Explaining Trends in Aggregate and Sectoral Energy Intensity

The Sectoral Energy Intensity Gap

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Outline

The Sectoral Energy Intensity Gap

Given the sectoral energy intensity in a sector $j \in \{m, s\}$, $\theta_{jt} = \frac{E_{jt}}{Y_{jt}}$, the **sectoral energy intensity gap** between manufacturing and services is

$$\chi_t \equiv \frac{\theta_{mt}}{\theta_{st}} > 1.$$

Why is the sectoral energy intensity gap important?

1. Environmental policy has **uneven effects across sectors** because of the intensity gap (cfr. CGE literature);
2. The aggregate impact of environmental policy might be increasing in the intensity gap in the long-run;
3. The intensity gap varies over time, differently across countries;

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Sectoral Energy Intensity Gap: Policy Impact

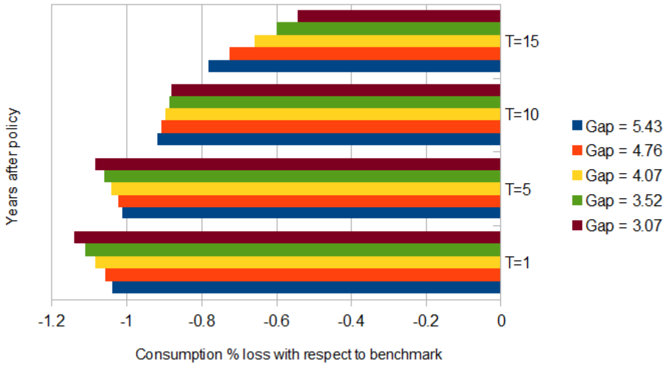

Figure: Percentage deviation from benchmark (no policy) of aggregate consumption, as function of the sectoral intensity gap. Policy: 20% cut in energy supply. Own calculation with basic model (see next).

Sectoral Energy Intensity Gap: Some Evidence

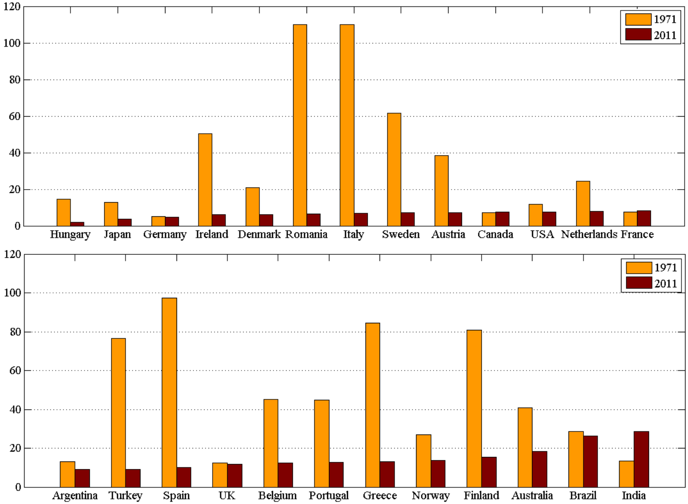

Figure: Relative energy intensity, manufacturing over services (IEA and UNSTAT, (*) 1975)

Outline

Looking for a Theory

- Basic Model: a **standard two-sector model** with exogenous TFP
  - closed economy;
  - CES final demand of sectoral goods and services;
  - non-homothetic demand (income elasticity of services > 1);
  - Cobb-Douglas production technology with labour and energy;
  - Sector-specific TFP;

Model: Exogenous TFP and Input Prices

Drivers of changes in the intensity gap:

$$\hat{\chi}_t \equiv \hat{\theta}_{mt} - \hat{\theta}_{st} = \hat{A}_{st} - \hat{A}_{mt} + (\alpha_m - \alpha_s)(\hat{p}_{Et} - \hat{w}_t),$$

- sectoral differences in **TFP growth** $\hat{A}_{jt}$,

  $\hat{A}_{mt} - \hat{A}_{st} \xrightarrow{-} \hat{\chi}_t$ (gap decreases);

- relative **input prices**,

  $\hat{p}_{Et} - \hat{w}_t \xrightarrow{+} \hat{\chi}_t$ (gap increases);

  given that the industrial sector has a higher energy cost share, $\alpha_m > \alpha_s$.

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Model: the role of Structural Transformation

- the sectoral energy intensity gap χ_t depends on relative prices

$$\chi_t = \frac{\mu_m}{\mu_s}\frac{A_{st}}{A_{mt}}\left(\frac{p_{Et}}{w_t}\right)^{\alpha_m-\alpha_s},$$

- relative prices depend on sectoral composition because sectors have heterogeneous factor cost shares $\alpha_m \neq \alpha_s$:

$$\frac{w_t}{p_{Et}} = \left[\frac{(1-\alpha_s)-(\alpha_m-\alpha_s)\omega_m}{(\alpha_m-\alpha_s)\,\omega_m+\alpha_s}\right]\frac{\bar{E}_t}{\bar{L}_t},$$

given the relative endowment of energy per worker $\frac{\bar{E}_t}{\bar{L}_t}$ and the manufacturing output share ω_m.

Outline

Model Calibration (1)

Table: Parameter Values

Parameter	Value	Target (Source)
Elasticities, Shares and Endowments		
ε	0.5	(Literature)
π	[0.23 - 0.42]	(Data)
α_m	[.147 - .368]	Manufacturing share on total labour employment
α_s	[.201 - .14]	Service share on total labour employment
$\bar{y}_s$	[.]	Aggregate consumption level
Productivity		
A_{mt}/A_{st}	[.]	Manufacturing share on value added

Model Calibration (2)

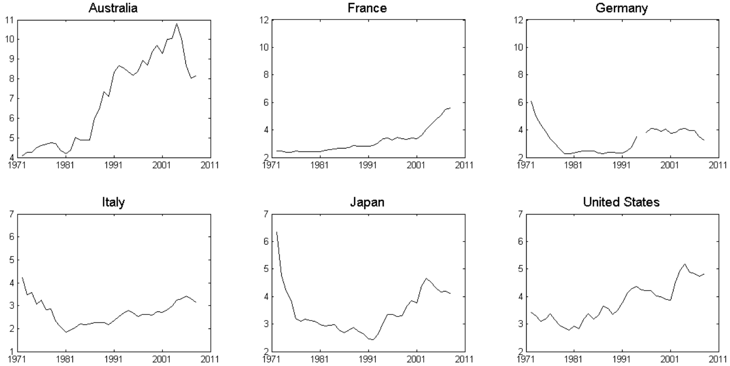

Figure: Relative sectoral TFP A_{mt}/A_{st}, selected countries (from model).

Drivers of the Sectoral Intensity Gap

Table: Counterfactual Exercises

	Contribution of	
	Factor Markets	relative TFP
Australia	.03	.97
Canada	.11	.89
Denmark	.04	.96
Finland	.33	.67
France	.03	.97
Germany	-	-
Italy	.08	.92
Japan	.07	.93
United States	.16	.84

Potential Extensions

Three extensions:

- *price-induced technological change (policy sensitive)*;
  Standard framework, with *endogenous research in productivity*, i.e. Bretschger and Pittel (2010).

$$\hat{p}_{Et} - \hat{w}_t \xrightarrow{-} \hat{\chi}_t \text{ (gap decreases)};$$

- *distance to frontier,* $\bar{\theta}_{jt}/\theta_{jt}$ *(unconditional convergence,* cfr. Rodrik 2013*)*;

$$\Delta_{it} = \underbrace{ln\left(\theta_{m,it}/\theta_{s,it}\right)}_{\text{Gap in the country}} - \underbrace{ln\left(\bar{\theta}_{mt}/\bar{\theta}_{st}\right)}_{\text{Gap on frontier}} \xrightarrow{-} \hat{\chi}_t \text{ (gap decreases)};$$

- *open economy,*
  manufacturing exposure to international trade;

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Final Remarks

Wrap-up:

- The sectoral energy intensity gap is important for the cost of environmental policy;
- We need theory-based investigations of the energy intensity gap between manufacturing and services;
- sectoral productivity (TFP) is the major driver of the intensity gap;
- policy might affect the sectoral intensity gap mostly through technological progress, not factor markets directly;

Open issues:

- more detailed understanding of how manufacturing and services changed over time;
- Endogenise energy supply;
- Extend results to more countries.

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Looking forward to your comments

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Model Overview

- Tailored to developed countries: manufacturing and service sectors;
- non-homothetic preferences;
- heterogeneous TFP growth across sectors;
- production inputs: labour and energy (no capital);
- intermediate goods omitted, constant fraction of output (sectoral value added functions exist).

Preferences

Infinitely living household with preferences over a sequence of final consumption bundles $\{C_t\}$ given by:

$$U = \sum_{t=0}^{\infty} \delta^t \ln C_t, \tag{1}$$

with $0 < \delta < 1$. In each period the final consumption bundle is an aggregation of sectoral consumption goods as

$$C_t = \left[\pi (y_m)^{\frac{\varepsilon - 1}{\varepsilon}} + (1 - \pi)(y_s + \bar{y}_s)^{\frac{\varepsilon - 1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon - 1}}, \tag{2}$$

where $0 < \pi < 1$, $\varepsilon < 1$ and $\bar{y}_s > 0$.

Sectoral Technology

The production function for sector j, $j \in \{m, s\}$, is

$$Y_{jt} = A_{jt} E_{jt}^{\alpha_j} L_{jt}^{1-\alpha_j}, \tag{3}$$

Assumptions:

- manufacturing is more energy-intensive: $\alpha_m > \alpha_s$;
- TFP is sector-specific and $\hat{A}_{mt} > \hat{A}_{st}$;

Sectoral Energy Intensity

Sectoral energy intensities in each sector:

$$\theta_{jt} = \frac{E_{jt}}{Y_{jt}} = \frac{\mu_j}{A_{jt}} \left(\frac{w_t}{p_{Et}} \right)^{1-\alpha_j}, \tag{4}$$

Difference in the sectoral energy intensity gap

$$\hat{\chi}_t = [1 + (\alpha_m - \alpha_s)\Lambda_2 (1-\varepsilon)] \left(\hat{A}_{st} - \hat{A}_{mt} \right) - (\alpha_m - \alpha_s)\Lambda_1 \widehat{\left(\frac{\bar{E}_t}{\bar{L}_t} \right)} - (\alpha_m - \alpha_s)\Lambda_2 \hat{\psi}_s$$

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Structural Transformation

Manufacturing expenditure share

$$\omega_m = \frac{1}{1 + \psi_s \left(\frac{1-\pi}{\pi}\right)^{\varepsilon} \left(\frac{p_s}{p_m}\right)^{1-\varepsilon}}. \tag{5}$$

Market Equilibrium

7 variables (c_t, ω_m, ϑ_L^m, ϑ_L^s, y_{mt}, y_{st} and ψ_s) and 7 equations.
Per capita aggregate consumption

$$c_t \equiv \frac{C_t}{L_t} = \left[\pi \left(\vartheta_L^m y_m \right)^{\frac{\varepsilon - 1}{\varepsilon}} + (1 - \pi) \left(\vartheta_L^m y_s + \frac{\bar{y}_s}{L} \right)^{\frac{\varepsilon - 1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon - 1}},$$

$$\psi_s = \frac{1}{1 + \frac{\frac{\bar{y}_s}{L} / c_t}{(1 - \omega_m)}}$$

Market Equilibrium (cont.)

Sectoral output per worker

$$y_{mt} = A_{mt} \left(\left[\frac{(1-\alpha_s) - (\alpha_m - \alpha_s)\omega_m}{(\alpha_m - \alpha_s)\,\omega_m + \alpha_s} \right] \frac{\bar{E}_t}{\bar{L}_t} \right)^{\alpha_m} \tag{6}$$

$$y_{st} = A_{st} \left(\left[\frac{(1-\alpha_s) - (\alpha_m - \alpha_s)\omega_m}{(\alpha_m - \alpha_s)\,\omega_m + \alpha_s} \right] \frac{\bar{E}_t}{\bar{L}_t} \right)^{\alpha_s} \tag{7}$$

Market Equilibrium (cont.)

Manufacturing output share and sectoral employment shares

$$\omega_m = \left[1 + \psi_s \left(\frac{1-\pi}{\pi} \right)^{\varepsilon} \left(\frac{A_{mt}}{A_{st}} \frac{\alpha_m}{\alpha_s} \frac{\mu_s}{\mu_m} \right)^{1-\varepsilon} \left(\left[\frac{(1-\alpha_s)-(\alpha_m-\alpha_s)\omega_m}{(\alpha_m-\alpha_s)\,\omega_m+\alpha_s} \right] \frac{\bar{E}_t}{\bar{L}_t} \right)^{(\alpha_m-\alpha_s)}$$

$$\vartheta_L^m \equiv \frac{L_{mt}}{L} = \frac{(1-\alpha_m)\omega_m}{(1-\alpha_m)\omega_m+(1-\alpha_s)\omega_s}$$

$$\vartheta_L^s \equiv \frac{L_{st}}{L} = \frac{(1-\alpha_m)(1-\omega_m)}{(1-\alpha_m)\omega_m+(1-\alpha_s)\omega_s}$$

Ext. 1: Price-Induced Technological Change

Standard framework, with *endogenous research in productivity*, i.e. Bretschger and Pittel (2010).

Relative **input prices** determine sectoral differences in energy intensity change $\hat{\chi}_t$:

$$\hat{p}_{Et} - \hat{w}_t \xrightarrow{-} \hat{\chi}_t \text{ (gap decreases);}$$

given a higher cost share in the industrial sector and complementarity between goods in final demand. There are now two effects:

1. $\hat{p}_{Et} - \hat{w}_t \xrightarrow{+} \hat{\chi}_t$, as in the base model;
2. $\hat{p}_{Et} - \hat{w}_t \xrightarrow{-} \hat{\chi}_t$,
   because $\hat{p}_{Et} - \hat{w}_t \xrightarrow{+} \hat{A}_{mt} - \hat{A}_{st}$ and $\hat{A}_{mt} - \hat{A}_{st} \xrightarrow{-} \hat{\chi}_t$

Ext. 2: Distance to Frontier

Standard framework, with endogenous sectoral productivity driven by the international technology frontier.

Determinants of sectoral differences in energy intensity change $\hat{\chi}_t$:

- **distance to sector-specific frontier**, $\bar{\theta}_{jt}/\theta_{jt}$, (the installed technology might lag behind the available technological frontier)

$$\Delta_{it} = \underbrace{ln\left(\bar{\theta}_{mt}/\bar{\theta}_{st}\right)}_{\text{Gap on frontier}} - \underbrace{ln\left(\theta_{m,it}/\theta_{s,it}\right)}_{\text{Gap in the country}} \xrightarrow{+} \hat{\chi}_t \text{ (gap increases);}$$

Ext. 2: Distance to Frontier

Figure: Relationship between Δ_{it} and $\hat{\chi}_t$.

Static vs Dynamic Efficiency Improvements

Achilles or the Tortoise?

- **Manufacturing sector** (Achilles),
  relatively high energy intensity but *high productivity growth*.
- **Service sector** (Tortoise),
  relatively low energy intensity but *low productivity growth*.

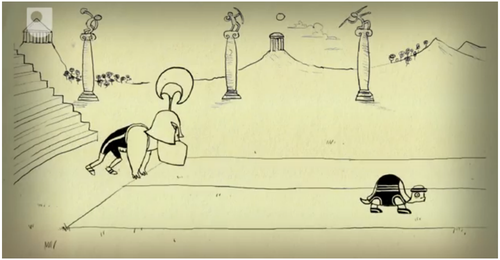

Figure: Manufacturing vs Services: a new paradox?