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Structural Change and Green Growth in Korea, 1980~2020

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ABSTRACT

Greenhouse gas emission policy in Korea and elsewhere is based on emissions projections, a key element of which is the projected path of structural change from high productivity growth to low productivity growth economic sectors given sector specific labor productivity growth, emissions abatement across sectors and population growth. Thus, it is important to model the source of the structural change to forecast emissions correctly. Using data for the Korean economy, this study constructs and quantitatively evaluates a model of structural change and green growth to generate policy implications for Korea and the international greenhouse gas debate.

한국 및 여타 국가들의 온실가스 배출 관련 정책들은 기본적으로 배출 전망치를 바탕으로 수립되는바, 노동생산성이 높은 증가세를 보이는 부문에서 낮은 증가세를 보이는 부문으로 진행되는 구조적 변화–산업별 노동생산성 증가, 산업 전반의 배출 저감, 인구 증가를 고려한–의 예상경로가 핵심 요소가 된다. 따라서 구조적 변화의 원인을 모델화하는 작업은 배출량의 정확한 예측을 위해서 중요하다. 본 보고서는 한국경제 데이터를 활용하여 구조적 변화와 녹색성장 모델을 수립 및 평가함으로써 한국과 국제사회의 온실가스 담론을 위한 정책 함의성을 도출한다.

I. Motivation

Greenhouse gas emission policy in Korea and elsewhere is based on emissions projections, a key element of which is the projected path of structural change from high productivity growth to low productivity growth economic sectors given sector specific labor productivity growth, emissions abatement across sectors and population growth. Thus, it is important to model the source of the structural change to forecast emissions correctly. Using data for the Korean economy, I construct and quantitatively evaluate a model of structural change and green growth to generate policy implications for Korea and the international greenhouse gas debate.

Korea's experience is very instructive both for the reasons that Korea's GDP and aggregate greenhouse gas emissions have increased a lot over the past 30 years, and that its experience constitutes a link between the emissions scenarios of developed economies and developing economies. In particular, this paper will argue that Korea's experience sits in the middle of rich and poor countries, and its experience of the *de-coupling* between emissions and GDP growth is instructive for the international greenhouse gas debate.

A recent OECD report by Jones and Yoo (2010) on Korea's emissions experience and policy summarizes the situation by,

"Korea's greenhouse gas emissions almost doubled between 1990 and 2005, the highest growth rate in the OECD area. Korea recently set a target of reducing emissions by 30% by 2020 relative to a "business as usual" baseline, implying a 4% cut from the 2005 level. Achieving this objective in a cost-effective manner requires moving from a strategy based on voluntary commitments by firms to market-based instruments. The priority is to establish a comprehensive cap-and-trade scheme, supplemented, if necessary, by carbon taxes in areas not covered by trading. Achieving a significant cut in emissions requires a shift from energy-intensive industries to low-carbon ones. Korea is strongly committed to promoting green growth through its Five-Year Plan, which envisages spending 2% of GDP per year through 2013."

This OECD summary for Korea represents the typical view in policy circles that the de-coupling of GDP growth and emissions growth is achieved through an acceleration of abatement of greenhouse gases through various active policies such as voluntary commitments, cap and trade systems and carbon taxes. Jones and Yoo

(2010) conclude by targeting the key role played by expenditures on developing green technologies and warn of the risks inherent in industrial policy.

The current paper takes an alternative view about the mechanics of achieving the policy targets of the Korea greenhouse gas policy. I will argue that an important component of the de-coupling phenomenon has not received the required attention of the policy making debate. At the center of this analysis is the view that along the growth process there are structural shifts in the composition of the economy from high productivity growth to low productivity growth economic sectors which are key source of de-coupling.

While such a view has been recognized before, a limit to the discussion has been the *quantitative assessment* of the effect of such compositional shifts.[1] Specifically, policy discussions have lacked a *theoretical framework* which models the underlying source of such shifts which can be used to conduct a *counterfactual quantitative analysis* of changes to emissions when such structural shifts do and do not occur. Only then would the policy maker be able to quantify the role of structural change on emissions and the de-coupling process.

This paper develops and applies a new theoretical framework designed to achieve this purpose. I focus on the compositional change in production and consumption of goods versus services in an economy to highlight the role of structural change into the service sector in the de-coupling process. This framework is applied to data on the Korean economy to assess how the transition of the Korean economy into the service sector has accounted for the changes in emissions in the past. Using counterfactual analysis, the model is then used to account for the role of such transition in generating a de-coupling of emissions and GDP growth for the Korean economy going into the future.

Policy discussions have mentioned other reasons for changes in emission trends. One already mentioned above is gas emissions abatement efforts. Another is the slowdown of productivity growth as Korea becomes a frontier technology economy. Yet another is the slowdown of population growth. The analysis is able to distinguish between all these *trends* and identify the quantitative role of each trend along with the role of structural transformation into the service sector economy.

The paper focuses the aggregate policy analysis on the Korean greenhouse gas policy target for 2020, which aims to lower aggregate emissions by 4% of the 2005 level. The conclusions are:

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1 See Grossman and Krueger (1995), Janicke, Binder and Monch (1997), Vincent and Panayotou (1997), and Pascala and Socolow (2004) among others.

(i) Korea is roughly on target to meet this level by 2020 as long as structural change into the service sector proceeds as expected, and abatement and productivity growth follow their historical trends.
(ii) In the absence of structural change, aggregate emissions will become substantially above target.

These insights are new to the greenhouse gas reduction policy debate both in Korea and the international context. They provide a fresh perspective in the policy debate of this issue on which Korea and its experience can take a leading opinion making role.

While the analysis incorporates *trends* in abatement, productivity growth, population growth and structural change, an accurate forecast of emissions is not a key objective of the paper. This is because changes in greenhouse gas policy may affect the trends in these variables over time into 2020. Instead, the key policy message of the paper is that incorporating features of structural change is important in making BAU (business as usual) emissions calculations against which policy achievements can be judged. I conclude that ignoring these features can lead to an exaggeration in policy success in achieving emission abatement goals.

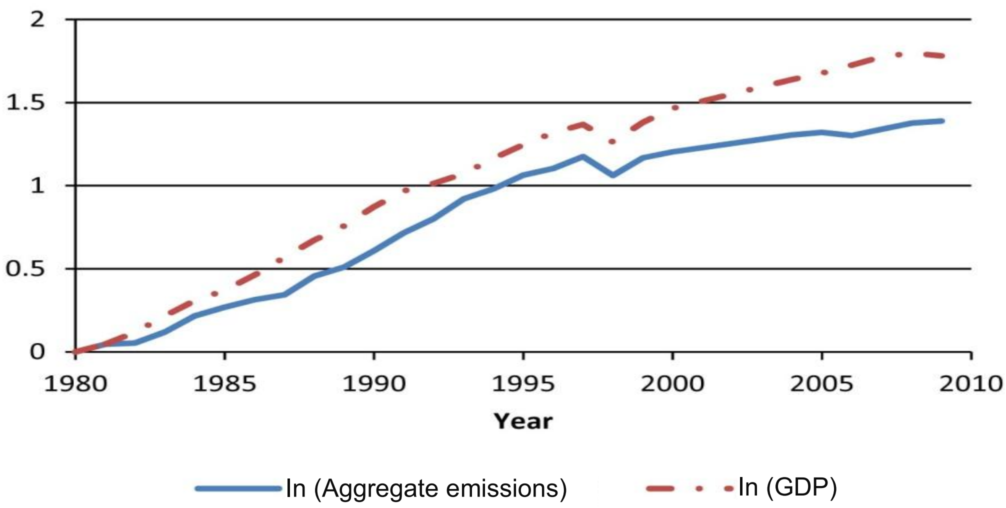
This paper is structured as follows. In Section II, the Korean experience is reviewed, and the paper will argue its relevance for the international policy making agenda regarding greenhouse gas emissions. In Section III, the theoretical framework adopted is developed and discussed. Section IV conducts the quantitative analysis using the theoretical framework. Section V will discuss counterfactual outcomes and policy implications of the results. The last Section concludes with directions for future research.

II. The Korean Experience & Its International Relevance

[Figure 1] shows the log of aggregate emissions and log of GDP between 1980~2009 for Korea.[2] Both series are normalized to be zero in 1980. Emissions grew by an average growth rate of 4.86% annually between 1980~2009. Emissions per capita grew by an average rate of 4.03% annually between 1980~2009, and population grew by an average growth rate of 0.083% annually. However the trend in emissions has clearly decelerated. During the first part of the sample period

2 All data sources used in the paper are discussed in the Appendix.

[Figure 1] Log (Aggregate Emission) vs. Log (GDP), Korea 1980~2009



1980~1995, emissions per capita grew at an average growth rate of 6.15% annually, but the growth rate was only 1.82% annually between 1995~2009.

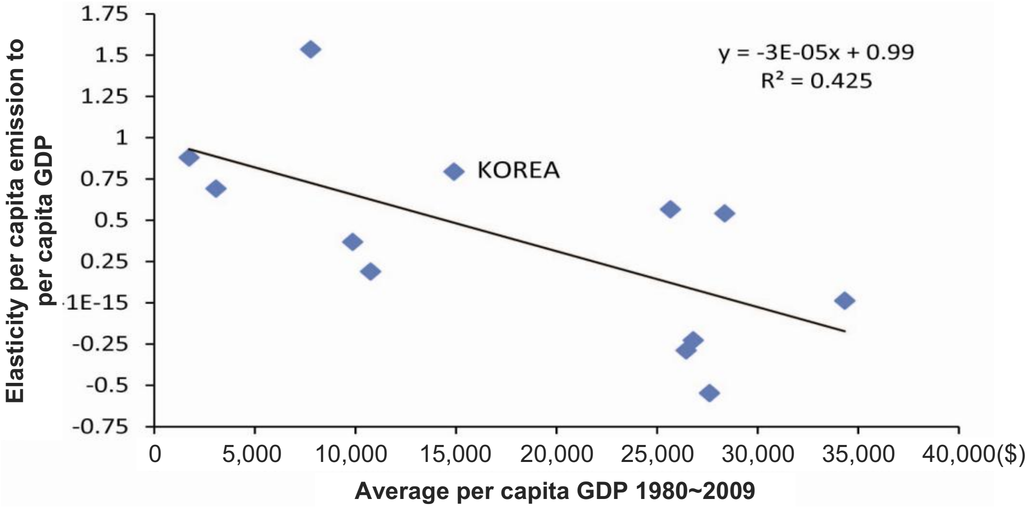
GDP grew at a larger average growth rate of 5.45% annually between 1980~2009. Again, the trend in GDP growth has clearly decelerated. During the first part of the sample period 1980~1995, the average growth rate was 7.45% annually, but the growth rate was lower at 3.35% annually between 1995~2009. Since GDP grew faster, the ratio of aggregate emission to GDP has been reduced over the sample period, by a factor of 0.68 (a decline of 32%).

The Korean greenhouse gas policy target for 2020, aims to lower aggregate emissions by 4% of the 2005 level. In 2009, aggregate emissions were already 6.95% above the 2005 level implying the aggregate emission was 10.95% above the 2020 target. Thus, aggregate emissions would need to fall for the policy target to be approached.

[Figure 2] shows the relationship between average per capita GDP during 1980~2009 and the elasticity of aggregate emissions to changes in aggregate GDP during this time period for the major global economies.[3] These economies represent the 12 largest economies in terms of real GDP in 2011 (based on purchasing power parity

3 When conducting comparisons between economies, it is useful to normalize the emissions and GDP per capita to filter away the role of population size on emissions and GDP. The analysis here is conducted for 12 major economies. These countries are the US, Japan, Germany, France, UK, Italy, Korea, Mexico, and the BRICs countries (Brazil, Russia, India, China).

[Figure 2] Per Capita GDP vs. Elasticity of Aggregate Emissions to GDP,
12 Major Economies



calculations of the IMF), and they collectively represent 68% of world GDP in 2011. This elasticity is defined as $\frac{d \text{ in } Emission}{d \text{ in } GDP}$. What is striking is the well documented fact that the positive response of emissions to GDP gets weaker as countries get richer and approaches zero (and is sometimes negative) for the richest countries. This is the phenomenon of *emissions and GDP de-coupling* which is a focus of this paper. Korea's experience sits in the middle of these observations and motivates an example straddling between the experience of rich and poor major economies. A simple linear regression of the elasticity of aggregate emissions to GDP on per capita income in [Figure 2] yields a R^2= 0.425.

There are several reasons why emissions and GDP growth can become de-coupled. One reason is slower population growth. Another is slower growth in labor productivity. In this paper, emphasis is placed on the structural change from economic activities (both in terms of production and consumption) with high growth to activities with low growth in emissions. In particular, I focus on the transition from non-service sector activities to service sector activities since this is the major dimension of change in terms of consumption and employment share for the developed and developing economies where we observe the phenomenon of emissions de-coupling. I control for changes in population and allow productivity growth to decelerate at the rate observed during the data sample period, when conducting my analyses.

The fact that Korea's experience sits in the middle of the major rich and poor country emission experiences is important for global greenhouse gas emission debates in these times. The EIA (2011) estimates that non-OECD carbon dioxide emissions exceeded OECD emissions around 2005. By 2025, it expects non-OECD emissions to reach a level which is double that of OECD emissions. Thus, the issue of greenhouse gas emissions is rapidly shifting from a developed economy concern to a developing economy concern, at the middle of which Korea's experience can facilitate the global policy debate.[4]

III. A Model of Structural Change and Green Growth

1. Structural Change & Emissions per Capita

Aggregate greenhouse gas emissions can be sourced from production and consumption in the service sector and non-service sector. Let L_t denote the total population, $n_{s,t}$ the workforce share in the service sector, $\{A_{s,t}, A_{ns,t}\}$ the labor productivity in the service and non-service sectors respectively, $\{z_{s,t}, z_{ns,t}\}$ the emissions through production and consumption per unit output of service and non-service products respectively. Then, aggregate emissions is defined as

$$E_t \equiv L_t(z_{s,t}A_{s,t}\, n_{s,t} + z_{ns,t}A_{ns,t}(1 - n_{s,t})). \tag{1}$$

Aggregate emissions can change due to a number of explanations here. One is through population L_t. Another is through emissions per unit output through $z_{s,t}, z_{ns,t}$, which we think of as falling over time through abatement efforts. Another explanation is labor productivity per worker $A_{s,t}, A_{ns,t}$ which we expect to increase over time.

Finally, we can consider structural change of the production and consumption decisions of households in the economy toward the service sector, represented as an increase in $n_{s,t}$ over time: If the growth rate of emissions per worker are lower in the service sector, we can expect structural change to be a force for lowering the growth rate of emissions over time. The analysis focuses on the transformation

4 [Appendix Figure 1] further shows the relationship between per capita GDP and per capita emissions for the major economies. Again, the per capita GDP and per capita emissions experience of Korea since 1980 fits squarely in between these countries.

between two sectors, non-service to service, since this is the key quantitatively relevant dimension of change we observe in developed and developing economies where we see the de-coupling phenomenon.

Define the emissions per unit output as $z_{s,t} = \lambda_s \theta^t, z_{ns,t} = \lambda_{ns} \theta^t$, and define the labor productivity per worker $A_{s,t} = \phi_s^t \phi^{t^2}, A_{s,t} = \phi_{ns}^t \phi^{t^2}$ as

$$
\begin{aligned}
&z_{s,t} A_{s,t} \equiv \lambda_s \theta^t \phi_s^t \phi^{t^2}, \\
&z_{ns,t} A_{ns,t} \equiv \lambda_{ns} \theta^t \phi_{ns}^t \phi^{t^2}.
\end{aligned} \tag{2}
$$

λ_s, λ_{ns} are sector specific constants which denote emissions per unit output in the initial period when $t = 0$. $\theta < 1$ is the common emissions abatement factor across sectors which is a combination of lower carbon intensity of energy supply and lower energy intensity of economic activity. Since greenhouse gas emissions are the result of production in a small number of intermediary goods sectors (electricity, gas and water supply; air transportation; water transportation; land transportation etc.), it is reasonable to assume abatement is occurring at a common rate across service and non-service sectors.[5]

$\phi_s \phi^t, \phi_{ns} \phi^t$ are the sector specific growth factors of service and non-service labor productivity respectively. These growth factors are allowed to vary over time through the ϕ term which is common to both sectors. This is included to allow for the aggregate productivity to decelerate overtime as an economy such as Korea's approaches the technology frontier of rich economies. A potential source of emissions and GDP de-coupling is the deceleration of productivity growth over time which is incorporated in the analysis in this way.[6]

Note that here the measurement of production units across the two sectors has also been normalized such that for the initial period $t = 0$, labor productivity is the same in both sectors (that is $A_{s,0} = A_{ns,0} = 1$). This is something we can do without loss of generality for the quantitative analysis.

Then the log per capita emissions $\ln \frac{E_t}{L_t} = \ln e_t$ can be expressed as

$$
\ln e_t = \ln \lambda_s + t \ln \theta \phi_s + t^2 \ln \phi + \ln \left[n_{s,t} + \frac{\lambda_{ns}}{\lambda_s} \left(\frac{\phi_{ns}}{\phi_s} \right)^t (1 - n_{s,t}) \right]. \tag{3}
$$

5 See for instance OECD (2011).

6 Although emissions rates differ within each sector, what the analysis highlights is the average emission between non-service and service sectors arising from their differences in productivity growth.

The ratio $\frac{\lambda_{ns}}{\lambda_s}$ determines the gap in emissions per worker at the initial period. Note that no presumption is made here that the initial emissions per worker is higher or lower between the two sectors. The higher productivity growth of the non-service sector means $\left(\frac{\phi_{ns}}{\phi_s}\right)^t > 1$ grows over time such that the emissions gap between service and non-service production changes over time. Thus, a key element of the change in emissions per capita over time is the structural change through the change in $n_{s,t}$ over time.

Following the existing empirical literature on structural change and economic growth, I model structural change as proceeding in a way such that the ratio $\frac{1-n_{s,t}}{n_{s,t}}$ grows at a constant factor given by $\gamma < 1$.[7] This implies that the log of $\frac{1-n_{s,t}}{n_{s,t}}$, the variable $\ln\frac{1-n_{s,t}}{n_{s,t}}$, has fallen linearly in the data which we confirm is indeed true in the quantitative analysis later. Substantively, this assumption will be used in the quantitative analysis to make predictions to the service sector employment share going toward 2020. Using this specification, the service sector employment share is predicted to grow from 68% observed in 2007 to 80% by 2020.[8]

The analysis will also relate this growth factor γ to the underlying difference in productivity growth between the service and non-service sectors in the section Ⅲ.3. Thus, I model structural change of the laborforce across the two sectors as

$$\frac{1-n_{s,t}}{n_{s,t}} = \alpha\gamma^t \Rightarrow n_{s,t} = \frac{1}{1+\alpha\gamma^t}, 1 - n_{s,t} = \frac{\alpha\gamma^t}{1+\alpha\gamma^t}. \tag{4}$$

Using these expressions for $n_{s,t}$ and $1 - n_{s,t}$, we can express the log aggregate emissions per capita $\ln e_t$ as

$$\ln e_t = \ln\lambda_s + t\ln\theta\phi_s + t^2\ln\phi + \ln\left[\frac{1+\frac{\lambda_{ns}}{\lambda_s}\alpha\left(\frac{\phi_{ns}}{\phi_s}\gamma\right)^t}{1+\alpha\gamma^t}\right]. \tag{5}$$

Using a second order Taylor approximation of the term in square brackets (derivation is in the Appendix), we can express the log emissions per capita as a quadratic function of time *t* as

7 Ngai and Pissarides (2007) provide a canonical analysis of strucutural change. See also the references therein.

8 Note however that very long term extrapolations may not be practical under the specification.

$$\ln e_t \simeq \left[\ln \lambda_s + \ln\left[\frac{1+\frac{\lambda_{ns}}{\lambda_s}\alpha}{1+\alpha}\right]\right] \tag{6}$$

$$+ t\left[\ln \theta\phi_s + \left[\frac{\lambda_{ns}}{\lambda_s}\alpha\frac{\ln\frac{\phi_{ns}}{\phi_s}\gamma}{1+\frac{\lambda_{ns}}{\lambda_s}\alpha} - \alpha\frac{\ln\gamma}{1+\alpha}\right]\right]$$

$$+ t^2\left[\ln\phi + \frac{1}{2}\left[\frac{\lambda_{ns}}{\lambda_s}\alpha\left[\frac{\ln\frac{\phi_{ns}}{\phi_s}\gamma}{1+\frac{\lambda_{ns}}{\lambda_s}\alpha}\right]^2 - \alpha\left[\frac{\ln\gamma}{1+\alpha}\right]^2\right]\right].$$

This specification will be used in the quantitative analysis.

2. Structural Change & GDP per Capita

The aggregate real GDP is given by

$$Y_t \equiv L_t \pi(A_{s,t}n_{s,t} + A_{ns,t}(1-n_{s,t})), \tag{7}$$

where π is a constant which scales the real GDP to match the units of measurement. Real GDP per capita is calculated using constant relative prices as assumed here (constant relative price of one).

The log of aggregate per capita real GDP y_t is then given by

$$\ln y_t \equiv \ln\pi\,[A_{s,t}n_{s,t} + A_{ns,t}(1-n_{s,t})] \tag{8}$$

$$= \ln\pi + t\ln\phi_s + t^2\ln\phi + \ln\left[\frac{1+\alpha\left(\frac{\phi_{ns}}{\phi_s}\gamma\right)^t}{1+\alpha\gamma^t}\right].$$

Using a second order Taylor approximation of the term in square brackets (derivation is in the Appendix), we can express the log GDP per capita as a quadratic function of time *t* as

$$\ln y_t \simeq [\ln\pi] \tag{9}$$

$$+ t\left[\ln\phi_s + \frac{\alpha}{1+\alpha}\ln\frac{\phi_{ns}}{\phi_s}\right]$$

$$+ t^2\left[\ln\phi + \frac{\alpha}{[1+\alpha]^2}\left[\left(\ln\frac{\phi_{ns}}{\phi_s}\right)^2 + 2\ln\frac{\phi_{ns}}{\phi_s}\ln\gamma\right]\right].$$

This specification will be used in the quantitative analysis.

3. Structural Change & Productivity Growth

In this section, I use standard economic theory to construct a link between the growth factor γ and the growth factor $\frac{\phi_{ns}}{\phi_s}$ as implied by canonical analyses of structural change to further pin down parameters of the quantitative analysis. Let $\varepsilon \geq 0$ define the elasticity of substitution in people's preferences between service sector products and non-service sector products. Then, utility optimization by households implies the marginal rate of substitution between service and non service goods is equal to the relative price between non-serivce and service sector products

$$\tilde{\alpha}\left(\frac{A_{ns,t}n_{ns,t}}{A_{s,t}n_{s,t}}\right)^{-\frac{1}{\varepsilon}} = \frac{p_{ns,t}}{p_{s,t}} \tag{10}$$

where $p_{ns,t}, p_{s,t}$ denote the nominal prices of each sector's products. The value-added per worker in each sector is given by $p_{ns,t}A_{ns,t}, p_{s,t}A_{s,t}$. Free labor mobility implies equalization of labor productivity (in terms of value added) which implies

$$p_{ns,t}A_{ns,t} = p_{s,t}A_{s,t}. \tag{11}$$

Note here the relative price in the initial period $t = 0$ is $p_{ns,t} \,/\, p_{s,t} = 1$, which is consistent with the relative price assumption we used for the calculation of real GDP in equation (7). Using these two equations, we can derive the ratio of non-service to service sector employment shares as

$$\tilde{\alpha}\left(\left(\frac{\phi_{ns}}{\phi_s}\right)^t \frac{n_{ns,t}}{n_{s,t}}\right)^{-\frac{1}{\varepsilon}} = \left(\frac{\phi_{ns}}{\phi_s}\right)^{-t} \Rightarrow \frac{1-n_{s,t}}{n_{s,t}} = \tilde{\alpha}^{\varepsilon}\left(\frac{\phi_{ns}}{\phi_s}\right)^{(\varepsilon-1)t}.$$

After defining $\alpha \equiv \tilde{\alpha}^{\varepsilon}$, this expression, when compared to equation (4), implies that

$$\ln\frac{\phi_{ns}}{\phi_s} = \frac{1}{\varepsilon-1}\ln\gamma. \tag{12}$$

This is an equation which links the growth factor $\frac{\phi_{ns}}{\phi_s}$ with the growth factor γ.

Typically, we think of $\varepsilon < 1$, such that the non-service sector (which is declining in terms of laborforce share) is a sector with higher productivity growth such that $\frac{\phi_{ns}}{\phi_s} > 1$. This specification will be used in the quantitative analysis.

IV. Quantitative Analysis

In this section, we regress the log of the non-service sector to service sector employment share on a linear time trend and constant and the log of emissions per capita and the log of GDP per capita on a quadratic time trend and constant, and interpret the coefficients from these regressions as functions of the underlying variables of the structural model. This interpretation is then used to infer the values of the structural variables from these coefficients. In the next section, we use these parameter values to conduct a counterfactual analysis of emissions changes in Korea to determine the role of various factors including structural change in accounting for emissions dynamics.

1. Regression Analysis

From equation (4), after taking logs, the OLS estimation of

$$\ln \frac{1-n_{s,t}}{n_{s,t}} = \ln \alpha + t \ln \gamma + \epsilon_{n,t} \tag{13}$$

identifies the parameter estimates for $\ln\alpha$ and $\ln\gamma$. These estimates are reported in <Table 1>. All coefficients are tightly estimated and the R^2 is high.

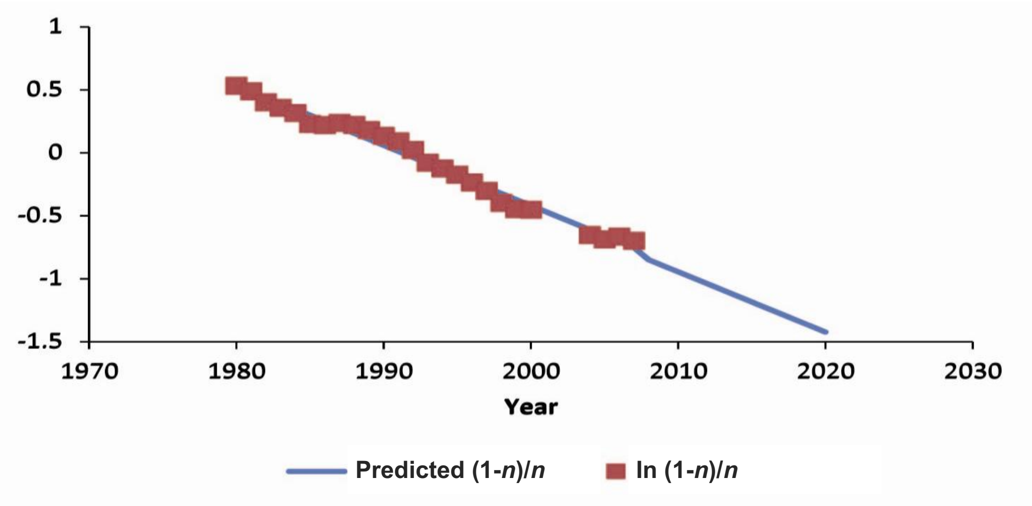
[Figure 3] compares the actual path of $\ln\frac{1-n_{s,t}}{n_{s,t}}$ with its predicted path using the estimates in <Table 1>. The linear predicted path does a remarkable job of fitting the actual trend in this ratio. This is consistent with other studies of structural transition which predict this kind of linear change in the log of ratio of non-service to service sector workers. Predictions are taken forward to 2020 using the estimated coefficients for $\ln\alpha$ and $\ln\gamma$.

<Table 1> Estimates of Laborforce Share Equation

Parameter	lnα	lnγ
Value	0.539	-0.048
Standard error	0.019	0.001

Note: R^2 = 0.985.

[Figure 3] Log (Non-Service/Service) Labor Share, Actual vs. Predicted



From equation (6), the estimation of the log emissions per capita on a quadratic time trend is

$$\ln e_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \epsilon_{e,t}, \tag{14}$$

which is estimated using simple OLS. The coefficients from this estimation will identify

$$\beta_0 = \ln \lambda_s + \ln\left[\frac{1+\frac{\lambda_{ns}}{\lambda_s}\alpha}{1+\alpha}\right], \tag{15}$$

$$\beta_1 = \ln \theta \phi_s + \left[\frac{\lambda_{ns}}{\lambda_s}\alpha \frac{\ln\frac{\phi_{ns}}{\phi_s}\gamma}{1+\frac{\lambda_{ns}}{\lambda_s}\alpha} - \alpha \frac{\ln\gamma}{1+\alpha}\right],$$

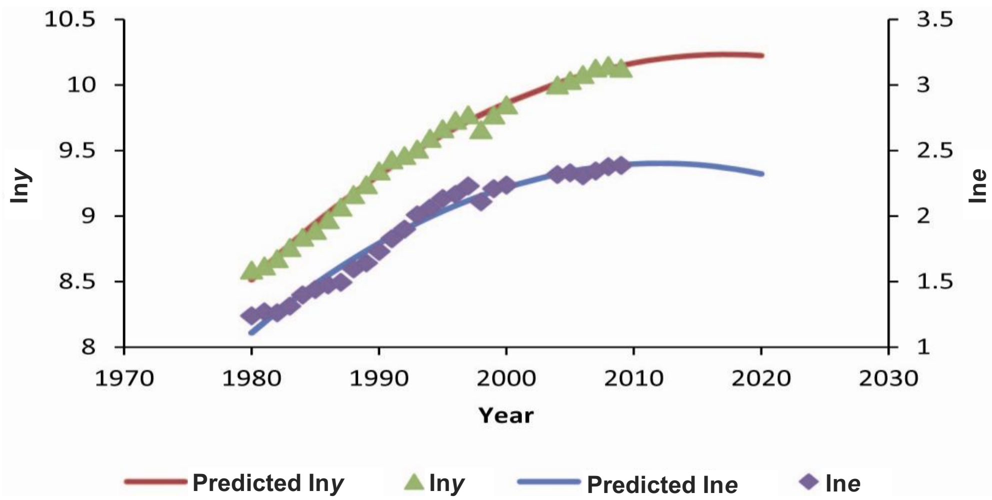
$$\beta_2 = \ln\phi + \frac{1}{2}\alpha\left[\frac{\lambda_{ns}}{\lambda_s}\left[\frac{\ln\frac{\phi_{ns}}{\phi_s}\gamma}{1+\frac{\lambda_{ns}}{\lambda_s}\alpha}\right]^2 - \left[\frac{\ln\gamma}{1+\alpha}\right]^2\right].$$

<Table 2> Estimates of Emissions per Capita Equation

Parameter	β_0	β_1	β_2
Value	1.110	0.081	-0.0013
Standard error	0.035	0.006	0.0002

Note : $R^2 = 0.975$.

[Figure 4] Log per Capita Emissions (ln*e*) and Log per Capita GDP (ln*y*), Actual vs. Predicted



These estimates are reported in <Table 2>. All coefficients are tightly estimated and the R^2 is high.

[Figure 4] compares the actual paths of $\ln e_t$ with their predicted path using the estimates of <Table 2>. Predictions from the quadratic time trend path are taken forward to 2020. The predicted path follows the actual path very closely, and the concave path of per capita emissions is expected to continue into 2020.

From equation (9), the estimation of the log GDP per capita on a quadratic time trend is

$$\ln y_t = \eta_0 + \eta_1 t + \eta_2 t^2 + \epsilon_{y,t}, \tag{16}$$

which is estimated by simple OLS. The coefficients of this estimation identify

$$\eta_0 = \ln \pi, \tag{17}$$
$$\eta_1 = \ln \phi_s + \frac{\alpha}{1+\alpha} \ln \frac{\phi_{ns}}{\phi_s},$$
$$\eta_2 = \ln \phi + \frac{1}{2} \frac{\alpha}{[1+\alpha]^2} \left[\left(\ln \frac{\phi_{ns}}{\phi_s} \right)^2 - 2 \ln \frac{\phi_{ns}}{\phi_s} \ln \gamma \right].$$

These estimates are reported in <Table 3>. Again, all coefficients are tightly estimated and the R^2 is remarkably high.

[Figure 4] also compares the actual paths of $\ln y_t$ with their predicted path using the estimates of <Table 3>. Predictions from the quadratic time trend path are taken forward to 2020. The predicted path follows the actual path very closely, and the concave path of per capita GDP is expected to continue into 2020.

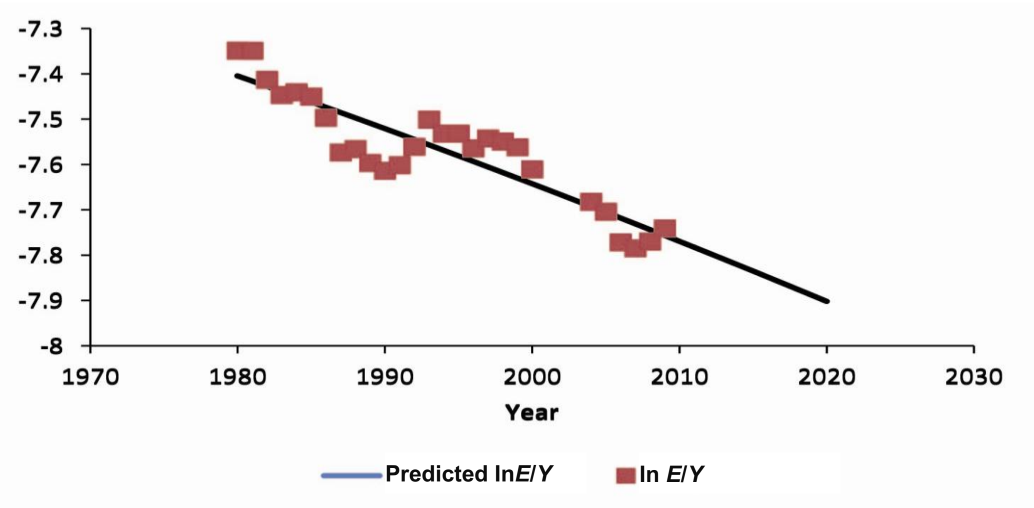
[Figure 5] compares the log of the ratio of aggregate emissions to GDP, $\ln \frac{E_t}{Y_t}$ since 1980 with its predicted path. The 32% decline in the $\frac{E_t}{Y_t}$ ratio has occurred

<Table 3> Estimates of GDP per Capita Equation

Parameter	η_0	η_1	η_2
Value	8.515	0.092	-0.0012
Standard error	0.022	0.004	0.0001

Note: $R^2 = 0.993$.

[Figure 5] Log (Emission/GDP), Actual vs. Predicted



along a linear path for the log of this ratio $\ln\frac{E_t}{Y_t}$, such that we can see the rate of decline has been close to constant.

This linear path is being matched well by the predicted path of $\ln\frac{E_t}{Y_t}$, which is predicted to continue into 2020 at the estimated coefficients. Here, the predicted $\ln\frac{E_t}{Y_t}$ is constructed using the predicted $\ln e_t$, $\ln y_t$ from their quadratic time trend paths (discussed above) given that $\ln\frac{E_t}{Y_t} = \ln\frac{e_t}{y_t} \equiv \ln e_t - \ln y_t$.

2. Technology Parameters

Recall that we typically think of the elasticity of substitution parameter $\varepsilon < 1$, such that the non-service sector which is declining in terms of labor share is a sector with higher productivity growth such that $\frac{\phi_{ns}}{\phi_s} > 1$. For the elasticity of substitution between service and non-service goods, I will use the typical parameter of $\varepsilon = 0.5$. See for instance Ngai and Pissarides (2007), Acemoglu and Guerrieri (2008) and Buera and Kaboski (2009) who use similar elasticity parameters. Then from equation (12), we can determine $\frac{\phi_{ns}}{\phi_s}$ as a function of γ.

Given ε and equation (12), the eight estimates in <Tables 1>~<Tables 3>, and the six equations in (15) and (17), we can calculate the ten technology parameters of the model.[9] The point estimates for the ten technology parameters are reported in <Table 4>. Given the tight coefficient estimates, and the high R^2 associated with the estimations of regressions above, we can be confident of the implied point estimates reported here.

The estimate for growth factor γ means that the ratio $\frac{1-n_{s,t}}{n_{s,t}}$ has been falling at a rate of 4.7% over the past 30 years. From equation (12), the estimate for relative productivity growth factor $\frac{\phi_{ns}}{\phi_s}$=1.10, means that productivity growth in the non-service sector is 10% higher in the non-service sector than service sector over the

<Table 4> Implied Point Estimates

Parameter	ε	π	α	γ	ϕ_s	ϕ_{ns}	ϕ	λ_s	λ_{ns}	θ
Value	0.5	4998	1.714	0.953	1.032	1.136	0.999	2.45	3.38	0.985

9 This inference is explained in detail in the Appendix.

past 30 years.[10]

Due to the estimate of $\phi < 1$, productivity growth has slowed down over time, such that in the non-service sector productivity growth is 13.6% annually in 1980, and only 5.8% annually in 2009. This captures the well known feature that productivity growth in sectors of the Korean economy has been decelerating since 1980.

The estimate for the initial relative emission parameter $\frac{\lambda_{ns}}{\lambda_s} = 1.38$ means that in 1980, the production of output per worker in the non-service sector led to emissions (through both production and consumption) that are 38% greater than the production per worker in the service sector. Since then, labor productivity has gone up faster in the non-service sector, so this gap has widened further. This parameter is likely to be country specific (given the country specific industrial mix of non-service and service sectors), and appears to be a reasonable value.

Finally, the estimates indicate abatement has been a feature of production over the past 30 years. From the point estimate for the emissions growth factor θ, we can infer that emission abatement has occurred at a rate of 1.5% annually. This rate is very similar to the world average rate of abatement at 2.0% recently forecasted by the EIA (2011) in their *International Energy Outlook* for the 2008~2035 period. Moreover, it falls well within the range of forecast abatement rate calculations of 0.9% and 3.0% for various geographic regions reported by the EIA (2011).

The objective of this research is to use these parameter values to understand the sources of the de-coupling effect, which is conducted in the following section on counterfactual analysis.

V. Counterfactual Analysis & Policy Implications

1. Counterfactual Analysis

Using the point estimates reported in <Table 4>, we can conduct various forms of counterfactual analyses to quantitatively distinguish between various sources of changes in greenhouse gas emissions. There are several sources of emission change

10 Using a lower elasticity of $\varepsilon = 0.25$ would imply that the productivity growth gap would be lower at $\frac{\phi_{ns}}{\phi_s} = 1.06$.

permitted through the analysis:

1. Structural change from non-service production and consumption to service consumption and production
2. Trend productivity growth in service and non-service sectors, which leads to more production and consumption of these products
3. Trend abatement efforts to reduce emissions per unit of production in service and non-service sectors respectively
4. Trend population change

We are able to decompose the sources of emissions change through the framework we have developed here.

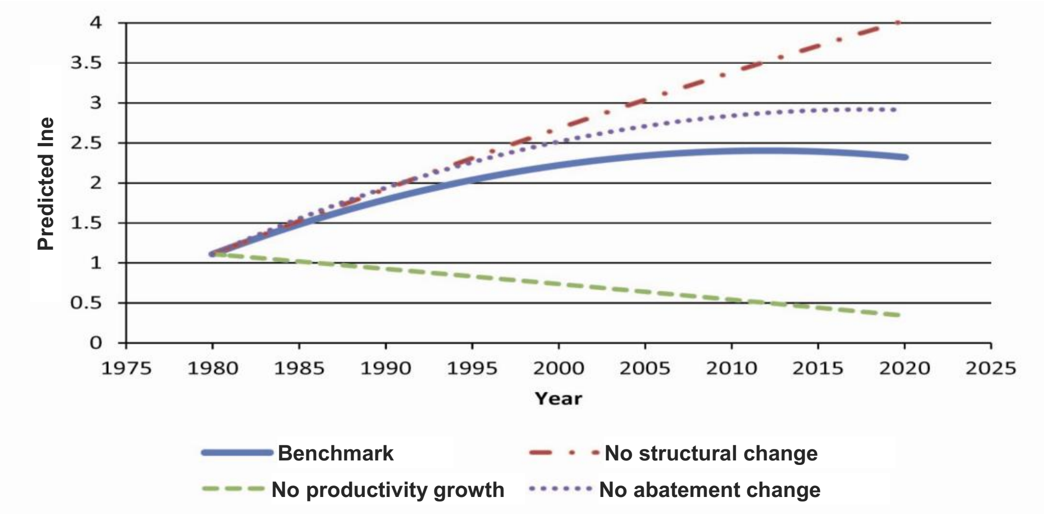
1) Implications for per Capita Emissions

First begin the analysis by looking at the implications for the log of emissions per capita $\ln e_t$. For the counterfactual scenario with no structural change, I calculate the predicted path of per capita emissions after setting the growth factor $\gamma = 1$, and keeping all other parameters as in <Table 4>. For the counterfactual scenario with no productivity growth, I calculate the predicted path of per capita emissions after setting the growth factors $\phi_s = \phi_{ns} = \phi = 1$. For the counterfactual scenario with no emission abatement, I calculate the predicted path of per capita emissions after setting the abatement factor $\theta = 1$.

[Figure 6] shows the predicted change in emissions per capita under various counterfactual scenarios. The Figure shows that structural change is the key component driving the de-coupling process. In the absence of structural change into the service sector, per capita emissions in 2009 would have been 152% higher than what they actually were. In the absence of trend productivity growth in both the service and non-service sectors, per capita emissions in 2009 would have been 84% lower than what they actually were.

In the absence of trend emissions abatement in both the service and non-service sectors, per capita emissions in 2009 would have been 53% higher than what they actually were. However, this does not necessarily imply that structural change is a more important factor in leads to emissions de-coupling than abatement. Changes in policy can alter the trend path of emissions abatement and contribute to a larger extent to the emission reduction, and we can use the current analysis to provide a counterfactual emissions scenario in the absence of such policy changes.

[Figure 6] Log (Emission per Capita), Benchmark Predicted vs. Counterfactual Predicted



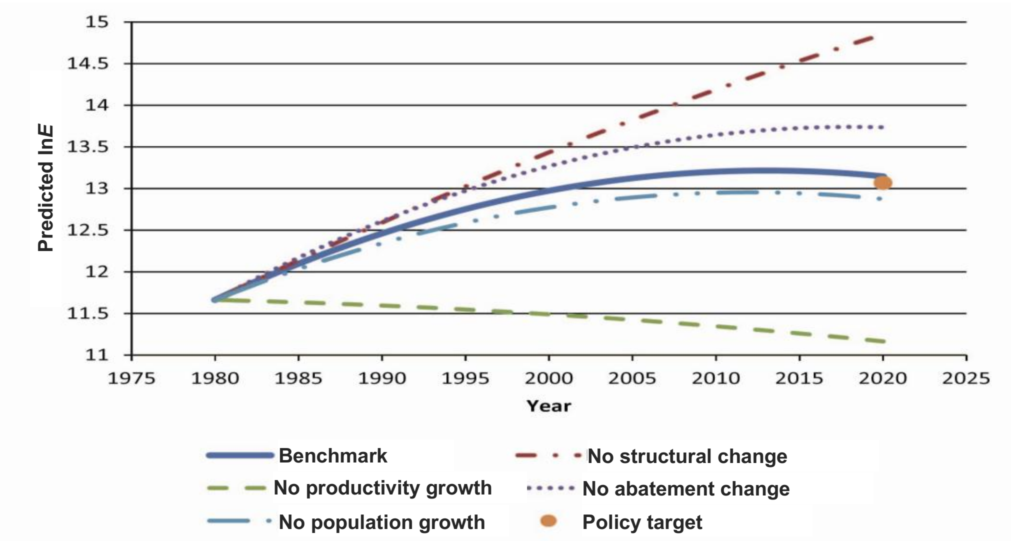
2) Implications for Aggregate Emissions

Now consider the implications for the log of aggregate emissions $\ln E_t$. The counterfactual scenarios under various cases are constructed similarly as the case with emissions per capita. In addition, population forecasts are conducted into 2020 by modelling the log of the Korean population as a quadratic function of time.[11] A potential source of de-coupling is the deceleration of population growth over time which is incorporated in the analysis in this way. Furthermore, for the counterfactual scenario with no population growth, I calculate the predicted path of aggregate emissions holding the population constant at its 1980 level.

[Figure 7] shows the predicted change in aggregate emissions under various counterfactual scenarios. Again, the Figure shows that structural change is an important component driving the de-coupling process for aggregate emissions. In the absence of structural change into the service sector, aggregate emissions in 2009 would have been 152% higher than what they actually were. In the absence of trend productivity growth in both the service and non-service sectors, aggregate emissions in 2009 would have been 84% lower than what they actually were. In the absence of trend emissions abatement in both the service and non-service sectors, aggregate emissions in 2009 would have been 53% higher than what they actually were. In the absence of trend population growth, aggregate emissions in 2009 would have been

11 The associated $R^2 = 0.999$.

[Figure 7] Log (Aggregate Emissions), Benchmark Predicted vs. Counterfactual Predicted and Policy Target



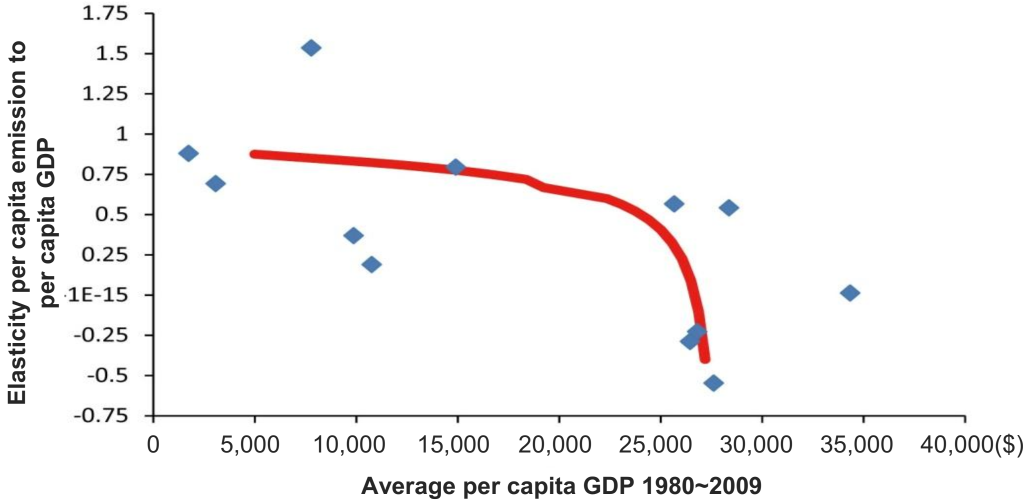
22% lower than what they actually were.

[Figure 7] also shows that the 2020 policy target is feasible given the trend pace of structural change, productivity growth, abatement, and population growth. The aggregate emission is expected to *decline* between 2010 and 2020 such that aggregate emissions in 2020 are expected to be 2.19% higher in 2020 than its 2005 level. This would imply that aggregate emissions are expected to be only 6.19% above the policy target which would be a substantive achievement from the viewpoint of existing policy making discussions.

2. Discussion of Policy Implications

The quantitative analysis shows that explicit efforts to reduce greenhouse gas emissions through accelerated pace of abatement may not be *critical* to achieve the target emission levels and de-coupling of GDP growth and emissions growth envisioned for Korea. As indicated by the counterfactual analysis, Korea looks on course to meet its target as a result of the expected de-coupling which follows as a result of the structural transition of its economy into the service sector. Industrial policy need not change dramatically to achieve this target, as long as the structural change is expected to proceed at the same trend pace it has been achieved over the

[Figure 8] Per Capita GDP vs. Elasticity of Aggregate Emissions to GDP (12 Major Economies) vs. Predicted Relationship Using Korean Experience



past 30 years.

The key policy message of the paper is that BAU calculations for emissions projections should incorporate the deceleration in emissions growth resulting from the expected structural change of the Korean economy. As shown in [Figure 3], such change has been proceeding at a very stable pace and can be expected to continue to proceed in this way. Ignoring this feature of the economy in making BAU calculations can lead to exaggerated claims about the success of greenhouse gas policy in reducing the pace of growth of emissions.

[Figure 8] compares the relationship between GDP per capita and the elasticity of the aggregate emission to GDP implied by the time series trends for log emissions per capita and log GDP per capita for the Korean economy. On the same graph I show the relationship between these variables for the cross-section of major economies from [Figure 2].

The Korean experience predicts a very dramatic de-coupling in the sense that as real per capita GDP levels exceed $25,000, the positive link between emissions and GDP seems to break down very dramatically and even becomes negative. This is associated with a very stark process of de-coupling. This experience fits the experiences of the cross section of major economies well, given the position and variation of the Korean experience straddled between the major rich and poor economies.

In the world economy, there is greater room for reducing the distribution of production and consumption between service and non-service sectors in poorer countries than richer countries. This is because richer economies are further along this transition than poorer economies. Such an observation suggests that international efforts to de-couple emissions and GDP on a global scale should proceed by targeting the structural change into services in poor countries.

VI. Conclusions

Structural change has previously not played a major role as a quantitatively important source of the de-coupling of greenhouse gas emissions and GDP growth. This research shows however it is a key component of the de-coupling process using data from Korea.

Future research can extend this analysis to a larger group of countries and consider the different aspects of emissions and structural change between rich versus poor countries. Depending on the level of development, the appropriate emission reduction policy may differ in terms of emphasizing structural change versus improved emission abatement versus limiting population growth. A quantitative assessment would be desired here.

Another important avenue for future research is the role of international trade on structural transition into the service sector. A prevailing view exists that abatement efforts which just relocate emissions to other economies are not affective in abating global greenhouse gas emissions. One would again want to see a quantitative assessment of such a mechanism which would be empirically relevant for a major trading economy such as Korea.

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Appendix

1. Data Sources

The data used in this analysis is as follows. The greenhouse gas emission per capita is from the Energy Information Administration of the United States Department of Energy (EIA, 1980-2009) measured as the per capita carbon dioxide emissions from the consumption of energy (metric tons of carbon dioxide per person) combining all carbon emissions fuel types (coal, natural gas and liquids). Real GDP per capita (using purchasing power parity measures with 2005 as base year) and population statistics are from the Penn World Tables Version 7.0 (PWT 7.0, 1980~2009). Data on the laborforce distribution across sectors is from the International Labor Organization (ILO, 1980~2007). These data are adopted since they are the most accessible and are constructed in a consistent way for comparison with other country experiences.

The international carbon dioxide emissions data can be accessed from:

http://www.eia.gov/tools/models/datatools.cfm.

The international real GDP data at purchasing power parity can be accessed from:

http://pwt.econ.upenn.edu/.

The international data on distribution of the laborforce across sectors can be accessed from:

http://laborsta.ilo.org/.

2. Derivations

A second order Taylor approximation of the term in square brackets in equation (5) implies

$$\ln\left[\frac{1+\frac{\lambda_{ns}}{\lambda_s}\alpha\left(\frac{\phi_{ns}}{\phi_s}\gamma\right)^t}{1+\alpha\gamma^t}\right] \simeq \ln\left[\frac{1+\frac{\lambda_{ns}}{\lambda_s}\alpha}{1+\alpha}\right] + t\times\left[\frac{\lambda_{ns}}{\lambda_s}\alpha\frac{\ln\frac{\phi_{ns}}{\phi_s}\gamma}{1+\frac{\lambda_{ns}}{\lambda_s}\alpha} - \alpha\frac{\ln\gamma}{1+\alpha}\right] \tag{18}$$

$$+\frac{t^2}{2}\times\left[\frac{\lambda_{ns}}{\lambda_s}\alpha\left[\frac{\ln\frac{\phi_{ns}}{\phi_s}\gamma}{1+\frac{\lambda_{ns}}{\lambda_s}\alpha}\right]^2 - \alpha\left[\frac{\ln\gamma}{1+\alpha}\right]^2\right].$$

A second order Taylor approximation of the term in square brackets in equation (8) implies

$$\ln\left[\frac{1+\alpha\left(\frac{\phi_{ns}}{\phi_s}\gamma\right)^t}{1+\alpha\gamma^t}\right] \simeq t \times \left[\alpha\frac{\ln\frac{\phi_{ns}}{\phi_s}\gamma}{1+\alpha} - \alpha\frac{\ln\gamma}{1+\alpha}\right] + \frac{t^2}{2} \times \left[\alpha\left[\frac{\ln\frac{\phi_{ns}}{\phi_s}\gamma}{1+\alpha}\right]^2 - \alpha\left[\frac{\ln\gamma}{1+\alpha}\right]^2\right] \quad (19)$$

$$= t \times \left[\frac{\alpha}{1+\alpha}\ln\frac{\phi_{ns}}{\phi_s}\right] + \frac{t^2}{2} \times \frac{\alpha}{[1+\alpha]^2}\left[\left(\ln\frac{\phi_{ns}}{\phi_s}\right)^2 + 2\ln\frac{\phi_{ns}}{\phi_s}\ln\gamma\right].$$

3. Inference of Technology Parameters

Given ε and the estimates for α and γ in <Table 1>, we use equation of (12) to determine $\frac{\phi_{ns}}{\phi_s}$. Then using the third equation of (17), we can determine ϕ. Then using the second equation of (17) we can determine ϕ_s, after which we can determine ϕ_{ns} using $\frac{\phi_{ns}}{\phi_s}$. We can determine π from the first equation of (17).

Then using the third equation of (15), we can determine $\frac{\lambda_{ns}}{\lambda_s}$. Then using the second equation of (15), we can determine θ. Finally, we can determine λ_s from the first equation of (15), after which we can determine λ_{ns} using $\frac{\lambda_{ns}}{\lambda_s}$.

[Appendix Figure 1] Log (per Capita Emission) vs. Log (per Capita GDP), 12 Major Economies 1980~2009