How Dependent is Output Growth from Primary Energy?

Gael Giraud
CNRS, PSE, CES, Labex REFI
and
Z. Kahraman, TSP

March 28, 2014
I. Why is this relationship important?

I.1. Kaya’s equation

![Graph showing the relationship between GDP and energy consumption]

\[ y = 7,039x - 15298 \]
\[ R^2 = 0,9855 \]

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I. Why is this relationship important?
I.1. Kaya’s equation
I.2. Why is this relationship ignored?

II. The empirical estimation
II.1. A PMG approach
II. The empirical estimation

Source: OECD.
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\[
\Delta \frac{Y}{Pop} = \Delta \left( \frac{E}{Pop} \times \frac{Y}{E} \right).
\]

\(\Delta \frac{Y}{Pop}\) := growth of GDP per capita.
\(\Delta \frac{E}{Pop}\) := growth of energy consumption per capita.
\(\Delta \frac{Y}{E}\) := growth of energy efficiency.
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Taking the log...

\[
\Delta \ln \frac{Y}{Pop} = \Delta \ln \frac{E}{Pop} + \Delta \ln \frac{Y}{E}.
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The relationship in terms of per capita quantities:

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- 1965-1981: world average
  3.5% = 2.5% + 1%
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- 1965-1981: world average
  \[ 3.5\% = 2.5\% + 1\% \]

- 1981-2013: world average
  \[ 1.5\% = 0.5\% + 1\% \]
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- 1965-1981: world average
  3.5% = 2.5% + 1%

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  1.5% = 0.5% + 1%

- Japan: 2000-2013:
  0% = 0% + 0%...
• 1965-1981: world average
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Consommation mondiale annuelle d'énergie, par habitant

Source: BP Statistical Review of World Energy
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Production mondiale d'énergie primaire

Sources: US EIA Historical Statistics for 1981-2010; The Shift Project
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II. The empirical estimation
I. Why is this relationship important?

I.2. Why is this relationship ignored?

- No such obvious relation in terms of energy prices.

![Graph showing relationship between GDP and oil price per barrel](image-url)
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Les dépenses de l'énergie dans le PIB - États-Unis

Source: Bureau of Economic Analysis, Energy Information Agency
The cost-share theorem

$$\max_x Y(x) - p \cdot x$$  \hspace{1cm} (1)
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The cost-share theorem

\[
\max_x Y(x) - p \cdot x
\]  

\[
\varepsilon_i := \frac{x_i}{Y(x)} \times \frac{\partial Y}{\partial x_i}(x) = \frac{p_i x_i}{p \cdot x}
\]
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\[
\max_x Y(x) - p \cdot x \quad \text{s.t. } f(x) = 0 \tag{3}
\]

\( f(\cdot) \): geological, technical, political... constraints.
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\max_x Y(x) - p \cdot x \quad \text{s.t.} \quad f(x) = 0 \tag{3}
\]

\[f(\cdot) : \text{geological, technical, political... constraints.}\]

\[
\varepsilon_i = \frac{x_i (p_i - \lambda \frac{\partial f(x)}{\partial x_i})}{p \cdot x - \lambda x_i \frac{\partial f(x)}{\partial x_i}}. \tag{4}
\]

\[\lambda = \text{Lagrange multiplier.}\]
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\varepsilon_i = \frac{x_i (p_i - \lambda \frac{\partial f(x)}{\partial x_i})}{p \cdot x - \lambda x_i \frac{\partial f(x)}{\partial x_i}}.
\]

\[
\lambda = \text{Lagrange multiplier.}
\]

Decoupling between output elasticity and cost share.
II. The empirical estimation

II.1. A PMG approach

- Cointegration $\neq$ Correlation.
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Table: Country List

| Austria | Greece | Slovak Republic
|---------|--------|----------------|
| Belgium | Ireland | Spain
| Finland | Italy | United Kingdom
| France | Netherlands | Japan
| Germany | Portugal | United States

From 1970 to 2011.
Variables under scrutiny:

Logarithm of:

- **Primary energy consumption** (million tons of oil equivalents) - BP Statistical Review of World Energy 2012.

- **GDP** (in 2000 U.S $) World Bank, World Development Indicators.


- **Population data** - World Bank, World Development Indicators.
The main equation:

\[
\ln GDP_{i,t} = \beta_{i,0} + \beta_{i,1} \ln NRJ_{i,t} + \beta_{i,2} \ln EFF_{i,t-1} + \beta_{i,3} \ln K_{i,t} + \varepsilon_{i,t}.
\]

All the variables are per capita.
○ The main equation:

\[ \ln GDP_{i,t} = \beta_{i,0} + \beta_{i,1} \ln NRJ_{i,t} + \beta_{i,2} \ln EFF_{i,t-1} + \beta_{i,3} \ln K_{i,t} + \varepsilon_{i,t}. \]

All the variables are per capita.

○ Energy efficiency is lagged in order to avoid tautological over-identification.
Is there a (hidden) long-run relationship?

<table>
<thead>
<tr>
<th>Table . Pedroni Residual Cointegration Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deterministic intercept and trend</td>
</tr>
<tr>
<td></td>
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<td>Alternative hypothesis: common AR coeffs. (within-dimension)</td>
</tr>
<tr>
<td>Panel v-Statistic</td>
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<td>Panel ADF-Statistic</td>
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<tr>
<td></td>
</tr>
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Is there a (hidden) long-run relationship?

- Westerlund panel cointegration test also strongly reject the (no-cointegration) null hypothesis.

Table. Pedroni Residual Cointegration Test

<table>
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<tr>
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<th>Deterministic intercept and trend</th>
<th>No deterministic intercept and trend</th>
</tr>
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<td>Alternative hypothesis: common AR coefs. (within-dimension)</td>
<td>Alternative hypothesis: individual AR coefs. (between-dimension)</td>
</tr>
<tr>
<td>Panel v-Statistic</td>
<td>Statistic 2.716057, Prob. 0.0033</td>
<td>Statistic 6.801555, Prob. 0.0000</td>
</tr>
<tr>
<td>Panel rho-Statistic</td>
<td>Statistic -6.842150, Prob. 0.0000</td>
<td>Statistic -9.435575, Prob. 0.0000</td>
</tr>
<tr>
<td>Panel PP-Statistic</td>
<td>Statistic -18.61345, Prob. 0.0000</td>
<td>Statistic -14.51132, Prob. 0.0000</td>
</tr>
<tr>
<td>Panel ADF-Statistic</td>
<td>Statistic -15.77301, Prob. 0.0000</td>
<td>Statistic -13.23211, Prob. 0.0000</td>
</tr>
</tbody>
</table>

Westerlund panel cointegration test also strongly reject the (no-cointegration) null hypothesis.
Can we quantify this long-run relationship? The short-run speed of convergence towards the equilibrium relation? An ECM approach:

\[
\Delta \ln Y_t = \gamma_e \Delta \ln E_t - \beta_e (\ln Y_t - \alpha_e \ln E_t) + \varepsilon_t.
\]

\(\alpha_e\): long-run output elasticity of energy use. \(\beta_e\): speed of convergence. \(\gamma_e\): out-of-equilibrium short-run output elasticity of energy.
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Table 7. Selection of the estimation method

<table>
<thead>
<tr>
<th>Model:</th>
<th>PMG</th>
<th>MG</th>
<th>CCE - MG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent variable: $\Delta Y_{it}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy consumption per capita ($C_{it}$)</td>
<td>0.6740*** (0.062)**</td>
<td>0.6075*** (0.126)**</td>
<td>0.6102*** (0.165)**</td>
</tr>
<tr>
<td>Energy efficiency ($E_{it-1}$)</td>
<td>0.6036*** (0.070)**</td>
<td>0.5833*** (0.279)**</td>
<td>0.4864*** (0.183)**</td>
</tr>
<tr>
<td>Capital formation per capita ($K_{it}$)</td>
<td>0.1244*** (0.022)**</td>
<td>0.1972*** (0.082)**</td>
<td>0.1643*** (0.036)**</td>
</tr>
<tr>
<td>Convergence coefficient ($Y_{it-1}$)</td>
<td>-0.6230*** (0.124)**</td>
<td>-1.6958*** (0.814)**</td>
<td>-0.9554*** (0.189)**</td>
</tr>
<tr>
<td>Hausman test p value</td>
<td>0.419</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: *** significant at the 1% level; ** at the 5% level; * at the 10% level. Standard errors are given in parentheses. The lag structure is ARDL (1, 1, 2, 1).
Is there a causality link?

  Non-conclusive causal relationship between quantities
  Except for Sweden over 1 century (Stern (2011)).
  Strong relationship in terms of prices. (Cf. Hamilton...)
Is there a causality link?

  Non-conclusive causal relationship between quantities
  Except for Sweden over 1 century (Stern (2011)).
  Strong relationship in terms of prices. (Cf. Hamilton...)
- Granger panel tests (valid since cointegration):

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Short run</th>
<th>Sources of causation (independent variables)</th>
<th>Long run</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta Y$</td>
<td>$\Delta E$</td>
<td>$\Delta C$</td>
</tr>
<tr>
<td>$\Delta Y$</td>
<td>-</td>
<td>1.26</td>
<td>23.03***</td>
</tr>
<tr>
<td>$\Delta E$</td>
<td>1228.4***</td>
<td>-</td>
<td>8702.6***</td>
</tr>
<tr>
<td>$\Delta C$</td>
<td>0.41</td>
<td>0.16</td>
<td>-</td>
</tr>
<tr>
<td>$\Delta K$</td>
<td>47.59***</td>
<td>2.35</td>
<td>39.13***</td>
</tr>
</tbody>
</table>

Notes: Wald chi-squared test statistics for short-run causality. The lag length is one. ECT represents the coefficient of the error-correction terms. ***, ** and * indicate that the null hypothesis of no causation is rejected at the 1%, 5% and 10% levels, respectively.