Electricity Production with Intermittent Sources of Energy

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motivation

- Electricity is not storable,
  - … but primary fuels are,
  - … except for along-the-river water, photovoltaic energy, wind energy,
  - … and the latter additionally are available according to random processes.
- Nevertheless, solar and wind energies
  - are available for free,
  - are not under the control of aggressive foreigners,
  - and do not emit pollutants.

political momentum

- Green energy is promoted both by national governments and the EC authorities
  - Directive 2001/77/EC on the promotion of the electricity produced from renewable energy sources
  - Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport
  - Renewable Energy Road Map January 2007
  - and more to come …

economic analysis of intermittent sources

- we (economists) are a bit late
- questions to address
  - by how much is it economically efficient to substitute intermittent sources for non-intermittent sources?
  - which type of public intervention is best adapted to approximate first best?
  - can market mechanisms implement the optimal level of substitution?
  - how to inject intermittent energies into the grid whereas it has been designed for non random energy sources?
  - ...
- this paper only addresses the problem of the cost of guarantying electricity supply when wind-power is available.

model setting

$S\left(q_f + q_i\right)$ gross surplus, increasing and concave

$q_f \leq K_f$ fuel production at costs *c* and r_f

$q_i \leq K_i$ wind production at costs *0* and r_i

w state of nature with wind, proba ν

$\overline{w}$ state of nature without wind, proba $\left(1-\nu\right)$

capacity and energy

K_f, K_i "long run" decisions

q_f^w, q_i^w dispatch in state w

$q_f^{\overline{w}}, q_i^{\overline{w}}$ dispatch in state $\overline{w}$

but $q_i^{\overline{w}} \equiv 0, \quad q_i^w \equiv K_i, \quad q_f^{\overline{w}} = K_f,$

then only three unknowns remain: K_i, K_f, q_f^w

first best problem

$$\max_{K_i, K_f} \nu \left[\max_{q_f^w} S(K_i + q_f^w) - c q_f^w \right]$$

$$+ (1-\nu)[S(K_f) - cK_f]$$

$$- r_f K_f - r_i K_i$$

$$s.t. \quad q_f^w \geq 0, \quad q_f^w \leq K_f, \quad K_i \geq 0$$

first best solution

- for $\frac{r_i}{v} > c + r_f$

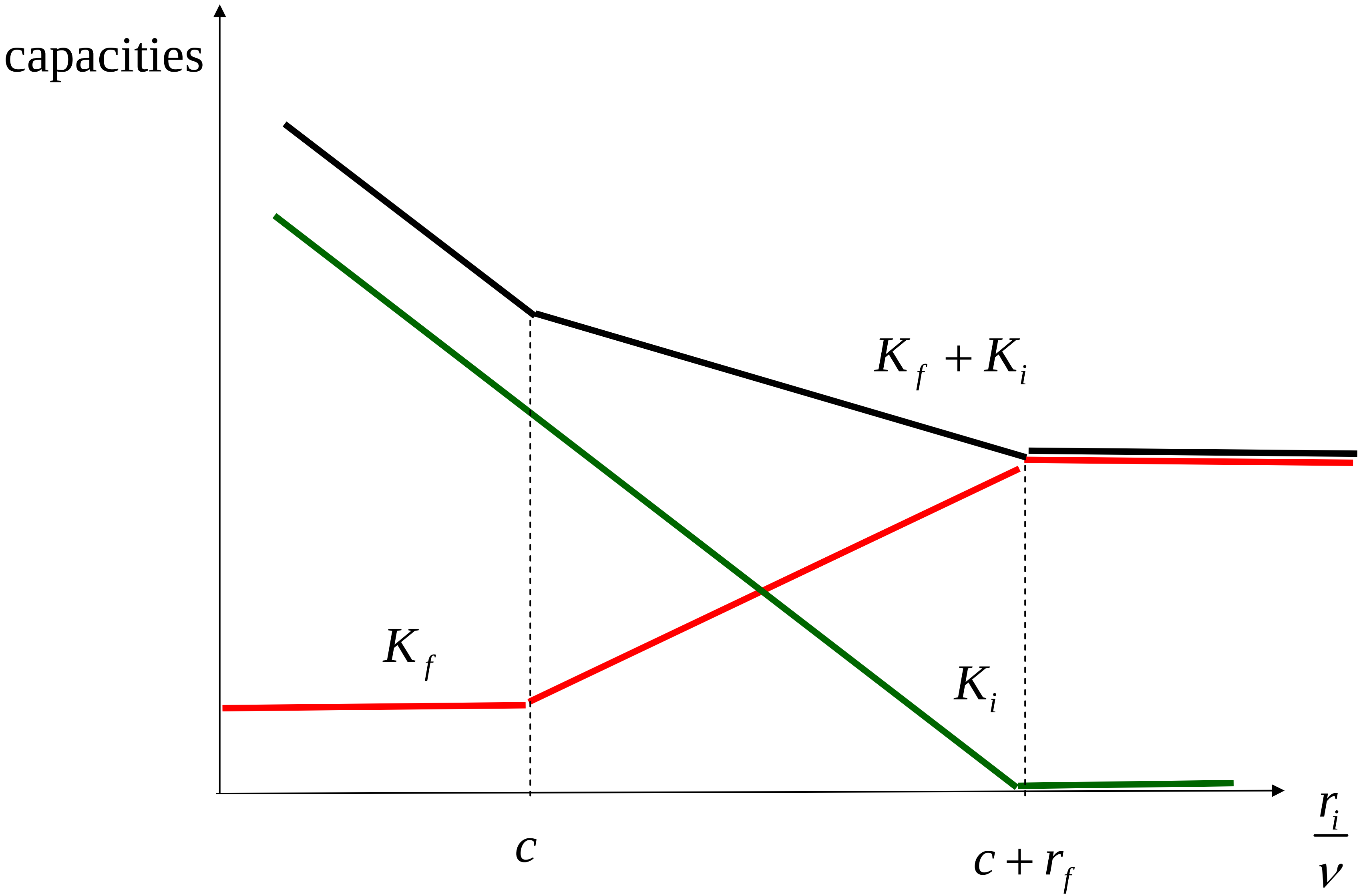
$$q_f^w = \overline{q_f^w} = K_f = S'^{-1}(c + r_f), \qquad q_i^w = K_i = 0$$

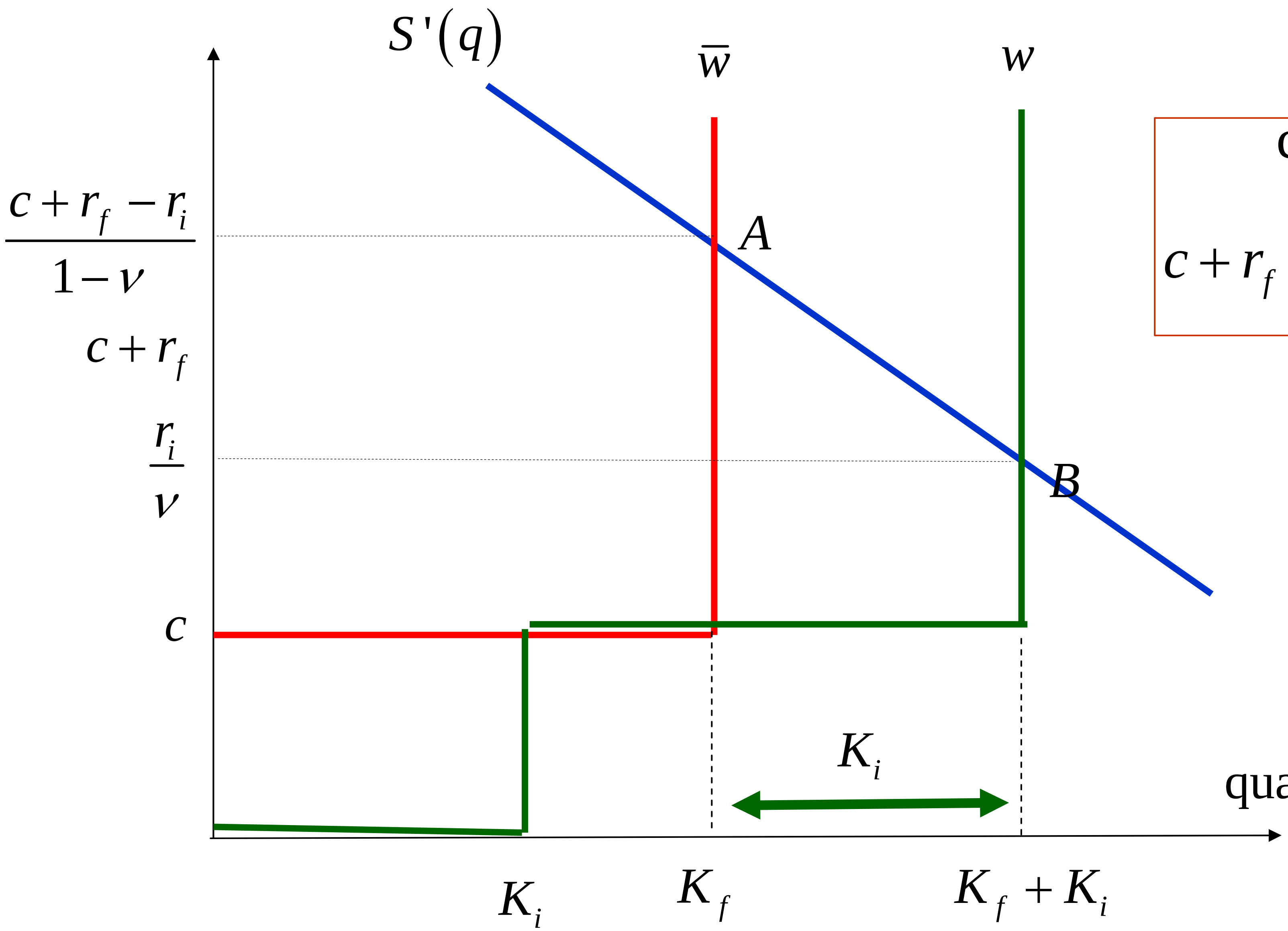
- for $c > \frac{r_i}{v}$

$$q_f^w = 0 < \overline{q_f^w} = K_f = S'^{-1}\left(c + \frac{r_f}{1-v}\right), \; q_i^w = K_i = S'^{-1}\left(\frac{r_i}{v}\right)$$

- for $c + r_f > \frac{r_i}{v} > c$

$$q_f^w = \overline{q_f^w} = K_f = S'^{-1}\left(\frac{c + r_f - r_i}{1-v}\right), \quad q_i^w = K_i = S'^{-1}\left(\frac{r_i}{v}\right) - S'^{-1}\left(\frac{c + r_f - r_i}{1-v}\right)$$


capacities
$K_f + K_i$
K_f
K_i
c
$c + r_f$
$\frac{r_i}{v}$



case

$$c+r_f>\frac{r_i}{\nu}>c$$

Market implementation with reactive consumers

- for $\frac{r_i}{\nu} > c + r_f$, $\quad p^w = p^{\bar{w}} = c + r_f$

- for $c > \frac{r_i}{\nu}$, $\quad p^w = \frac{r_i}{\nu}, \ p^{\bar{w}} = c + \frac{r_f}{1-\nu}$

- for $c + r_f > \frac{r_i}{\nu} > c$, $\quad p^w = \frac{r_i}{\nu}, \ p^{\bar{w}} = \frac{c + r_f - r_i}{1-\nu}$

allow to implement first best
and balance the expected budget of producers.

drawback: when the two technologies are installed, prices must be state contingent $\quad p^{\bar{w}} > p^w$

consumers are not price reactive

- « no smart meters » means uniform price, which means $q_i^w + q_f^w = q_f^{\bar{w}}$
- then, in state *w* the two technologies are perfect substitutes
- consequently $q_i^w > 0$ AND $q_f^w > 0$ cannot be efficient at the optimum constrained by uniform pricing.

second best solution

- If $c < \frac{r_i}{\nu}$ only technology *f* is installed and $S^{'}(K_f) = c + r_f = \tilde{p}^w = \tilde{p}^{\bar{w}}$.
- If $c > \frac{r_i}{\nu}$, both technologies are installed but only technology *i* is used in state *w* with $S^{'}(K_f) = S^{'}(K_i) = (1-\nu)c + r_f + r_i = \tilde{p}^w = \tilde{p}^{\bar{w}}$.

second best is not directly implementable

- When $c > \frac{r_i}{\nu}$ both technologies are installed, but the budget is only globally balanced: $\nu \tilde{p}^{w} - r_i + (1-\nu)(\tilde{p}^{\bar{w}} - c) - r_f = 0$
- Thus the division operating technology *i* obtains positive cash flows

$$\nu \tilde{p}^{w} - r_i = \nu \left[(1-\nu)(c - \frac{r_i}{\nu}) + r_f \right] > 0$$

- whereas the fossil energy *f* division incurs financial losses $(1-\nu)(\tilde{p}^{\bar{w}} - c) - r_f < 0$.

integration or subsidization?

uniform prices distort capacities

- since $p^{\bar{w}*} = c + \frac{r_f}{1-\nu} > \tilde{p}^{w} = \tilde{p}^{\bar{w}} > p^{w*} = \frac{r_i}{\nu}$ and prices signal investment opportunities, the capacity of intermittent energy installed under uniform price is smaller than at first-best whereas the opposite stands for fossil energy

$$\tilde{K}_i < K_i^* \text{ and } \tilde{K}_f > K_f^* .$$

extension: two sources of intermittent energy

- four states of nature:
  - in state 1 only the intermittent source of energy 1 is available,
  - in state 2 only the intermittent source of energy 2 is available,
  - in state 12 both are available
  - in state $\bar{w}$ none of them are available

1 or 2 turbines?

- If sources 1 and 2 are only available at the same time (perfect positive correlation $\nu_1 = \nu_2 = 0$), only the most efficient source of intermittent energy will be installed.
- Formally, even though $\frac{r_i}{\nu_{12}} < c$ for $i = 1,2$ so that the two sources of intermittent energy are more efficient than *f* in state 12,

$$r_1 < r_2 \Rightarrow K_1 > 0, K_2 = 0.$$

- By contrast, if sources 1 and 2 are never available at the same time (perfect negative correlation $\nu_{12} = 0$), as long as $\frac{r_i}{\nu_i} < c$ for $i = 1,2$ both sources of intermittent energy is to be installed. In particular, source 2 must be built even if $r_2 > r_1$.

Conclusion

- normative economics are lacking whereas political and technical arguments are leading the wind and photovoltaic momentum
- other extensions
  - day ahead commitment in wholesale markets
  - CO_2 savings and public aids
  - market power
  - network and smart meters
  - and so on

Figure 1.1 – Cost of generating electricity (pence per kWh) with no cost of CO_2 emissions included.

source "The Costs of Generating Electricity", *The Royal Academy of Engineering,* March 2004

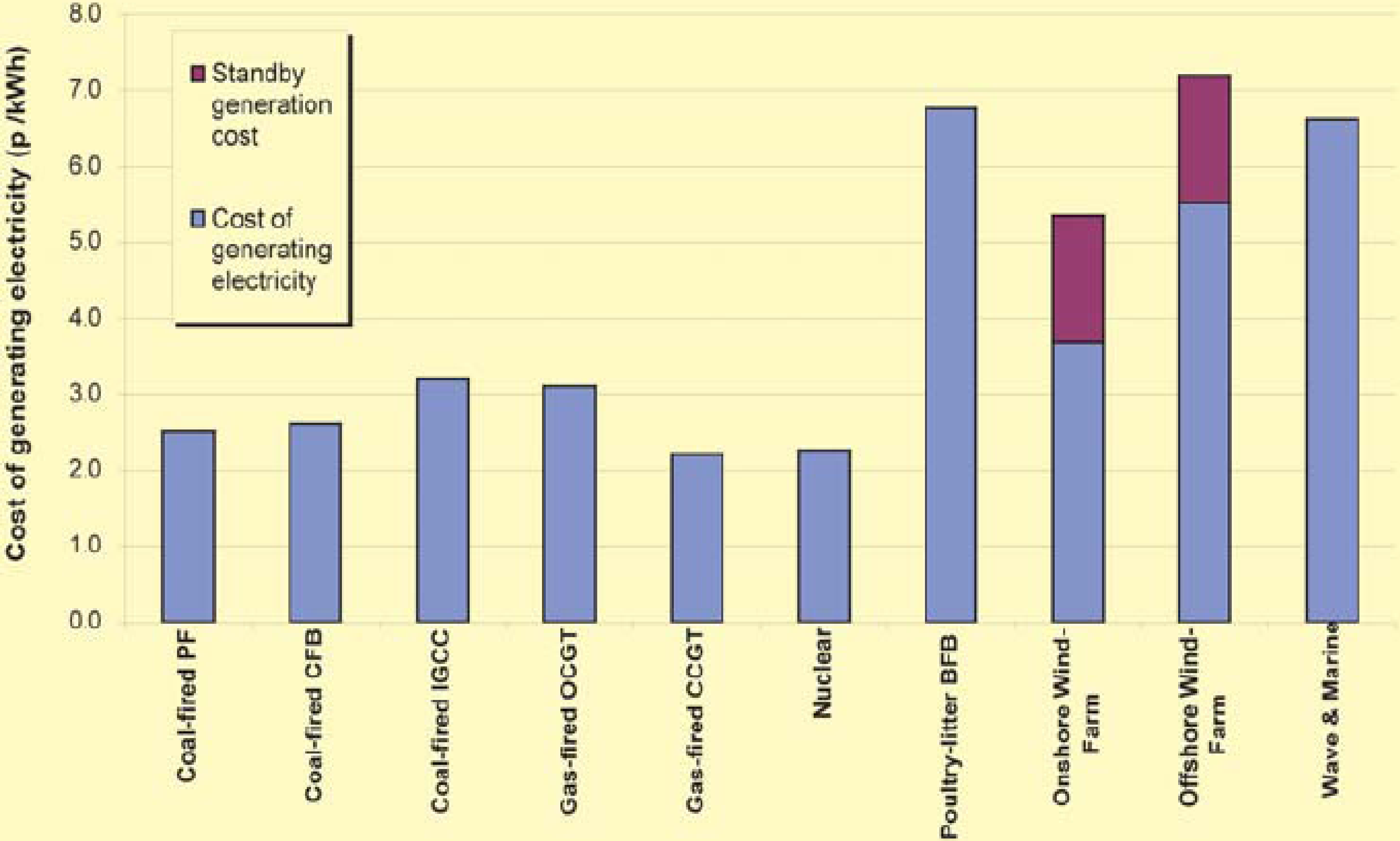


Figure 1.3 – Cost of generating electricity with respect to carbon dioxide emission costs. (Zero to £30 per tonne)

source "The Costs of Generating Electricity", *The Royal Academy of Engineering,* March 2004