	0.311***	-0.069***	-0.585***	0.075***	-0.087***
	(5.920)	(-3.567)	(-4.494)	(6.925)	(-3.467)
$\Delta\ln X_t$	0.665	0.064	-2.476	-0.032	0.111
	(1.138)	(0.295)	(-1.711)	(-0.271)	(0.398)
$\Delta\ln M_t$	1.465***	-0.639***	0.715	0.241**	-0.813***
	(3.303)	(-3.897)	(0.652)	(2.655)	(-3.854)

t-values in parentheses. Critical values for t-test(d.f=13) are 1.771(α = 10%), 2.160(α = 5%), 3.012(α = 1%).
* significant at α=10%, ** significant at α=5%, *** significant at α=1%
Lag length of ECM is set as p=3, and drift terms are included in the ECM.

<Table 4.21> shows the result of the restriction test on β and α coefficients for the model with export and import. Estimated coefficients $\hat{\beta}$s of all the variables are significant in the cointegrating relationships. Especially, the likelihood ratio test statistic(20.73, 23.44) for export and import exceed the critical values(7.81, 7.81) respectively, which means that both export and import can't be excluded from the cointegrating relationship of the production function.

<Table 4.21>

Restriction Test(LR test) on α and β

for the Model with Export and Import

ECM : $\Delta Z_t = \pi_0 + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \Pi Z_{t-1} + \varepsilon_t$, where Z_t = [$\ln Y_t$, $\ln K_t$, $\ln L_t$, $\ln X_t$, $\ln M_t$]'

Restrictions (Coefficient=0)	χ^2 statistic	Critical Value[1] at α=5%	p-value	
lnK	12.13	$\chi^2(3)$= 7.81	0.01	reject the null
lnL	23.21	$\chi^2(3)$= 7.81	0.00	reject the null
lnX	20.73	$\chi^2(3)$= 7.81	0.00	reject the null
lnM	23.44	$\chi^2(3)$= 7.81	0.00	reject the null
lnX & lnM	42.73	$\chi^2(6)$= 12.59	0.00	reject the null
α_Y	21.92	$\chi^2(3)$= 7.81	0.00	reject the null
α_K	19.65	$\chi^2(3)$= 7.81	0.00	reject the null
α_L	19.39	$\chi^2(3)$= 7.81	0.00	reject the null
α_X	5.20	$\chi^2(3)$= 7.81	0.16	don't reject the null
α_M	12.52	$\chi^2(3)$= 7.81	0.01	reject the null
α_X & α_M	17.74	$\chi^2(6)$= 12.59	0.01	reject the null
lnX & α_X	26.73	$\chi^2(6)$= 12.59	0.00	reject the null
lnM & α_M	24.57	$\chi^2(6)$= 12.59	0.00	reject the null
lnX,lnM,α_X,α_M	56.91	$\chi^2(12)$= 21.03	0.00	reject the null

[1] Parenthesis denotes the degree of freedom.

Adjustment speed vector $\hat{\alpha}$ s are also significant for most variables except that of export($\hat{\alpha}_x$) in the system. LR test statistic(5.20) of export(i.e. $\hat{\alpha}_x$) does not exceed the critical value(7.81), and so the null hypothesis of α_x=0 is not rejected at 5% (or 10%) significance level. This implies that export is weakly exogenous in the system, but necessary for cointegrating relationship. In contrast, import and the other variables(lnY, lnK, lnL) is not only necessary for cointegration, but also endogenous in the system.

<Table 4.22> shows the results of restriction test on each cointegrating vector β_i. For the joint null hypotheses(i.e. joint restrictions) of $\beta_{1L}=\beta_{1X}=\beta_{2X}=\beta_{2M}=\beta_{3K}=\beta_{3L}=\beta_{3M}=0$, the LR test statistic(0.02) does not exceed the critical value(5.99) at 5% significant level. This means that the joint null is not rejected and the relevant coefficients are all insignificant.

In contrast, for the null of $\beta_{1K}=0$, the Wald test statistic is $\chi^2=(-0.304/0.016)^2=361$, which far exceeds the critical value(5.99). Also, for the null of $\beta_{1M}=0$, $\beta_{2L}=0$ and $\beta_{3X}=0$, the Wald test statistics are $\chi^2=(-0.386/0.015)^2=662$, $(-2.745/0.146)^2=353$ and $(-0.624/0.019)^2=1079$ respectively, which reveals that the estimated coefficients are significant at 5% significant level. However, for the null of $\beta_{2K}=0$, the Wald statistic(0.52) does not exceed the critical value and so insignificant at the usual significance level.

As shown in <Table 4.22>, all of the significant coefficients in the three restricted cointegrating vectors have the expected signs. Especially, the coefficients of import(lnM) in the first cointegrating vector $\hat{\beta}_1^r$ and export(lnX) in the third cointegrating vector $\hat{\beta}_3^r$ have opposite signs to those of output(lnY)

It is interesting to find that the second cointegrating vector in <Table 4.22> (i.e. model with export and import) is very similar in its sign and size to the second cointegrating vector in <Table 4.15> (i.e. model with export), while the third cointegrating vector in <Table 4.22> is very similar to the first cointegrating vector in <Table 4.15>.

However, <Table 4.22> contains one more cointegrating vector(i.e. first cointegrating vector $\hat{\beta}_1^r$) that is not contained in <Table 4.15>. This means that the model with export and import can find one more cointegrating vector other than what the model only with export can find. This first cointegrating equation(i.e. restricted equation) in <Table 4.22> reflects the long-run equilibrium relationship between output, capital and import such that

$$\ln Y - 0.304*\ln K - 0.386*\ln M = 0.$$

These results imply that both export and import have worked to increase the output in the long-run equilibrium relationship through positive externality effect.

<Table 4.22>

<u>Restriction Test on Each Cointegrating Vector</u>

<u>& The Restricted Cointegrating Vectors[1]</u>

<u>for the Model with Export and Import</u>

Restricted Cointegrating vector	lnY	lnK	lnL	lnX	lnM
$\hat{\beta}_1^r$	1.00***	-0.304***	0.00	0.00	-0.386***
		(0.016)			(0.015)
$\hat{\beta}_2^r$	1.00***	-0.028	-2.745***	0.00	0.00
		(0.039)	(0.146)		
$\hat{\beta}_3^r$	1.00***	0.00	0.00	-0.624***	0.00
				(0.019)	

[1] Endogenous variables : Z_t = [$\ln Y_t$, $\ln K_t$, $\ln L_t$, $\ln X_t$, $\ln M_t$]'. Lag length of ECM is set as 3, and drift terms are included in the ECM.
LR test statistic for the joint null of $\beta_{1L}=\beta_{1X}=\beta_{2X}=\beta_{2M}=\beta_{3K}=\beta_{3L}=\beta_{3M}=0$ is 0.02, which does not exceed the critical value(i.e. $\chi^2(2)=5.99$) at 5% significant level. Parenthesis denotes standard error of each coefficient. *** significant at $\alpha=1\%$

<Table 4.23>

Johansen Cointegration Test

: Estimation of ECM with Export and Import

ECM : $\Delta Z_t = \pi_0 + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \Pi Z_{t-1} + \varepsilon_t$, where Z_t = [$\ln Y_t$, $\ln K_t$, $\ln L_t$, $\ln X_t$, $\ln M_t$]'

Explanatory (Regressor) Variables	Dependent	(Left-side)	Variables	(ΔZ_t)	
	$\Delta\ln Y_t$	$\Delta\ln K_t$	$\Delta\ln L_t$	$\Delta\ln X_t$	$\Delta\ln M_t$
$\beta_1' Z_{t-1}$	0.242***	[illegible]	0.192***	-0.159	2.2290*
	[0.007]	[0.001]	[0.003]	[0.659]	[0.069]
$\beta_2' Z_{t-1}$	-0.136***	[illegible]	0.190***	0.291	-0.3880*
	[0.007]	[0.001]	[0.003]	[0.659]	[0.069]
$\beta_3' Z_{t-1}$	-0.116***	[illegible]	-0.100***	0.128	-0.4045*
	[0.007]	[0.001]	[0.003]	[0.659]	[0.069]
$\Delta\ln Y_{t-1}$	-0.456	-0.225	-0.476**	-1.348	-1.6027
	[0.162]	[0.176]	[0.012]	[0.663]	[0.176]
$\Delta\ln Y_{t-2}$	-0.050	-0.147	-0.177**	-0.343	-1.4335
	[0.162]	[0.176]	[0.012]	[0.663]	[0.176]
$\Delta\ln K_{t-1}$	0.297***	1.075***	0.195	-0.310	1.6059
	[0.001]	[0.001]	[0.642]	[0.784]	[0.652]
$\Delta\ln K_{t-2}$	-1.331***	-0.572***	-0.206	-0.721	-1.3889
	[0.001]	[0.001]	[0.642]	[0.784]	[0.652]
$\Delta\ln L_{t-1}$	-0.094	-0.402	0.027	0.647	-2.6525
	[0.435]	[0.367]	[0.456]	[0.749]	[0.314]
$\Delta\ln L_{t-2}$	-0.456	-0.166	0.259	1.728	-0.3290
	[0.435]	[0.367]	[0.456]	[0.749]	[0.314]
$\Delta\ln X_{t-1}$	0.058**	0.033	0.031	0.272	0.2711
	[0.050]	[0.496]	[0.471]	[0.582]	[0.390]
$\Delta\ln X_{t-2}$	-0.107**	0.002	-0.010	-0.098	-0.004
	[0.050]	[0.496]	[0.471]	[0.582]	[0.390]
$\Delta\ln M_{t-1}$	0.070***	0.031**	0.024	-0.088	0.2618
	[0.008]	[0.031]	[0.541]	[0.777]	[0.283]
$\Delta\ln M_{t-2}$	0.150***	0.081**	0.021	0.139	0.241
	[0.008]	[0.031]	[0.541]	[0.777]	[0.283]
Constant	-2.141	-2.698**	2.640*	6.049	-12.152
Drift(trend)	[0.362]	[0.026]	[0.074]	[0.683]	[0.264]
R^2	0.8345	0.9109	0.7381	0.5617	0.7313
($\bar{R}^2$)	(0.6911)	(0.8337)	(0.5112)	(0.1818)	(0.4985)
D.W.	2.2580	1.7783	2.2115	2.0027	2.6671

The restricted cointegrating vectors from Johansen test are used to compute the error correction terms, $\beta_i' Z_{t-1}$.
Significance of all the estimated coefficients in the table are tested by F-test except drift(constant) terms.. In this case, the null hypothesis is either the joint hypothesis that coefficients of lagged values of the same explanatory variables are zero at the same time(i.e. coefficient of $\Delta\ln Y_{t-1} = \Delta\ln Y_{t-2} = 0$ or coefficient of $\Delta\ln K_{t-1} = \Delta\ln K_{t-2} = 0$ or coefficient of $\Delta\ln X_{t-1} = \Delta\ln X_{t-2} = 0$ etc.), or the joint hypothesis that coefficients of the 3 error correction terms are zero at the same time(i.e. coefficients of $\beta_1' Z_{t-1} = \beta_2' Z_{t-1} = \beta_3' Z_{t-1} = 0$). Thus, the number of restriction in each F-test is two (for lagged values) or three (for error correction terms).
p-values,i.e., the marginal significance level of a test of the hypothesis that the coefficient is zero are given in square bracket.
* significant at α=10%, ** significant at α=5%, *** significant at α=1%

<Table 4.23> shows the estimation result of ECM with export and import, which also provides a consistent result with those of restriction tests on β and α shown in <Table 4.21>. In <Table 4.23>, output(ΔlnY_t) and physical capital(ΔlnK_t) are affected by lagged values of export and/or import. Also, both output and capital are affected by export and import through long-run equilibrium relationships.

In contrast, export(ΔlnX_t) and import(ΔlnM_t) are not affected by lagged values of the other variables. However, there is a difference between export equation and import equation: In export equation(ΔlnX_t), error correction terms are insignificant, while error correction terms are significant in import equation(ΔlnM_t). This fact is consistent with the restriction test in <Table 4.21> in which coefficients of adjustment speed for export equation(α_X) are insignificant, and coefficients of adjustment speed for import equation(α_M) are significant.

These results imply that export is exogenous, while the other variables including import are endogenous in the system.

In summary, Johansen cointegration test of the model with export and import shows that export and import can't be excluded for the cointegration of the production function, and that export is weakly exogenous, while the other variables including import are endogenous in the system. In terms of the Granger causality, the causality between output and export is uni-directional from export to output, while the causality between output and import is bi-directional. Besides, signs of export and import are shown to be opposite to those of output in the restricted cointegrating vectors(i.e. long-run equilibrium relationships), which is expected from the endogenous growth theories.

4.5.6 Conclusions of Engle-Granger Test and Johansen Test

Johansen test and Engle-Granger test bear several similarity and difference. The conclusions from the two tests can be summarized as following.[27]

The first conclusion is that there exists at least one cointegrating vector with which export has played a significant role to produce co-movement of the variables in the national production function. Since export is included as a kind of production factor exerting externality effect through knowledge spillover etc., the significance of export in the cointegrating relationship implies that export has played some role of , for example, external economy which is not explained by the other production factors such as capital and labor in the production function.

Johansen test also reveals that neither export nor import can be excluded for the cointegration of the production function.

The signs of the coefficients of both export and import in the long-run equilibrium equation are significant and positive, which means the positive externalities of export and import.

[27] In case that the results from the two tests are contradictory, the final conclusions in this dissertation are drawn from those of Johansen test of the model with both export and import. This is because Johansen test is perceived as superior to Engle-Granger test, and the model with both export and import can overcome any possible problem from the model with only export.

The second conclusion is about the causality between output and trade: both tests admit a bi-directional causality between trade and output. However, there is a slight difference between the tests. The causality conclusion from output to export in Engle-Granger test is not so robust, while the causality from export to output is robust and strong. In contrast, Johansen test of the model with export and import finds that there exists a bi-directional causality between output and import, but an uni-directional causality between output and export(i.e. from export to output).

It needs to be noted that there are also several differences between the results from the two tests. One of the differences is that Johansen test finds multiple cointegrating vectors when the ECM over 2 lags is considered. Engle-Granger test, however, is designed to find only one cointegrating vector and use the same unique cointegrating vector in estimating each equation in ECM.

Another difference lies on the issue of including import in the cointegrating relationship. Johansen test reveals that neither export nor import can be excluded for the cointegration, while Engle-Granger test excludes import for the cointegration of the production function. However, accepting that Johansen test is superior, it can be concluded that both export and import have worked as a kind of production factors exerting externalities in the production function.

[27] According to the Johansen tests, the externalities of trade can be either positive or negative, which are realized through different cointegrating vectors.

<Table 4.24>

Comparison of Engle-Granger Test and Johansen Test

Test & Model	Lag (p)	Number of coint. vector	Coef. of export in coint. eq.	Coef. of import in coint. eq.	Causality b/n Y(output) and X(exp.) or M(imp.)	Exogeneity of X(export)
Eng.-Grang. test (Y,K,L,X)	2 or 3	1	significant at 10% (positive)		bi-directional: Y ← X: robust Y → X: not robust	endogenous (but, not robust)
Johansen test (Y,K,L,X)	3	2	significant at 1% (positive)[1]		bi-directional: Y ↔ X	endogenous
Johansen test (Y,K,L,X,M)	3	3	significant at 1% (positive)[1]	significant (positive)[1]	bi-directional: Y← X&M Y↛ X (X exog.) Y → M (M endog.)	exogenous

[1] Restricted cointegrating vectors

4.5.7 Comparison with the Other Studies

As surveyed in section 2.3.4, empirical studies on the export(or trade)-economic growth nexus have been conducted along either bi-variate causality test or growth accounting analysis using production function type model.

As shown in <Table 4.25>, most of the early time series studies used simple bi-variate causality tests such as Granger(1969), Sims(1972) and Hsiao(1981) test. Using these tests, Jung and Marshall(1985), Hsiao(1987) and Dodaro(1993) found no or little evidence of causality between output and export, while Chow(1987) found bi-directional causality in the 4 Asian NICs including Korea.

<Table 4.25>
Summary of Time Series Analysis of the Relationship between Trade and Growth in Asian Countries

	Author	Sample	Method	Result
Causality Analysis	Bahmani & Alse (1991)	1973I-88IV(quarter -ly data); Kor, Pak, Phil,Sing,Thai	Bi-variate(X,Y) Engle-Granger cointegration test	Xand Y nonstationary I(1) in most country Bi-directional causality in most countries incl. Kor,Pak,Phil,Sing,Thai
	Chow (1987)	1960-80; 8NICs, incl.HK,Kor,Sing, Taiw	Bi-variate(X,Y) Hsiao(1981) test	Bi-directional causality in HK,Kor,Sing,Taiw
	Dodaro (1993)	1967-86; 87 countri -es incl.Bang,HK, Indi,Kor,Mal,Nep, Pak	Bi-variate(X,Y) Granger(1969) test	Bi-dir. in Indddo,Pap Uni-dir. in Bang,Mal,Sing No caus. in HK,Indi,Kor,Nep,Pak,Phil,Sri, Thai
	Dutt & Ghosh (1996)	1953-91;14 countri -es include. Kor, Pak,Phil,Turk	Bi-variate(X,Y) Engle-Granger cointegration test & unit-root tests (D-F,P-P, KPSS)	Xand Y nonstationary in most countries Uni-directional causality in Phil,Turk,Pak No causality in Kor
	Hsiao (1987)	HK,Kor,Sing,Taiw	Bi-variate(X,Y) Hsiao(1981) test	No causality
	Jung & Marshall (1985)	varying periods; 37 countries include. Indi,Indo,Kor,Pak, Phil,Sing,Taiw,Tha	Bi-variate(X,Y) Granger(1969) test	X causes Y in just 4 out of 37 No causality in Kor ; only Indo in Asian countries
			Explanatory variables in eq.	
Regression Analysis	Berg (1996)	varying period;Indi ,Indo,Kor('54-94), Mal,Pak,Phil,Sing, Sri,Taiw,Thai	Production func. (3SLS) I/Y, $\hat{N}$, $\hat{X}$, $\hat{M}$ & Unit-root tests (D-F, KPSS test)	Most variables stationary I(0) except N. $\hat{X}$ in $\hat{Y}$ eq. significant in most country except Pak,Sing; $\hat{M}$ in $\hat{Y}$ eq. significant in most countries except Indi,Mal,Pak; $\hat{Y}$ in $\hat{X}$ eq. significant in most countries except Pak; $\hat{Y}$ in $\hat{M}$ eq. significant in Indo,Kor,Sing,Sri,Taiw
	Greenwa y& Sapsf ord(1990	1957-85; Kor,Pak, Phil,Sing,Sri	Production func. (OLS) /Y, $\hat{L}$, $\hat{X}$	$\hat{X}$ significant in Kor,Pak
	Ram (1987)	1960-82; 88 countr -ies include. Kor	Production func. (OLS) I/Y, $\hat{L}$, $\hat{G}$ $\hat{X}$.	$\hat{X}$ significant in 38 out of 88; but no country-specific result reported
	Salvatore &Hatche r(1991)	1963-85; Bang, Indi,Kor,Mal,Pak, Phil,Sing	Production func. (OLS)Inv, $\hat{X}$, $\hat{R}$ (industrialProd)	$\hat{X}$ significant in Indi,Kor,Mal,Turk
	Sengupta (1993)	1967-86; Kor,Phil, Taiw	Production func. (OLS)ΔK,ΔL,ΔX	ΔX significant in Kor, but insignificant in Phil,Taiw

Notes: 1. Abbreviations are Bang(Bangladesh),HK(HongKong),Indi(India),Indo(Indonesia),Kor(S.Korea),Mal(Malaysia), Nep(Nepal), Pak (Pakistan),Pap(Papua NewGuinea),Phil(Philippines),Sing(Singapore),Sri(Sri Lanka), Taiw(Taiwan),Thai(Thailand).

2. Y(GDP), K(capital stock), I(investment), N(population), L(labor), X(export),M(import) and the hat(∧) over a letter means rate of change of the variable.

3. Some content of the above table is quoted from Berg(1996), but confirmed by the original papers except Hsiao(1987). Also, Several journals are added to the Berg's table.

However, these tests have been criticized on the grounds that they are valid only if the original time series are stationary. Bahmani-Oskooee and Alse(1993) applied the bi-variate Engle-Granger cointegration test finding the bi-directional causality in five Asian countries,which was performed after the preliminary tests in which export and output are confirmed to be nonstationary unit root processes.

To complement a weakness of Bahmani-Oskooee and Alse(1993) that used quarterly data, Dutt and Ghosh(1996) used annual data, and applied Engle-Granger cointegration test for 14 countries including 4 Asian countries. Their unit root tests(i.e. Phillips-Perron test and KPSS test) found that export and output are nonstationary unit root processes in most countries including Korea. Their findings, however, are a little contradictory between countries: there exists uni-directional causality in Philippines and Pakistan, but no causality in Korea between export and output.

Overall speaking, these bi-variate causality tests lack a theoretical foundation, and so can lead to a omitted variable bias.

In contrast, several studies such as Greenway and Sapsford(1994), Ram(1987), Salvatore and Hatcher(1991), Sengupta(1991,1993) applied regression analysis to the production function type equation to find whether or not the coefficient of export is positive and significant. As shown in <Table 4.25>, their results are mixed, even though it is commonly significant in case of Korea.

However, since those studies use the variables in the form of rate of change that are close to the concept of first differencing to avoid the nonstationarity problem, they could lose much of the information included in the original variable. As indicated by Bahmani-Oskooee and Alse(1993), first differencing filters out low-frequency (long-run) information.[28] Moreover, their single equation models don't deal with the simultaneity problem.

To deal with these problem, Berg(1996) first applied unit-root tests(Dickey-Fuller test and KPSS test) to the time series data of 10 Asian NICs, and concludes that most variables(GDP, investment, export and import) except population[29] are stationary I(0) variables. To deal with the simultaneity issue, Berg applied 3SLS estimation to the simultaneous equation system. Berg found not only that the signs of export and import in output equation are significant, but also that the signs of output in export equation and in import equation are significant, which implies a bi-directional causality between output and trade(i.e. export and import).

However, it must be noted that the estimation of Berg(1996) is based on the results of unit-root test. If the variables in the model are not stationary, which has been confirmed by several studies such as Bahmani-Oskooee and Alse(1991), Dutt and Ghosh(1996) through the same unit-root tests, then the Berg's models may imply a misspecification.[30] In this case, cointegration test and estimation of Error Correction Model based on production function can be a solution, as performed in this dissertation.

[28] Refer to Bahmani-Oskooee and Alse(1993,p536). To remedy those problem, the cointegration technique and error correction modeling are recommended. ECM tries to establish causality between two variables after reintroducing the low-frequency information through the error correction term into the analysis.
[29] In Berg(1996), population is used as a proxy for labor input.
[30] Berg(1996)'s sample is based on the IMF IFS data denoted in US$ and deflated by US inflation rate to get real values of the variables, while this dissertation uses real value data denoted in Korea currency unit (billion Won).

Based on the unit-root tests(Dickey-Fuller test and Phillips-Perron test) about the time series data of Korea, this dissertation adopts the two kind of cointegration tests reaching the same conclusion as Berg(1996): (1) significant and positive externality effect(or knowledge spillover effect) of trade as suggested by the endogenous growth theories and (2) the bi-directional causality between output growth and trade growth.

4.6 TFP Analysis and Interaction Analysis

4.6.1 Justification of the Production Function through TFP Analysis

Up to now, it is assumed that export and import contribute significantly to the technological development. Thus, the production function Y=A(X,M)•f(K,L) which includes export and import as a kind of production inputs exerting externality effect through international knowledge spillover etc., has been used for the cointegration test in the earlier sections. This functional form can be statistically justified by showing that export and/or import have significantly contributed to the growth rate of total factor productivity. For this purpose, the **growth accounting technique**[31] is adopted as following.

If a factor input can generate externalities, then it means that the factor contributes to economic growth in excess of what the factor itself earns. These externalities are realized either through the interaction between factor inputs(K,L),[32] or through the economic

[31] For the study of growth accounting through productivity growth analysis, Jorgenson(1990) distinguishes the contribution of capital and labor quality from the contribution of capital stock and hours worked based on the strict neo-classical assumption of constant returns to scale. Boskin and Lau(1992) employs the meta-production function to identify separately the degree of returns to scale, the rate of technical progress and the bias of technical progress. These models are modified by Chou(1995) to take into account the externality factor and exports. Chou(1995) applies the model only to Taiwanese case for empirical test. I modify Chou's model to take into account imports as well as exports ,and apply the modified model to South Korea for empirical test.

[32] Chou(1995,p118-9) categorizes the potential interaction effects between K and L in three aspects : (1) Substantial capital accumulation is needed to put new investment into practice and to affect employment widespread.(Solow(1988), Wolff(1991)) (2) The improvement in labor quality due to both the changing age-sex composition of work force and the decline of work hours[32] could affect total factor productivity(TFP). (Denison(1979)) The conventional argument for labor improvement includes improvement in educational achievement in the production function of two inputs, i.e. capital and labor. However, in case human capital is added as another factor input, then an improvement in education attainment will contribute directly to human capital and so affect on the improvement in labor quality in terms of interaction effect. (3) There is an interaction between human capital and TFP. Lucas(1988) argued that human capital accumulation is a social activity: the more educated workers interact with other educated people, the more new ideas come about which improve production efficiency. Thus, human

activity such as export and import, which are assumed to provide conduits for international technology spillover.

Total factor productivity(TFP) is usually defined as the ratio of output(Y) to a geometrically weighted average of physical capital input(K) and labor input(L) :

$TFP = Y / K^{\alpha}L^{1-\alpha}$ ....<4.22>

Thus, growth rate of TFP is defined as the residual of output growth equation that is not explained by the usual factor growth:

$\hat{TFP} = \hat{Y} - \alpha\ \hat{K} - (1-\alpha)\ \hat{L}$..................<4.23>

where constant returns to scale is assumed to clarify the interaction effect by any production factor and the hat (∧) indicates the relative growth rate.

Now, if the possible interaction effect (or externality effect) by any factor(Q) is addressed into the production function, then

$Y = A\,K^{\alpha}L^{1-\alpha}Q^{\delta}$,$\delta > 0$ ....< 4.24>

and $\hat{TFP} = \hat{A} + \delta\,\hat{Q}$ ....<4.25>

where $\hat{Q}$ is one of $\hat{K}$, $\hat{L}, \hat{X}, \hat{M}$ or $\hat{XM}$.

Especially, if export and import exert the externality effect raising TFP, it is possible to replace $\hat{Q}$ by trade trade growth(i.e. $\hat{X}, \hat{M}$ or $\hat{XM}$).

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capital can exert two effects- the internal effect of an individual's human capital on his own productivity and the external effect that no individual human capital accumulation decision can take into account.

Equation <4.24> and <4.25> can be used as a simple model to test what production factors have played significant roles in raising TFP. If growth rate of trade volume significantly explains growth rate of TFP, then it means that trade has contributed significantly to the technological development. In this case, the production function Y= A(X,M)•f(K,L) which was used for the cointegration test in the earlier sections can be statistically justified, since trade can contribute to the increase of TFP directly.

<Table 4.26>

Analysis of TFP (Total Factor Productivity)

: The Case of OLS Estimation of the Output Growth Equation

Output growth equation : $\hat{Y} = c + \alpha \hat{K} + (1-\alpha) \hat{L}$, was estimated using OLS.

Model : $\hat{TFP} = \hat{A} + \delta \hat{Q} + \varepsilon_t$

Right-Side Variable $\hat{Q}$	(1) Coeff.	(2) Coeff.	(3) Coeff.	(4) Coeff.	(5) Coeff.
$\hat{K}$	-0.0416 [0.795]				
$\hat{L}$		-0.2255 [0.544]			
$\hat{X}$			0.0586* [0.100]		
$\hat{M}$				0.0883** [0.015]	
$\hat{XM}$					0.1012** [0.012]
$\hat{A}$ (Constant)	4.9385** [0.012]	5.1956*** [0.000]	3.3551*** [0.001]	3.0831*** [0.000]	2.7693*** [0.002]
R^2	0.0024	0.0129	0.0747	0.1882	0.1975
D.W.	2.2422	2.1082	2.2017	2.1500	2.0897

p-values,i.e., the marginal significance level of a two-tailed test of the hypothesis that the coefficient is zero are given in square brackets under the estimated coefficients.
* significant at α=10% , ** significant at α=5%, *** significant at α=1%
Data: All the variables are in the form of growth rate for the period 1963-94.

<Table 4.26> summarizes OLS(Ordinary Least Square) estimation result of the equation <4.25> ,i.e. $\hat{TFP} = \hat{A} + \delta \hat{Q}$. In this case, the preliminary output growth equation is regressed using OLS to calculate the time series of growth rate of TFP.

OLS estimation reveals that none of $\hat{K}$ and $\hat{L}$ statistically explain the growth rate of total factor productivity($\hat{TFP}$).

In contrast, coefficients of growth rate of export($\hat{X}$) or import($\hat{M}$) are positive(0.0586, 0.0883 respectively) and significant at 10% and 5% significance levels respectively. Moreover, estimated coefficient(0.1012) of the growth rate of export plus import($\hat{XM}$) is larger than that of export growth or import growth alone and significant at 5% significance level.

To circumvent any possible single equation extimation bias of OLS, which is mainly due to the possible endogeneity of the variables, 2SLS estimation was used to regress the output growth on the growth rates of factors in equation <4.23>. In this case, 5 variables(i.e. total savings ratio, bond discount rate, growth rate of real wage in manufacture, effective exchange rate and secondary school enrollment ratio[33]) are used as exogenous variables or instrumental vatiables, since these fundamental variables can be viewed to determine the endogenous variables(Y,K,L) in the equation <4.23>.

[33] Secondary school enrollment ratio are used as a proxy of human capital in several studies such as Barro(1991) and Romer(1993).

The table in the <Appendix-B> summarizes the result for which 2SLS is applied to estimate the TFP equation <4.23>. However, there is little difference between <Table 4.26> and the table in the <Appendix-B> in the point that trade growth still explains the TFP growth well, while growth rates of capital and labor don't explain it.

These results statistically justify the production function that includes export and import as a kind of production factor, i.e. Y= A(X,M)•f(K,L), which was used for the cointegration test in the earlier sections.

Export clearly raises TFP by exerting the externality effect through international knowledge spillover, scale economy and efficiency of resource allocation, etc.. Import also raises TFP by exerting externalities through knowledge spillover, faster capital accumulation(i.e. higher labor productivity) etc.. These roles of export and import as production factors are clearly distinguished from those as components of aggregate effective demand(i.e. injection or leakage) in the flow of national output.

4.6.2 Analysis of Interaction Effect Strengthened by Trade

As an alternative, interaction effect strengthened by export and import can be analyzed as suggested by Chou(1995). To check any other possible interaction effect affecting TFP, Chou postulates the hypothesis that "export expansion" will generate scale economy which coexists with and enhances the externalities (i.e. interaction effect) of the other factor inputs(K,L) in productivity growth.

This dissertation extends the hypothesis such that "trade(i.e. export plus import) expansion" will generate scale economy which coexists with and enhances the interaction effect of the other factors. Then, the equation <4.24> and <4.25> can be modified into

$$Y = A K^{\alpha} L^{1-\alpha} Q^{f(\hat{XM})} \qquad \text{.............................} < 4.26>$$

where Q is one of K or L and $\hat{XM}$ is the growth rate of export plus import. Equation <4.26> implies that the interaction effect of factor input Q will be enhanced by the scale effect of trade expansion, i.e. $f(\hat{XM})$.

If we assume that the scale effect is proportional to trade growth, that is,

$$f(\hat{XM}) = \delta \bullet \hat{XM}$$

Then,

$$\hat{TFP} = \hat{A} + \delta \bullet \hat{XM} \bullet \hat{Q} \qquad \text{................................} <4.27>$$

Equation <4.27> is used to test the **strengthened interaction hypothesis** along the context that factor interaction effect ($\hat{Q}$) interacts with the scale effect ($\hat{XM}$ or $f(\hat{XM})$) generated by trade expansion. In this model, the impact of factor growth on productivity is not independent of trade growth.

<Table 4.27> shows the strengtheened externality effect of factor growth($\hat{Q}$) augmented by trade growth($\hat{XM}$). The estimated coefficient of interaction term of physical capital growth augmented by trade growth is positive(0.0085) and statistically significant at 5% significance level, while the coefficient of interaction of employment growth augmented by trade growth is not significant even at 10% significance level.

<Table 4.27>

Estimation of the Strengthened Interaction Effect by Trade

Output growth equation : $\hat{Y} = c + \alpha\hat{K} + (1-\alpha)\hat{L}$, was estimated using OLS.

Model : $\hat{TFP} = \hat{A} + \delta \bullet \hat{Q} \bullet \hat{XM} + \varepsilon_t$, where $XM \equiv X + M$

Right-Side Variables	(1) Coefficient	(2) Coefficient
$\hat{K} \bullet \hat{XM}$	0.0085** [0.025]	
$\hat{L} \bullet \hat{XM}$		0.0121 [0.163]
$\hat{A}$ (Constant)	2.8952*** [0.002]	3.7594*** [0.000]
R^2	0.1616	0.0661
D.W.	2.0604	2.1722

p-values,i.e., the marginal significance level of a two-tailed test of the hypothesis that the coefficient is zero are given in square brackets under the the estimated coefficients.
* significant at α=10%, ** significant at α=5%, *** significant at α=1%
Data: All the variables are in the form of growth rate for the period 1963-94.

This result implies that the externality effect of export and import has been realized not only through promoting the knowledge spillover or technological development, but also through augmenting the possible interaction effect with the traditional factor such as physical capital or investment.[34]

[34] It was also shown in <Table 4.6>,<4.7> and <4.16> that export has responded to the change of the lagged physical capital (or investment), which implies that the increase in export has followed huge investment in physical capital. Since major portion of the investment in physical capital in Korea is achieved through import of foreign capital goods, the productivity effect of trade growth may have been strengthened by the interaction between trade and investment.

4.7 Issue of Growth Slowing-down

4.7.1 Hypothesis of Growth Slowing-down

As proved in the section 4.1.2 and surveyed in the section 2.4, the endogenous growth theories entail in the hypothesis of growth slowing-down of the export oriented developing country. For example, Grossman and Helpman(1991a-e) that emphasize the knowledge spillover effect of trade imply the "S-shaped path" of technology transfers: accelerating and then decelerating. This means that the growth of a small developing economy can be slowed down and converge on the steady-state rate, as the general knowledge gap narrows down.

4.7.2 Re-interpretation of the Other Empirical Studies

Several existing studies about the source of growth in Korea contain the empirical results that can be re-interpreted to support the hypothesis of growth slowing-down, even though they did not indicate the phenomenon and the reason explicitly.

4.7.2.1 Empirical Studies about the Sources of Growth

<Table 4.28> reveals that the growth of Korea has depended more heavily on the increase of input supply, especially labor supply, than on the advances in technology. Contribution of labor has been persistently greater than that of capital in all 3 sub-periods, accounting for more than 30 percent. The rapid expansion of manufactured export and the concurrent expansion of the service sector has become a major source of labor absorption.

<Table 4.28> also shows that slightly less than half of Korean output growth was due

<Table 4.28>

Sources of Growth in Korea

Sources of Growth	1963-72	1972-82	1982-92
Growth Rate of Real GNP	8.2 (100.0) %	8.1 (100.0) %	8.0 (100.0) %
Total Factor Input	4.2 (51.2)	5.6 (69.1)	4.8 (60.0)
Labor	3.1 (37.8)	3.5 (43.2)	2.9 (36.3)
Physical Capital	1.1 (13.4)	2.1 (25.9)	1.9 (23.8)
Total Factor Productivity	4.0 (48.8)	2.5 (30.9)	3.2 (40.0)
Improved Resource Allocation	0.6 (7.3)	0.7 (8.6)	0.6 (7.5)
Scale Economies	**1.5 (18.3)**	**1.5 (18.5)**	**1.6 (20.0)**
Tech.Advance etc.	**1.9 (23.2)**	**0.3 (3.7)**	**1.0 (12.5)**

Relative contribution of each factor is noted in the parentheses.
Source: Kim and Park(1985) for 1963-72 and 1972-82; Hong(1991). requoted from Nam(1995).

<Table 4.29>

Comparison of Sources of Growth between Countries

Sources of Growth	U.S.A. (1948-73)	West Germany (1950-62)	Japan (1953-71)
Growth Rate of Real GNP	3.8 (100.0) %	6.3 (100.0) %	8.0 (100.0) %
Total Factor Input	2.1 (55.3)	2.8 (44.4)	4.0 (45.5)
Labor	1.4 (36.8)	1.4 (22.2)	1.9 (21.6)
Physical Capital	0.7 (18.4)	1.4 (22.2)	2.1 (23.9)
Total Factor Productivity	1.7 (44.7)	3.5 (55.6)	4.9 (55.7)
Improved Resource Allocation	0.3 (7.9)	1.0 (15.9)	1.0 (11.4)
Scale Economies	0.3 (7.9)	1.6 (25.4)	1.9 (21.6)
Tech.Advance etc.	1.1 (28.9)	0.9 (14.3)	2.0 (22.7)

Relative contribution of each factor is noted in the parentheses.
Source: Denison and Chung(1976) for Japan and West Germany; Denison(1979) for U.S.A.. requoted from Nam(1995).

to the growth of total factor productivity. The contribution of improved resource allocation, which is due to the shift of resources from low productivity agriculture to high productivity nonagricultural sectors, is steady at 7-8 percent. Economies of scale has also been steady, but very significant accounting for about 18-20% of total output growth.

In contrast, the contribution of technological advances dropped sharply from 23% in the early stage of economic development(1960s) to 3-12% in the later stage of the export-drive development.

This means that the knowledge (or technology) spillover via trade[35] has diminished significantly as the Korean economy achieves both higher income and the change of export structure from light industry to heavy industry. The contribution of scale economy is relatively stationary at around 20% due to the huge investment in plant and equipment. However, with relatively small size of R&D investment for innovation, the contribution of knowledge spillover(i.e. the externalities) from trade has declined significantly.

4.7.2.2 Empirical Studies about the Intersectoral Externalities

Applying the Feder(1982) model, Sengupta(1991,1993) set up a model to find the dominance of the externality effect of export (F_X) over that of non-export sector(G_N) : the growth of the export sector affects that of the non-export sector much more strongly than in the reverse direction.

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[35] Note that <Table 4.28> and <4.29> can't explain what is the more basic sources of technological advances and scale economy. The model set up in this dissertation seeks for a solution to the question by testing the hypothesis that trade is the main source of knowledge spillover (i.e. imitation) as suggested by the endogenous growth theories. In this sense, this dissertation and the several studies such as Kim and Park(1985), Hong(1991) and Nam(1995) complement each other.

These externalities are incorporated in the two sector general equilibrium model as:

$N = F(K^N, L^N, X)$ .... <4.29>

$X = G(K^X, L^X, N)$ .... <4.30>

,where N and X are the output of non-export sector and export sector, respectively. F and G are their respective production functions, so that there is an externality from the export sector to the non-export sector and the reverse. K^j and L^j denote capital and labor force respectively of sector j (j = N,X) .

Differentiating the above equation <4.29> and <4.30> with respect to time yields

$\Delta N = F_K \Delta K^N + F_L \Delta L^N + F_X \Delta X$ .... <4.31>

$\Delta X = G_K \Delta K^X + G_L \Delta L^X + G_N \Delta N$ .... <4.32>

,where the coefficients F_i and G_i (i=K,L,X,N) denote the marginal productivity of the respective inputs in the two sectors.

<Table 4.30>

Estimates of Intersectoral Externalities in Korea

Sources of Growth	1964-83	1964-86	1969-86
F_X (Externality of Export to Non-export Sector)	1.92	1.00	0.99
G_N (Externality of Non-export to Export Sector)	0.28	0.31	0.32
F_X/G_N (Marginal Externality of Export to Non-export Sector)	6.9	3.2	3.1

Overlapping sample periods are considered to show the time trend of the estimated coefficients.

Source: Sengupta(1993).

<Table 4.30> shows the estimates of the growth equation <4.31> and <4.32>. It reveals that, since the ratio F_X / G_N of marginal externality effect of export to that of the non-export sector is significantly greater than unity, it tends to confirm the dominant or leading role of the export sector. The dynamic externality effect from the export to the non-export sector sector is roughly between 3 and 7 times larger than the reverse effect from the non-export to the export sector. Sengupta(1993,p350-1) explains that this asymmetry confirms the theory of knowledge spillover associated with export.

However, the gap between the two externality effects is diminishing over time. Even though Sengupta does not mention clearly, this phenomenon is mainly due to the fact that the externality effect of export to the non-export sector(i.e. F_X) is rapidly diminishing. This result supports the hypothesis of growth slowing-down suggested in this dissertation in case of Korea.

Chapter 5. Summary and Conclusion

The main purpose of this dissertation is to test the endogenous growth theories for the developing country(S.Korea) using time series analysis: especially, the role of trade for economic development. To overcome several potential problem of the existing studies, this paper adopts two kind of cointegration test and Error Correction Model (Engle-Granger test and Johansen test) applying them to a special form of production function $Y=A(X,M)\bullet f(K,L)$, which treats export(X) and import(M) as a kind of production factor. Trade is hypothesized to exert externalities through international knowledge spillover etc. as suggested by the endogenous growth theories.

An important finding of the preliminary literature survey in Chapter2 is that many of the existing endogenous growth models(i.e. theoretical models) can be reinterpreted to support the hypothesis of growth slowing-down of developing countries in the later stage of development. Also, plugging the special form of production function set up in this dissertation into a macro equilibrium model, this dissertation could show mathematically that even in a neoclassical model of Solow type, the developing country with export(trade)-oriented strategy will enjoy a rapid growth in the early stage, but face growth slowing-down as the externality effect of trade diminishes.

Major findings of the empirical tests in Chapter4 are as following: (1) Unit-root tests(Dickey-Fuller test and Phillips-Perron test) reveal that all the variables under consideration(i.e. GDP, capital stock, labor, import and export in the Korean production function) are nonstationary I(1) variables.

(2) Johansen test and Engle-Granger test bear several similarities. First of all, there exists at least one cointegrating vector with which export has played a significant role to produce co-movement of the variables in the national production function. (3) Johansen test also reveals that neither export nor import can be excluded for the cointegration of the production function. (4) The signs of the coefficients of both export and import in the cointegrating vector(i.e. long-run equilibrium relationship) are significant and positive. (5) The significance of export and import in the cointegrating relationship implies that export and import have played some role of , for example, external economy which is not explained by the other production factors such as capital and labor in the production function.

(6) The other important conclusion is drawn from the ECM(Error Correction Model) about the causality between output and trade: both tests admit a bi-directional causality between trade and output. However, there is a slight difference between the tests. The causality conclusion from output to export in Engle-Granger test is not so robust, while the causality from export to output is robust and strong. In contrast, Johansen test of the model with export and import finds that there exists a bi-directional causality between output and import, but an uni-directional causality between output and export(i.e. from export to output).

(7) There are several differences between the results from the two kind of test. One of the differences is that Johansen test finds multiple cointegrating vectors when the ECM

over 2 lags is considered. Engle-Granger test, however, is designed to find only one cointegrating vector. (8)Another difference lies on the issue of including import in the cointegrating relationship. Johansen test reveals that neither export nor import can be excluded for the cointegration, while Engle-Granger test excludes import for the cointegration of the production function. However, accepting that Johansen test is superior, it can be concluded that both export and import have worked as a kind of production factors exerting externalities in the production function.

(9) The interaction analysis performed as a complement reveals that the growth rate of TFP(total factor productivity) is hardly explained by the growth rates of capital and labor. Instead, the growth rates of export and/or import well explain the TFP growth, which implies that trade is working as a production factor exerting the externalities. These results statistically justify the special form of production function which is used in the above cointegration test.

All of these results imply that both export and import have exerted some externalities for economic growth in case of Korea, as suggested by the endogenous growth theories. The policy implication from the tests is that opening and increasing the international trade (both export and import) can be one of the greatest way for economic development of small developing countries, because it will provide an efficient way of capital accumulation through importing cheaper foreign capital goods, and more importantly a systematic mechanism for promoting the knowledge spillover(externality effect) from developed economies, which may in turn enable the economy to achieve the increasing returns in the production and marketing etc.

The last part of this paper re-interprets several existing studies to support the hypothesis of growth slowing-down empirically that can be distinguished in the later stage of export-oriented development strategy. The mathematical proof in the section 4.1.2 and the survey of the endogenous growth theories in Chapter2 have already introduced the possibility of the "S-shaped path" of technology transfers: accelerating and then decelerating.

The hypothesis suggests that growth of the small developing country with export-oriented development strategy can be slowed down and converge on the steady-state rate, as the general knowledge gap narrows down. This result suggests an important policy implication: once the rapid growth is achieved in the developing countries, then the primary sources of growth are the same as those of developed countries: a variety of factors that affect the incentive for industrial research and innovation rate such as the rate of time preference, the degree of monopoly power, the intertemporal elasticity of substitution and the size of resource base.

However, this part is not complete and just introduced as a stepping stone for further research of the interesting hypothesis of "growth slowing-down" of the Asian NICs.

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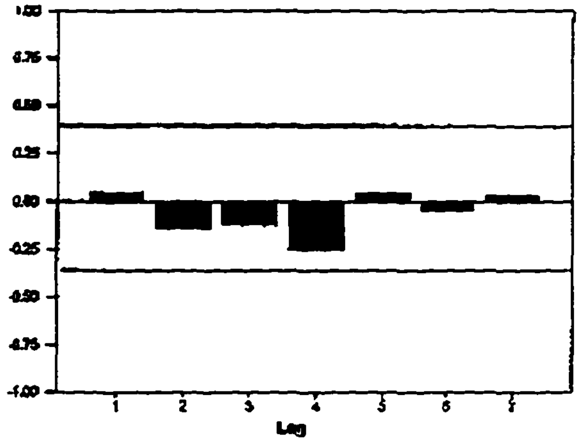
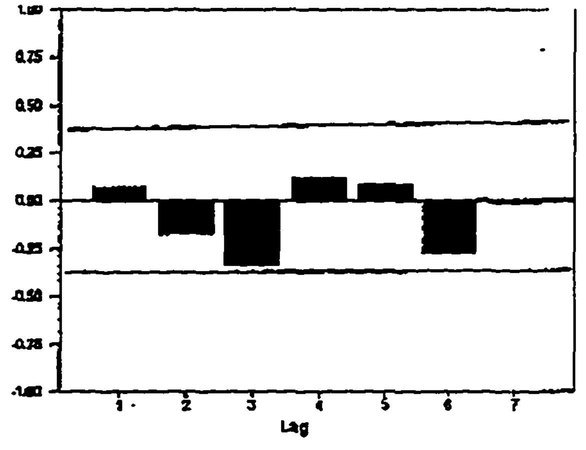
<Appendix - A>

<Figure A.1> Correlogram of the ECM with Export[1]

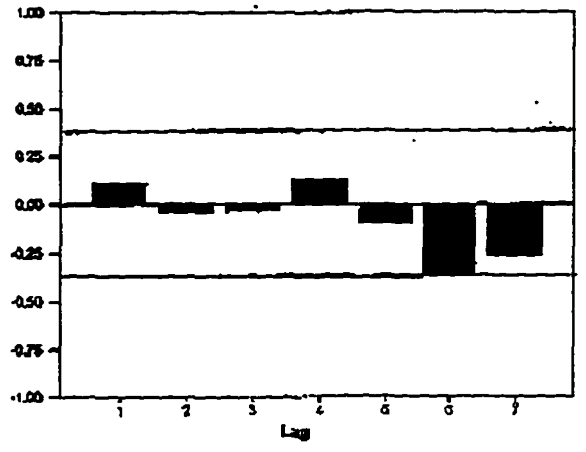
ΔlnY



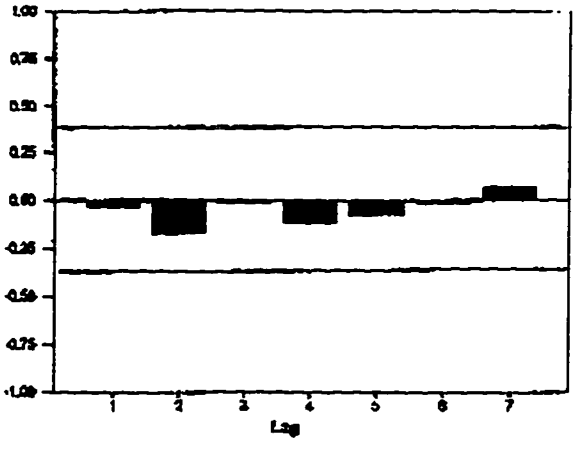
ΔlnK



ΔlnL



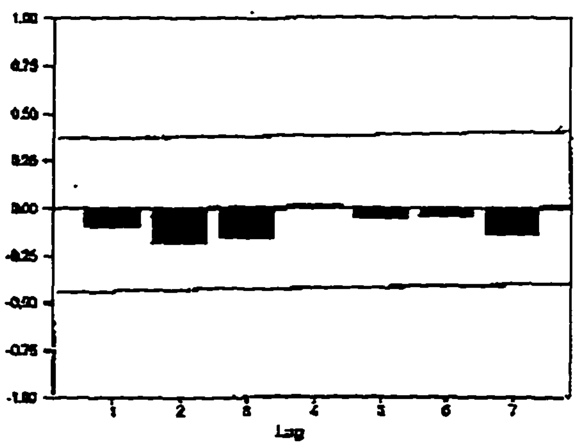
ΔlnX



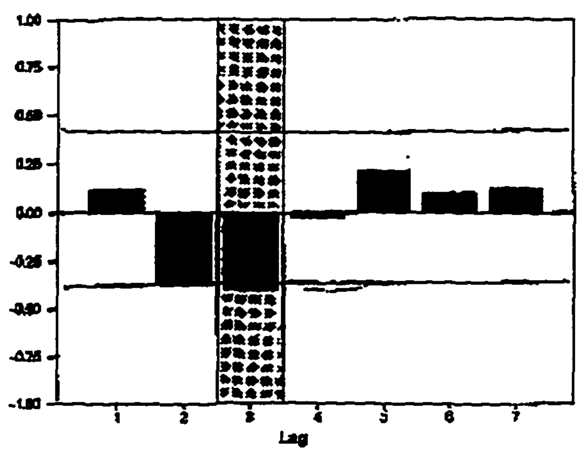
[1] The critical values for the null hypothesis of no-autocorrelation are ±0.3578 at 5% significance level and are marked as lines inside the boxes.

<Figure A.2> Correlogram of the ECM with Export and Import

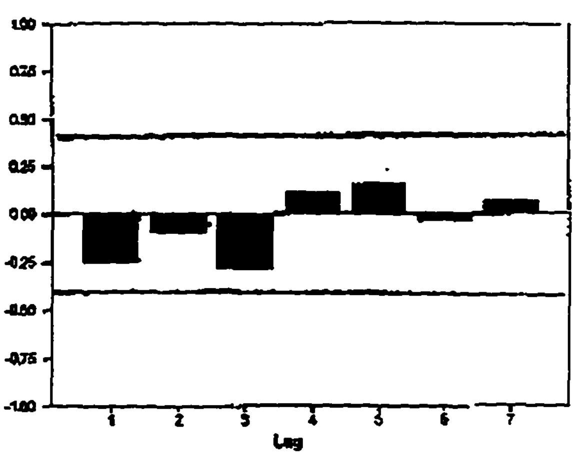
$\Delta \ln Y$



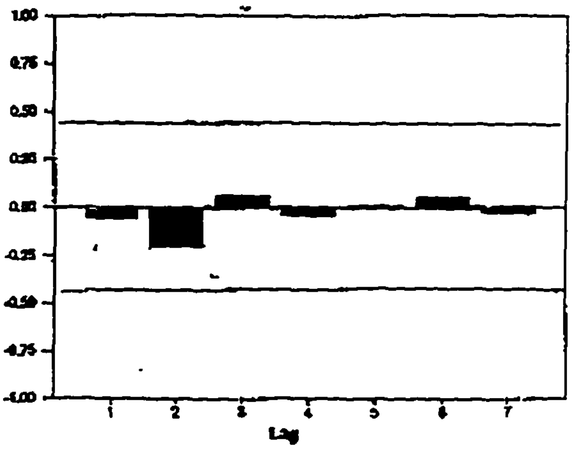
$\Delta \ln K$



$\Delta \ln L$

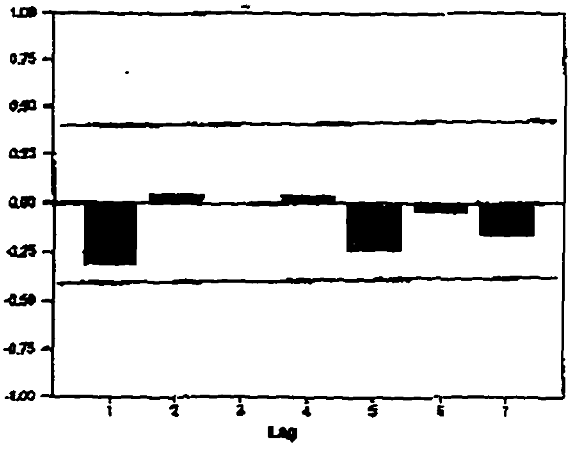


ΔlnX



1.00
0.75
0.50
0.00
-0.75
-1.00
1
2
3
4
5
6
7
Lag

ΔlnM



0.75
0.00
-0.25
-0.50
-0.75
-1.00
1
2
3
4
5
6
7
Lag

<Appendix -B> Analysis of TFP using 2SLS Estimation

<Table B.1>

Analysis of TFP : 2SLS Estimation of the Output Growth Equation

Output growth equation : $\hat{Y} = c + \alpha \hat{K} + (1-\alpha) \hat{L}$, was estimated using 2SLS.

Model : $\hat{TFP} = \hat{A} + \delta \hat{Q} + \varepsilon_t$

Right-Side Variable $\hat{Q}$	(1) Coeff.	(2) Coeff.	(3) Coeff.	(4) Coeff.	(5) Coeff.
$\hat{K}$	-0.1280 [0.424]				
$\hat{L}$		-0.1365 [0.715]			
$\hat{X}$			0.0683* [0.083]		
$\hat{M}$				0.0871** [0.017]	
$\hat{XM}$					0.1041*** [0.010]
$\hat{A}$ (Constant)	5.2170*** [0.008]	4.2408*** [0.003]	2.4961*** [0.010]	2.4301*** [0.003]	2.0474** [0.018]
R^2	0.0222	0.0047	0.1002	0.1807	0.2065
D.W.	2.2085	2.0061	2.0933	2.0059	1.9631

p-values,i.e., the marginal significance level of a two-tailed test of the hypothesis that the coefficient is zero are given in square brackets under the estimated coefficients. * significant at α=10%, ** significant at α=5%, *** significant at α=1%

Data: All the variables are in the form of growth rate for the period 1963-94.

<Table B.2>

Estimation of the Strengthened Interaction Effect by Trade

Output growth equation : $\hat{Y} = c + \alpha \hat{K} + (1\text{-}\alpha)\hat{L}$, was estimated using OLS.

Model : $\hat{TFP} = \hat{A} + \delta \bullet \hat{Q} \bullet \hat{XM} + \varepsilon_t$, where $XM \equiv X + M$

Right-Side Variables	(1) Coefficient	(2) Coefficient
$\hat{K} \bullet \hat{XM}$	0.0081** [0.035]	
$\hat{L} \bullet \hat{XM}$		0.0128 [0.142]
$\hat{A}$ (Constant)	2.3044** [0.012]	3.0458*** [0.000]
R^2	0.1436	0.0729
D.W.	1.8986	2.0318

p-values,i.e., the marginal significance level of a two-tailed test of the hypothesis that the coefficient is zero are given in square brackets under the the estimated coefficients. * significant at α=10% , ** significant at α=5%, *** significant at α=1%
Data: All the variables are in the form of growth rate for the period 1963-94.