Energy transition, consumers, and efficiency

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Introduction

Energy transition: "decarbonization" of the economy by means of renewable energy

- in Germany's "Energiewende" renewables are to replace old "carbon technologies" and supply 80% of total electricity consumption by 2050.

Introduction

Many find that this not a good idea...

- "[...] the Energiewende will kill German industry". *The Economist*, June 5th, 2013
- "The windmills in northern Germany are religious buildings to meet green creeds, but not the result of a rational energy policy for the population and the economy. The de-industrialization that we currently implement in the energy sector, by scrapping functioning power plants, is one of the sins that we commit to our descendants." Hans-Werner Sinn, *Die Zeit*, May 6th, 2013

Concerns

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  - *intermittency* implies potentially large system-wide costs
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Appropriate pricing of carbon should take care of the investment incentives without policy-determined technology targets

This paper

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1. carbon costs are uncertain, but not the availability of renewables
   - *renewables*: wind, sun, and hydro uncertainties are idiosyncratic; perfectly predictable
   - *carbon technologies*: carbon cost uncertainty is persistent; very hard to predict beyond 5 or 10 years.

This paper

2. Energy transition = transition from high to low marginal costs and from persistent to idiosyncratic uncertainties

This paper: tractable model of the transition

Invalidates the main concerns presented

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Invalidates the main concerns presented

- Consumers always gain from subsidizing
- Gain delivered by a novel dynamic mechanism: shift from persistent to idiosyncratic uncertainties
- Energy cost is more predictable and, on average, lower than without the subsidies

Intuition

- Persistent uncertainty creates a WINDFALL to the existing structure of carbon technologies
  - can explain why investments scant in deregulated energy markets
- WINDFALL is extracted and can more than finance the subsidies

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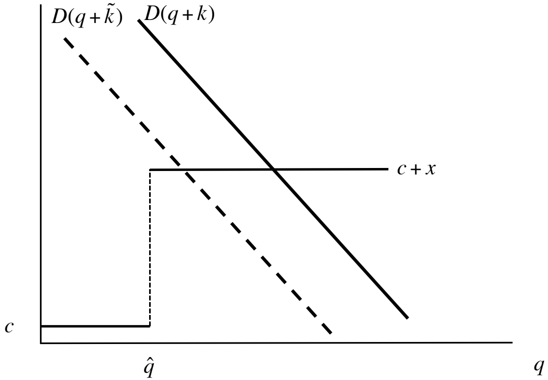
  –*carbon technology*: $S(q, x)$ supply cost increases in carbon cost x
  –*renewable capacity*: k but availability $\tilde{k}$. $E[\tilde{k}] = k$, marginal cost zero
- total supply $q_t + \tilde{k}$

$$\Rightarrow p = u'(q_t + \tilde{k}) = D(q_t + \tilde{k})$$


$D(q+\tilde{k})$
$D(q+k)$
$c+x$
c
$\hat{q}$
q

The model: dynamics

- carbon cost $x \in \{x^L, x^H\}$
  –current $x = x^H$
  –next period $x = x^L$ with prob $\pi > 0$
  –Absorbing state: persistence!

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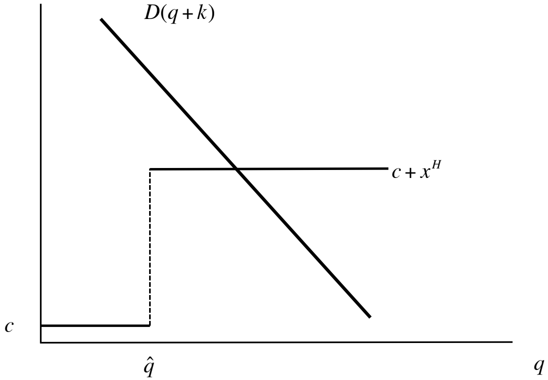
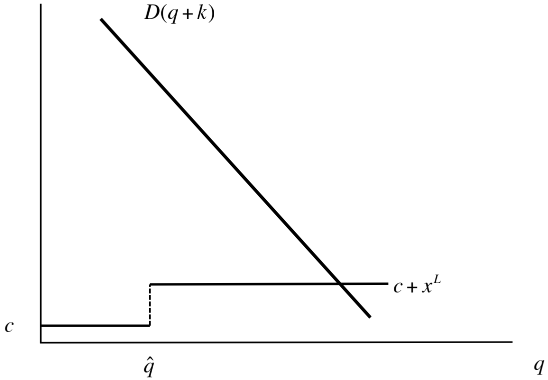
  –Absorbing state: persistence!
- entry
  –upfront cost I per unit of k. Discount factor δ
  –irreversible
  –lives forever

High state

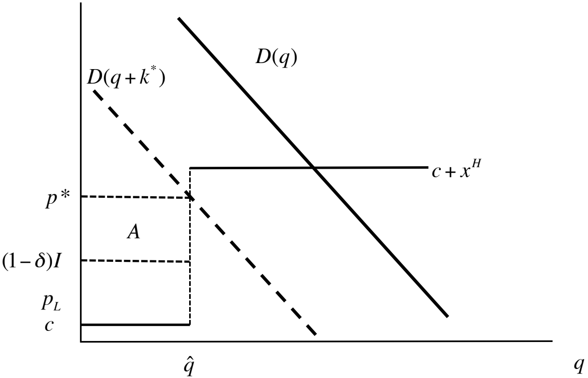


Low state



Entry

Persistence creates Windfall A



Value of a renewable unit in place

$$
\begin{aligned}
V^H &= p^* + \delta \left[\pi V^L + (1-\pi) V^H \right] \\
V^L &= \frac{p^L}{1-\delta} \Rightarrow \\
V^H &= \frac{p^* + \pi \delta p^L}{1-(1-\pi)\delta}.
\end{aligned}
$$

Zero profits and entry when market is good

$$
\begin{aligned}
V^H - I &= 0 \\
&\Rightarrow \\
p^* &= (1-\delta)I + \pi\delta I - \frac{\pi\delta}{1-\delta}p^L \\
&\Rightarrow \\
p^* - (1-\delta)I &= \pi\delta(I - V^L) > 0
\end{aligned}
$$

Subsidy program

–Feed-in tariff: $p^L + \Delta$ in low state; zero otherwise
–Immediate drop in the entry price:

$$\begin{aligned} p^* - (1-\delta)I &= \pi\delta(I - V^L(\Delta)) \\ &\Rightarrow \frac{\partial p^*}{\partial \Delta} = -\frac{\pi\delta}{1-\delta}. \end{aligned}$$

–but consumers must finance the subsidy

Subsidy program

Proposition

Assume that renewable entry is optimal when $\Delta = 0$ *and* $x = x^H$. *Then,*
(i) the consumer-optimal subsidy always positive, $\Delta > 0$;
(ii) full insurance subsidy $\Delta = (1-\delta)I - x^L$ *that exhausts the windfall is consumer-optimal only if*

$$J \equiv \hat{q} - \frac{\pi\delta}{1-\delta}\Delta D_c'(p^*) > 0$$

The consumer-optimal subsidy depends critically on (i) the size of the windfall and (ii) the consumer responsiveness to prices. Both items very favorable to this argument in electricity markets.

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- intermittency has no material impact on the equilibrium
- subsidy distorts the overall efficiency (but only in transition)

next steps

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2. Quantifying consumer welfare gain from subsidies
   –Competitive equilibrium with subsidies

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3. Application to an electricity market
   –Nordic market

The Planner

$$\max_{\{k_t\}_{t=0}^{\infty}} \mathbb{E} \sum_{t=0}^{\infty} \delta^t \left(\int_0^{k_t} P(X_t, k_t)\, dk - \int_{k_{t-1}}^{k_t} C(k) dk \right)$$

$$k_{t+1} \geq k_t$$

$$X_t \in \mathbb{X} \subset \mathbb{R}^n.$$

where P compresses the marginal social value of one k unit, and X_t is a general Markov process,

$$\Pr(X_{t+1} = x \,|X_t = y) = F(x, y),$$

where $F(x, y')$ is first order stochastically dominant over $F(x, y)$ if $y' \geq y$.

The Planner

This is a standard dynamic programming problem with value function

$$V(k,x) = \max_{k' \geq k} \left(\left(\int_0^{k_t} P(X,k)\,dk - \int_k^{k'} C(k)dk \right) + \delta \mathbb{E}\left(V(X',k') \,|x \right) \right)$$

Solution is a capital accumulation path $\mathbf{k} = \{k_t\}_{t=0}^{\infty}$ that is an increasing sequence of positive real numbers.

Theorem

The optimal path has a recursive form

$$k_t = \max\left(k^*\left(X_t\right), k_{t-1}\right) \text{ for all } t = 1, 2, ...$$

where $k^*\left(x_t\right)$ is increasing for every $x_t \in \mathbb{X}$. The path is also the competitive equilibrium path (in absence of subsidies)

This is our tool for quantifying the windfall.

Towards competitive equilibrium

Given k the following, split the Planning problem to a sequence of stopping decisions $\tau(k)$ that maximizes:

$$\max \mathbb{E}\left[\sum_{t=\tau(k)}^{\infty} \delta^t P(x_t, k) - \delta^{\tau(k)} C(k)\right]$$

Entering $t = 0$ gives

$$\overline{V}(x, k) := \mathbb{E}\left[\sum_{t=0}^{\infty} \delta^t P(X_t, k) - C(k) \,|X_0 = x\right].$$

Towards competitive equilibrium

Then,

$$\begin{aligned} & \mathbb{E}\left[\sum_{t=\tau(k)}^{\infty} \delta^t P(X_t, k) - \delta^{\tau(k)} C(k)\right] \\ = \; & \overline{V}(x, k) - \mathbb{E}\left[\sum_{t=0}^{\tau(k)-1} \delta^t P(X_t, k) - \left(1 - \delta^{\tau(k)}\right) C(k)\right] \\ = \; & \overline{V}(x, k) - \mathbb{E}\left[\sum_{t=0}^{\tau(k)-1} \delta^t \left[P(x_t, k) - (1-\delta) C(k)\right]\right]. \end{aligned}$$

Note that $\overline{V}(x, k)$ does not depend on entry time τ. Hence, each unit k should enter at $\tau(k)$ that minimizes the opportunity cost of waiting. Only bad news matter: the entry decisions look only at the downside

Towards competitive equilibrium

Each marginal entrant should enter to minimize the waiting cost part

$$V(x,k) = min \mathbb{E}\left[\sum_{t=0}^{\tau(k)-1} \delta^t \left[P(x_t,k) - (1-\delta)\, C(k)\right]\right]$$

$$\Rightarrow$$

$$\max \mathbb{E}\left[\sum_{t=\tau(k)}^{\infty} \delta^t P(x_t,k) - \delta^{\tau(k)} C(k)\right]$$

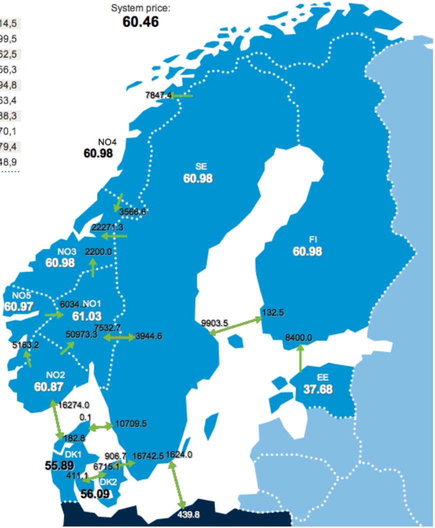
This is our tool for analyzing the entry equilibrium with SUBSIDIES

Subsidies $\Rightarrow$ competitive equilibrium $\neq$ Planning problem.

Application: Nordic Market

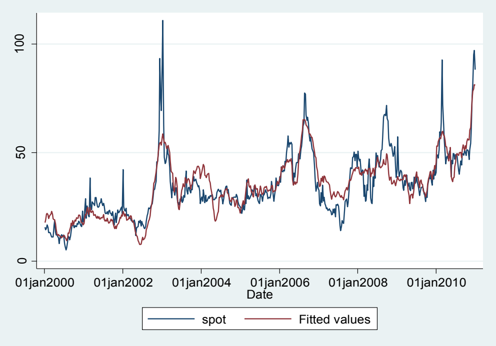
Elspot volumes

	Buy	Sell
NO1	98 810,4	40 414,5
NO2	48 454,2	88 499,5
NO3	46 300,4	18 262,5
NO4	28 637,1	24 356,3
NO5	27 023,5	27 894,8
DK1	40 758,8	73 863,4
DK2	36 356,5	45 888,3
SE	348 379,5	345 770,1
FI	124 608,4	125 979,4
EE	8 448,9	16 848,9



Estimation of revenues of entrants

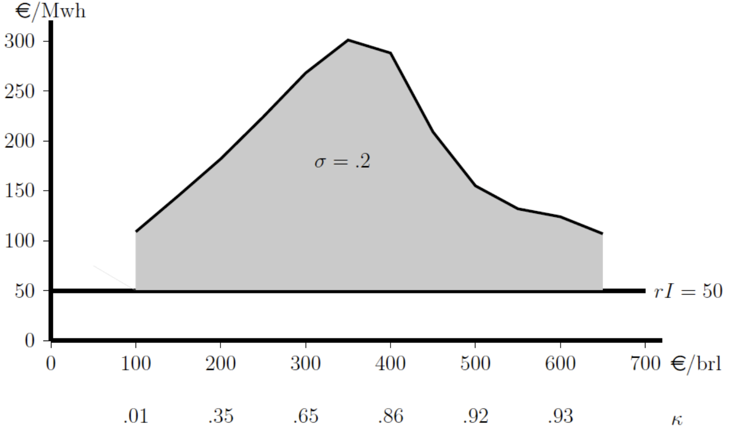
–estimate supply, using demand as instrument (figure)
–take the demand process from data to generate expected annual payoff



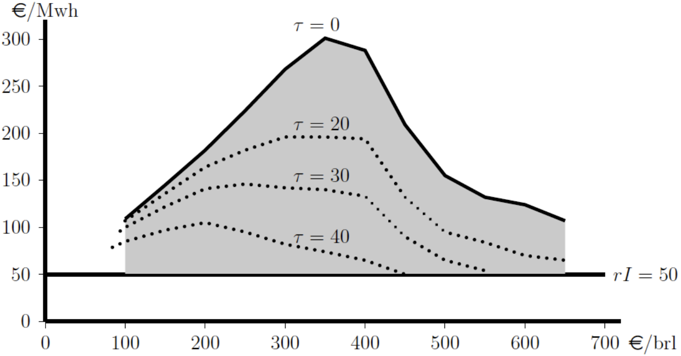
Blue: observed spot Price 2000-2010

Red: predicted price by regression on vector of costs and demand shifters

The Windfall as function of oil price



The effect of feed-in tariff



.01	.35	.65	.86	.92	.93	$\kappa_{\tau=0}$
.01	.39	.71	.89	.94	.96	$\kappa_{\tau=20}$
.03	.43	.75	.92	.96	.98	$\kappa_{\tau=30}$
.07	.49	.81	.95	.99	.99	$\kappa_{\tau=40}$

Consumer gain, Windfall extraction, and the social loss

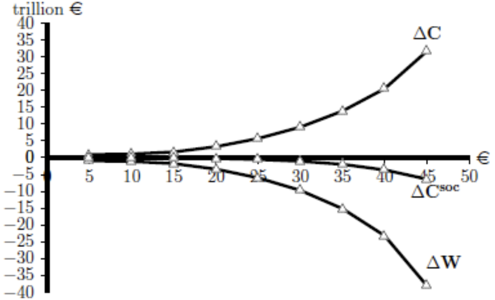


Figure 14: Consumers' gain ($\Delta\mathbf{C}$), producers' loss ($\Delta\mathbf{W}$), and the total welfare loss ($\Delta\mathbf{C}^{\mathbf{soc}}$) for tariff levels $\tau = 5, 10, 15, ..., 45$. All expressions evaluated at the fuel price of the first entry when $\tau = 45$.