Energy Consumption, Energy Intensity and Economic Development between 1995 and 2009: A Structural Decomposition Approach

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CONTENTS

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- Energy consumption: growing with the economic development

    - Scarce resource: fossil fuel, destruction of ecosystems, pollution, etc.

- Energy efficiency: a solution to economic, environmental and social problems caused by increasing energy consumption

   - Policy and political support, for example, the EU 2020 strategy.

- Research questions:

  - What are the influencing factors driving the dynamics of energy consumption and energy intensity differentials across various economies?

  - What is the relationship between energy intensity and economic development?

- Target:

 - To provide guidance for policy making and the updating of policy

- Two concepts:

  - Supply side energy consumption: energy used for production;

  - Demand side energy consumption: energy embodied in the products consumed by the economy.

- Trends:

  - Increasing over time but a decline in developed economies;

  - Difference between supply side and demand side.

Supply side energy consumption (millions TJ)
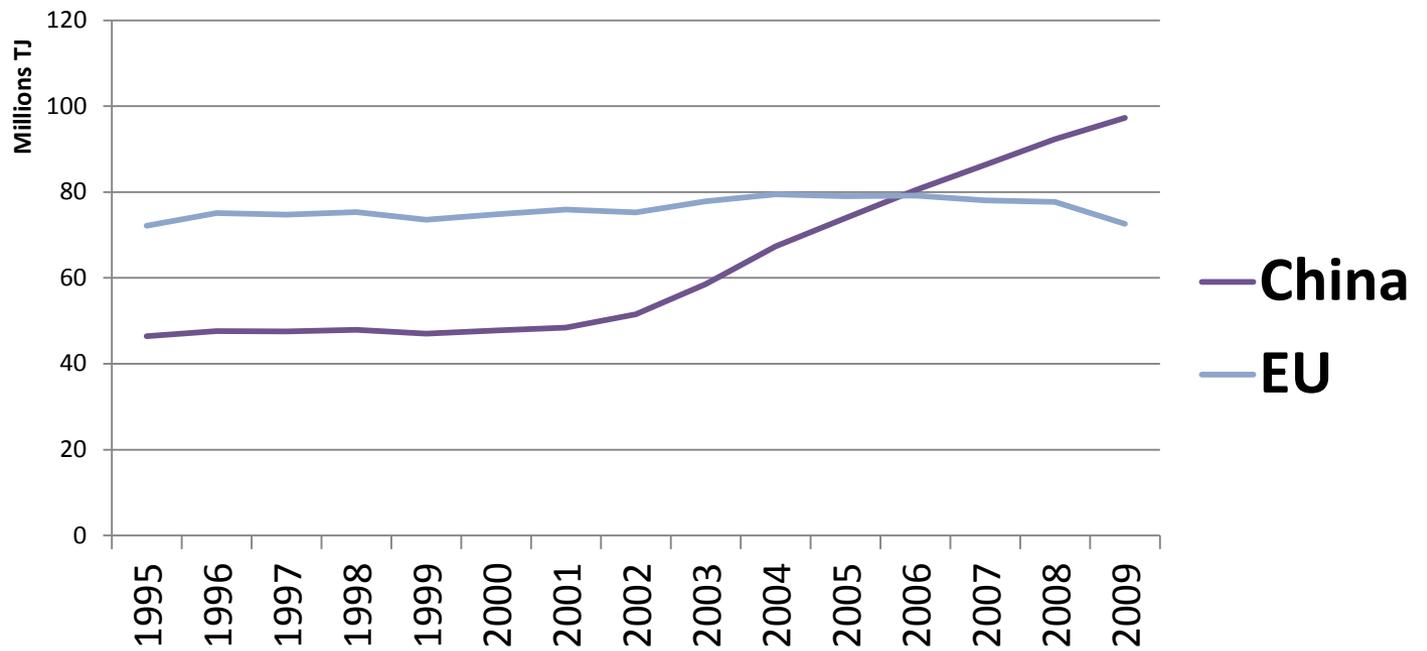
Demand side energy consumption (millions TJ)
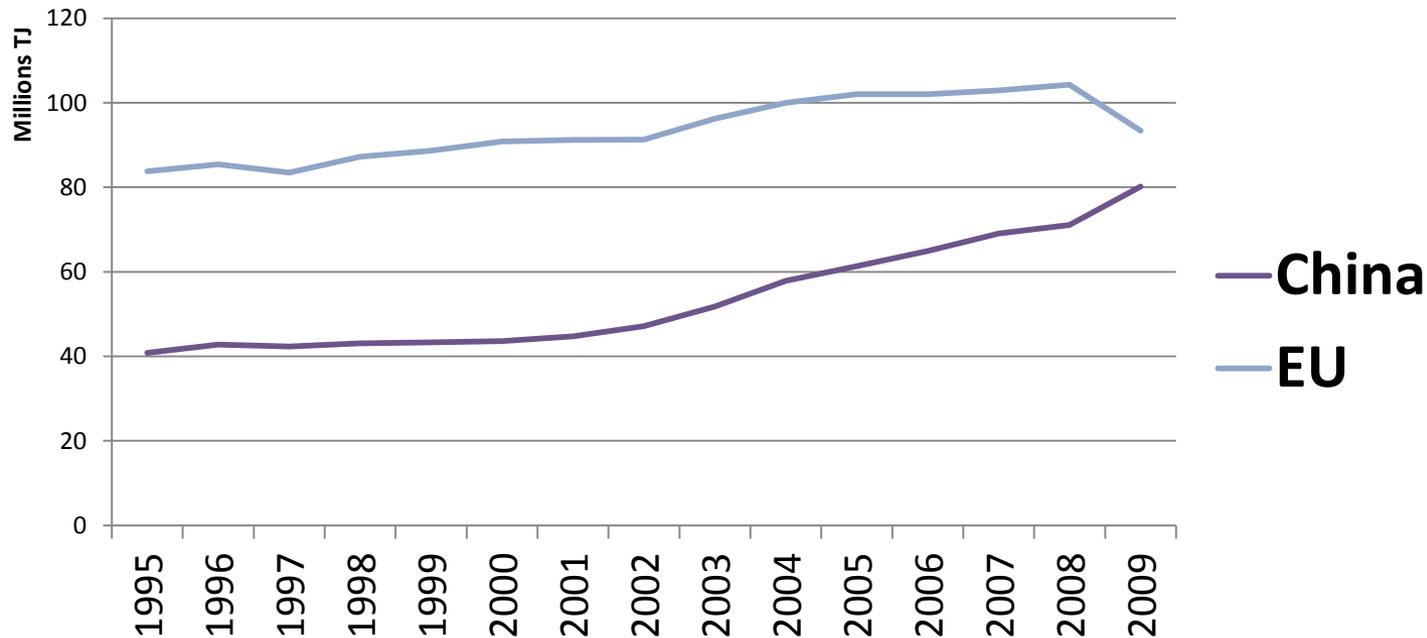
Source: own elaboration using WIOD data

- Methods:

  - Structural decomposition using input-output models

    - "Data mining"; A technique to discover new knowledge in data-intensive matrix form dataset;

    - Recent development of input-output database.

      - WIOD: constructed by University of Groningen, European Commission 7th Framework Programme, available since 2012.

  - Multilevel mixed-effect model

    - A suitable method for dataset in nested structure.

World Input-Output Database

- Data sources:

  - The World Bank Development Indicators: 1185 data points

    - GDP and GDP per capita (ppp, 2005 constant US$).

  - The World Input-Output database (WIOD)

    - 41 major economies (27 EU states, 13 major economies and the rest of the world) and 35 sectors across the world over 1995 to 2009;

    - Energy consumption data (in TJ): 22140 data points;

    - Trade data (in US$): 68248600 data points (current prices and previous years' prices);

- WIOD trade data structure in a single year: 41 major economies and 35 sectors:

Trade matrix (in US$)		Buyer (1435 columns): Intermediate inputs					Buyer (41 columns): Final demand		
		Sector 1 in Economy 1	...	Sector 35 in Economy 1	...	Sector 35 in Economy 41	Final demand of Economy 1	...	Final demand of Economy 41
Seller (1435 rows)	Sector 1 in Economy 1								
	...								
	Sector 35 in Economy 1								
	...								
	Sector 35 in Economy 41								

- ## What to do?

  ▪ Transform trade matrix into energy transaction matrix using energy consumption vector and input-output model (linear algebra operations);

Energy transaction matrix (in TJ)		Buyer (41 columns)		
		Economy 1	…	Economy 41
Seller (41 rows)	Economy 1			
	…			
	Economy 41			

Supply side: row sum

Demand side : column sum

- How?

Total energy consumption = energy used in sectors + energy used in households

- Expressions of energy consumption for each economy in a single year:

  - Supply side: $E_s = n\hat{e}(I - A^{*\circ}A^T)^{-1}sC + H$

  - Demand side: $E_d = r\hat{e}(I - A^{*\circ}A^T)^{-1}s\hat{C} + H'$

$\hat{e}$: diagonal matrix of energy intensity;
A^*: matrix of total intermediate inputs per unit of gross output;
A^T: matrix of intermediate trade coefficients;

s: matrix of structural change coefficients in final demand;
C: vector of economies' total final demand;
H: vector of energy used in households.

n, r: aggregation matrices;

- Calculate the change between 1995 and 2009;

- Decompose the change into 6 factors after linear algebra rearrangement, constructing chain index for inflation correction

$$\frac{E_{2009}}{E_{1995}} = factor\ 1 * factor\ 2 * factor\ 3 * factor\ 4 * factor\ 5 * factor\ 6$$

factor 1: change in e, **energy efficiency effect;**
factor 2: change in A^*, **effect of change in inter-industry structure;**
factor 3: change in A^T, **trade effect in intermediate inputs;**
factor 4: change in s, **structural change effect in final demand;**
factor 5: change in C, **final demand effect;**
factor 6: change in H, **household consumption effect.**

- Do the same for $\dfrac{Energy\ intensity\ in\ 2009}{Energy\ intensity\ in\ 1995}$

- Example of supply side energy consumption for the year 1 and 0

$$\frac{E_1}{E_0} = factor\ 1 * factor\ 2 * factor\ 3 * factor\ 4 * factor\ 5 * factor\ 6$$

Change in energy intensity in sectors: $factor\ 1 = \frac{e_1' L_1 f_1 + t H_1}{e_0' L_1 f_1 + t H_1};$

Change in A star: $factor\ 2 = \frac{e_0' L_1 f_1 + t H_1}{e_0' (I - A_0^{*} \circ A_1^{T})^{-1} f_1 + t H_1};$

Change in A trade: $factor\ 3 = \frac{e_0' (I - A_0^{*} \circ A_1^{T})^{-1} f_1 + t H_1}{e_0' (I - A_0^{*} \circ A_0^{T})^{-1} f_1 + t H_1};$

Change in structural coefficient matrix s: $factor\ 4 = \frac{e_0' L_0 f_1 + t H_1}{e_0' L_0 s_0 C_1 + t H_1};$

Change in country's final demand: $factor\ 5 = \frac{e_0' L_0 s_0 C_1 + t H_1}{e_0' L_0 s_0 C_0 + t H_1};$

Change in primary energy use by households: $factor\ 6 = \frac{e_0' L_0 f_0 + t H_1}{e_0' L_0 f_0 + t H_0}$

- Example of supply side energy intensity decomposition for the year 1 and 0

$$\frac{\frac{E_1}{x_1}}{\frac{E_0}{x_0}} = factor\ 1 * factor\ 2 * factor\ 3 * factor\ 4 * factor\ 5 * factor\ 6$$

Change in energy intensity in sectors: $factor\ 1 = \frac{e_1'L_1f_1 + tH_1}{e_0'L_1f_1 + tH_1}$;

Change in A star: $factor\ 2 = \frac{e_0'L_1f_1 + tH_1}{e_0'(I - A_0^{*\circ}A_1^T)^{-1}f_1 + tH_1} * \frac{i(I - A_0^{*\circ}A_1^T)^{-1}f_1}{i(I - A_1^{*\circ}A_1^T)^{-1}f_1}$;

Change in A trade: $factor\ 3 = \frac{e_0'(I - A_0^{*\circ}A_1^T)^{-1}f_1 + tH_1}{e_0'(I - A_0^{*\circ}A_0^T)^{-1}f_1 + tH_1} * \frac{iL_0f_1}{i(I - A_0^{*\circ}A_1^T)^{-1}f_1}$;

Change in structural coefficient matrix s: $factor\ 4 = \frac{e_0'L_0f_1 + tH_1}{e_0'L_0s_0C_1 + tH_1} * \frac{iL_0s_0C_1}{iL_0f_1}$;

Change in country's final demand: $factor\ 5 = \frac{e_0'L_0s_0C_1 + tH_1}{e_0'L_0s_0C_0 + tH_1} * \frac{iL_0f_0}{iL_0s_0C_1}$;

Change in primary energy use by households: $factor\ 6 = \frac{e_0'L_0f_0 + tH_1}{e_0'L_0f_0 + tH_0}$

- Convergence analysis:

  - Simple OLS: relative energy intensity (independent variable) and growth of relative energy intensity (dependent variable)

$$Energy\ intensity = \frac{Total\ primary\ energy\ use}{GDP, ppp, constant\ 2005\ US\$}$$

$$Relative\ energy\ intensity\ (REI) = \frac{Energy\ intensity\ of\ an\ economy}{Energy\ intensity\ of\ the\ world}$$

$$Growth\ of\ relative\ energy\ intensity = \frac{REI\ in\ 2009 - REI\ in\ 1995}{REI\ in\ 1995}$$

- Multilevel mixed-effect model:

  - Panel data; 39 economies over 1995 to 2009;

  - Relationship between energy intensity and GDP per capita;

For economy j in the year t (t=1995,…,2009):

  - Supply side: random intercept ($\mu_{0,j}$) and random slope ($\mu_{1,j}$)

$$\log\left(EI_{t,j}^{supply}\right) = \beta_0 + \beta_1 \log\left(GDP\_PC_{t,j}\right) + \beta_2 [\log(GDP\_PC_{t,j})]^2 + \mu_{0,j} + \mu_{1,j} \log\left(GDP\_PC_{t,j}\right) + \varepsilon_{t,j}$$

  - Demand side: only random intercept ($\mu_{0,j}$)

$$\log\left(EI_{t,j}^{Demand}\right) = \beta_0 + \beta_1 \log\left(GDP\_PC_{t,j}\right) + \beta_2 [\log(GDP\_PC_{t,j})]^2 + \mu_{0,j} + \varepsilon_{t,j}$$

3. Results

- For major manufacturing economies, the change of energy use on supply side is larger than that on demand side;

- Manufacturing outsourcing.

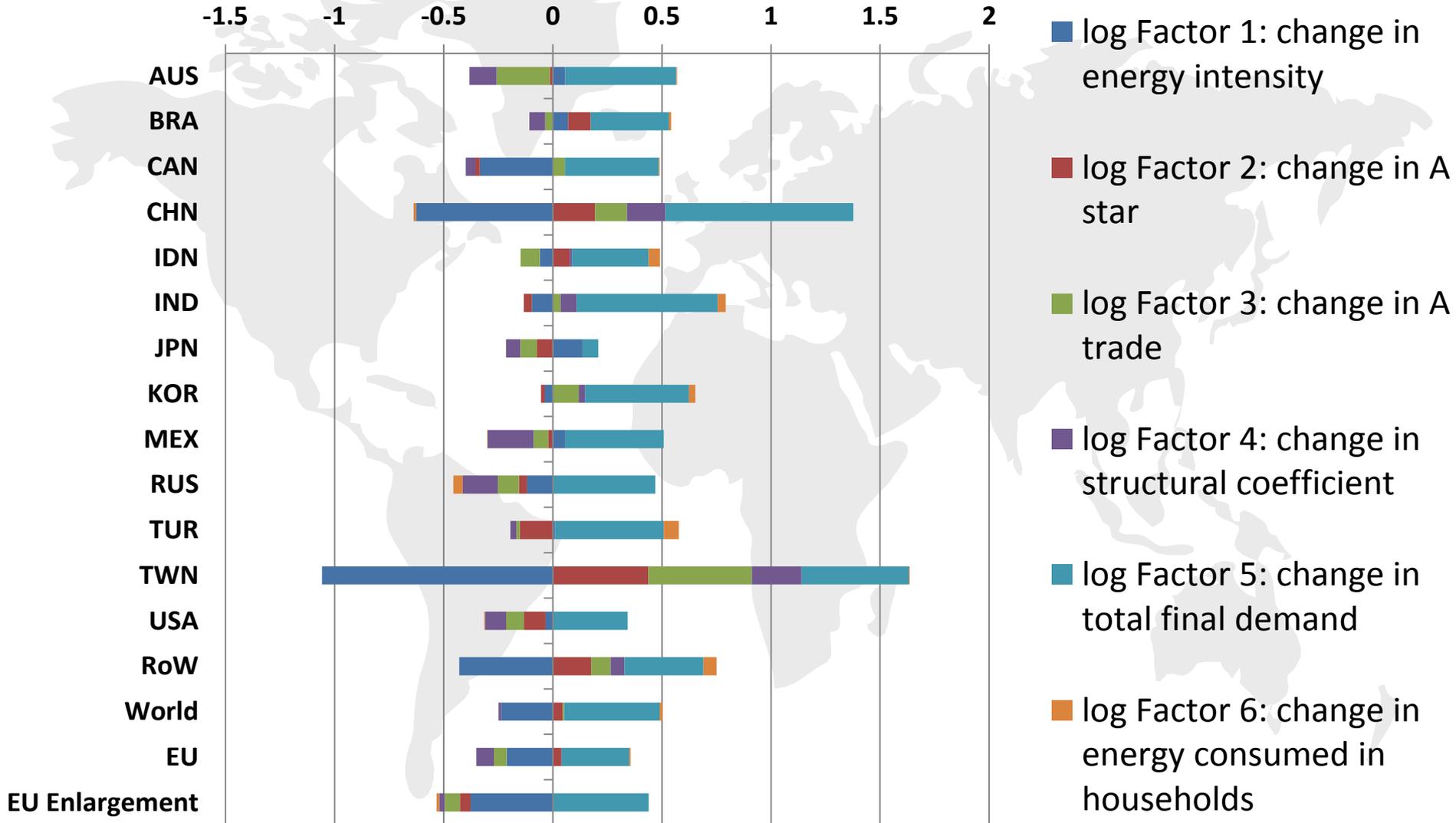| Economy	Change of supply side energy use	Change of demand side energy use
AUS	1.2054	1.7234
BRA	1.5439	1.5164
CAN	1.0937	1.2957
CHN	2.0936	1.9632
IDN	1.4098	1.6823
IND	1.9318	1.8699
JPN	0.9943	0.9507
KOR	1.8218	1.4585
MEX	1.2317	1.4251
RUS	1.0144	1.0076
TUR	1.4681	1.7035
TWN	1.7825	1.1615
USA	1.0296	1.1263
RoW	1.3804	1.3142
World	1.2901	1.2901
EU	1.0060	1.1148
EU Enlargement	0.9110	1.0865

- Structural decomposition of energy consumption: supply side and demand side:

  - Compensation effect:

    - The strongest positive factor: effect due to change in final demand;

    - The strongest negative factor: effect due to change in energy intensity;

  - Small household consumption effect.

- Structural decomposition of energy intensity: supply side and demand side:

  - The most crucial negative factor: effect due to change in energy intensity in sectors.
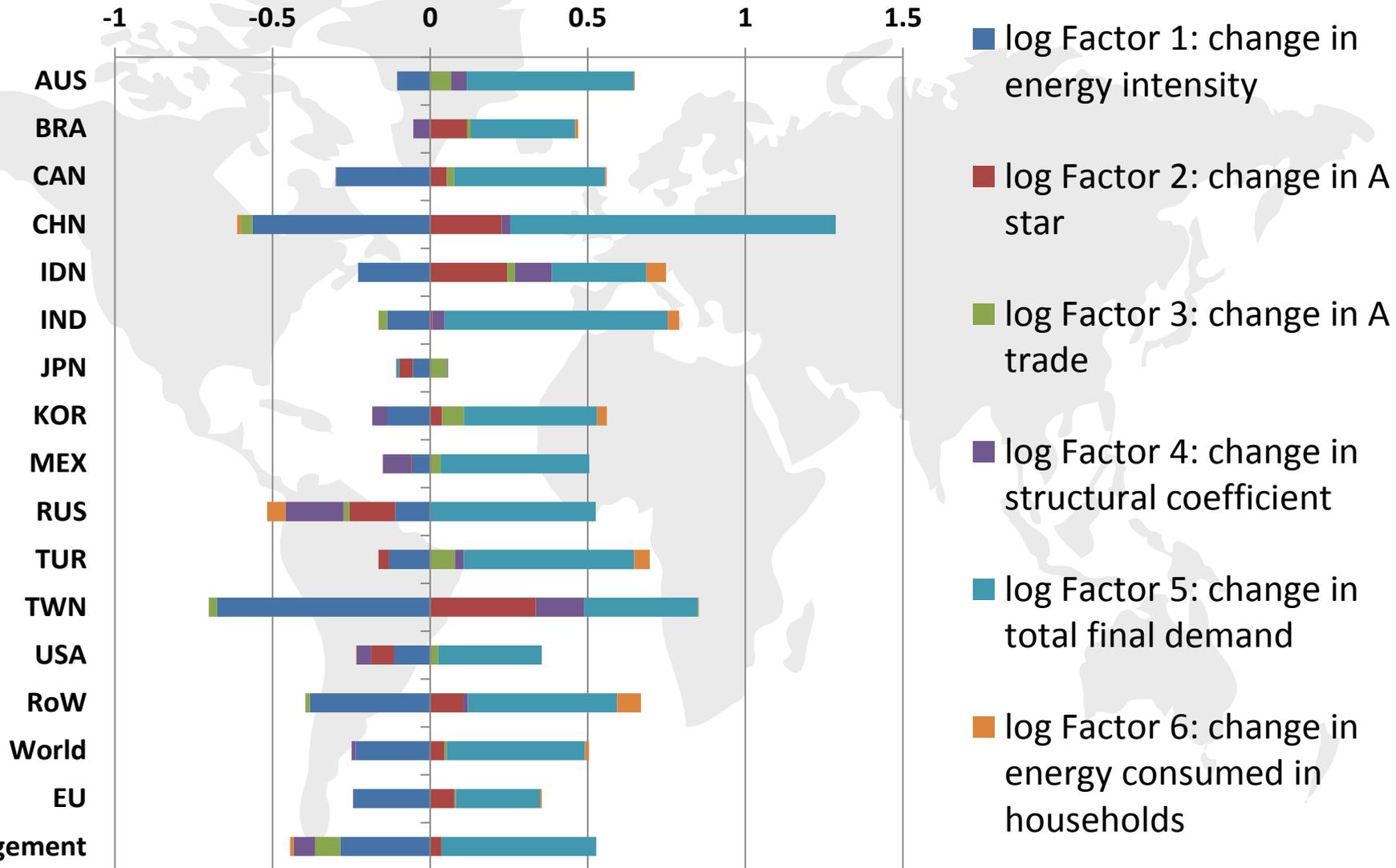
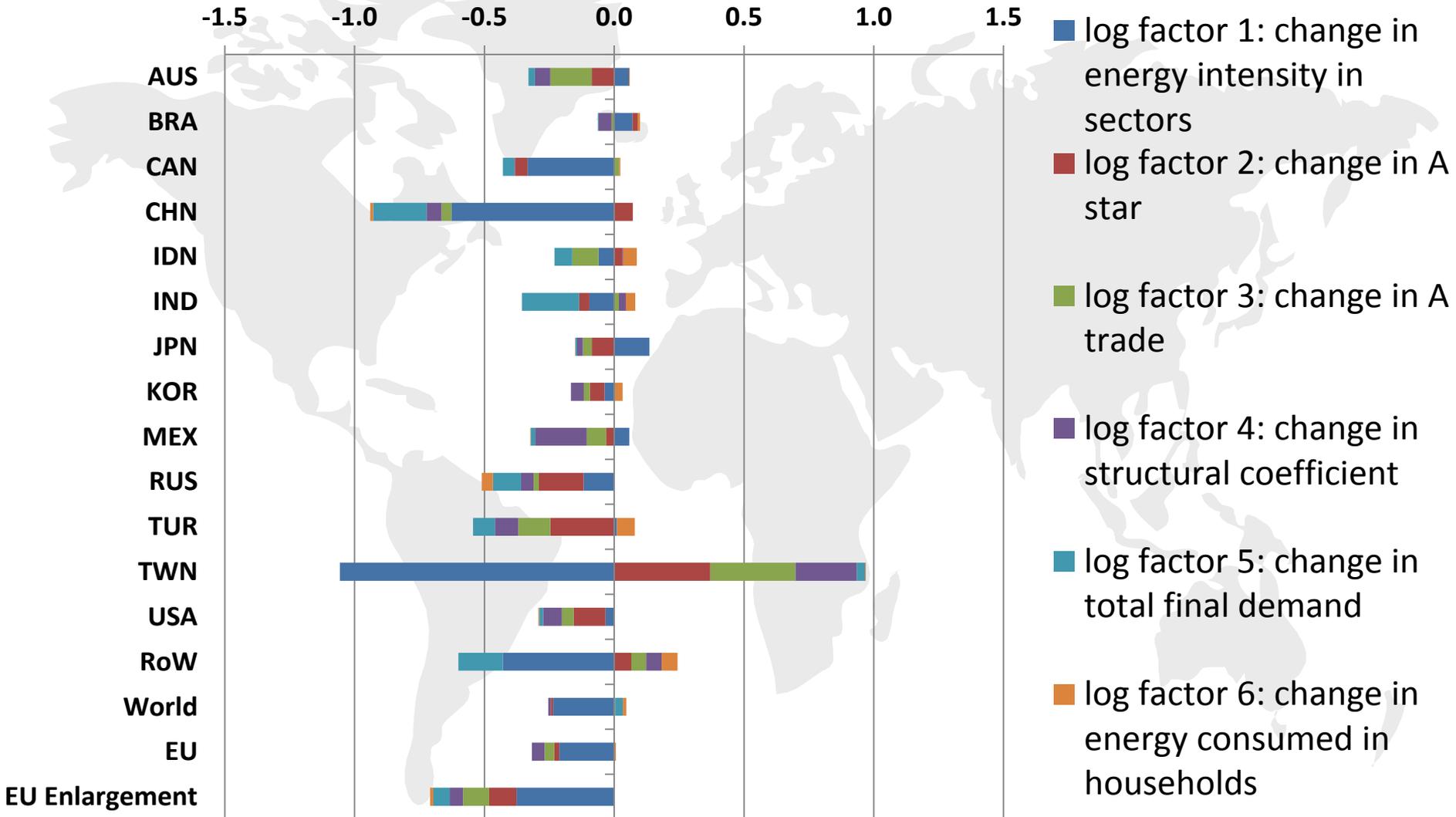- Energy consumption decomposition: supply side (log points)

Legend:
- log Factor 1: change in energy intensity
- log Factor 2: change in A star
- log Factor 3: change in A trade
- log Factor 4: change in structural coefficient
- log Factor 5: change in total final demand
- log Factor 6: change in energy consumed in households

3. Results

- Energy consumption decomposition: demand side (log points)

Legend:
- log Factor 1: change in energy intensity
- log Factor 2: change in A star
- log Factor 3: change in A trade
- log Factor 4: change in structural coefficient
- log Factor 5: change in total final demand
- log Factor 6: change in energy consumed in households

Countries/regions: AUS, BRA, CAN, CHN, IDN, IND, JPN, KOR, MEX, RUS, TUR, TWN, USA, RoW, World, EU, EU Enlargement

- Energy intensity decomposition: supply side (log points)

Legend:
- log factor 1: change in energy intensity in sectors
- log factor 2: change in A star
- log factor 3: change in A trade
- log factor 4: change in structural coefficient
- log factor 5: change in total final demand
- log factor 6: change in energy consumed in households

Chart categories (top to bottom): AUS, BRA, CAN, CHN, IDN, IND, JPN, KOR, MEX, RUS, TUR, TWN, USA, RoW, World, EU, EU Enlargement

Axis values: -1.5, -1.0, -0.5, 0.0, 0.5, 1.0, 1.5

- Energy intensity decomposition: demand side (log points)

log factor 1: change in energy intensity in sectors

log factor 2: change in A star

log factor 3: change in A trade

log factor 4: change in structural coefficient

log factor 5: change in total final demand

log factor 6: change in energy consumed in households
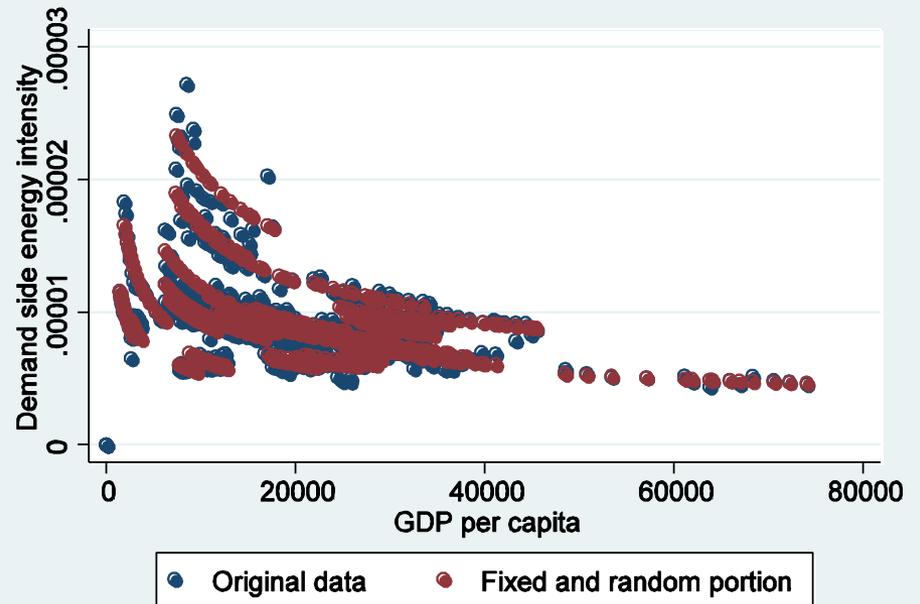
3. Results

- Convergence analysis (CYP and MLT are removed)

Supply side
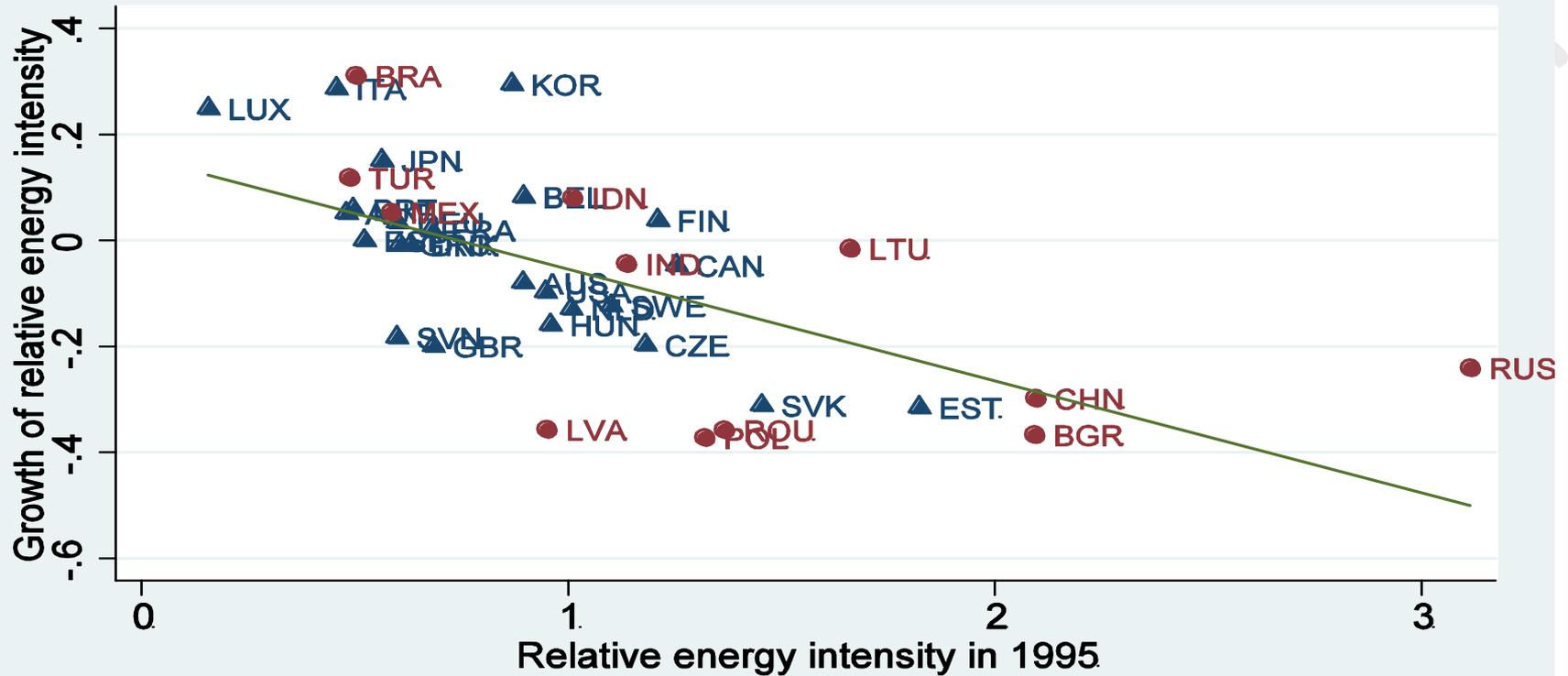
Own elaboration using WIOD and the World Bank data. Note that Cyprus and Malta are removed.

- Convergence analysis

Demand side
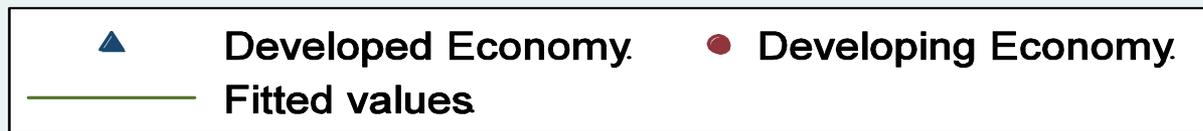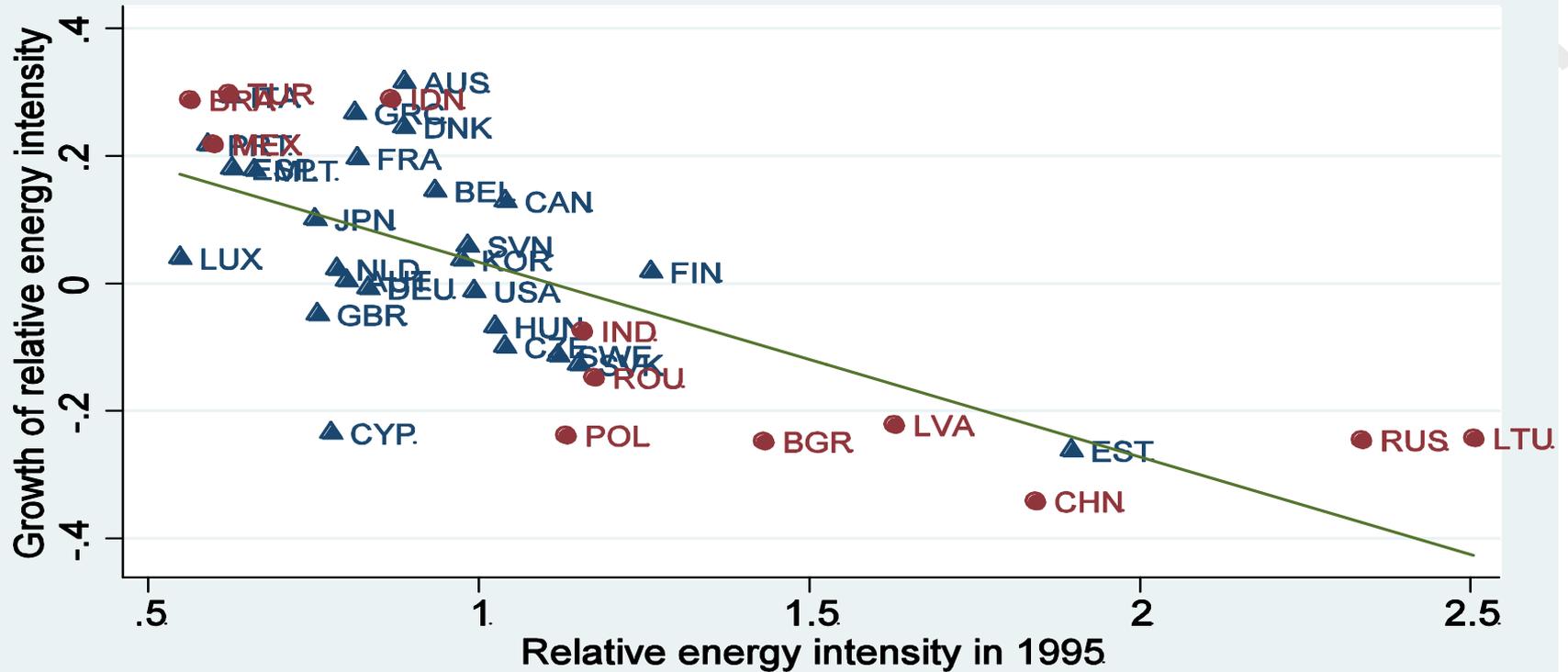
Own elaboration using WIOD and the World Bank data

- Multilevel mixed-effect model:

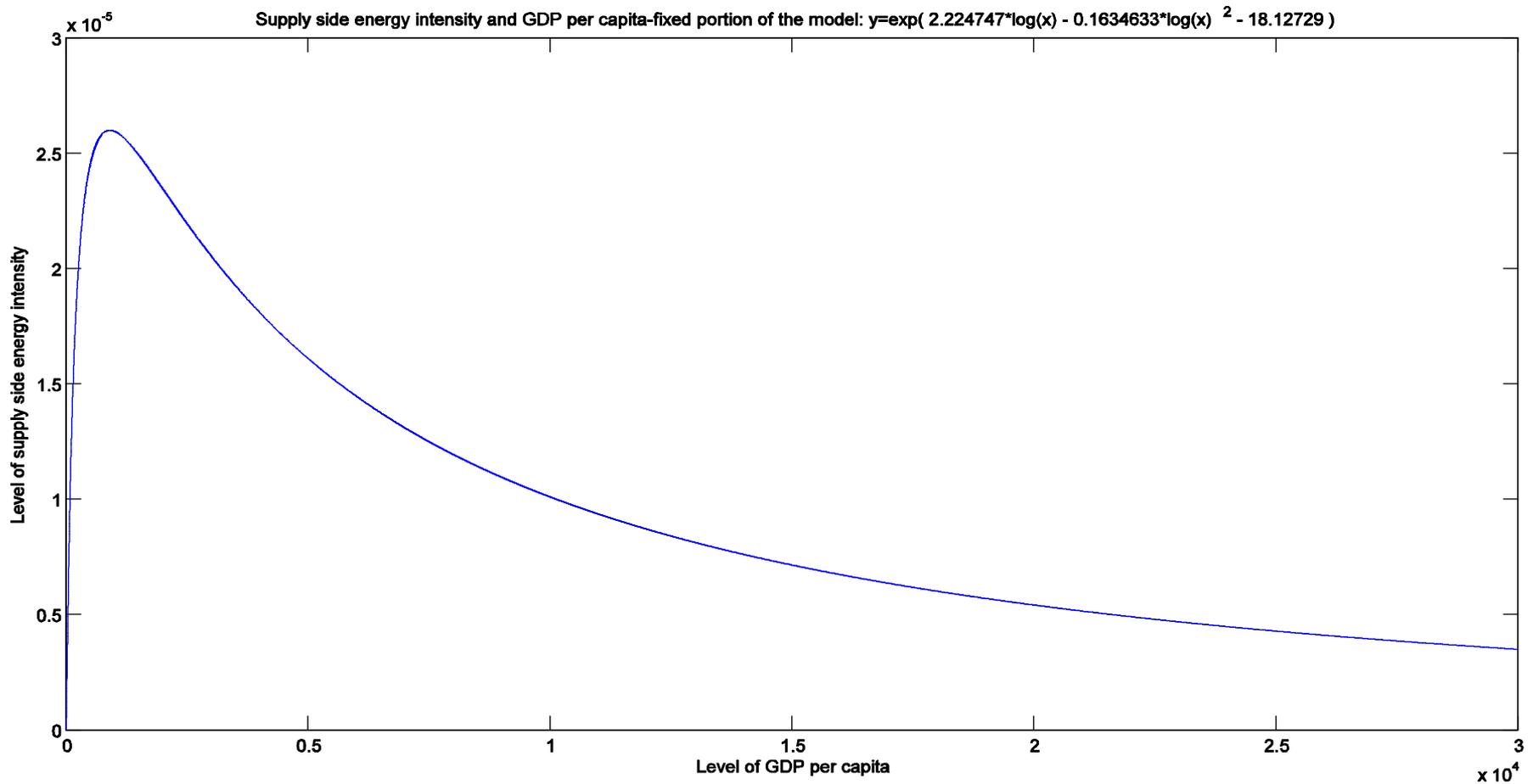|		Supply Side	Demand Side
Number of observations		574	580
Number of groups (group variable: economy)		39	39
Dependent variable		$\log EI_{t,j}^{Supply}$	$\log EI_{t,j}^{Demand}$
Independent variable	$\log GDP\_PC_{t,j}$	2.2247**	-0.8890***
		(0.8196)	(0.2329)
	$(\log GDP\_PC_{t,j})^2$	-0.1634***	0.0256**
		(0.0444)	(0.0125)
Constant		-18.1273***	-5.435859***
		(3.7706)	(1.0824)
Random-effects parameters	Sd($\log GDP\_PC_{t,j}$)	0.1315	
		(0.0150)	
	Sd(constant)	4.66e-11	0.3293
		(1.49e-07)	(0.0383)
	Sd(residual)	0.2715	0.0751
		(0.0083)	(0.0022)
Log likelihood		-178.9815	568.5664
Wald chi2		143.73***	476.37***
Chibar2		1358.33***	1290.69***

Note that: (1) *, ** and * denote for significance level at 10%, 5% and 1% respectively; (2) Std. Err. is in the brackets.**
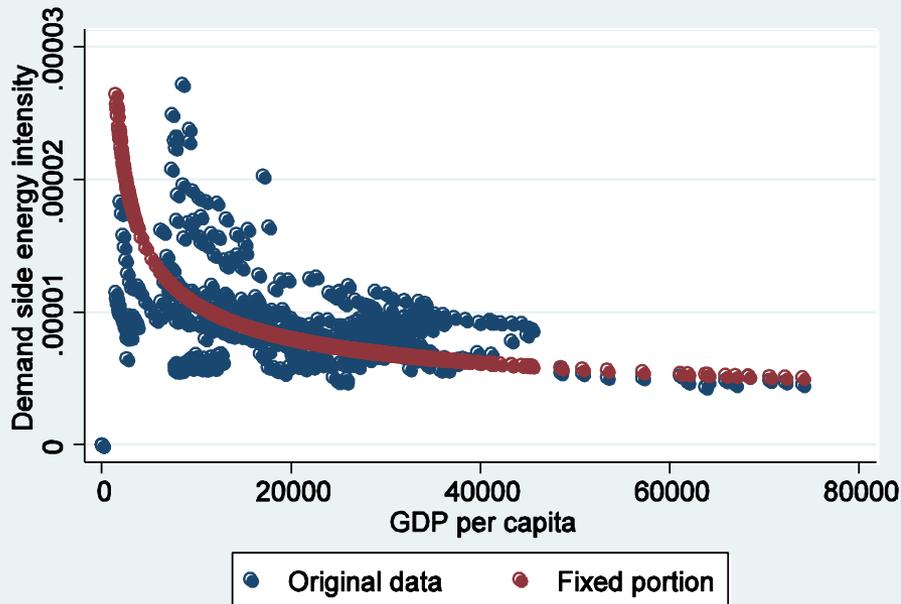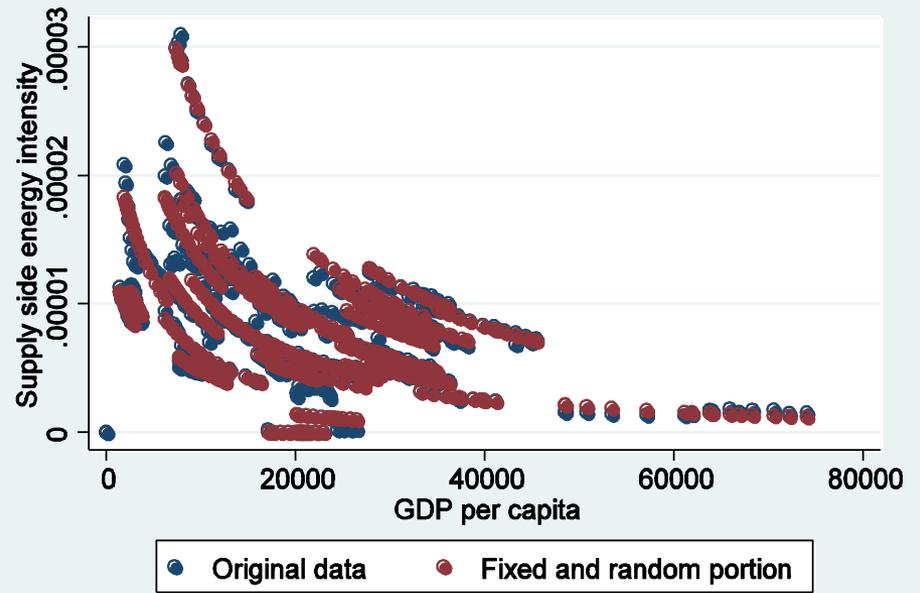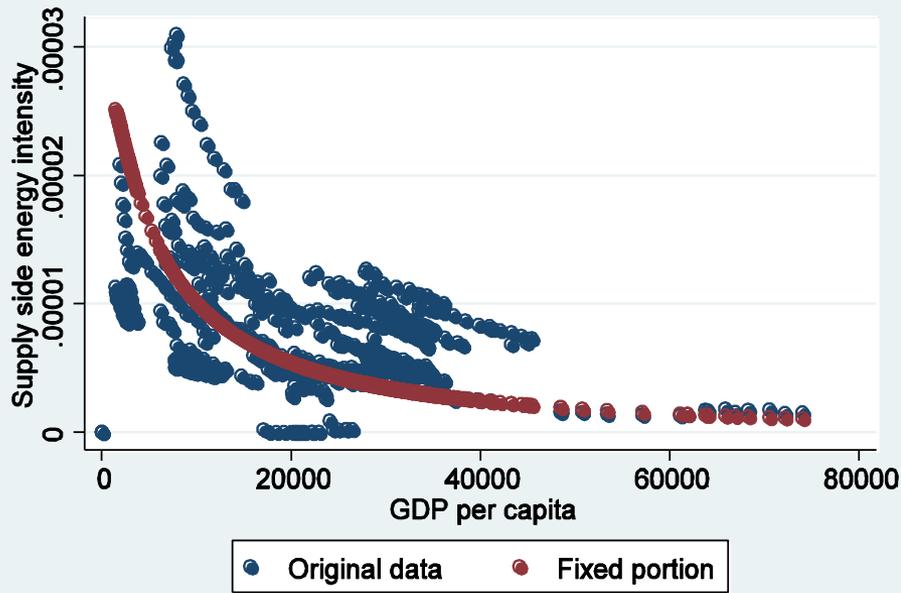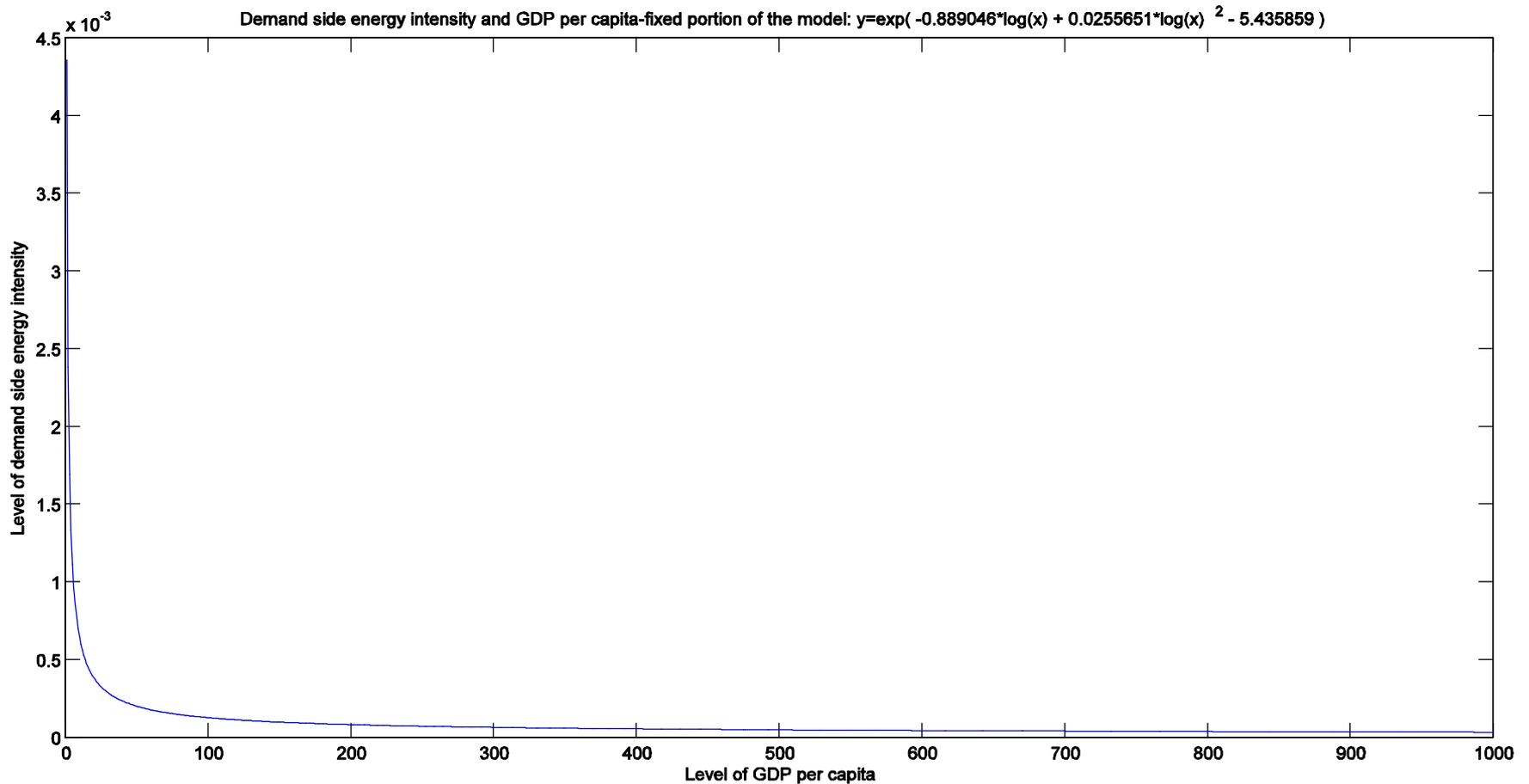
Source: Own elaboration

- Multilevel mixed-effect model

  - Supply side: prediction of fixed portion

Supply side energy intensity and GDP per capita-fixed portion of the model: $y=\exp(2.224747*\log(x) - 0.1634633*\log(x)^2 - 18.12729)$

- Multilevel mixed-effect model:

    - Demand side: prediction of fixed portion

Demand side energy intensity and GDP per capita-fixed portion of the model: y=exp(-0.889046*log(x) + 0.0255651*log(x)^2 - 5.435859)

- For development: can developing countries reach the stage of development that is comparable to that of developed countries?

- Structural decomposition

  - Larger increase in supply side energy use in manufacturing economies

    - Manufacturing outsourcing;

  - Energy consumption:

    - Compensation effect: increase in energy use driven by final demand effect can be largely (or partially) offset by energy efficiency effect;

  - Energy intensity:

    - Crucial role of reducing energy intensity in sectors.

- Convergence analysis:

  - For supply side and demand side, energy intensity converges on the world level (the world level is 1)

    - Probably because of technology diffusion through trade

- Multilevel mixed-effect model: relationship between energy intensity and GDP per capita

  - Supply side: probably an inverted-U relationship

  - Demand side: strictly decreasing

Thank You for Your Attention!

- **Comments?**
- **Questions?**

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- What to do next?

Empirical examination – to understand the world better: "what it is"		Theoretical modeling – to make a better decision with scarce resources: "what it should be"	
Macro level	Micro level	Computational economics methods	Traditional optimal control method (if possible)
Energy consumption and energy intensity decomposition; CO_2 emission decomposition	Firm level, household level and building level data; quasi-experimental designs: causality or correlation?	Agent-based model: to design optimal policy scenario. "Policy engineering"	

- WIOD energy consumption data structure in a single year: 41 major economies and 35 sectors:

Energy user	Energy consumption vector (in TJ): Sum of primary energy
Sector 1 in Economy 1	
…	
Sector 35 in Economy 1	
…	
Sector 1 in Economy 41	
…	
Sector 35 in Economy 41	

- Primary energy: hard coal, natural gas, hydroelectric, lignite, geothermal, crude oil, heat, solar, wind power, other renewable energy, nuclear, other sources.

Appendix

- Input-Output model:

$$A = Z\hat{x}^{-1}; \text{ where:}$$

A: matrix of production coefficients; Z: matrix of intermediate inputs;

$\hat{x}$: diagonal matrix of gross outputs;

Then,

$$x = Z + f = Ax + f; \text{ where:}$$

f: matrix of final demands;

Then,

$$x = (I - A)^{-1}f; \text{ where:}$$

$(I - A)^{-1}$: Leontief inverse matrix.

Appendix

- Expressions of primary energy consumption for each economy:

  - Supply side: $E_s = n\hat{e}(I - A^{*\circ}A^T)^{-1}sC + H$

  - Demand side: $E_d = r\hat{e}(I - A^{*\circ}A^T)^{-1}s\hat{C} + H'$

- E_s: supply side energy use vector (41*1); E_d: demand side energy use vector (1*41); $\hat{e}$: diagonal matrix of energy intensity (1435*1435); I: identity matrix (1435*4135); s: final demand structural coefficient matrix (1435*41), the share of a sector in an economy's final demand; $\hat{C}$: diagonal matrix (41*41) of final demand vector C (41*1);

- A^*: matrix of aggregate intermediate inputs per unit of gross output by sector by country (1435*1435); for flows from Sector i in Country r to Sector j in Country s, $\forall r$: $[A^*]_{ij}^{rs} = \sum_1^{41} A_{ij}^{rs}$;

- A^T : matrix of intermediate trade coefficients (1435*1435); defined as: $[A^T]_{ij}^{rs} = A_{ij}^{rs}/[A^*]_{ij}^{rs}$;

- H: vector of energy used in households (41*1); r: summation vector for column sum (1*1435);

- n: economy aggregation matrix (41*1435):

	Sector 1 in Economy 1	Sector 2 in Economy 1	…	Sector 1 in Economy 2	…
Economy 1	1	1	…	0	…
Economy 2	0	0	…	1	…
…	…	…	…	…	…

Appendix

- Example of supply side: inflation correction using chain mechanism

  - The value of US$ is changing over time;

  - $Change\ between\ 1995\ and\ 2009 = \prod_{i=1995}^{2008} \frac{the\ year\ (i+1)'s\ data\ in\ previous\ years\ prices}{the\ year\ i's\ data\ in\ current\ prices}$;

  - The second decomposition method:
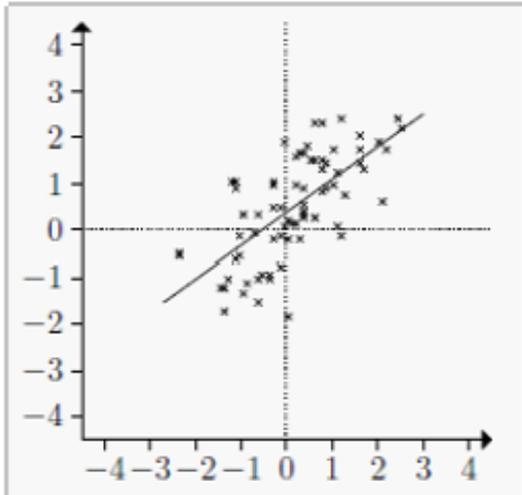
    - just need to reverse the subscripts of the weights

    - Example: $factor\ 6 = \frac{e_0'L_0f_0 + tH_1}{e_0'L_0f_0 + tH_0}$
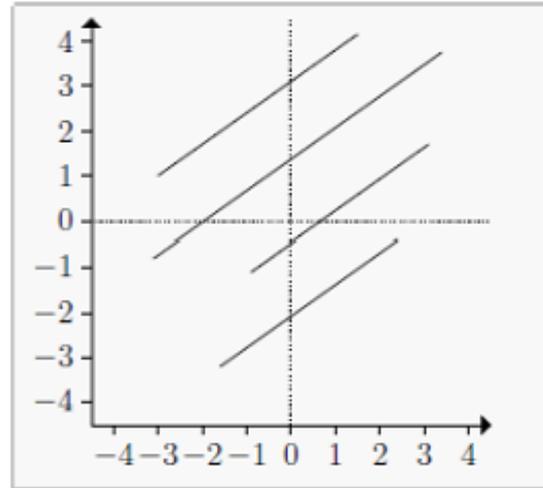
  - The average of log points of results from two methods:

  - $\log(final\ result) = \frac{\log(result\ from\ Method\ 1) + \log(result\ from\ Method\ 2)}{2}$
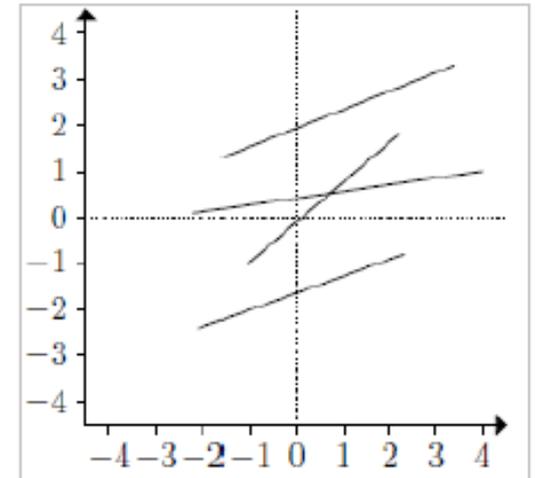
- Multilevel mixed-effect model (MME)

  - (1) Normal OLS, (2) MME model with random intercept, and (3) MME model with random intercept and random slope.

(1)   (2)   (3)

Appendix

- For example, MME specification on supply side:

Name	Type	Dependent variable	Independent variable	Likelihood ratio test result
Model 1	Only random intercept	Log of supply side energy intensity	Log of GDP per capita	Model 4 selected from all the 4 models, using likelihood ratio test
Model 2			Log of GDP per capita and square of log of GDP per capita	
Model 3	Random intercept and random slope		Log of GDP per capita	
Model 4			Log of GDP per capita and square of log of GDP per capita	