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R&D Activities, Imperfect Competition and Economic Growth

R&D 및 불완전경쟁과 경제성장

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목 차

국 문 요 약

아이디어는 소멸하지 않으며 지식생산과정에 수확체감의 법칙이 작용하지도 않는다. 그럼에도 불구하고, 사적측면만을 고려하는 단순한 내생적 성장모형에서는 지속적 경제성장이 달성되지 않게 된다. 그러나, 지식자본의 비전유성을 고려하여 이를 공적자본으로 간주하게 되면 지속적 경제성장은 달성될 수 있게 된다.

우리 경제에 대한 실증분석 결과가 지식의 공적자본으로서의 성격을 강하게 뒷받침함을 확인할 수 있다. 즉, 제품혁신 생산함수에 대한 모든 함수형태에서 지식자본이 사적재화라는 귀무가설을 모두 기각할 수 있다. 이상의 결과로부터 우리 경제는 제품혁신을 통해 지속적 경제성장을 달성할 수 있다는 시사점을 얻을 수 있다.

핵심어 : R&D 투자, 제품혁신, 지식자본, 공적자본, 지속성장, 독점적 경쟁

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ABSTRACT

Ideas do not become exhausted, and there are no diminishing returns in the creation of knowledge. Nonetheless, growth ultimately ceases in this simplest model of endogeneous innovation. The reasons are similar to those that are discussed in the context of the neoclassical model of capital accumulation. Even if the resource cost of creating new goods does not rise, the economic return to invention may decline as the number of available products increases. When the rate of return to R&D falls to the level of the discount rate, private agents cease to be willing to defer consumption in order to invest in product development. But, if we treat knowledge capital as a public capital considering of its non-appropriable benefits, economic growth can be sustained in the economy.

Romer(1986) has pointed out that growth might be sustainable if the accumulation of knowledge is not subject to long-run diminishing returns. Actually Romer assumed diminishing returns in the production of private knowledge from available resources, but increasing returns in the production of output from labor and total (public and private) knowledge. His condition for the sustainability of long-run growth amounts to an assumption that the diminishing returns in the former activity do not outweigh the increasing returns in the latter.

The Johansen(1988) cointegration test method is used for finding long-run equilibrium relationship between R&D input and the product innovation. Test results indicate the existence of cointegrating equation between each pair of regression variables including dependent variable in the knowledge production function. And, the signs of cointegrating vectors are well accord to the prediction of sustainable growth.

In the empirical analysis, from all cases of the form for the knowledge production function, we could not reject the null hypothesis that R&D spillover effect is significant(H_0: $\gamma=1$).

In summary, we showed that considering goodness of fit of regression model, we can see that the empirical evidence is strongly in favor of the character of knowledge as the public knowledge capital. So, we can expect that by product innovation, economic growth can be sustained in the Korean economy.

Key words : R&D investment, product innovation, knowledge capital, public capital, sustained growth, monopolistic competition

1. Introduction

In the 1920s and 1930s considerable progress was made in the analysis of economic equilibrium, "monopolistic competition revolution". Monopolistic competition was introduced by Chamberlin(1933). His concern was to deal with market structures characterized by advertising and product differentiation. If a firm is making a profit selling a product in an industry, and other firms are not allowed to perfectly reproduce that product, they still may find it profitable to enter that industry and produce a similar but distinctive product. Economists refer to this phenomenon as product differentiation. Each product has its following of consumers, and so has some degree of market power.

Since Harrod(1939) and Domar(1946), economists have looked to captital formation for their explanation of rising standards of living. It was Solow(1956) who formalized the idea that capital deepening could cause labor productivity to rise in a dynamic process of investment and growth. The model's critical assumption concerning the product function is that it has CRS(constant returns to scale) in its two arguments, capital and labor. In addition, intangibles such as human capital and knowledge capital have pecular economic properties that may not be well represented by the standard formulations.

The starting point for discussions of the pure theory of trade and productivity is Ricardo's *Principles*. A country will choose to obtain goods through trade when a unit of labor applied to exports will produce more goods for home use than will result from the application of labor to produce these goods domestically. This will be the case whenever the relative labor costs involved in the production of different commodities differ from one country to another. This difference comes mainly from the difference of productivity.

Although Linder(1961) stressed increasing returns to scale(IRS) in trade theory, it was not until much later (Krugman, 1979) that a more formal treatment of productivity under IRS was provided. One of the problems with incorporating IRS into a theory of productivity is the need to deal with imperfect competition.

Krugman uses a model of monopolistic competition to show that trade can be viewed as a means of exploiting economies of scale in the presence of a less than completely elastic home market.

Romer(1986) has pointed out that growth might be sustainable if the accumulation of knowledge is not subject to long-run diminishing returns. Actually Romer assumed diminishing returns in the production of private knowledge from available resources, but increasing returns in the production of output from labor and total (public and private) knowledge. His condition for the sustainability of long-run growth amounts to an assumption that the diminishing returns in the former activity do not outweigh the increasing returns in the latter.

Grossman and Helpman(1991) developed coherent theoretical framework that previous discussions of trade, growth, development, industrial organization(IO) and innovation have lacked. They attempted to integrate the theory of IO with the theory of growth. As growth theory, they focused on the economic determinants of technological progress. As IO theory, they applied tools from the theory of IO to develop aggregate models of ongoing investments in new technologies. Their premise was that new technologies stem from the intentional actions of economic agents responding to market incentives.

Cho et al.(2006) used panel data consisted of 15 manufacturing sector in Korea for testing the validity of various endogeneous growth models. They concluded that the explanatory power of semi-endogeneous growth model[1] is high. But, they used DSUR estimation method and not TFP but patent data.

In this paper, we review new models of intentional industrial innovation. We deal with innovation that serves to expand the range of goods avaliable on the market. Firms devote resources to R&D in order to invent new goods that substitute imperfectly for existing brands. Producers of unique products earn monopoly rents, which serve as the reward for their prior R&D investments. In addition, we adapt new growth theory to real Korean economy data by empirical analysis.

The remainder of the paper is organized as follows. We begin in Section 2 by

[1] Jones(1995).

developing a general expanding product variety growth model. And, we describe the estimation results and analyze the implication of the basic growth model. Section 3 concludes.

2. Economic model and empirical analysis

2.1 Imperfect competition and new growth theory

It was Solow(1956) who formalized the idea that capital deepening could cause labor productivity to rise in a dynamic process of investment and growth.

Many of the early models treated technological progress as an exogeneous process driven only by time. The view that innovation is driven by basic research, which is implicit in the models with exogeneous technology, was made explicit in a paper by Shell(1967).

Arrow(1962) was the first to view technological progress as an outgrowth of activities in the economic realm. Romer(1986), who discussed the possibility that learning-by-doing might be a source of growth, maintained this treatment of technological progress as wholly the outgrowth of an external economy.

Now we let the productivity of labor depend upon the economywide cumulative experience in the investment activity, that is, on the aggregate stock of capital. Then aggregate output of Z will be given by

$$Z=F[K, A(K)L].$$

The first argument in F( ) represents the private input of capital by all firms in the economy. The second argument reflects their aggregate employment of effective labor, which depends in part upon the state of technology, as represented by the term A(K).

Romer(1986) provides an alternative interpretation of this specification. He views K itself as knowledge. Knowledge is created via an R&D process. Firms invest in private knowledge, but at the same time they contribute inadvertently to a public pool of knowledge, which is represented here by A(K).

Shell(1967) makes knowledge the intended output of those who create it. The production function $F[K_Z, AL_Z]$ describes the relationship between inputs and output of the final good. We assume that the same production function applies to the generation of knowledge as applies to the production of tangible commodities:

$$\Delta A = F[K_A, AL_A]$$

where K_A and L_A are the inputs of capital and labor, respectively, into the research activity.

Grossman and Helpman(1991) developed endogenous growth based on intentional innovation. Industrial research may be aimed at inventing entirely new commodities(product innovation). They incorporated tools from the theory of industrial organization(IO), and their extensions in trade theory to general equilibrium settings to develop aggregate models of ongoing investments in new technologies. They represent the set of brands available on the market by the interval [0, n]. With this convention n is the measure of products invented. They referred to n as the "number" of available varieties.

Monopolistic competition was introduced by Chamberlin(1933). It is probably the most prevalent form of industry structure. If a firm is making a profit selling a product in an industry, and other firms are not allowed to perfectly reproduce that product, they still may find it profitable to enter that industry and produce a similar but distinctive product. Economists refer to this phenomenon as product differentiation. Each product has its following of consumers, and so has some degree of market power.

We can describe the (long-run) equilibrium of the industry in the following way:

(i) Each firm faces a downward-sloping demand.
(ii) Each firm makes no profit.
(iii) A price change by one firm has negligible effect.

Suppose that firms have U-shaped average-cost curves. Let $D_i(p_i, p_{-i})$ be the residual demand curve of firm i; that is, its demand curve given the vector of prices p_{-i} charged by the other firms. A free-entry equilibrium requires that each firm make zero profit.

If we treat commercial research as an ordinary economic activity, returns to R&D come in the form of monopoly rents in (short-run) imperfectly competitive product markets.

The representative household maximizes utility over an infinite horizon.

$$U(t)=\int_t^{\infty} e^{-\rho(\tau-t)}\log D(\tau)d\tau$$

Here $\log D(\tau)$ represents an index of consumption at time τ, and ρ is the subjective discount rate.

We adopt for D a specification that imposes a constant elasticity of substitution between every pair of goods. It is straightforward to show that, with these preferences, the elasticity of substitution between any two products is $\varepsilon = 1/(1-\alpha)$ (>1).

$$D=[\int_0^{n} x(j)^{\alpha}dj]^{(1/\alpha)} \qquad (2.1)$$

where x(j) denotes consumption of brand j.

It is useful to develop an interpretation of the consumption index D. We may think of households as consuming a single homogeneous consumption good in quantity D. We suppose that the final good is assembled from differentiated intermediate inputs or producer services.

In equilibrium manufacturers of consumer goods would employ equal quantities x(j)=x of each. Then (2.1) implies that $D = n^{(1/\alpha)}x$.

Then final output per unit of primary input(TFP) is given by $D/X = n^{(1-\alpha)/\alpha}$ 2)

Firms may enter freely into R&D. An entrepreneur who devotes *l* units of labor to R&D for a time interval of length *dt* acquires the ability to produce $dn=(l/a)dt$ new products. The effort creates value for the entrepreneur of $v(l/a)dt$, since each blueprint has a market value of *v*.[3]

$\Delta n=F[L_N]$

It is known that when the initial number of brands exceeds n_0, there always exists a perfect foresight equilibrium with no product development.(〈Appendix〉)

Ideas do not become exhausted, and there are no diminishing returns in the creation of knowledge. Nonetheless, growth ultimately ceases in this simplest model of endogeneous innovation. The reasons are similar to those that are discussed in the context of the neoclassical model of capital accumulation. Even if the resource cost of creating new goods does not rise, the economic return to invention may decline as the number of available products increases. When the rate of return to R&D falls to the level of the discount rate, private agents cease to be willing to defer consumption in order to invest in product development.[4]

As yet, we treated knowledge capital as a private good. But, the originators of many new ideas often cannot appropriate all of the potential benefits from their creations.

So in this point, we modify formulation of knowledge creation to allow for the existence of non-appropriable benefits from industrial research.

Romer(1990) argued that each research project also contributes to a stock of general knowledge capital $K_N(t)$.

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2) We can use X=nx to measure the resources embodied in final goods.

3) From the above equation for TFP, we know that the log of final output lnD increases by an amount equal to $(1/\alpha)$ each time a new innovations occurs. However, the real time interval between two successive innovations is random. Therefore, the time path of the log of final output lnD may itself be a random step function. But, in this paper, we assume that successive innovations occur continuously.

4) Thus product development ultimately drives the profit rate down to the level of the discount rate. When that occurs, there is no further incentive to invest in R&D. In both the neoclassical growth model and the model of product deveopment described in this article, the process of investment run into diminishing returns.(Grossman and Helpman, 1991)

In place of technology for product innovation $\Delta n=F[L_N]$, we assume that

$$\Delta n=F[K_N,\ L_N]=(1/a)(K_N L_N)$$

where K_N and L_N are stock of general knowledge capital and aggregate employment in R&D, respectively. Of course the previous formulation is a special case of this equation with $K_N(t)\equiv 1$.

We take the knowledge capital stock to be proportional to the economy's cumulative experience at R&D.

$$K_N=n$$

Let's ask what the equilibrium implies about the rate of growth of final output and the rate of growth of GDP. When the differentiated products are interpreted to be intermediate goods, clearly faster innovation implies faster output growth.

It is apparent that the economy innovates faster the larger is its resource base(large L), the more productive are its resources in the industrial research lab(small a), the more patient are its households(small ρ), and the greater is the perceived differentiation of products(small α).

If we treat knowledge capital as a public capital considering of its non-appropriable benefits, economic growth can be sustained in the economy.(〈Appendix〉)

IO economists have long tried to summarize the distribution of market shares among firms in a single index to be used in econometric and antitrust analysis. Such an aggregate index is called a concentration index.

The 3-firm concentration ratio(CR3), which adds up the 3 highest shares in the economy has been changed as in 〈Fig. 1〉 From this, we can infer that oligopolistic market structure like monopolistic competition is probably the most prevalent form of Korean industry structure.

〈Figure 1〉 3-firm concentration ratio of Korea(CR3)

2.2 Data and empirical analysis

The term "panel data" refers to data sets where we have data on the same individual(industry; i) over several periods of time(t). The main advantage is that it allows us to test and relax the assumptions that are implicit in cross-sectional analysis.[5]

The data set consists of 5 industries in manufacturing sector observed yearly for 15 years(1990-2004), a "balanced panel". Because of no missing data on some of the variables, we obtained 75 observations. All the data sets are obtained from OECD, KOSIS and BOK.

We examined a simple model for the technology for product innovation of 5 industries in manufacturing sector:[6]

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[5] Recently constructed longitudinal data sets contain observations on thousands of individuals, each observed at several points in time. But, panel data sets are more oriented toward cross-section analyses; they are wide but short. Heterogeneity across units is an integral part - indeed, often the central focus - of the analysis. In this paper, the advantage of a panel data set over a cross section is that it will allow greater flexibility in modeling differences in behavior(or relationship) across industries. In principle, it is desirable to deal more industries than 5 industries, but it is thought to be sufficiently enough to analyse aggregated 5 manufacturing sectors, because of similar patterns between particular industries in each aggregated sector.

[6] In this point, we need to consider Schumpeter's(1943) thesis about the link between market structure and

$n_{it} = \alpha_i + \beta' x_{it} + \varepsilon_{it}$

n: the number of firms in each industry[7]

x: R&D investment, R&D stock, R&D personnel

The fixed effects approach takes α_i to be a group(industry) specific constant term in the regression model. The random effects approach specifies that takes α_i is a group(industry) specific disturbance in the regression model.

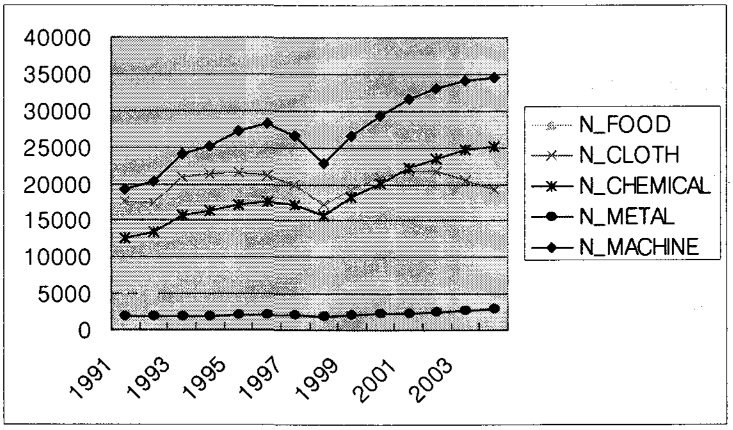
〈Table 2〉 Panel data by industry classification

Industy variable (1990-2004)	R&D(OECD, KOSIS) Value Added, Number of firms(KOSIS)
FOOD	Food products, beverages and tobacco
CLOTH	Textiles, textile products, leather and footwear
CHEMICAL	Chemical, rubber, plastics and fuel products
METAL	Basic metals
MACHINE	Machinery and equipment, instruments and transport equipment

R&D. Schumpeter's basic point - that monopoly situations and R&D are intimately related - is articulated in the following clearly distinct argument: that if one wants to induce firms to undertake R&D one must accept the creation of monopolies as a necessary evil. While all firms stand prepared to use useful information created by other firms, no one firm is willing to pay the sums of money necessary to produce it without compensation. In practice, such compensation often comes through the granting of a patent that provides the innovating firm with a temporary monopoly. Previous empirical studies on Schumpeter hypothesis show that the prediction of Schumpeter does not accord well with empirical observation of Korean economy.(Lee and Cheong 1985, Kim and Cho 1989, Kim 2005, Sung 2005)

7) Strictly speaking, n(t) is the measure of products invented before time t. Grossman and Helpman(1991) referred to n as the "number" of available varieties. In this paper, we use the number of firms for n due to limitation of getting data for the number of products by industry. This may be the limit of the paper.

⟨Figure 2⟩ The number of firms in panel data by industry classification



Fixed and random effects regression produces the following results. Estimated standard errors are given together. ⟨Table⟩ also contains the estimated technology for product innovation equations with individual industry effects.

⟨Table 3⟩ contains the estimated production function for blueprints(knowledge) with individual industry disturbances. Considering chi-squared statistic for testing for the fixed and random effects, we can see that the evidence is strongly in favor of the random effects model.

We examined the following model for the technology for product innovation of 5 industries in manufacturing sector:

$$n_{it} = \alpha_i + \beta' x_{it} + \gamma GDP_t + \varepsilon_{it}$$

x: R&D investment

Significantly estimated elasticity of R&D to the number of firms in each industry is 0.14. It means that if firms increase R&D by 1%, then the number of blueprint is increased by 0.14%. GDP variable is used to control confounding factors(eg. business cycle).[8]

[8] If the equation is estimated without the relevant economic variable, the estimated coefficients will be biased. For this possibility of omission of relevant variables, we performed the specification analysis(RESET), and did not reject the null hypothesis that the original model has not specification error.

〈Table 3〉 Random-effects model estimation for panel data[9]

Dependent Variable: LOG(N?)				
Method: Pooled EGLS (Cross-section random effects)				
Sample (adjusted): 1991 2004				
Included observations: 14 after adjustments				
Cross-sections included: 5				
Total pool (balanced) observations: 70				
Swamy and Arora estimator of component variances				
Period SUR (PCSE) standard errors & covariance (d.f. corrected)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.464819	1.136276	2.169208	0.0336*
LOG(RD?(0))	0.137833	0.044106	3.125044	0.0026*
LOG(GDP(-1))	0.38548	0.09349	4.123231	0.0001*
Random Effects (Cross)				
_FOOD--C	-0.37473			
_CLOTH--C	0.851245			
_CHEMICAL--C	0.425791			
_METAL--C	-1.46356			
_MACHINE--C	0.561251			
	Effects Specification			
Cross-section random S.D. / Rho			1.013221	0.9933
Idiosyncratic random S.D. / Rho			0.083326	0.0067
	Weighted Statistics			
R-squared	0.729983	Mean dependent var		0.203608
Adjusted R-squared	0.721923	S.D. dependent var		0.157329
S.E. of regression	0.082965	Sum squared resid		0.461168
F-statistic	90.5662	Durbin-Watson stat		0.874371
Prob(F-statistic)	0.00			

The assumption that x_{it} and ε_{it} are uncorrelated has been crucial in the estimation thus far. But, there are any number of applications in economies in which this assumption is untenable. Without this assumption, none of the characters of consistency of LS estimator will hold up. There is an alternative method of estimation called the method of instrumental variables(IV).

In the above equation for the technology for product innovation of 5 industries in manufacturing sector, by construction, the model violates the assumptions of the

9) From this estimation table after, if estimated coefficient is statistically significant, we denote *, or **, by 5% or 10% confidence level, respectively.

classical regression model. Therefore, although the precise relationship between innovation *n*, and R&D *x*, economic situation *GDP*, $n = f(x, GDP, \varepsilon)$, is ambiguous and is a suitable candidate for modeling, it is clear that innovation (and therefore ε) is one of the main determinants of *x* and *GDP*. It is reasonable to assume that ε_{it} is uncorrelated with inflation *infla*, and government expenditure *gexpend*. Therefore, in this model, we might consider *infla* and *gexpend* as suitable instrumental variables.

$$n_{it} = \alpha_i + \beta' x_{it} + \gamma GDP_t + \varepsilon_{it}$$

x: R&D investment, infla and gexpend: instruments

Significantly estimated elasticity of R&D to the number of firms in each industry is 1.41. It means that if firms increase R&D by 1%, then the number of blueprint is increased by 1.41%. GDP variable is also used to control confounding factors(eg. business cycle).

〈Table 4〉 Random-effects model estimation for panel data

Dependent Variable: LOG(N?)				
Method: Pooled IV/Two-stage EGLS (Cross-section random effects)				
Sample (adjusted): 1992 2004				
Included observations: 13 after adjustments				
Cross-sections included: 5				
Total pool (balanced) observations: 65				
Instrument list: c infla gexpend9 log(n?(-1))				
Swamy and Arora estimator of component variances				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	24.02627	4.305121	5.580858	0.0000
LOG(RD(0))	1.412609	0.265719	5.316174	0.0000*
LOG(GDP(-1))	-2.380762	0.559999	-4.251366	0.0001*
Random Effects (Cross)				
_FOOD--C	-0.512277			
_CLOTH--C	0.624793			
_CHEMICAL--C	0.547829			
_METAL--C	-1.599569			
_MACHINE--C	0.939223			

The data on product innovation analyzed above are typical of count data. Clearly discrete nature of the dependent variable suggest that we could improve on LS and the linear model with a specification that accounts for this characteristics. The Poisson regression model has been widely used to study such data.

The Poisson regression model specifies that each n_i is drawn from a Poisson distribution with parameter λ_i, which is related to the regressors x_i. The primary equation of the model is

$$Prob(N_i=n_i)= e^{-\lambda}\lambda^{n}/ n_i!$$

The most common form for λ_i is the log-linear model,

$$\ln\lambda_i = \beta'x$$

x: R&D, GDP

The z-statistic of the R&D coefficient is highly significant, leading us to reject the no explanatory power of R&D variable.

⟨Table 5⟩ Poisson estimation for count data

Dependent Variable: N				
Method: ML/QML - Poisson Count (Quadratic hill climbing)				
Sample (adjusted): 1991 2004				
Included observations: 14 after adjustments				
Convergence achieved after 9 iterations				
Covariance matrix computed using second derivatives				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	12.77473	0.179995	70.97278	0.0000
LOG(RD)	0.634724	0.011680	54.34077	0.0000*
LOG(GDP(-1))	-0.880431	0.027364	-32.17537	0.0000*
R-squared	0.914881		Mean dependent var	74408.71
Adjusted R-squared	0.899404		S.D. dependent var	11057.84
S.E. of regression	3507.192		Akaike info criterion	141.6787
Sum squared resid	1.35E+08		Schwarz criterion	141.8156
Log likelihood	-988.7509		Hannan-Quinn criter.	141.6660
Restr. log likelihood	-10879.77		Avg. log likelihood	-70.62506
LR statistic (2 df)	19782.04		LR index (Pseudo-R2)	0.909120
Probability(LR stat)	0.000000			

Next, we examined the following model for the economic growth by product differentiation of 5 industries in manufacturing sector:

〈Table 6〉 contains the estimated growth rate function in each industry by product differentiation with individual industry effects. Considering F statistic for testing the joint significance of the industry effects, we can see that the evidence is strongly in favor of a industry specific effect in the data.

$$(\Delta V/V)_{it} = \alpha_i + \beta \, `n_{it} + \gamma GDP_{t-1} + \varepsilon_{it}$$

V: Value added by industry

Significantly estimated elasticity of product differentiation to the economic growth in each industry is 0.18. It means that if firms increase product differentiation by 1%, then the grow rate of industry is increased by 0.18%. Lagged GDP variable is used to control confounding factors(eg. business cycle).

〈Table 6〉 Fixed-effects model estimation for panel data

Dependent Variable: LOG(V?)-LOG(V?(-1))				
Method: Pooled Least Squares				
Sample (adjusted): 1992 2003				
Included observations: 12 after adjustments				
Cross-sections included: 5				
Total pool (balanced) observations: 60				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.126298	0.662803	3.208037	0.0023*
LOG(N?(0))	0.178434	0.102772	1.736217	0.0883**
LOG(GDP(-1))	-0.282846	0.071846	-3.936838	0.0002
Fixed Effects (Cross)				
_FOOD--C	0.074848			
_CLOTH--C	-0.151938			
_CHEMICAL--C	-0.083044			
_METAL--C	0.288039			
_MACHINE--C	-0.127905			
Effects Specification				
Cross-section fixed (dummy variables)				
R-squared	0.345753		Mean dependent var	0.079265
Adjusted R-squared	0.271688		S.D. dependent var	0.078827
S.E. of regression	0.067272		Akaike info criterion	-2.450877
Sum squared resid	0.239850		Schwarz criterion	-2.206537
Log likelihood	80.52631		F-statistic	4.668201
Durbin-Watson stat	2.252562		Prob(F-statistic)	0.000704

Next, we examined the following model for the production function for blueprints(knowledge). We analysed the model to see whether the knowledge is a private good or public capital.

Considering goodness of fit, we can see that the evidence is strongly in favor of the character as the public knowledge capital.

We examined the following three models for the technology for product innovation of 5 industries in manufacturing sector:

$$\ln(\Delta n_{it}) = \alpha_i + \beta' \ln(L_{Nit}) + \gamma \ln(n_{it}) + \varepsilon_{it} \qquad (2.2)$$

n: the number of firms in each industry

The above equation is derived by taking logs of the following production function for blueprints(knowledge):

$$\Delta n = F[K_N,\ L_N] = (1/a)(K_N L_N) = (1/a)(L_N)^{\beta} n^{\gamma} \qquad (2.3)$$

$$\Delta n/n = (1/a)(L_N)^{\beta} n^{\gamma - 1} \qquad (2.4)$$

Significantly estimated elasticity of product innovation to the production of knowledge in each industry is 1.18.(〈Table 7〉)

The parameter γ reflects the effect of the existing stock of blueprints on the success of R&D. This effect can operate in positive direction. Past discoveries may provide ideas and tools that make future discoveries easier.

When γ is exactly equal to 1 in the production function for blueprints, existing blueprints are just productive enough in generating new blueprint that the production of new knowledge is proportional to the stock.[10] In this case, expressions (2.3) and (2.4) for (Δn) and (Δn/n) simplify to:

$$\Delta n = \alpha (L_N)^{\beta} n \qquad (2.5)$$

$$(\Delta n/n) = \alpha (L_N)^{\beta} \qquad (2.6)$$

10) When γ is larger than 0, we can say this phenomenon as spillover effect or "standing on shoulders" effect of R&D.

⟨Table 7⟩ Pooled LS estimation for panel data

Dependent Variable: LOG(N?(0)-N?(-1))				
Method: Pooled Least Squares				
Sample (adjusted): 1992 2004				
Included observations: 11 after adjustments				
Cross-sections included: 5				
Total pool (unbalanced) observations: 48				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.148216	7.467068	0.555535	0.5813
LOG(N?)	1.175704	0.147096	7.992748	0.0000*
LOG(RDL)	-0.719558	0.606875	-1.185677	0.2420
R-squared	0.587487		Mean dependent var	6.217950
Adjusted R-squared	0.569153		S.D. dependent var	1.487177
S.E. of regression	0.976167		Akaike info criterion	2.850095
Sum squared resid	42.88058		Schwarz criterion	2.967045
Log likelihood	-65.40228		F-statistic	32.04375
Durbin-Watson stat	2.173729		Prob(F-statistic)	0.000000

$$\ln(\Delta n_{it}) = \alpha_i + \beta' \ln(K_{N it}) + \gamma \ln(n_{it}) + \epsilon_{it} \qquad (2.7)$$

RK: R&D capital(stock)

Significantly estimated elasticity of product differentiation to the production of knowledge in each industry is 1.17.(⟨Table 8⟩)

⟨Table 8⟩ Pooled LS estimation for panel data

Dependent Variable: LOG(N?(0)-N?(-1))				
Method: Pooled Least Squares				
Sample (adjusted): 1992 2004				
Included observations: 11 after adjustments				
Cross-sections included: 5				
Total pool (unbalanced) observations: 48				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1.727818	4.746207	-0.364042	0.7175
LOG(N?)	1.167162	0.148597	7.854574	0.0000*
LOG(RDSTOCK)	-0.167249	0.268541	-0.622808	0.5366
R-squared	0.578235	Mean dependent var		6.21795
AdjustedR-squared	0.55949	S.D. dependent var		1.487177
S.E. of regression	0.987053	Akaike info criterion		2.872275
Sum squared resid	43.84228	Schwarz criterion		2.989225
Log likelihood	-65.9346	F-statistic		30.8473
Durbin-Watson	2.195918	Prob(F-statistic)		0.00

$$\ln(\Delta n_{it}) = \alpha_i + \beta' \ln(L_{Nit}) + \gamma \ln(n_{it}) + \delta \ln(K_{Nit}) + \varepsilon_{it} \qquad (2.8)$$

Significantly estimated elasticity of product differentiation to the production of knowledge in each industry is 1.19.(〈Table 9〉)

〈Table 9〉 Pooled LS estimation for panel data

Dependent Variable: LOG(N?(0)-N?(-1))				
Method: Pooled Least Squares				
Sample (adjusted): 1992 2004				
Included observations: 11 after adjustments				
Cross-sections included: 5				
Total pool (unbalanced) observations: 48				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	30.91205	13.14028	2.352464	0.0232*
LOG(N?)	1.188201	0.139846	8.496496	0.0000*
LOG(RDL)	-6.671516	2.526445	-2.640674	0.0114*
LOG(RDSTOCK)	2.675276	1.105616	2.419717	0.0197*
R-squared	0.635933		Mean dependent var	6.217950
Adjusted R-squared	0.611110		S.D. dependent var	1.487177
S.E. of regression	0.927419		Akaike info criterion	2.766832
Sum squared resid	37.84464		Schwarz criterion	2.922765
Log likelihood	-62.40397		F-statistic	25.61896
Durbin-Watson stat	1.916236		Prob(F-statistic)	0.000000

In all three cases for the knowledge production function, we could not reject the null hypothesis H_0: $\gamma=1$.

And, considering goodness of fit of regression model, we can see that the empirical evidence is strongly in favor of the character of knowledge as the public (knowledge) capital. In all cases, individual coefficient for n is statistically significant at 5% confidence level.[11] This result gives the implication that by

[11] In particular, in the three log-linear model cases, estimated regression coeficients are all lager than 1. This gives the implication that the process of knowledge accumulation may be characterized by increasing returns. This can be explained by the fact, for example, if there exist important complementarities between different ideas. Actually Romer(1986) assumed increasing returns in the production of output from labor and total (public and private) knowledge. His condition for the sustainability of long-run growth amounts to an assumption that the accumulation of knowledge is not subject to diminishing returns.

product innovation, economic growth can be sustained in the Korean economy.

Meanwhile, there is a danger of obtaining apparently significant regression results from unrelated data when using nonstationary series in regression analysis. Such regressions are said to be spurious. So, we performed two widely used unit root tests: the augmented Dickey-Fuller(ADF) test, and the Phillips-Perron test.

For unit root tests, consider first an AR(1) process.

$$x_t = \alpha_1 + \rho x_{t-1} + \varepsilon_{1t}$$

Both the ADF and the PP tests the unit root as the null hypothesis H_0: $\rho = 1$.

The test is carried out by estimating an equation with x_{t-1} subtracted from both sides of the equation:

$$\Delta x_t = \alpha_1 + \rho^* x_{t-1} + \varepsilon_{1t}$$

where $\rho^* = \rho - 1$, and the null hypothesis is

H_0: $\rho^* = 0$

Test results report the test statistic as follows.

〈Table 10〉 Unit root test statistics

	lnRD	lnN	ΔlnRD	ΔlnN
ADF	-3.14	-2.86	-3.13	-2.85**
PP	-0.41	-2.01	-9.12*	-2.85**

The Johansen(1988) cointegration test method is used for finding long-run equilibrium relationship between R&D input and the product innovation. Test results indicate the existence of cointegrating equation between each pair of regression variables including dependent variable in the knowledge production function.[12] And, the signs of cointegrating vectors are well accord to the prediction of sustainable growth.

12) Strictly speaking, there should be cointegration relationships among Δn, n, and RD. In this paper, we analysed only bivariate cointegration relationships due to limitation of getting long-term data for the number of products by industry. This also may be the limit of the paper. In addition, the series n should be I(2), in principle, but, we omitted the test results.

〈Table 11〉 Cointegration test statistics

Sample (adjusted): 1994 2004				
Included observations: 7 after adjustments				
Trend assumption: Linear deterministic trend				
Series: LOG(N-N(-1)) LOG(N)				
Lags interval (in first differences): 1 to 1				
Unrestricted Cointegration Rank Test (Trace)				
Hypothesized Trace		0.05		
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.999835	61.74493	15.49471	0
At most 1	0.106046	0.784704	3.841466	0.3757
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level				
* denotes rejection of the hypothesis at the 0.05 level				
**MacKinnon-Haug-Michelis (1999) p-values				
1 Cointegrating Equation(s): Log likelihood		45.08658		
Normalized cointegrating coefficients (standard error in parentheses)				
LOG(N-N(-2))	LOG(N)			
1	-2.32301			
	-0.02408			

〈Table 12〉 Cointegration test statistics

Sample (adjusted): 1994 2004				
Included observations: 7 after adjustments				
Trend assumption: Linear deterministic trend				
Series: LOG(N-N(-1)) LOG(RDL)				
Lags interval (in first differences): 1 to 1				
Unrestricted Cointegration Rank Test (Trace)				
Hypothesized Trace		0.05		
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.974697	27.09766	15.49471	0.0006
At most 1	0.176568	1.359919	3.841466	0.2436
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level				
* denotes rejection of the hypothesis at the 0.05 level				
1Cointegrating Equation(s):Log likelihood		20.20158		
Normalized cointegrating coefficients (standard error in parentheses)				
LOG(N-N(-2))	LOG(RDL)			
1	-1.55382			
	-0.21272			

In the above, from all cases of the form for the knowledge production function, we could not reject the null hypothesis that R&D spillover effect is significant (H_0: γ=1).

3. Summary and conclusion

Grossman and Helpman(1991) presented the models of endogeneous growth based on intentional industrial innovation. Innovations serve to expand the range of available products. They find that if the creation of knowledge generates nonappropriable benefits that allow later generations of researchers to proceed at lower resource cost than their predecessors, then the process of endogeneous innovation and growth may be sustained.

But, in the endogeneous growth model which treats knowledge capital as a private good, it is known that when the initial number of brands exceeds some number(eg. n_0), there always exists a perfect foresight equilibrium with no product development.

Ideas do not become exhausted, and there are no diminishing returns in the creation of knowledge. Nonetheless, growth ultimately ceases in this simplest model of endogeneous innovation.

If we treat knowledge capital as a public capital considering of its non-appropriable benefits, economic growth, however, can be sustained in the economy.

We showed that considering goodness of fit of regression model, we can see that the empirical evidence is strongly in favor of the character of knowledge as the public knowledge capital.(〈Table 13〉)

So, we can expect that by product innovation, economic growth can be sustained in the Korean economy.

〈Table 13〉 Panel analysis summary

Causal relationship	Innovation	(Elasticity)	Industry structure	(Elasticity)	Growth
Monopolistic competition	R&D investment(X)	⇒(0.14)	Product innovation (n)	⇒(0.18)	Economic growth in industry($\Delta V/V$)

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김병우

서울대학교에서 경제학 학사 및 박사학위(학위논문: 전력시장의 시장지배력)를 취득하고 현재 과학기술정책연구원 부연구위원으로 재직중이다. 주요 연구분야는 경제성장론, 기술경제학, 산업조직론, 응용계량경제 등이며 R&D정책제안을 통해 과학기술발전 및 이를 통한 성장전략 수립에 기여하고 있다.

〈Appendix〉

In the momentary equilibrium all varieties are priced equally at p, where

$p=w/\alpha$

(The specified technology makes marginal manufacturing costs equal to the wage rate w.)

With symmetric demands and E(aggregate spending)=1, this pricing strategy yields per brand operating profits of

$\pi=(1-\alpha)/n$

This inverse relationship between the number of available varieties and profits per brand suggests that product development may never get underway if an economy inherits a sufficiently diverse set of differentiated commodities. In other words, in the endogeneous growth model which treats knowledge capital as a private good, when the initial number of brands exceeds some number(eg. n_0), there always exists a perfect foresight equilibrium with no product development. We can see that with these initial conditions, the dynamic equilibrium without any R&D is unique.

But, if we treat knowledge capital as a public capital considering of its non-appropriable benefits, economic growth can be sustained in the economy. In this case, the higher is the rate of innovation, the greater is employment in R&D. In the steady-state equilibrium, product development continues indefinitely, always at a constant rate. We may calculate the steady-state rate of innovation as follows:
$g=(1-\alpha)/(L/a)-\alpha\rho$

L: labor supply

Sustained innovation is possible in this case because the cost of product development falls with the accumulation of knowledge capital, even as the return to the marginal innovation declines. The nonappopriable benefits from R&D keep the state of knowledge moving forward, and so the private incentives for further research are maintained.