Development trajectory of energy consumption and carbon emissions in developing countries

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Abstract

This paper uses a complete decomposition model to study cross-country comparison of development trajectories of energy utilization and carbon emissions in developing economies. Variation in total energy consumption and carbon emissions is dominated by economic activity effect in 83 developing countries from 1980 to 2003. Country-specific contribution and comparative intensity analysis reveal that improvements in energy efficiency can be accompanied by a slower switch to cleaner or less carbon intensive fuels.
Keywords: decomposition, energy efficiency, carbon intensity, fuel-switching.

1 Introduction

Climate change mitigation requires broader and meaningful participation of all countries. However, most developing countries remain reluctant to coordinate policies and commitment to global mitigation effort. Although the Kyoto Protocol suggests *common but differentiated responsibilities* [1] from all countries, whether developing countries are able to engage in emissions reduction strategy is still open to debate.

In this paper, we use a decomposition model introduced by Sun [2] to explain the sources of variation in energy consumption and carbon emissions in an expanded data set of 83 developing economies. Unlike the usual end-time period comparison in the literature, we compare annual values to a base year. As in Luukkanen and Kaivo-oja [3, 4] and Lise [5], we continue analysis on the dynamics of energy use and carbon emissions using the Kyoto prescribed 1990 base year. An analysis on the deviation from the baseline period contributes in designing and planning climate change strategies and policies at the national level, and in search for more meaningful participation of developing countries at an international level.

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We proceed as follows. Section 2 presents the decomposition model and data used in the analysis. Section 3 discusses the result from the analysis conducted from 1980-2003. The final section summarizes the results and concludes.

2 Data and methodology

This section presents the decomposition model and describes the data used to provide comparison of the development of aggregate energy use and carbon emissions. Our three-factor model of energy consumption is: $E^t = \sum_i Q_i^t \times eI_i^t \times s_i^t$ or $E^t = Q^t \sum_i eI_i^t \times s_i^t$ where subscript i refers to a particular country/ income-group and $s_i = \frac{Q_i}{Q}$ is the share of country i to total production $Q^t = \sum_i^n Q_i^t$. Activity effect(**Q**) indicates energy demand due to economic activity; intensity effect(**eI**) reveals technological change in then production system and; structure effect(**s**) reflects a country's share in total production. Through time $[0, t]$, the change in energy consumption $\Delta E = E^t - E^0$, where superscript 0 refers to the 1990 baseyear value and t refers to annual values, is influenced by the following effects:

$$EQ^t = \Delta Q \sum_i eI_i^0 s_i^0 + \frac{1}{2}\Delta Q \sum_i (eI_i^0 \Delta s_i + s_i^0 \Delta eI_i) + \frac{1}{3}\Delta Q \sum_i \Delta s_i \Delta eI_i,$$

$$EI^t = Q^0 \sum_i s_i^0 \Delta eI_i + \frac{1}{2}\Delta eI_i \sum_i (s_i^0 \Delta Q + Q^0 \Delta s_i) + \frac{1}{3}\Delta Q \sum_i \Delta s_i \Delta eI_i,$$

$$Es^t = Q^0 \sum_i eI_i^0 \Delta s_i + \frac{1}{2}\Delta s_i \sum_i (eI_i^0 \Delta Q + Q^0 \Delta eI_i) + \frac{1}{3}\Delta Q \sum_i \Delta s_i \Delta eI_i,$$

which is an exact decomposition so that $\Delta E = EQ^t + EI^t + Es^t$. Analogously, we write the decomposition model for carbon emissions as follows:

$$CQ^t = \Delta Q \sum_i cI_i^0 s_i^0 + \frac{1}{2}\Delta Q \sum_i (cI_i^0 \Delta s_i + s_i^0 \Delta cI_i) + \frac{1}{3}\Delta Q \sum_i \Delta s_i \Delta cI_i,$$

$$CI^t = Q^0 \sum_i s_i^0 \Delta cI_i + \frac{1}{2}\Delta cI_i \sum_i (s_i^0 \Delta Q + Q^0 \Delta s_i) + \frac{1}{3}\Delta Q \sum_i \Delta s_i \Delta cI_i,$$

$$Cs^t = Q^0 \sum_i cI_i^0 \Delta s_i + \frac{1}{2}\Delta s_i \sum_i (cI_i^0 \Delta Q + Q^0 \Delta cI_i) + \frac{1}{3}\Delta Q \sum_i \Delta s_i \Delta cI_i.$$

Thus, the total change in carbon emissions is $\Delta C = CQ^t + CI^t + Cs^t$.

To describe fuel-switching scenario in developing countries, analysis proceeds with evaluation of country-specific contributions to total change in energy intensity and carbon intensity:

$$\Delta eI_{country} = s^o \Delta eI_i + eI^0 \Delta s_i + \Delta eI_i \Delta s_i \,, \tag{1}$$

$$\Delta cI_{country} = s^o \Delta cI_i + cI^0 \Delta s_i + \Delta cI_i \Delta s_i \,. \quad (2)$$

Eqns. (1) and (2) are expressed as percentage relative to 1990 values. Here, we define energy (carbon) intensity as the inverse of the ratio of economic outcome Q and energy input **E** (carbon emissions **C**).

2.1 Data description

Analysis on the factors explaining variation in energy consumption and carbon emissions covers 83 developing countries from 1980-2003. To minimize statistical influence on all other economies included in the study, we single-out economically and geographically larger countries like Argentina, Brazil, China, India, Mexico and South Africa as key developing countries. The remaining 77 countries are then classified according to three income categories. We base our income-groups from World Bank's Gross National Income (GNI)per capita-based country classifications of low-income and middle income economies. We include 36 countries in the low-income (LY) group, 23 and 22 economies in the lower-middle income (LMY) and upper-middle income (UMY) groups.

We use gross domestic product (GDP) as proxy variable for economic output Q. GDP of each country which are measured in foreign currency units are converted to U.S. dollars using year 2000 annual average foreign currency market exchange rates. Energy consumption is in British thermal units (Btu) per 2000 U.S. dollar exchange rates. Carbon emissions are in metric tons carbon equivalent (mtce) per thousand 2000 U.S. dollar exchange rates. All data from the International Energy Annual (IEA) statistics are macroeconomic and country level. Individual countries are treated as sectors i in the equations in Section 2 and the economic outcome Q is the total sum of GDPs.

3 Interpretation of results

Decomposing energy consumption and carbon emissions from 1980-2003 reveals that activity effect dominantly explain variation in energy consumption and carbon emissions in 83 developing countries.. Income groups and key developing countries show sharp divergence of activity effect from intensity and structural effects on variation in carbon emissions. Using a normalized scale, we present the result of decomposing the sources of variation in energy consumption and carbon emissions.

3.1 Variation in energy consumption

Figure 1 shows that economic growth has been exerting pressure on energy input in the production sectors of developing countries. Intensity effect on energy consumption suggests decline in energy content of a dollar of GDP declines through time by early 1990. Structural effect shows an indeterminate effect on energy consumption changes in the 1990s. Figure 2 reports that China, India and Brazil con-

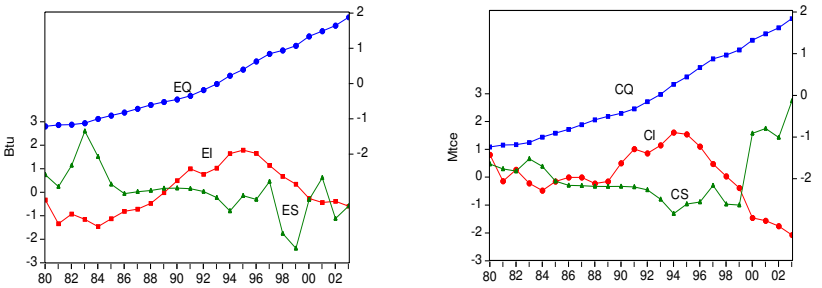

Figure 1: Decomposition of energy consumption and CO_2 emissions.

tribute more to total change in energy consumption compared to other key developing countries while changes in lower-income economies (LMY) have the greatest impact on total energy use among income groups.

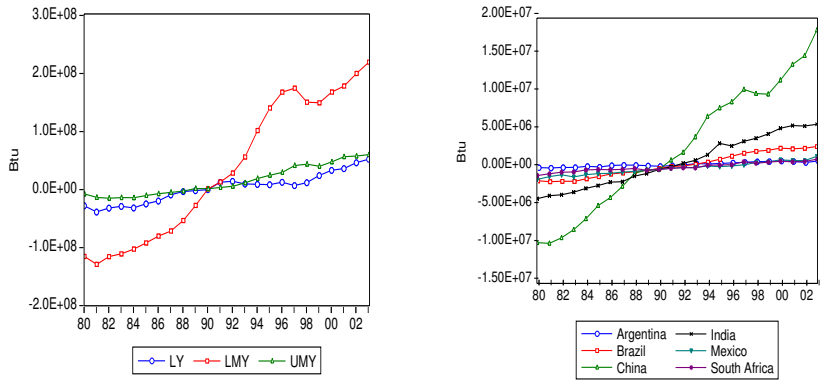

Figure 2: Contribution to total change in energy consumption.

3.2 Variation in carbon emissions

Activity effect also dominantly explains variation in carbon emissions in the developing region. Result on dominant activity effect in Figure 1 on variation in energy consumption supports findings on increasing emissions from primary energy sources (i.e fossil fuels) with GDP. Economic growth tends have positive influence in explaining continuous increase in emissions from primary energy consumption for the past two decades. Heavy consumers of energy are also heavy emitters of carbon dioxide. Although all the key developing countries show increasing contributions to total change in carbon emission, Figure 3 shows that China, India, and

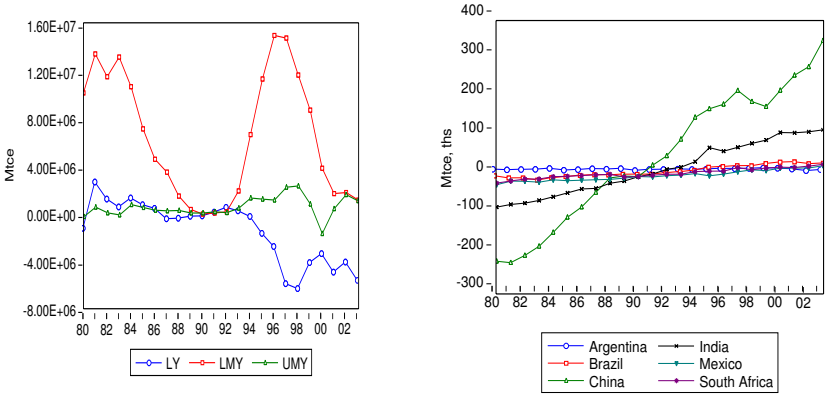

Figure 3: Contribution to total change in carbon emissions.

Brazil have greater contribution to carbon emissions dynamics. The left panel of Figure 3 shows declining contribution to changes in total carbon emissions from income groups. However, we observe rising positive contributions to total changes in emissions from LMY group between 1993 and 2001.

3.3 Comparative intensity

This section focuses on fuel-switching in macroeconomic production of developing economies. Fuel-switching refers to the difference between relative percentage change in energy and carbon intensities. Figure 4 shows an increasing and then decreasing pattern in intensity effect on aggregate energy and carbon emissions. Post-baseyear scenario suggests improving technological status and switching to cleaner fuels in macroeconomic production.

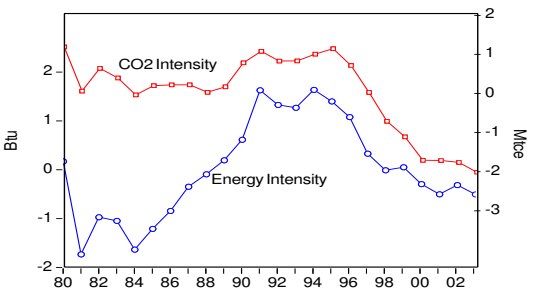

Figure 4: Aggregate intensity effect.

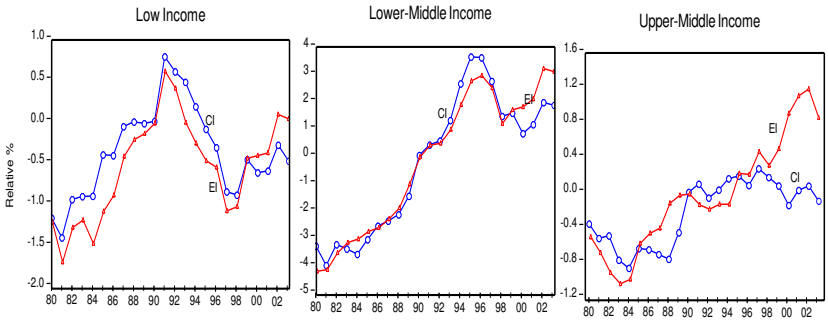

Figure 5: Comparative intensity effect by income group.

3.3.1 Income groups

Intensity effect on energy and carbon from LY group is rising in the 1980s but eventually declines in the 1990s. However, we see Figure 5 that percentage change in carbon intensity rises above energy intensity suggesting no marked switch to less carbon emitting fuel in low-income economies. Deviation from 1990 level in carbon emissions than in energy consumption is greater from LMY group in the 1980s. Energy consumption and carbon emissions increased by around 12% and 11%, respectively. Comparative analysis in Figure 5 shows that energy input and carbon dioxide content of per unit of GDP in LMY group of countries still remain high relative to the two other income-groups.

UMY group experience increasing trend in the technology factor between 1980 and 1995. Variation in intensity effects peak at approximately 4% and 2% for energy consumption and carbon emissions between 1993 and 2003, respectively.

3.3.2 Key developing economies

The indicators of energy efficiency and fuel-switching do not differ significantly in key developing countries. Although the indicators tend to decrease, carbon intensity in these economies tends to rise above energy intensity. Results in Figures 5 and 6 show that relative to 1990 level, most key developing countries and income groups experience greater percentage change in intensity factor on carbon emissions than on energy consumption. Developing countries have been heavy on energy demand and carbon emissions but have been traversing a lighter energy and carbon paths in the 1990s to early 2000s.

Figure 6 reveals that Argentina's intensity effect on total energy and carbon emissions is declining. Change in intensities relative to other key countries is also declining in Brazil. Although the country is becoming energy efficient and less-carbon intensive in the 1990s, its intensity effect relative to 1990 levels indicate that relative percentage change in intensity effect on carbon emissions is still greater. We find China becoming less energy and carbon intensive. Percentage decline in intensity effect on carbon emissions is greater suggesting switch to

less carbon-emitting and efficient energy source. In India, favorable energy efficiency performance is accompanied by positive percentage change in intensity effect on carbon emissions. Unlike India, Mexico is showing favorable performance in energy utilization and switch to less carbon intensive fuels. This result on lighter production structure in Mexican economy is similar with observations in Luukkannen and Kaivi-oja [3] and Aguayo and Gallagher [6]. South Africa also show the same downward trend in its comparative intensities. Post-baseline intensity effect scenario suggests South Africa to have a much environment-sensitive energy utilization path. However, the country's economic recession in the early 1990 can be a contributing factor in declining intensity effects [3, 7].

3.3.3 Fuel-switching

Fuel-switching by income group in Figure 7 and by key countries in Figure 8 show that between mid-1980s and early 1990, intensity effect on energy and emissions is declining. However, recall in Section 3.3 that improvements in energy efficiency can be accompanied by slower switch to cleaner or less carbon-intensive fuels. In Sun [8], declining energy intensity maybe due to restricted utilization of combustible renewables and wastes in the measurement of primary energy consumption. Figure 7 shows that low-income economies are still coping with decarbonization of its energy consumption. Among key developing countries, China heads to a clear shift to less-carbon intensive fuel. Figure 8 affirms that India and Brazil are still more carbon intensive compared with other key developing countries. Despite falling intensities, most key countries are still struggling to make their production sector more energy efficient and less carbon-intensive.

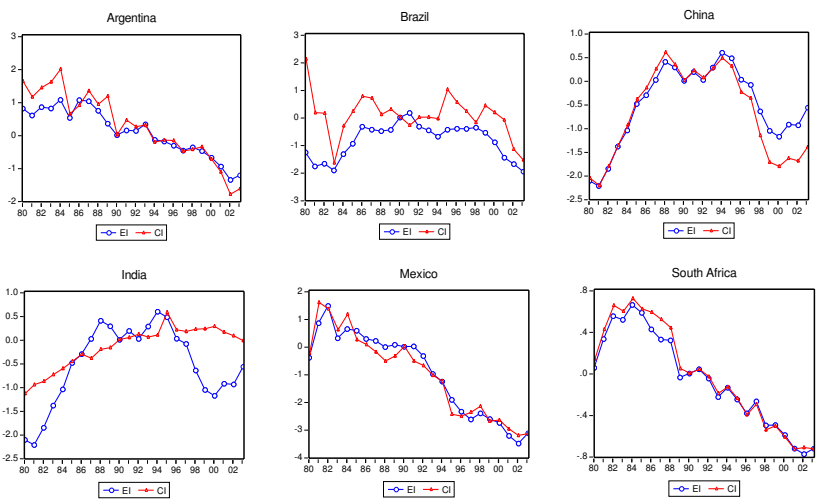

Figure 6: Comparative intensity effect in key countries (*in relative %*).

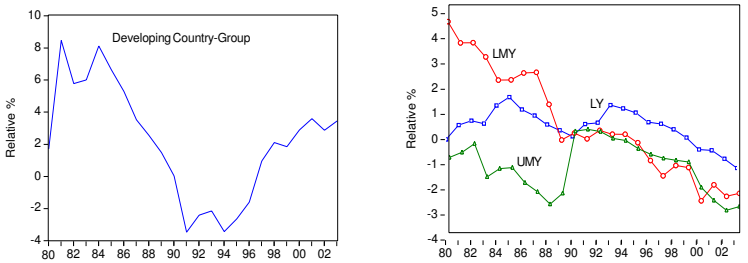

Figure 7: Fuel-switching in aggregate and by income group.

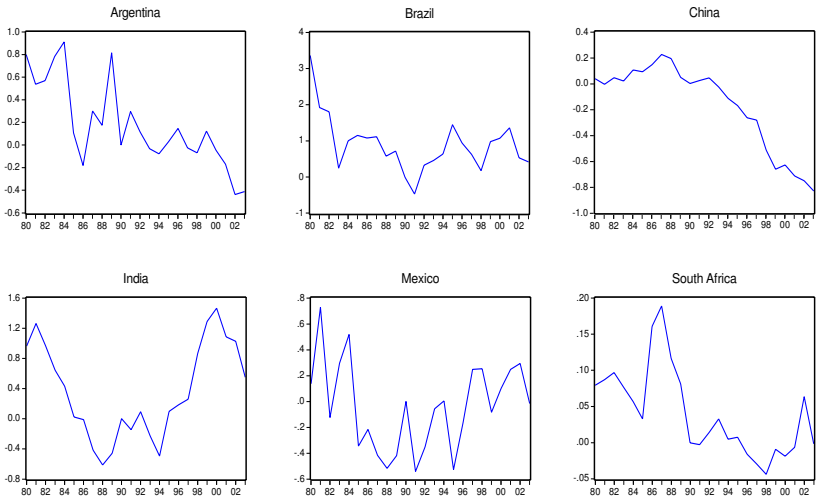

Figure 8: Fuel-switching in key developing countries (*in relative %*).

4 Summary and conclusion

Results suggest that developing economies are still coping with decarbonization of their energy consumption. From 1980-2003, variation in energy consumption and carbon dioxide emissions is dominated by activity effect on energy utilization. Intensity effect on carbon emissions relative to energy consumption is highest from lower-middle income group. Among key developing countries, China is heading to a clear shift to less-carbon intensive fuel while India and Brazil are still carbon-intensive.

Country-specific contribution and comparative intensity analysis reveal that improvements in energy efficiency can be accompanied by slower switch to cleaner or less carbon intensive fuels. As variations in energy consumption are strongly affected by economic expansion, and carbon emissions by production and technology factors, national energy and climate policies on sustainable use of

energy, energy-efficient technologies have to simultaneously support economic development in developing countries.

Interpretation of results on the development trajectory of energy consumption and carbon emission is within the limitations of our decomposition methodology and data set.

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