# *COMPARING ENERGY EFFICIENCY ACROSS COUNTRIES AND OVER TIME: A DECOMPOSITION APPROACH*

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## Overview

Comparisons of energy efficiency, whether across countries or over time, are of considerable policy significance. Tracing the evolution of energy efficiency over time can improve forecasts of future energy demand and provide insights into the effectiveness of energy efficiency policies. Cross-country comparisons can indicate which countries are relatively more efficient at using energy than others and provide an important input into the feasibility of coordinated international efforts at mitigating climate change.

Such comparisons, though, are hindered by the difficulty of obtaining ready-made energy efficiency indicators. The most straightforward indicator, aggregate energy intensity, can be misleading as it is determined by both the structure of the economy and the energy intensities of individual sectors. This issue has typically been tackled by using decomposition techniques to disentangle the effects of these two factors. A feature of the decomposition literature is that most studies have sought to decompose energy intensity *changes over time* into structural changes and intensity changes [1]. Even cross-country studies such as [2], [3] and [4] proceed by first decomposing energy intensity trends within individual countries and only then comparing across countries. By contrast, there is a much sparser literature examining the extent to which energy intensity *differences between countries* are a result of structural differences and differences in their sectoral energy intensities (an example is [5]).

This paper carries out a "panel decomposition" analysis that considers both differences in energy intensity between countries and changes in energy intensity over time within the same framework. The panel nature of the analysis allows us to examine interesting research questions that have not been adequately explored before. Are structural or sectoral intensity differences the key factor behind cross-country differences in aggregate energy intensity? Do structural and intensity factors determine cross-country energy intensity differences in a similar fashion to how they determine changes over time, and if not, how are they different? In addition, the framework outlined in this paper allows comparisons of energy intensity across countries to be made after accounting for structural differences, the idea being that an index which controls for the effect of structure is a better proxy for the "true" energy efficiency level than aggregate energy intensity. This could be useful in benchmarking a country's energy efficiency performance against others, contributing to recent literature in the area (see, for instance, [6]).

## Methods

For each sector, energy intensity is the ratio of energy consumption (measured in TJ) to the sectoral value-added, which is converted to PPP (constant 2005$) using industry-specific PPPs obtained from [7]. Both the energy use and the sectoral value-added data are taken from the World Input-Output Database (WIOD), which is a consistent dataset of input-output time series, covering the years 1995 to 2009 and disaggregated into 35 sectors [8]. 28 of these sectors are considered, with the refining and power generation sectors excluded as the study's focus is the efficiency of end-use of energy rather than energy transformation. The dataset utilized consists of 39 countries, including all the 27 countries in the EU, other OECD countries and major developing countries such as China and India. This is an advantage over most decomposition studies, which tend to focus on a more limited set of countries.

The study adapts the Fisher Ideal Index that has been frequently utilized for carrying out time series decomposition of energy intensity, for instance in [9] and [10]. The Fisher Ideal Index is the geometric mean of the Laspeyres and Paasche indices. Denoting aggregate energy intensity for a single country in the base year by $\boldsymbol{e_0}$, the aggregate energy intensity index in any year $\boldsymbol{t}$ can be written as $\boldsymbol{e_t/e_0}$. If $\boldsymbol{e_{it}}$ is the energy intensity in sector $\boldsymbol{i}$ at time $\boldsymbol{t}$ and $\boldsymbol{s_{it}}$ is the share of gross value-added for sector $\boldsymbol{i}$ at time $\boldsymbol{t}$, the aggregate energy intensity index for a single country can be decomposed across time into a structural change index $\boldsymbol{F_t^{str}}$ and intensity change index $\boldsymbol{F_t^{int}}$ as follows:

$$\frac{e_t}{e_0} = F_t^{str} F_t^{int} \text{ where } F_t^{str} = \sqrt{\frac{\sum_i e_{i0} s_{it}}{\sum_i e_{i0} s_{i0}} \frac{\sum_i e_{it} s_{it}}{\sum_i e_{it} s_{i0}}} \text{ and } F_t^{int} = \sqrt{\frac{\sum_i e_{it} s_{i0}}{\sum_i e_{i0} s_{i0}} \frac{\sum_i e_{it} s_{it}}{\sum_i e_{i0} s_{it}}} \quad (1)$$

Note that in single country decompositions, the structure and intensity indices for every year $\boldsymbol{t}$ are constructed relative to a single base year $\boldsymbol{0}$. An intuitive way to extend this approach to carry out a "panel decomposition" for multiple countries is to construct indices for each country $\boldsymbol{j}$ in every year $\boldsymbol{t}$ relative to a reference economy $\boldsymbol{R}$ in the

base year $\boldsymbol{0}$. The aggregate energy intensity index for country $\boldsymbol{j}$ can therefore be written as $\boldsymbol{e_{jt}/e_{R0}}$ and can be decomposed into a structure index $\boldsymbol{F_{jt}^{str}}$ and an intensity index $\boldsymbol{F_{jt}^{int}}$ as follows:

$$\frac{e_{jt}}{e_{R0}} = F_{jt}^{str} F_{jt}^{int} \text{ where } F_{jt}^{str} = \sqrt{\frac{\sum_i e_{iR0}\, s_{ijt}}{\sum_i e_{iR0}\, s_{iR0}} \frac{\sum_i e_{ijt}\, s_{ijt}}{\sum_i e_{ijt}\, s_{iR0}}} \text{ and } F_{jt}^{int} = \sqrt{\frac{\sum_i e_{ijt}\, s_{iR0}}{\sum_i e_{iR0}\, s_{iR0}} \frac{\sum_i e_{ijt}\, s_{ijt}}{\sum_i e_{iR0}\, s_{ijt}}} \qquad (2)$$

This framework allows comparisons of the structure and intensity indices to be made purely across countries (by setting $\boldsymbol{t}$ equal), purely over time (by setting $\boldsymbol{j}$ equal) and simultaneously across countries and over time (by allowing both $\boldsymbol{t}$ and $\boldsymbol{j}$ to vary). The reference economy $\boldsymbol{R}$ is chosen as the aggregate of all the countries in the sample.

## Results

The following are some of the key findings on the nature of differences in energy intensity between and within countries:

1) Within the 15-year, 39-country sample, aggregate energy intensity varies to a much more extent across countries than it does over time. Between-country variation is also significantly greater than within-country variation for both the intensity and the structure indices, the effect being especially pronounced for the structure indices.

2) The intensity effect dominates the structure effect in explaining both between-country differences in energy intensity and within-country changes in energy intensity.

3) Globally, 88% of the decline in energy intensity from 1995 to 2009 can be attributed to changes in the energy intensity of individual sectors, with only 12% attributable to changes in economic structure. On average for each country, it is changes in sectoral energy intensity, rather than changes in economic structure, that have primarily contributed to changes in energy intensity between 1995 and 2009.

4) Cross-country structural differences have remained almost constant between 1995 and 2009, whereas there has been a convergence in sectoral energy intensities across countries during the same period. Thus structural differences play an increasingly significant role in explaining cross-country energy intensity differences.

Because the intensity index controls for the effect of structure, it can be used to compare sectoral energy intensity levels across countries and rank them accordingly. Countries rankings based on the intensity index can vary substantially from rankings based on aggregate energy intensity: economies with highly energy-intensive structures (such as China) rank higher, while service-oriented economies such as France rank lower.

## Conclusions

While sectoral energy intensity effects are more significant than structural effects in determining aggregate energy intensity, structural differences play an increasingly significant role in explaining cross-country energy intensity differences and have a material impact on country rankings of energy intensity. This highlights the importance of accounting for the economy's structure when making energy efficiency comparisons.

Methodologically the study provides the first known instance of a panel decomposition of energy intensity, with the structure and intensity indices allowing comparisons to be made both across countries and over time. These indices can form the basis for further analysis into energy efficiency comparisons and benchmarking.

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