The Elasticity of Substitution between Clean and Dirty Inputs in the Production of Electricity

Martino Pelli

University of Lausanne – Department of Economics (deep)

Envecon 2011 – The Royal Society, London

Motivation

It is widely agreed that an **economic development** based on an intensive **depletion of natural resources** like the one we observe now **cannot be sustained in the long run**.

In order to understand how our economic development works and how we could change it we need a good understanding of the **true aggregate production function of the economy**.

This paper investigates the **elasticity of substitution between renewable and non renewable inputs** in a fundamental part of production. The one dealing with the **production of energy**.

Impossible to proceed in a standard way because of the lack of data.

Therefore, I use a model of endogenous growth in order to obtain an **estimable expression** for this elasticity.

This elasticity of substitution is key in understanding the **evolution of technical change** between renewable and non renewable resources. [*The Environment and Directed Technical Change*, Acemoglu et al. (2009)]

This helps formulating policies helping the switch in the direction of technical change. Mainly via **subsidies** to renewable research and **carbon taxes**.

The worse case scenario depicted in Acemoglu et al. (2009) assumes 3 as a value for the elasticity of substitution

i. Weak substitutes
ii. Switch comes only in 45 years
iii. Only with a carbon tax, increasing over the coming 300 years
iv. Coupled with important research subsidies

I find a value for the elasticity of **0.5**, meaning that the two inputs are complements.

The Model

The Model used is the one developed in Acemoglu et al. (2009), *The Environment and Directed Technical Change*.

It consists of an infinite-horizon discrete-time economy inhabited by a continuum of households comprising workers, entrepreneurs and scientists.

$$U = \sum_{t=0}^{\infty} \frac{1}{(1+\rho)^t} u(C_t, S_t) \qquad S_t \in [0, \bar{S}]$$

The final good (C_t) is produced with a CES production function

$$Y_t = (Y_{ct}^{-\sigma} + Y_{dt}^{-\sigma})^{-\frac{1}{\sigma}} \qquad \sigma = \frac{\varepsilon - 1}{\varepsilon}$$

The two intermediate goods are produced using Labor and a continuum of sector specific Machines

$$Y_{ft} = (L_{ft}A_{ft})^{1-\alpha} \int_0^1 x_f(\nu, t)^\alpha d\nu \qquad f \in \{c, d\}$$

The **average quality of machines** in a given sector evolves in the following way

$$A_{ft} = (1 + \gamma \eta_f s_{ft}) A_{f(t-1)} \qquad \gamma, \eta, s \in (0, 1)$$

Environmental quality S_t evolves in the following way

$$S_{t+1} = -\xi Y_{dt} + (1 + \delta) S_t \qquad \xi, \delta > 0$$

Laissez Faire Equilibrium

In this model the direction of technical change is dictated by the **scientists** decision to do research in one of the 2 sectors

→ **profit incentives**

$$\frac{\pi_{ct}}{\pi_{dt}} = \frac{\eta_c}{\eta_d} \underbrace{\left(\frac{p_{ct}}{p_{dt}}\right)^{\frac{1}{1-\alpha}}}_{Price\, E.} \underbrace{\frac{L_{ct}}{L_{dt}}}_{Market\, Size\, E.} \underbrace{\frac{A_{c(t-1)}}{A_{d(t-1)}}}_{Dir\, Prod\, E.}$$

Three forces shape this ratio:

i. *Price Effect* which encourages innovation toward the sector with higher prices

ii. *Market Size Effect* which encourages innovation in the sector with greater employment

iii. *Direct Productivity Effect*, innovation happens in the sector with higher productivity

Case I : The Inputs are Substitutes $\varepsilon > 1$

Innovation starts in the more advanced sector.
In the long term only A_d will grow and the aggregate growth rate of the economy will be $\gamma\eta_d$ → Environmental Disaster

Subsidies
$$\frac{\pi_{ct}}{\pi_{dt}} = (1+q_t)\frac{\eta_c}{\eta_d}\left(\frac{p_{ct}}{p_{dt}}\right)^{\frac{1}{1-\alpha}}\frac{L_{ct}}{L_{dt}}\frac{A_{c(t-1)}}{A_{d(t-1)}}$$

- Strong Substitutes → Temporary Subsidies
- Weak Substitutes → Permanent Subsidies

Case II : The Inputs are Complements $\varepsilon < 1$

Innovation starts in the more backward sector.
Once the backward sector catches up the two sectors keep growing at the same rate → Environmental Disaster

Derivation of the Elasticity of Substitution

Hypothesis	Perfect Capital Mobility between sectors within a country

This implies equality in the marginal products of capital in the 2 sectors, i.e.

$$\frac{MPK_c}{MPK_d} = 1 = \left(\frac{L_{ct}A_{ct}}{L_{dt}A_{dt}}\right)^{\sigma(\alpha-1)} \left(\frac{x_{ct}}{x_{dt}}\right)^{-\alpha\sigma-1}$$

From this I compute one estimable expression for the elasticity of substitution

$$\varepsilon = \frac{\alpha(X-N)+N}{\alpha(X-N)+N+X}$$

Where $N \equiv \ln\left(\frac{L_{ct}A_{ct}}{L_{dt}A_{dt}}\right)$ and $X \equiv \ln\left(\frac{x_{ct}}{x_{dt}}\right)$

I am able to apply this equation for the US, for other countries I have to go on to another expression.
From the model, I know that

$$p_t \equiv \frac{p_{ct}}{p_{dt}} = \left(\frac{Y_{ct}}{Y_{dt}}\right)^{-\sigma-1}$$

Hypothesis The price ratio equalizes between 2 countries

$$p_{tUS} = p_{tj}$$

And solve it for ε_j

$$\varepsilon_j = \frac{1}{2 + \frac{P}{Y}}$$

Where $P \equiv \ln(p_{tUS})$ and $Y \equiv \ln\left(\frac{Y_{ctj}}{Y_{dtj}}\right)$

Data

All data are expressed in *btu*, i.e. British Thermal Units

US *(U.S. Energy Information Administration)*

Data on : - Electricity Production (renewable vs non renewable)
- Capital used in Electricity Production (ren vs non ren)

Europe – D, UK, F, I, E, Nor, CH *(Eurostat)*

World – Aus, J, Tur, NZ, Mex, SouthK, Can, Bra, Chile, CN, Rus, Ind *(International Energy Agency)*

Data on : - Electricity Production (renewable vs non renewable)

The production function for the intermediate goods is Cobb-Douglas, hence I retrieve the value for efficient labor

$$L_{ft}A_{ft} = \left(\frac{Y_{ft}}{x_{ft}^{\alpha}}\right)^{\frac{1}{1-\alpha}}$$

Non Renewable:

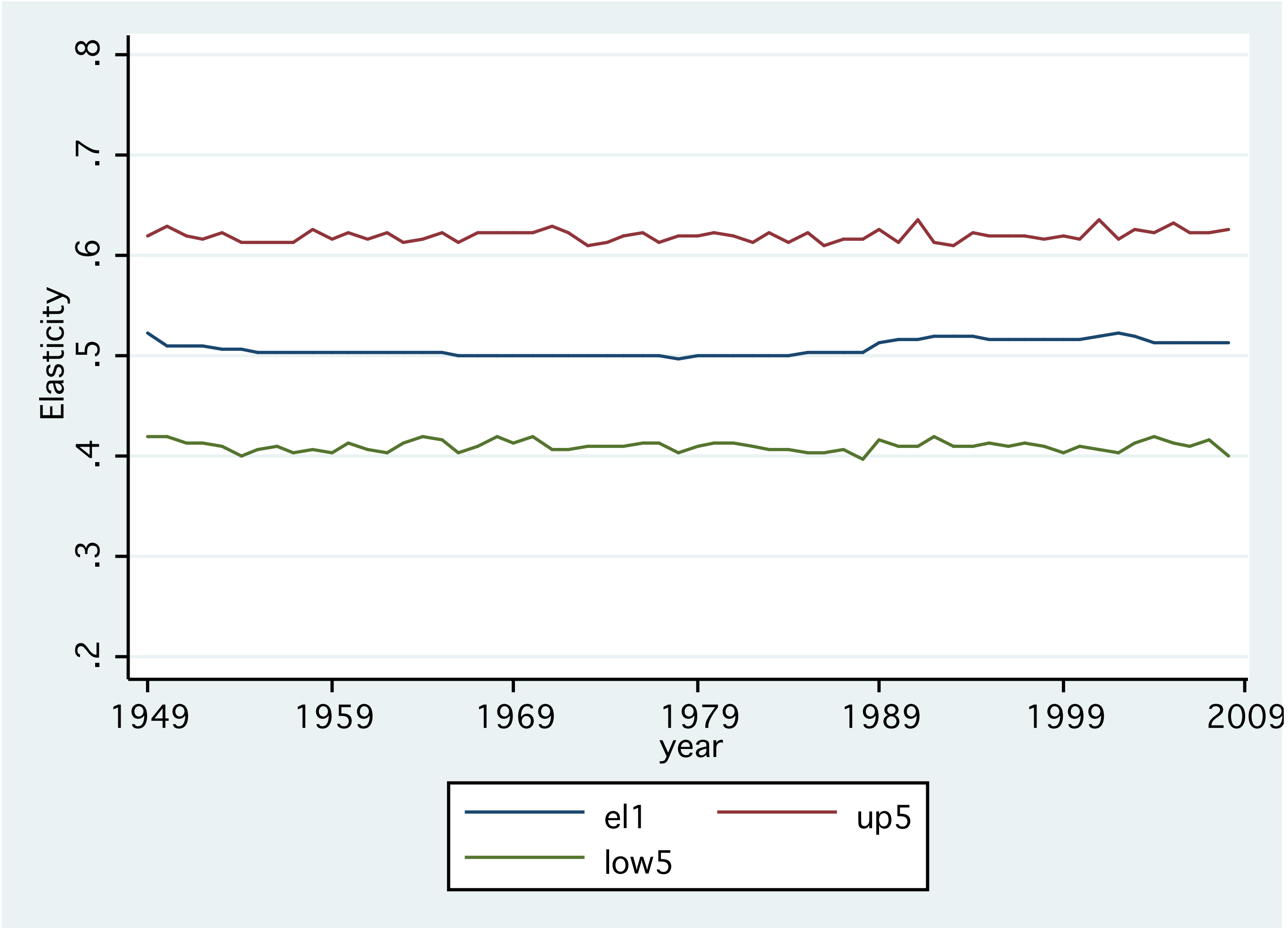
- Coal
- Petroleum
- Natural gas and other gases
- Nuclear

Renewable:

- Hydroelectric
- Biomass (Wood and Waste)
- Geothermal
- Solar/PV
- Wind

Results

US



Elasticity
.2
.3
.4
.5
.6
.7
.8
1949
1959
1969
1979
1989
1999
2009
year
el1
up5
low5

Why are the two inputs complements?

Renewable Inputs cannot insure a continuous production of electricity.

Why?

Electricity cannot be stored, what is usually stored is the resource necessary to produce it.

Non renewable resources are easily stocked (i.e. coal, petroleum, gas, …)

Renewable resources are difficult to store (i.e. wind, solar radiations, …)

→ At the moment we need a reserve of non renewable resources to use in order to produce electricity when renewable resources are not available.

Electricity cannot be produced using exclusively renewable resources, we always need non renewable resources, at least to start production.

Why?

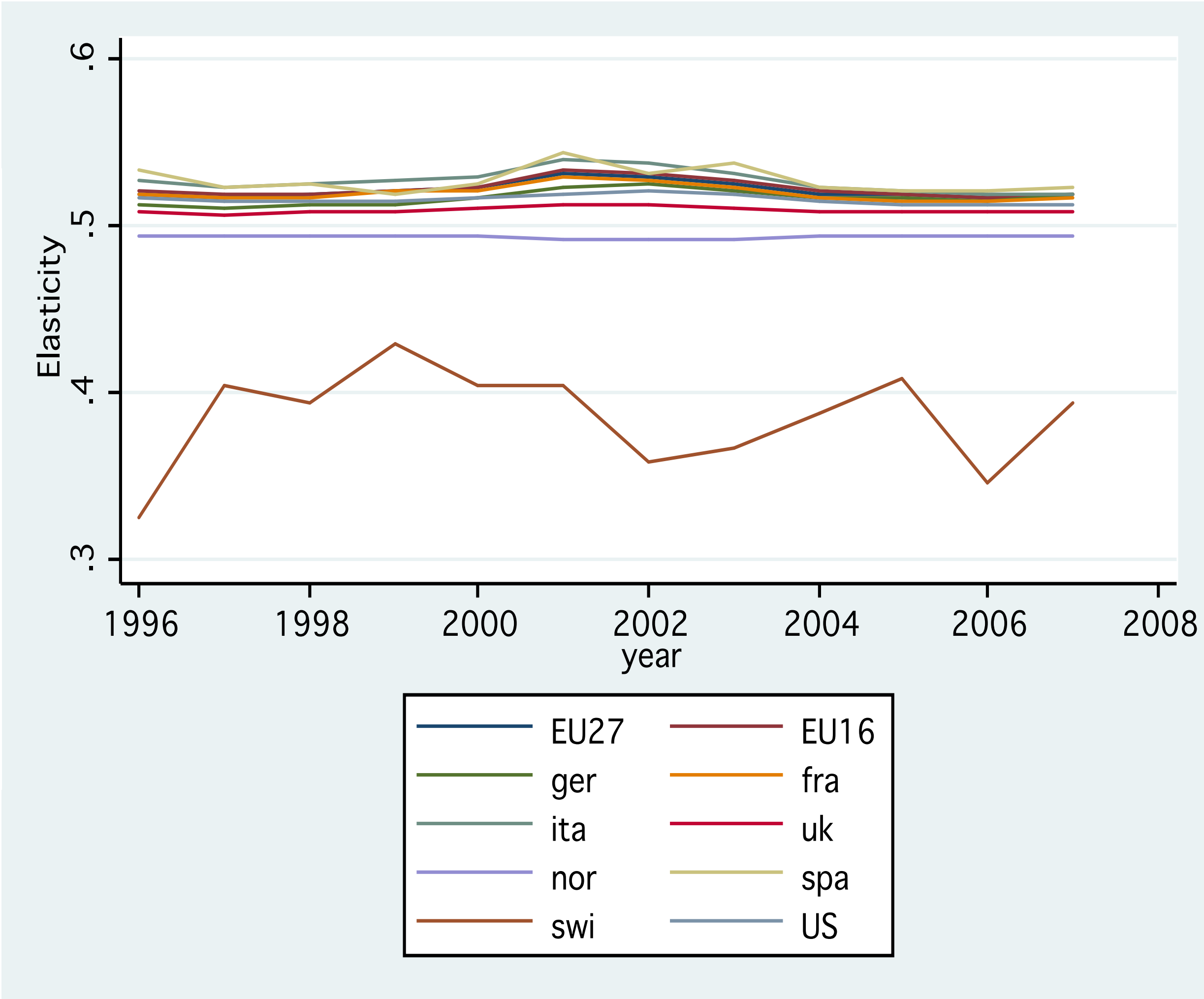
I could formulate it like this *Many Clean technologies hide Dirty secrets*, meaning that often in order to be able to use renewable inputs we have to first use non renewable ones.

Examples:

i. The construction of photovoltaic panels
ii. The construction of a dam
iii. The construction of an eolic turbine
iv. The usage of a geothermal pump to warm a house
v. …

European Countries

Variable	Mean	Std. Dev.
US	0.517	0.003
EU27	0.523	0.005
EU16	0.523	0.005
ger	0.518	0.004
fra	0.52	0.005
ita	0.527	0.007
spa	0.528	0.008
uk	0.51	0.002
nor	0.494	0.001
swi	0.386	0.03
N	12	



Other Countries

Variable	Mean
aus	0.513
jap	0.515
tur	0.523
nz	0.454
mex	0.519
kor	0.508
can	0.428
bra	0.485
chile	0.724
china	0.519
rus	0.522
ind	0.521
w	0.523

As shown in the tables and diagrams the two inputs are complements in a consistent way all around the world.

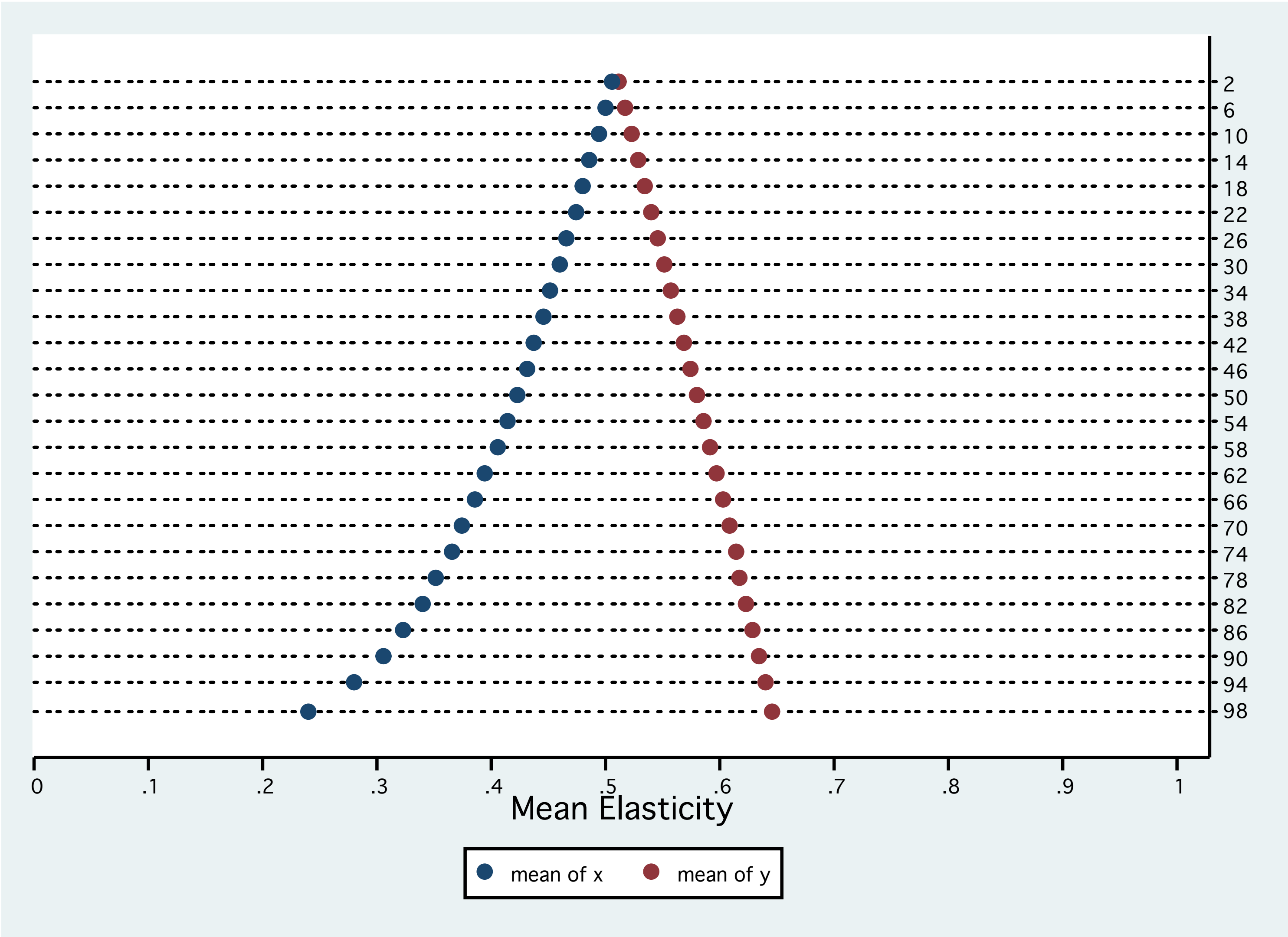
Robustness Check of the Perfect Capital Mobility Hypothesis

I want to check how relaxing this hypothesis affects the results.

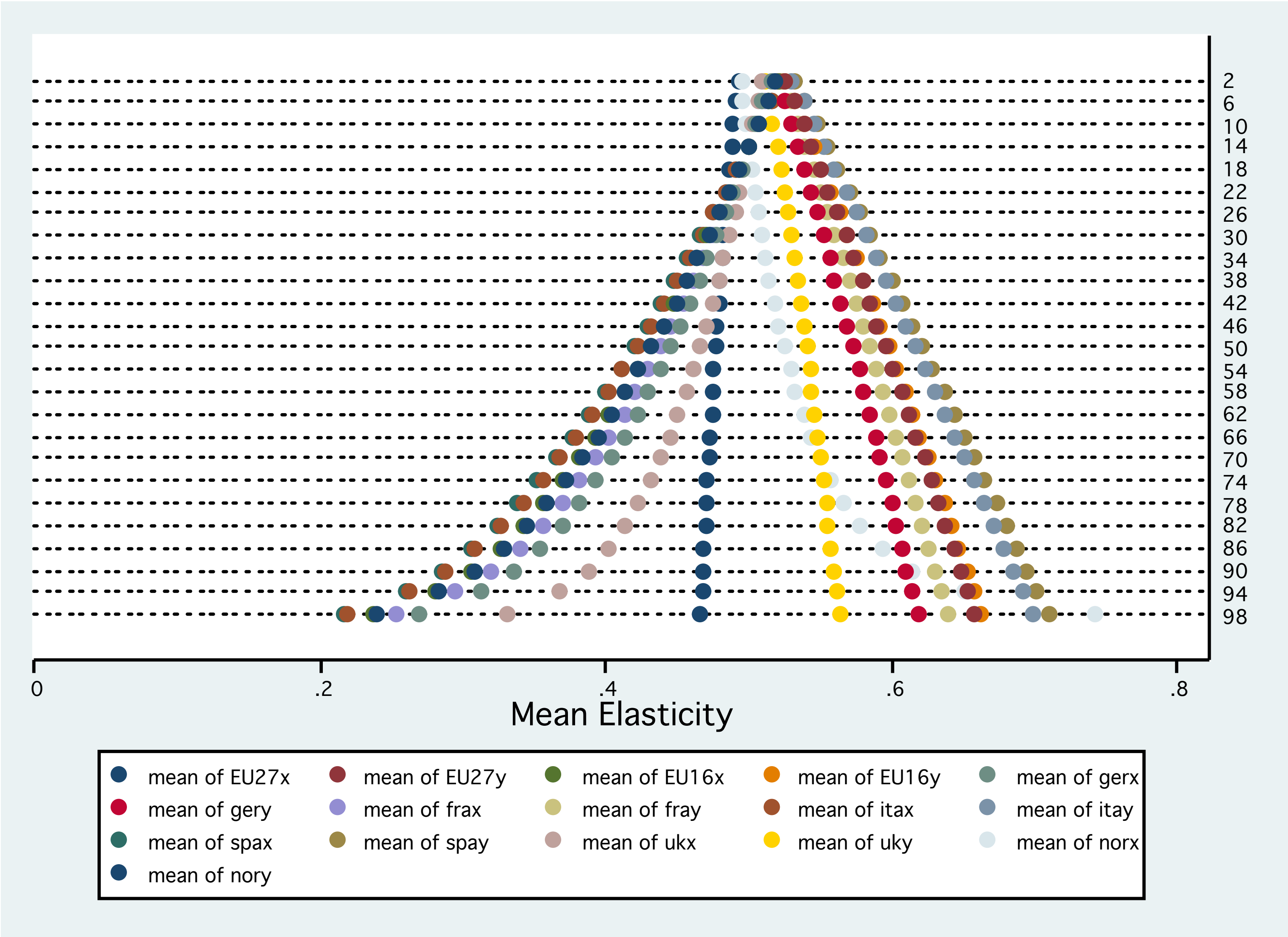
In order to do this, I introduce *Iceberg Transport Costs* on capital between the two sectors within a country.

$$\frac{MPK_c}{MPK_d} = (1-\tau) = \left(\frac{L_{ct}A_{ct}}{L_{dt}A_{dt}}\right)^{\sigma(\alpha-1)} \left(\frac{x_{ct}}{x_{dt}}\right)^{-\alpha\sigma-1}$$

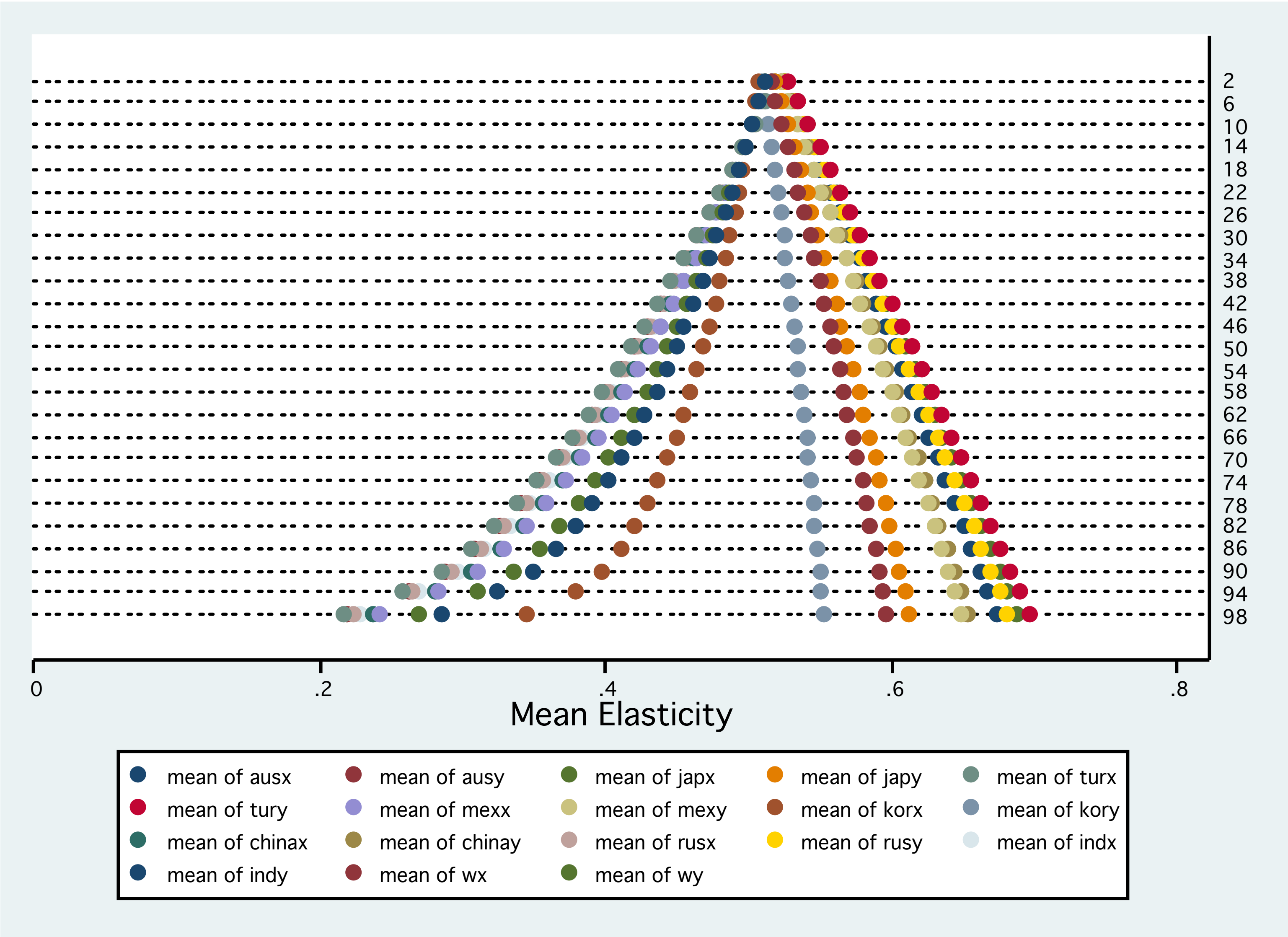
Impact of *Iceberg Transport Costs* on the elasticity in the U.S.



Impact of *Iceberg Transport Costs* on the elasticity in European Countries



Impact of *Iceberg Transport Costs* on the elasticity in other World Countries



Conclusion

I estimate **a value for the elasticity of substitution** between renewable and non renewable inputs in the production of electricity by adding the hypothesis of **perfect capital mobility** to a directed technical change endogenous growth model.

I find a value for this elasticity **lower than 1** for a number of country around the world. Value implying that the two inputs are **complements**.

Implementing this elasticity in the model by Acemoglu et al. (2009) generates difficult previsions.