Resources and Sustainable Development in Korea

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Summary

Through time-series plots, we can see relatively stable trend of energy factor share and the decreasing trend of relative energy prices (to wages) in Korea.

We can compromise these empirical facts with the following explanation: if elasticity of substitution between capital and energy is smaller than one(<1) in Korea, a change(decrease) in energy price can prevent income share of resources from rising in the process of economic growth. This is consistent with theoretical and empirical results that substitution between energy and capital is so difficult.

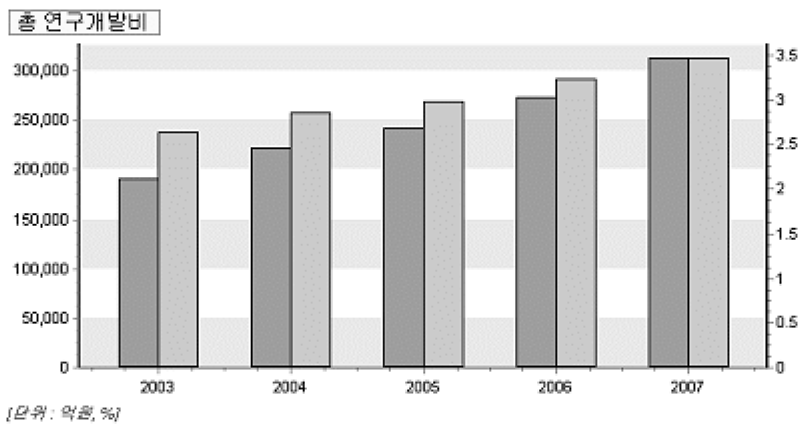
From simple empirical analysis and limited infomation, we can carefully infer that, in the past in Korea, resource-specific innovation was performed widely. Finally, If we are to reduce the magnitude of "growth drag", we should decrease energy factor share. This can be accomplished by energy-augmenting technical progress in the case of elasticity of substitution less than 1 as in Korea.

JEL classification: Q3; Q4

Key Words: nonrenewable resources, resource intensity, innovation, sustainable growth.

I. Introduction

Relative importance of spending on research in Korea compared to other economic activities has been steadily increasing. <Figure 1> depicts the trends in the ratio of R&D to value added in industry in the Korean economies.



<Figure 1> National Trend in R&D of Korea(Source: MOST)

[Right: percentage of GDP(%), Left: Total R&D expenditure(100 million Won)]

We can ask the following question: can these R&D efforts solve the problem of limited nonrenewable resources(especially, limited energy resources problem) in Korea?

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Economists incorporate natural resources, pollution and sustainable development into their enodogeneous growth theory considering the R&D incentive of profit-maximizing participants. This comes from their reaction for Brundtland Commision and issues of global warming. This reaction coincides with the basic principle of endogeneous theory that it's important to know whether or not an economy can sustain growth.(Aghion and Howitt, 1998)[1]

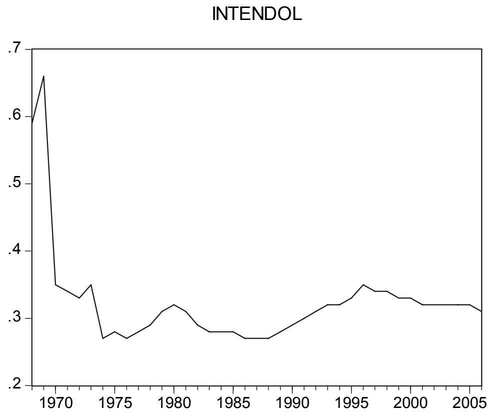
In general, it is known that the existence of nonrenewable resources reduces the growth rate. It is known that resource limitation may cause output to be falling. This is a drag on economic growth.[2]

But, it is also known that technical progress can spur economic growth. This effect can offset the effects of some drags on economic growth.(Romer, 2006)[3]

In our discussion for resources problem in economic growth process, we focus on three important issues: substitution relative prices and factor share.[4]

Also, in this paper, we mainly focus on nonrenewable energy resources in Korea. Energy is a particularly important resource. Their data are expressed in <Fig 2>. <Fig 2> shows the energy intensity ($) in GDP. It shows generally a stable trend.[5] A useful concept is the resource intensity of production (that is, the amount of energy needed per dollar of GDP) in discussing the relationship between resources and growth. It shows some decreasing trend in most developed countries, but stable trend in Korea.[6]

<Fig 3> shows the factor share($) of energy in GDP. It also shows generally a stable trend.



<Figure 2> Energy Intensity[Energy Consumption/GDP] of Korea
(Source: KEEI)[TOE/ (1,000 $)]

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1 The relationship between growth and resources is generally discussed in the title of "sustainable development".

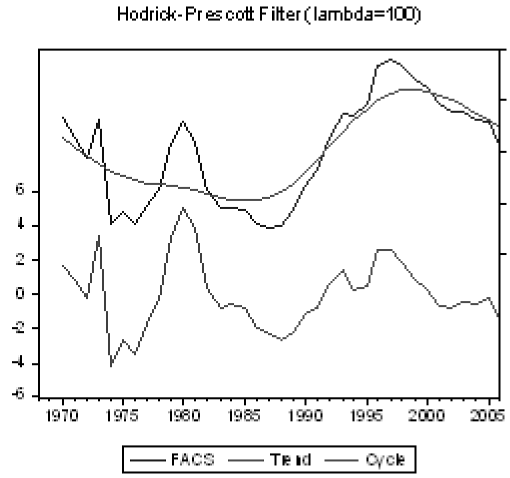
2 *"The Limits to Growth"*(Meadows et al., 1972) shows strong pessimism for future resources. According to their argument, output per capita peak around 2000, after which it falls sharply because of nonrenewable resources.

3 In contrast to this argument, a country's endowment of resource may have nothing to do with economic growth. This is because since countries can trade with each other, they can import the (nonrenewable) resources they need in production. But, for the world as a whole, nonrenewable resources can be big problem.(Weil, 2008)

4 The concept of factor share is intimately related with energy intensity.

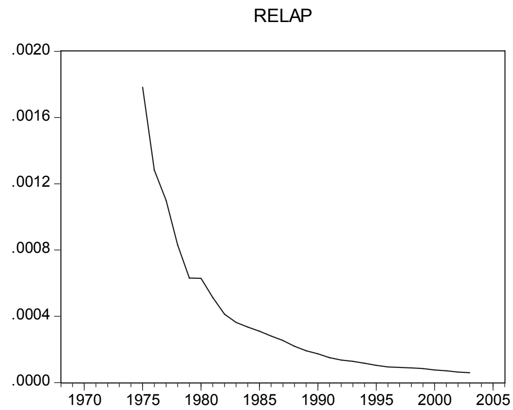
5 In addition, constructing time-series plots which shows energy intensity in terms of index(2000=100) also results in nonincreasing trend.

6 Theoretically, we could expect the energy intensity(E/Y) to decline. In this paper, we focus on this non-increasing characteristics of this ratio.



<Figure 3> Energy Factor Shares [Energy Consumption/GDP multiplied by the PPI of Energy] of Korea(Source: KEEI)[Index, 2000=100]

With the constant labor share in GDP, this stable trend of energy share implies increasing relative price of energy(to wage). In reality, the relative price of energy (to that of wage) shows declining trend in <Fig 4>. Nordhaus(1992) gave some comments to this phenomenon in the US.[7]

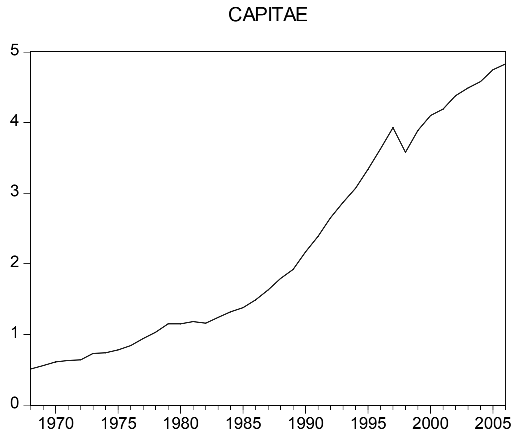


<Figure 4> Relative Price for Energy(to Wages) (Source: BOK, KEEI)[8]

In addition, the energy use per capita shows increasing trend. That is, energy consumption per person rises in Korea. (<Fig 5>)

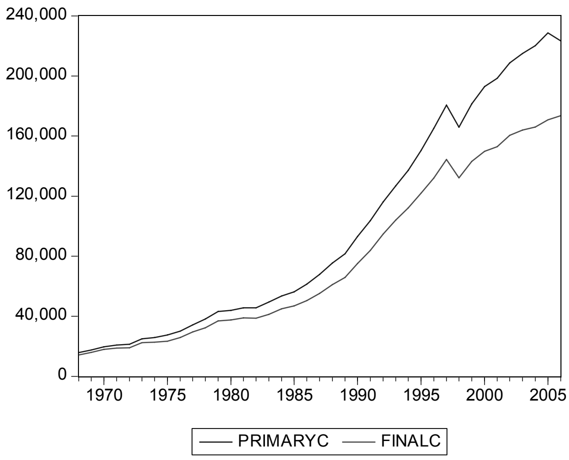
[7] Intuitively, we can assume that per capita energy use (energy/labor) should decline as economy grows up. It is due to the fact that population per finite resource grows and resources are used up in production.

[8] PPI of Energy/Wage index



<Figure 5> Per Capita Energy Consumption(TOE/Person, Source: BOK, KEEI)

In the previous <Fig 3>, we saw decreasing trend of the relative price of energy in Korea. But, per capita energy use(E/L) shows increasing trend. This contradicts with our intutition.(<Fig 5>)



<Figure 6> Trend in Energy Consumption of Primary(PRIMARYC) and Final(FINALC) Energy Product (1,000 TOE, Source: KEEI)

Finally, in the <Fig 6>, we can see increasing trend of (total) energy consumption in Korea.

In this paper, we try to give answers to the following questions.

First, intuitively, we can guess that 1) energy intensity to fall, 2) relative price of energy to wages to rise and 3) factor share of energy to rise in Korea. But, real data shows that 1) energy intensity is constant, 2) relative price of energy fell, and 3) factor share of energy is stable. How can we explain these puzzling phenomena?

Second, can we measure the growth drag from limited energy resources in Korea? If so, how large is growth drag?

This article consists of the following sections. Section 2 introduces the previous literatures and Schumpeterian growth theory for nonrenewable resources. And, this section tries to measure growth drag using simple Cobb-Douglas production function. Section 3 considers and estimates CES (aggregate) production function for explaing the puzzling phenomena in regards to resources. Section 4 concludes and gives some implications.

II. Economic Growth model and Empirical Analysis

2.1 Previous Literatures

Nordhaus(1992) uses income data to estimate the importance of resources in production. He continues on to present the estimate of growth drag due to energy limitation as of 0.24% point. That is, a quarter of 1% point per year.[9]

Stockey(1996) considers the problem of environmental pollution(and limited resources) in terms of endogeneous growth model, AK model. She asserts that sustained development is not possible in AK model. That is, The cost of clean technology in order to avoid pollution would reduce the social marginal product of capital.

But, Aghion and Howitt(1998) show that the marginal product capital does not decrease, only if intellectual capital grows sufficiently faster than physical(tangible) capital. That is, two-sector Schumpeterian approach with constant returns to scale makes it possible to sustain growth.

2.2 Schumpeterian Growth Model (Aghion and Howitt 1998, Stockey 1996)

Before discussing the relationship between natural resources and economic growth, we see the simplest Schumpeterian endogeneous growth model. This is because by glancing at the main structure of the theory, we can improve our insight for the relationship between growth and resources.

We can denote the stock of nonrenewable resources as S. Its rate of change is determined(negatively) by the flow of resource depletion, R.

$\Delta S = - R$

$R = s_E S$

R may be used in production process. s_E denotes the fraction of the remaining stock that is depleted(used in production process each year.

A single final-good sector produces a homogeneous output good C, according to the CES technology. Then, we can write the (aggregate) production function as:

$Y = L^{\beta} \left[\int_0^B x(i)^{\alpha}\, di\right] R^{\upsilon} = (K^{\alpha} B^{1-\alpha}) L^{\beta} R^{\upsilon}$

where B is the variety of goods, Y(i) is the final good, K is capital, L is labor and x(=K/B) is each intermediate good. And $0<\upsilon<1$ is related to the use of resources.

We can use the Euler equation and convert to a consumption growth equation.

$\Delta c/c = (1/\varepsilon)[\alpha(Y/K) - \rho]$

If intellectual capital(B) grows sufficiently faster than tangible capital(K), the marginal product of capital, $\alpha(Y/K)$ needs not decrease.

[9] In regards to pollution, he concludes that welfare costs are relatively small. Especially, global warming has an effect of a reduction in GDP of 1~2%. This is equal to 0.03% point in annual growth rate.

The existence of (nonrenewable) resources in production may retard long-run economic growth.(Jones, 2002) But, this negative effect of resources can be overcome through the following two methods. First, the energy-specific technical progress can make energy from scarce factor of production to non-scarce factor. Second, intellectual capital can grow much faster than tangible capital, enough to overcome the decline in the use of resources.

2.3 Data and Estimation

The data set used in this paper consists of some (macro) economic variables(energy prices, wages and energy consumption, etc.) observed for 39 years(1968-2006) in the Korean economy. They were obtained from KEEI, BOK, KOSIS and OECD.

We slightly change the above production function and assume that the production function exhibits constant returns to scale in physical capital and labor.

We estimate final-good production function as follows(<Table 1>):

$$Y= (K^{\alpha} L^{1-\alpha}) B^{\beta} R^{\upsilon}$$

From this production function, we can straightforwardly derive the following the growth rate of output per worker along steady-state:

$$g_y = g^* - \upsilon^* n - \upsilon^* s_E$$

$$g^*=(\Delta B/B)/(1-\alpha),\ \upsilon^*= \upsilon/(1-\alpha),\ n=(\Delta L/L)$$

We use the estimates from the (restricted)regression of production function, $\upsilon=0.4$, $\alpha=0.2$ and $s_E=0.005$.[10] <Table 1>

The growth drag from resources can be calculated as follows:

$$\upsilon^* n + \upsilon^* s_E= 0.5*0.01+0.5*0.005=0.00725$$

Following this simple calculation for growth drag, per capita growth in Korea is lower about 0.725% due to the limitation of resources. The growth drag is the difference in growth rate between the case not considering resource limitation and the case considering resource limit. The growth drag is increasing function of resource's share(υ), the rate that resource use is falling(s_E), capital's share(α) and population growth(n).

Nordhaus(1992) provides numerical calculation (for the US economy). He assumes $\upsilon=0.1$, $\alpha=0.2$, $n=0.01$ and $s_E=0.005$. In a competitive economy, υ is total factor payment to resources as a share of GDP. His analysis produce the estimate of growth drag as 0.31%, considering also the land limitation. Compared to that of Nordhaus(1992), the estimate for Korea is relatively high. This comes from lager share of factor payment of resourses.(=0.4)

[10] The choice of value for s E was based on Nordhaus(1992).

<Table 1> Estimation for Exponents in Production Function for Calibration(Data: BOK, KEEI)

Dependent Variable: LOG(GDP)
Method: Least Squares
Sample (adjusted): 1970 2004
Included observations: 35 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	-2.80	0.64	-4.33	0.00**
C(2)	0.20	0.05	3.54	0.00**
C(3)	0.00	0.03	0.14	0.88
C(4)	0.41	0.07	5.64	0.00**

Estimation Equation:

LOG(GDP)=C(1)+C(2)*LOG(K)+(C(3))*TFP+(1-C(2))*LOG(L)+C(4)
*(LOG(PRIMARYC+FINALC))

+

2.4 Relative Prices and Factor Shares of Energy(Jones, 2002)

We assume that the production function takes the form of Cobb-Douglas, so the factor share is equal to the exponents. So, we constructed CD production function focusing on energy(E).

We consider final-good production function as follows:

$$Y= (K^{\alpha} L^{1-\alpha-\upsilon}) E^{\upsilon}$$

We denote the share of income paid to energy and labor, f_E and f_L.

From some calculation, we can derive the following ratio of factor shares:

$$f_E / f_L = P_E E / wL$$

Arranging slightly, we get:

$$P_E / w = (f_E / f_L) / (E/ L)$$

When the population grows and resources get depleted, we would expect the denominator, (E/ L) to fall. This implies a rising relative prices of energy (P_E / w), with constant factor shares (f_E / f_L). Or, this may imply a rising factor shares (f_E / f_L), with constant relative prices of energy (P_E / w).

But, this intuition contradicts with the empirical facts in section 1. For these puzzling phenomena, we discuss more in the next section.

3. CES Production Function and Factor Shares of Energy

3.1 Empirical Results

Since it assumes implicity the elasticity of substitution is one, Cobb-Douglas production function may be irrelevant.(Jones, 2002) So, we construct CES production function with two factors, energy(E) and physical capital(K). By the way, someone may concern that this analysis ignores (Harrod-neutral) technological progress and labor. But, Jones(2002) shows that main implications from this simple CES production function analysis is also correct in the more general case that considers labor also.

CES (constant elasticity of substitution) production function may be estimated as follows:

$Y = \gamma[\delta K^{-\rho}+(1-\delta)E^{-\rho}]^{-(\upsilon/\rho)}$ ($\gamma > 0$, $0<\delta<1$, $\rho > -1$)

where γ: efficiency parameter, ν : the returns to scale parameter, δ: allocation parameter, ρ: substitution parameter.

Taylor series approximation around $\rho=0$ is:

$$\ln Y = \ln\gamma - (\nu/\rho)\ln[\delta K^{-\rho} + (1-\delta)E^{-\rho}] + \varepsilon$$
$$= \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \varepsilon'$$

where

$x_1 = 1$
$x_2 = \ln K$
$x_3 = \ln E$
$x_4 = -(1/2)[\ln^2(K/E)]$

The transformations of variables are:

$\gamma = e^{\beta 1}$
$\delta = \beta_2/(\beta_2 + \beta_3)$
$\nu = \beta_2 + \beta_3$
$\rho = \beta_4 (\beta_2 + \beta_3)/(\beta_2\beta_3)$

The elasticity of substitution between capital and energy is $\sigma=1/(1+\rho)$.

In the more general case that considers labor(L) also, CES production function may be written as follows:

$Y = \gamma[\delta K^{-\rho}+(1-\delta)E^{-\rho}]^{-(\upsilon/\rho)} [L]^{-(1-\upsilon)}$

<Table 2> Estimation for CES Production Function (Data: BOK, KEEI)

	Estimates
b1	1.11
b 2	0.60
b 3	0.33
b 4	0.49
Γ	3.03
Δ	0.65
υ	0.93
ρ	2.30
1/(1+ ρ)	0.30

The elasticity of substitution $\sigma=1/(1+\rho)$ is estimated to be less than one, 0.3. <Table 2>

We can consider energy's share of output, in the case of CES production form. If the price of energy is the marginal product, we can denote the factor share:

$f_E = P_E E/Y = (E/Y)^{-\rho}$

It is easy to understand that energy is a necessary (and scarce) input in production.($\sigma = 0.3$) If energy use converge to zero due to energy resource limitation, then the output also converge to zero.[11]

We can show relative income share of energy as follows:

$f_E / f_K = (P_E E)/(rK) = (P_E/r)(E/Y)$

If $\sigma<1$, a change(decrease) in energy price cause income share of resources to fall. In section 1, we saw decreasing trend of relative price of energy. This is consistent with theoretical and empirical results that substitution between energy and capital is so difficult, $\sigma<1$.

Jones(2002) explains the declining income share of resources as follow: He assume the case of $\sigma<1$. It makes the situation that as (E/Y) declines, energy share rises. But he focuses on the presence of energy-specific technological progress, A. He shows that if A is rising rapidly enough, (AE/Y) may be able to rise, and declining(or stable) income share might be possible:

$Y = \gamma[\delta K^{-\rho} + (1-\delta)(AE)^{-\rho}]^{-(\upsilon/\rho)}$
$f_E = P_E E/Y = (AE/Y)^{-\rho}$

Romer(2006) takes another approach. He admits that resources' shares have been decling (or stable) in spite of the fact that these factors become relatively scarce. He concludes that these phenomena comes from that fact that the elasticity of substitution is lager than one, $\sigma>1$.

3.2 Explaining Stable Factor Shares

Intuitively, we guess that 1) (E/Y) to fall, 2) (P_E /w) to rise, and 3) (f_E / f_L) to rise in Korea. But, real data shows that 1) (E/Y) to be stable, 2) (P_E /w) to fall, and 3) ($P_E E$ /Y) to be stable.

How can we explain these puzzling phenomena?

The answer is in the form of production function. That is, CD production function implies that the factor shares should be constant. But, we can generalize CD production function to CES function which relax the assumption of the unit elasticity of substitution(=1).

By estimating the aggregate CES production function in Korea, we know elasticity of substitution σ is less than one. In this case, a decrease in relative price of energy causes the income share to fall. So, we can explain that real data shows that 1) (E/Y) to be stable, 2) (P_E /w) to fall, and 3) f_E / f_L (or $P_E E$/Y) to be stable.

If we include the productivity(or knowledge) variable A into the aggregate production function, it can chage whole situation. If A is rising rapidly, it's possible for (AE/Y) to rise and nonincreasing income share of energy.

Especially, energy-specific technology progress could make energy from scarce factor into plentiful factor.(Jones, 2002)

[11] This concept of elasticity of substitution shows that as (E/Y) declines, energy share shows increasing trend.

IV. Conclusion

We used Solow growth model augmented with nonrenewable energy resources for discussing the importance of energy-specific technical progress. We can summarize the main findings in this paper as follows.

First, theoretically we could expect the energy intensity to decline in the process of economic growth in Korea. And this may cause the energy share to rise in the case of the elasticity of substitution less than one. But, real data do not correspond to this prediction. We guess that energy-specific technological progress could offset the above effects.

Second, theoretically we could also expect the energy use per capita to decline in the growth process. And this may cause the relative price of energy to rise of in the case of constant factor shares. But, real data also do not correspond to this prediction. We conclude the assumption that (E/L) is declining is false. This may also come from the fact that energy-specific technological progress occurred widely.

Third, according to simple calibration, the growth rate of (per capita) income is lower by 1.5 percentage points in Korea due to the limitation of energy resources. This figure is about five times larger than that of the U.S. This may be come from the fact that energy factor share in Korea is relatively large. From this, we can derive very important policy implication. If we are to reduce the magnitude of growth drag, we should decrease energy factor share. Once again, this can be accomplished by energy-specific technical progress in the case of elasticity of substitution less than 1 as in Korea.

In general, high (nominal) prices for resources have given firms an incentive to find new supply, while they cause consumers to find substitutes. They also induced innovators to develop new ways of production process.

Considering the limitation of resources is more suitable in endogeneous growth model than in neoclassical model. This is due to the fact that the possibility of sustainable growth depends on persistent flow of technical innovations.

From simple empirical analysis and limited infomation, we can carefully infer that, in the past in Korea, resource-specific innovation was performed widely. And, we expect that the growth of intellectual capital or energy-specific technical progress may offset the decreasing trend of social marginal product of physical capital in the near future.

Finally, we can use nested production function for nonseparable N-stage CES functional form. Perroni et al.(1995) apply this regular-flexible functional forms to cost function.

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<Appendix 1>

Simple Relationship between Energy and Growth(Weil, 2008)

Considering the notion of resource intensity, we can see what the growth of resource use, and the growth of GDP would be.

Resource intensity is defined as follows:

I=R/yL (y=Y/L)
I: resource intensity, R: resource consumption, y: per capita income, L: labor

Resource consumption is expressed:

R=IyL

We can denote the equation in terms of (percentage) growth rates:

$(\Delta R/R)^* = \Delta I/I + \Delta y/y + \Delta L/L$

This equation can be considered to imply long-run equilibrium relationship between variables.
We can perform simple calibration for Korean economy as follows:

$\Delta I/I = -1.7\%$
$\Delta y/y = 5\%$
$\Delta L/L = 1\%$
$(\Delta R/R)^* = 4.3\%$

But, real data for primary energy consumption in Korea shows ΔR/R=6.9%. This means energy intensity would increase in the near future.

<Appendix 2>

D. Romer(2006) regards natural resources, pollution and global warming totally as environmental problems. Weil(2008) examine the problem of global warming in terms of resource intensity. The resource of interest is emission of CO_2.

Using the same framework, we simply examine the problem of CO_2 emission in Korea.

The Kyoto Protocol require for developed countries to reduce greenhouse(CO_2) emissions by 7% below their 1990 levels by 2012.(Weil, 2008)

For Korea, CO_2 emissions in 2005 were 98.7% above the 1990 level. Therefore, reducing CO_2 emissions to 7% below the 1990 level by 2012 require decreasing CO_2 emissions at an average of 14% per year.

Suppose that per capita income growth is 3% and population growth is 1%.

From these, we can calculate the change of CO_2 intensity.

I=-0.14-0.03-0.01=-0.18

The CO_2 intensity of output should fall by 18% per year between 2005 and 2012.

<Appendix 3>

The environmental Kuznets curve is an upside-down U, curve showing the relationship between the economic growth and environmental pollution. In the stage of developing, countries do not care about pollution. But, as income grows, people are more and more rich enough to care about environmental pollution.

We estimated this (environmental) Kuznets curve using (cross-section) data for particulate(PARTI) of 16 local areas in Korea. Estimation results shows that the curve is well fitted for GRDP(mil. won) but, not for population(persons).

(i=Seoul, Busan,⋯, Jeju)

Dependent Variable: PARTI(ton)
Method: Least Squares
Sample: 1 16
Included observations: 16

	Coefficient	Std. Error	t-Statistic	Prob.
C	-11251.79	20491.35	-0.5491	0.5922
GRDP	0.002237	0.001051	2.12778	0.0531*
GRDP^2	-1.69E-11	7.75E-12	-2.181128	0.0481**

Dependent Variable: PARTI
Method: Least Squares
Sample: 1 16
Included observations: 15

	Coefficient	Std. Error	t-Statistic	Prob.
C	798.1212	21528.39	0.037073	0.971
POP	0.023811	0.015837	1.503466	0.1586
POP^2	-2.94E-09	1.87E-09	-1.575486	0.1411