Is Green Healthy for Competition?

Renewable Technologies, Optimal Generation Mix and Price Volatility in Competitive Electricity Markets

Irena Milstein and Asher Tishler

9th BIEE Academic Conference

St John's College, Oxford, England

19-20 September 2012

Background

Deregulated generation or regulated generation?

Generally, deregulation of electricity markets (USA, UK, other) failed to lower prices, increase service quality or reliability (there are some successes)

Deregulated generation will likely be the dominant market structure in the (possibly distant) future

There is a need to develop better models to determine optimal capacity mix and optimal production (with renewable energy) in regulated markets

Background

Environmental concerns:

- CO_2 emissions
- CO_2 tax (is it effective? Does it positively affect welfare?)
- Which renewable technologies to develop? Should the government support R&D in PV? Wind? Other renewable energy?
- Should the government subsidize renewable capacity?
- Market structure may affect electricity prices, CO_2 emissions

Main results

- **The share of PV in total capacity will be small in the near future.**
- **CO_2 tax will have only a minor effect on PV capacity and production.**
- **The average electricity price will rise if PV adoption will increase.**
- **Market structure will have a large effect on the average price, industry profits, social welfare, share of PV in total capacity.**
- **Welfare will decline should the regulator introduce CO_2 taxes.**

Model

- Building a new power plant requires a long lead time
- Daily and seasonal electricity demands fluctuate:
  - ✓ Day-time demands are higher than night-time demands
  - ✓ Summer and winter demands exceed spring and autumn demands
  - ✓ Extreme temperatures
- Weather-dependent renewable technologies add supply (non-symmetric) uncertainty (availability of the sun, say)

Connection to the literature

Restructuring (what to expect, cost-benefit analysis)

(Newbery, 2005; Green, 2004; Joskow, 2006; Murphy and Smeers, 2005; Tishler and Woo, 2006, 2007; Von der Fehr, et al., 2005)

Endogenous capacity

(Besanko and Dorazelski, 2004; Lu and Poddar, 2005; Allen et al., 2000; Gabszewicz and Poddar, 1997; Spulber, 1981; Tishler et al., 2008; Milstein and Tishler, 2011, 2012)

Two models (market structures) with weather-dependent capacity

(1) 'regular' technology (combined cycle gas turbines); G

(2) Weather-dependent renewable technology (PV); S

(i) Each producer can construct and operate only **one** type of generation technology.

(II) Producers can construct and operate **both** types of generation technologies.

Two-stage games:

Stage 1: capacity construction (capacity is endogenous)

Stage 2: Electricity production (bidding)

Model 1

Each producer can construct and operate only one type of generation technology

N **- number of identical S-using firms**

M **- number of identical G-using firms**

T **- number of days in the period (year)**

Q_{it}^{S} **production of the *i*-th firm that uses *PV* technology on day *t***

Q_{jt}^{G} **production of the *j*-th firm that uses *CCGT* technology on day *t***

Daily demand function

$$P_t = a - bQ_t + \varepsilon_t$$

Where total (industry) daily production is:

$$Q_t = \sum_{i=1}^{N} Q_{it}^{S} + \sum_{j=1}^{M} Q_{jt}^{G}$$

$$\varepsilon_t \sim f(\varepsilon_t) \;\; ; \; E(\varepsilon_t) = 0 \; , Var(\varepsilon_t) = \sigma^2$$

Cost functions

$$C_i(K_i^S, Q_i^S) = \theta^S K_i^S + c^S Q_i^S$$

$$C_j(K_j^G, Q_j^G) = \theta^G K_j^G + c^G Q_j^G$$

$$Q_i^S = \sum_{t=1}^{T} Q_{it}^S \qquad Q_j^G = \sum_{t=1}^{T} Q_{jt}^G$$

Capacity cost is $\$\theta^S$ or $\$\theta^G$ per MW/year ; $\theta^S > \theta^G$

Variable (marginal) cost is $\$c^S$ or $\$c^G$ per MWH ; $0 \cong c^S << c^G$

The availability of the capacity of technology S on day *t*

The availability of the capacity of technology S on day *t* is conditional on the weather.

The probability that the sun is shining on day *t* follows the Bernoulli distribution

- **probability ρ : the sun is shining and all of capacity S is available on day *t*.**
- **probability $1-\rho$: the availability of capacity S on day *t* is zero (no sun).**

Solution of the model

The decision process of the two-stage game

Stage 1:

Each of the *N* S-using and *M* G-using firms decides on its capacity investment, taking the capacities of the other *N+M-1* firms, the probability functions of ε_t and the availability of the sun as given.

Stage 2:

On day *t*, each firm knows ε_t and whether the sun is available or not, and decides how much electricity to produce on that day.

Solution

Stage 2

Sunny day:

Both technologies can be used by all producers up to the capacity levels which were determined in stage 1

No sun:

Available capacity of technology S, for all producers, is zero (electricity can be produced only by technology G)

Model 2

Each producer can construct and operate both types of generation technologies

All N + M **(identical) firms can construct capacity and generate electricity by technology S, or technology G, or both S and G**

Solution of the model

The decision process of the two-stage game:

Stage 1:

Each of the $N+M$ firms decides on its capacity of technology G and technology S, taking the capacities of the other $N+M-1$ firms, the probability functions of ε_t and the availability of the sun as given.

Stage 2:

On day t, each firm knows ε_t and whether the sun is available or not, and decides how much electricity to produce using technology S (if the sun is shining) and technology G on that day.

Application (Background)

Electricity market in Israel:

IEC is a (government owned) vertical monopoly

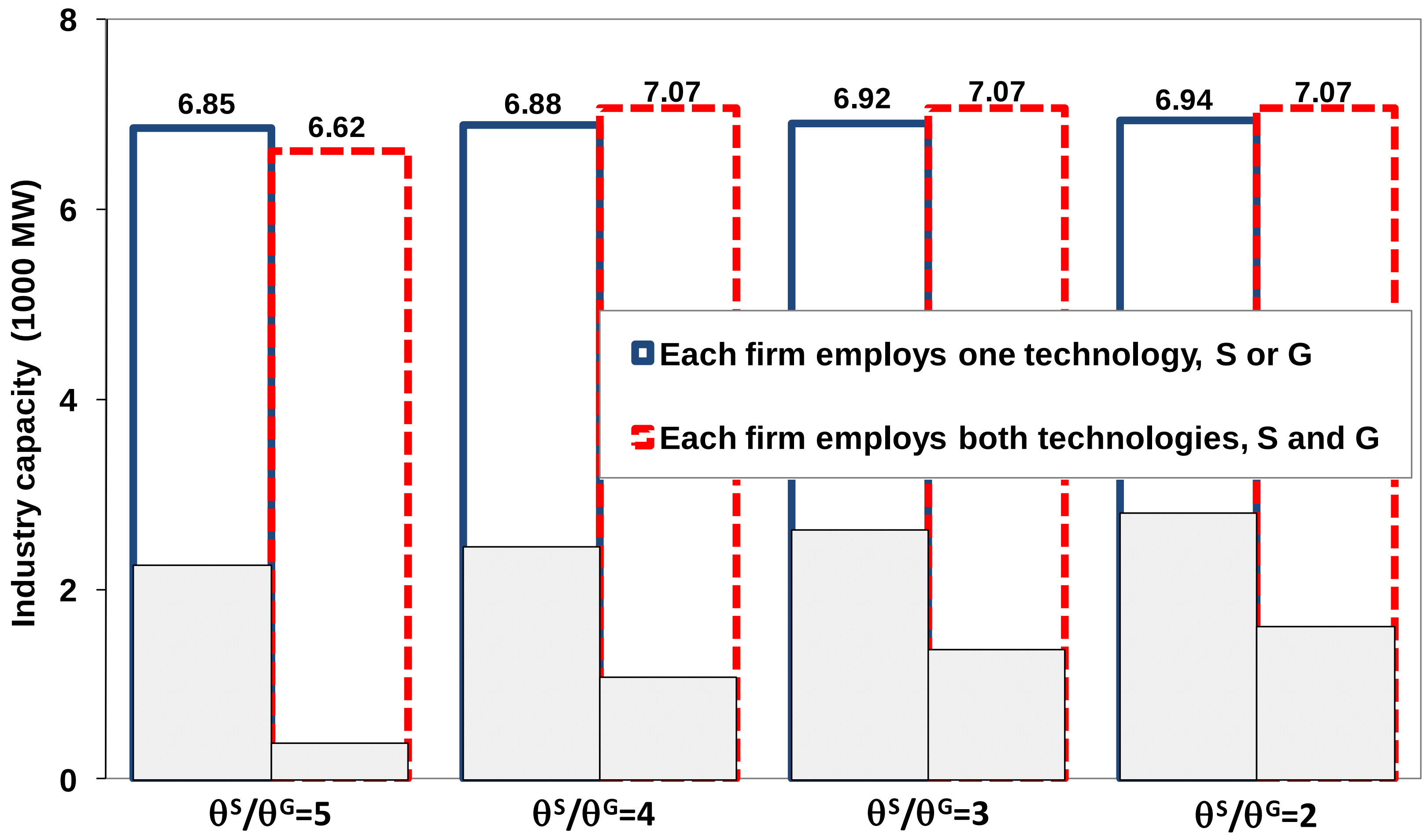
	Average hourly use (1000 MWH; 2011)	Maximal hourly use (1000 MWH; 2011)
Mean	**6.52**	**7.89**
Median	**6.43**	**7.87**
Sample standard deviation	**0.88**	**1.06**
Minimum	**4.64**	**5.62**
Maximum	**8.72**	**10.4**

Variability of daily averages and maximal values of hourly 2006 load data in Israel, New England, California, PJM and ERCOT

	Average hourly load			Maximal hourly load		
Market	Standard deviation / Average	Max - Min / Average	Mean / Median	Standard deviation / Average	Max - Min / Average	Mean / Median
Israel	**0.13**	**0.66**	**1.02**	**0.14**	**0.64**	**1.02**
New England	**0.12**	**0.80**	**1.02**	**0.13**	**0.81**	**1.02**
California	**0.13**	**0.71**	**1.04**	**0.15**	**0.78**	**1.05**
PJM	**0.13**	**0.78**	**1.03**	**0.15**	**0.83**	**1.03**
ERCOT	**0.18**	**0.67**	**1.06**	**0.22**	**0.78**	**1.06**

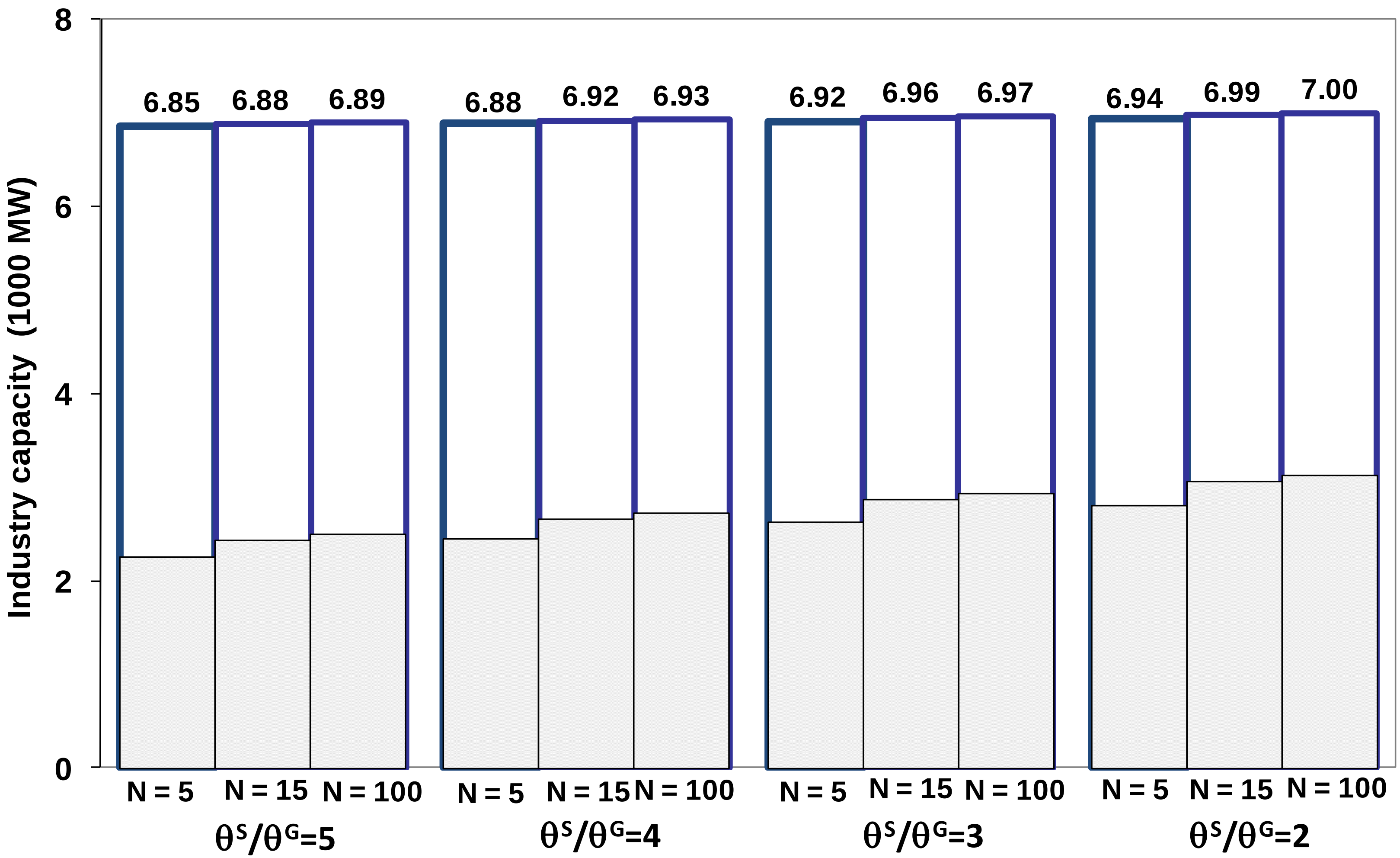
Industry capacity

(sun is available 48% of the year)



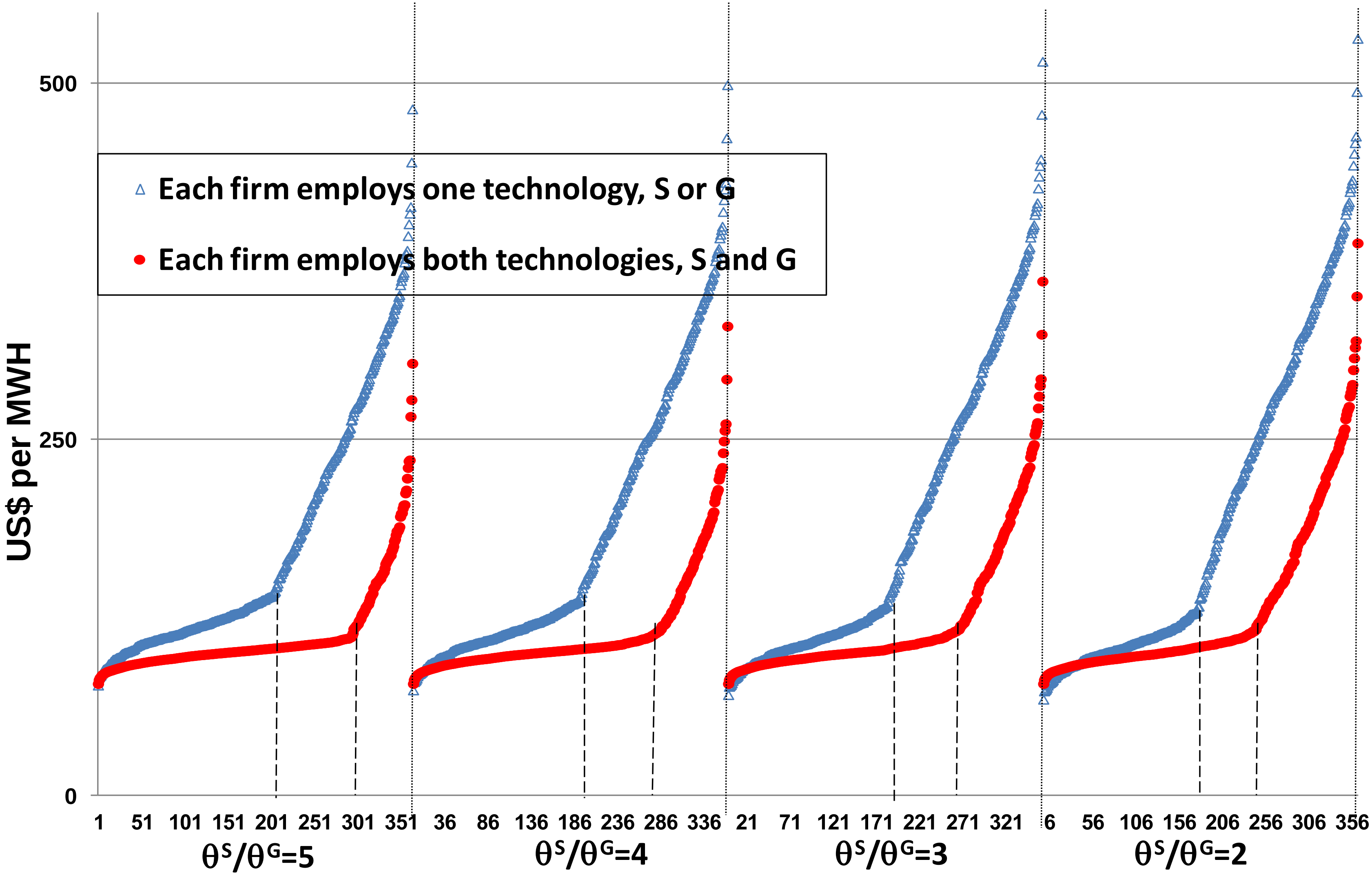
Industry capacity

(sun is available 48% of the year; M = 5)



Price distribution over the year

(sun is available 48% of the year)



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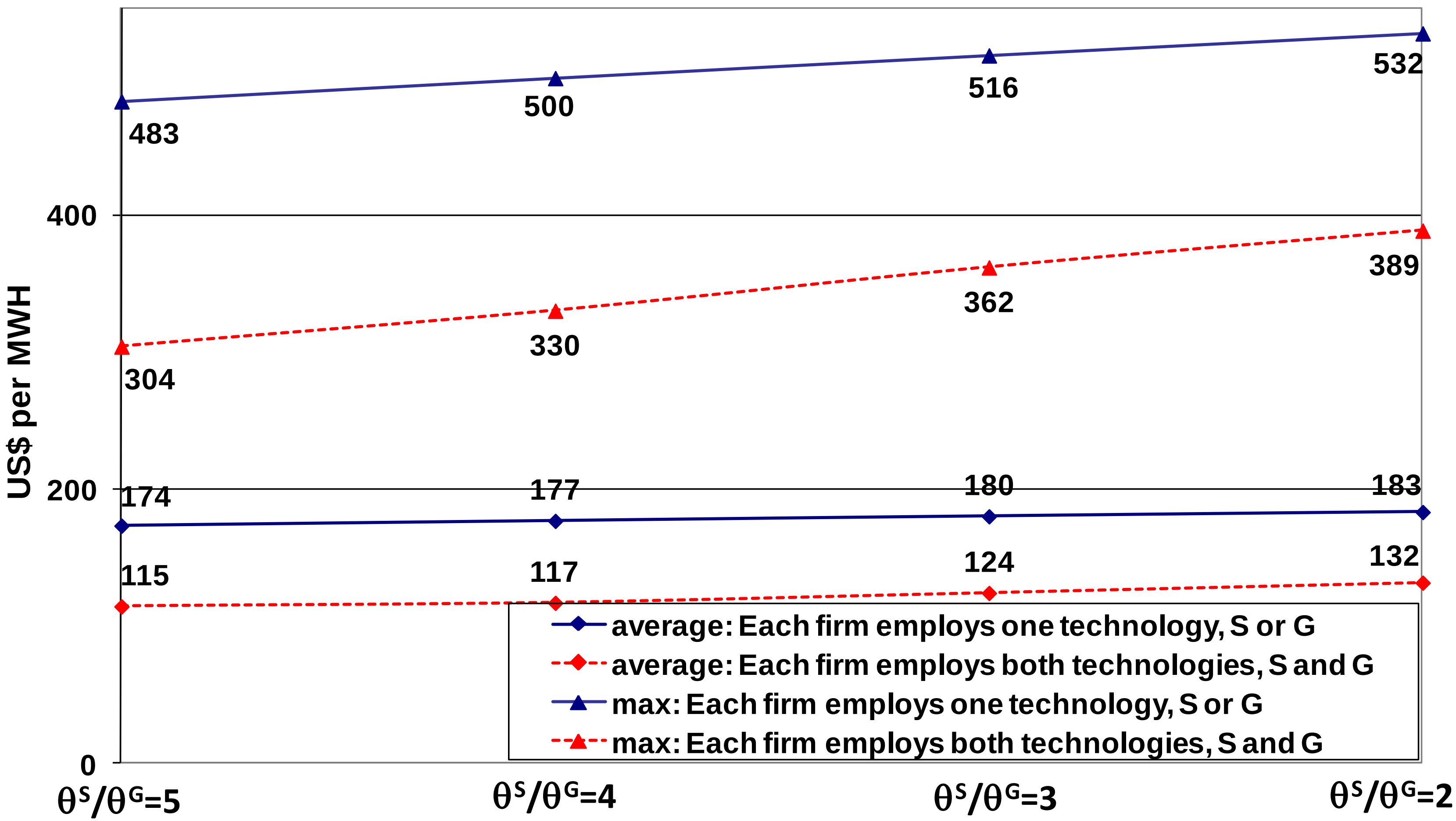
Average and maximal electricity price

(sun is available 48% of the year)



Average and maximal electricity price

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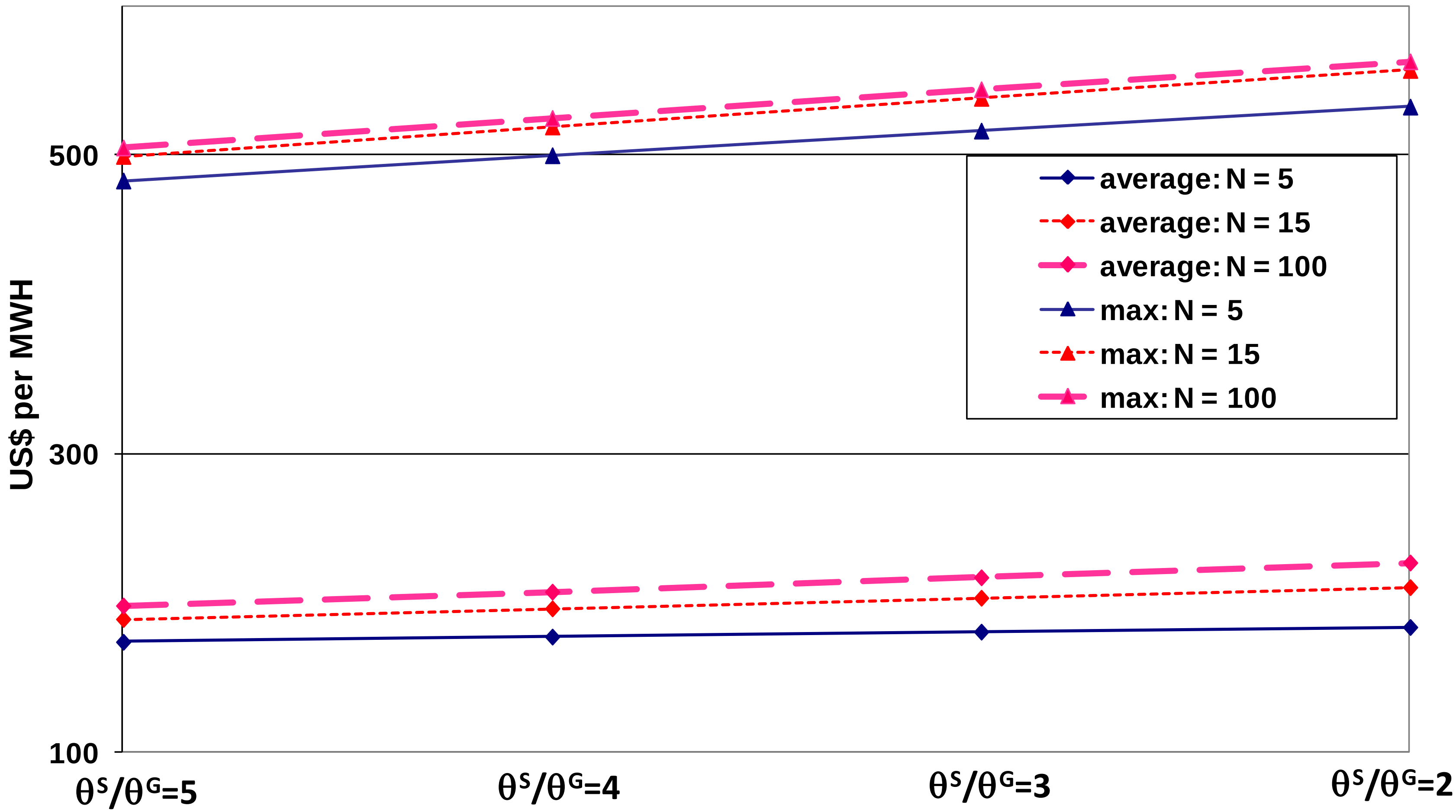
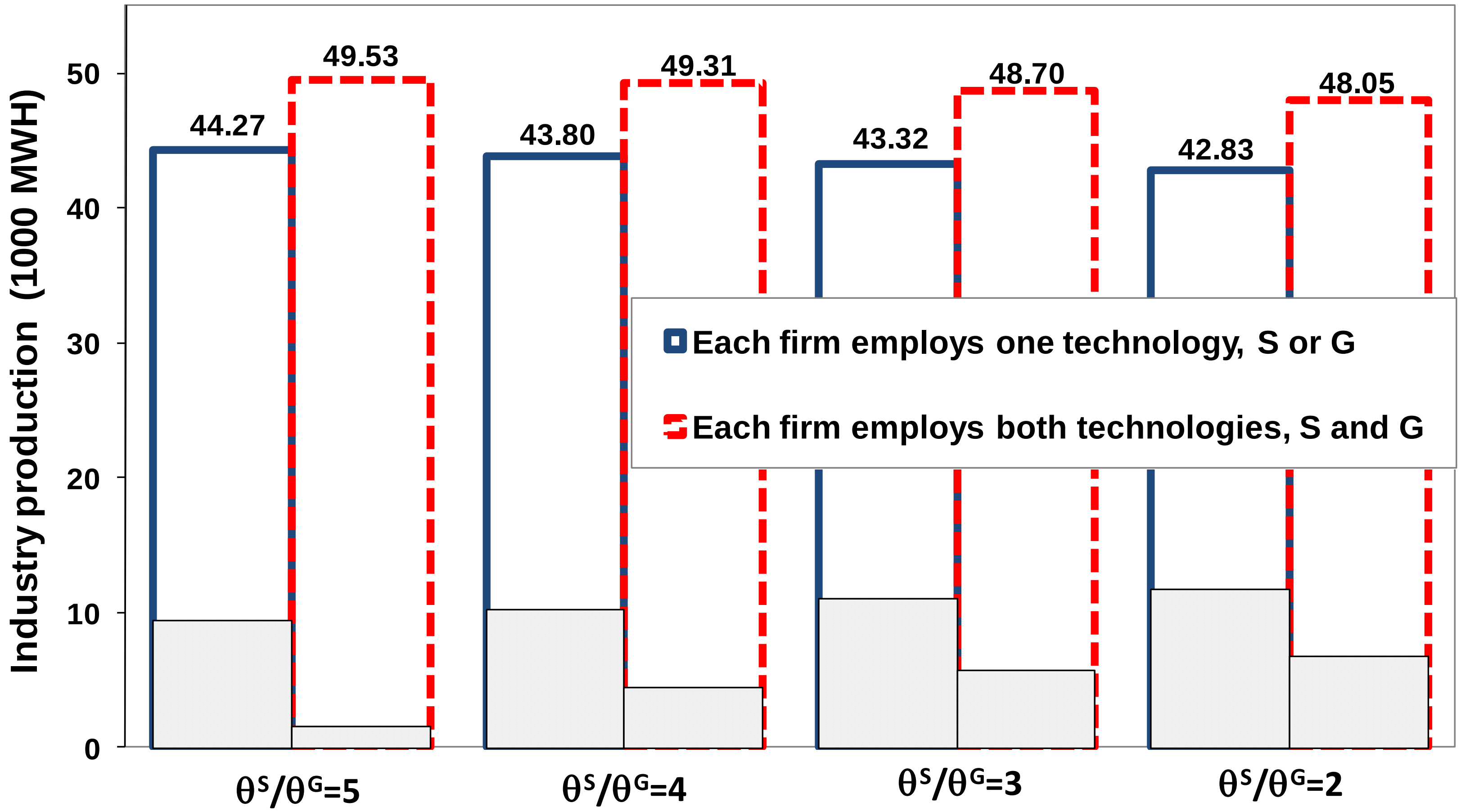


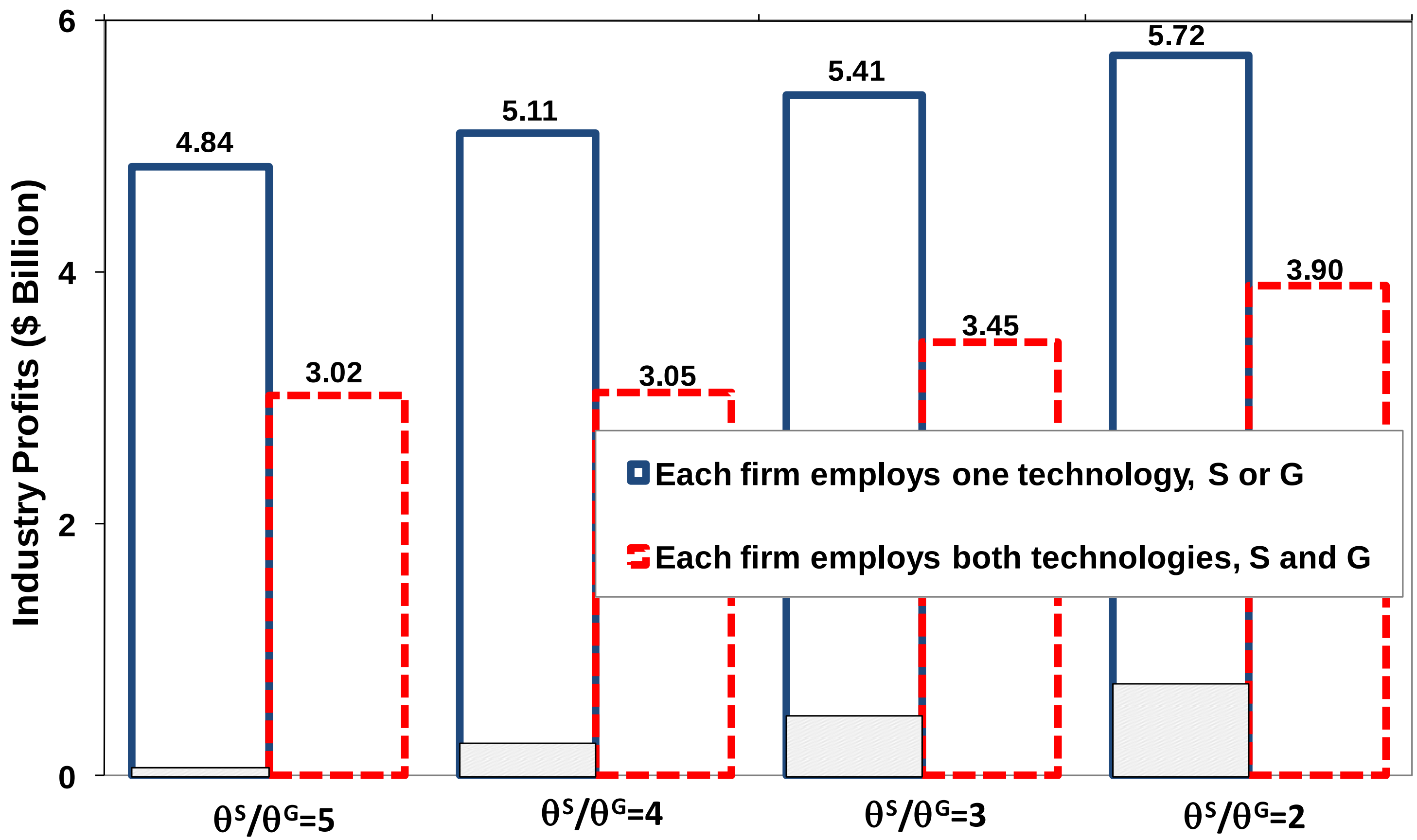
Industry production

(sun is available 48% of the year)



Industry profits

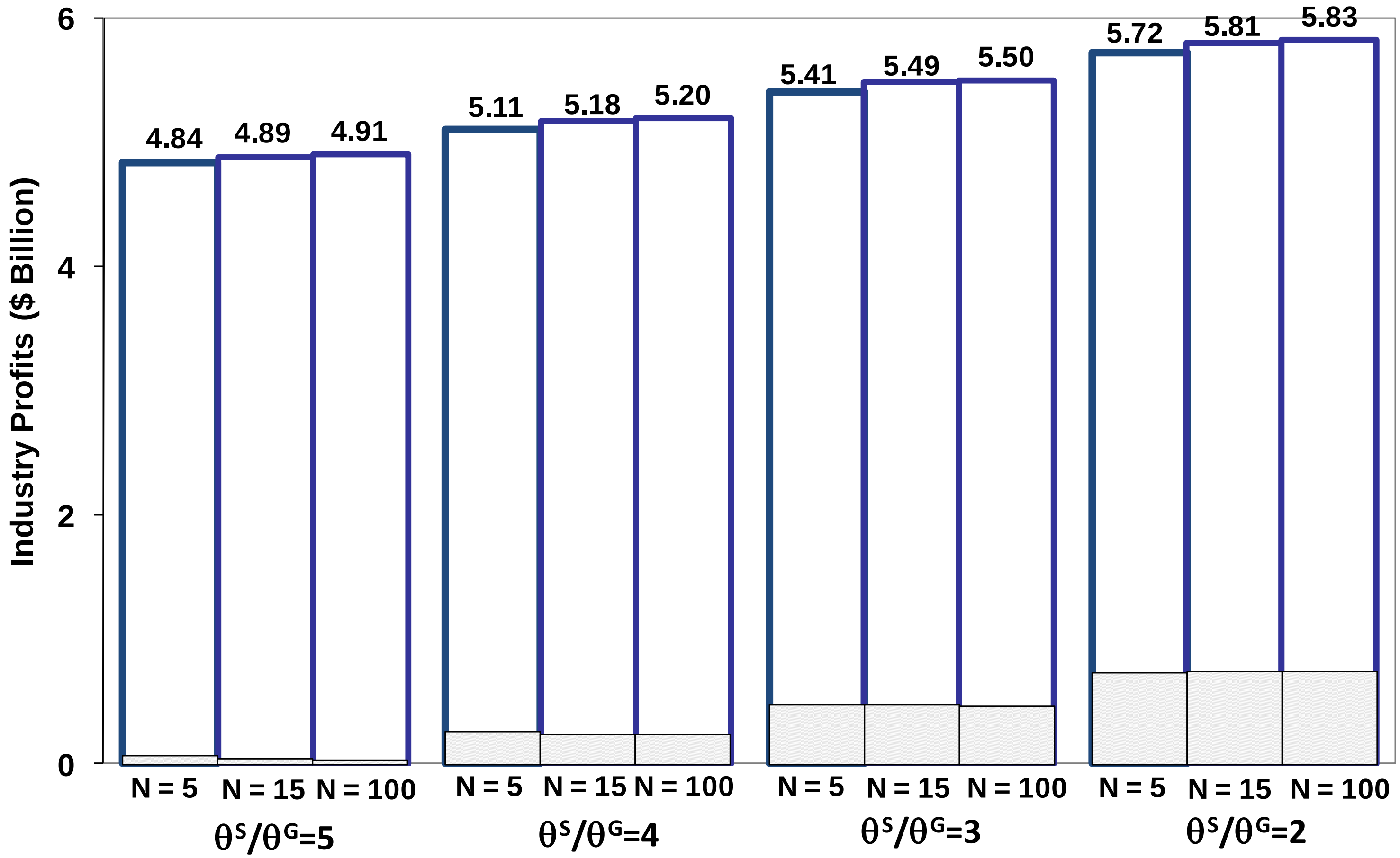
(sun is available 48% of the year)



Profits of the PV-using firms (technology S), when each firm employs only one technology, are depicted by the striped areas of the bars.
Profits of the firms that employ CCGTs (technology G), when each firm employs only one technology, are depicted by the white areas of the bars.

Industry profits

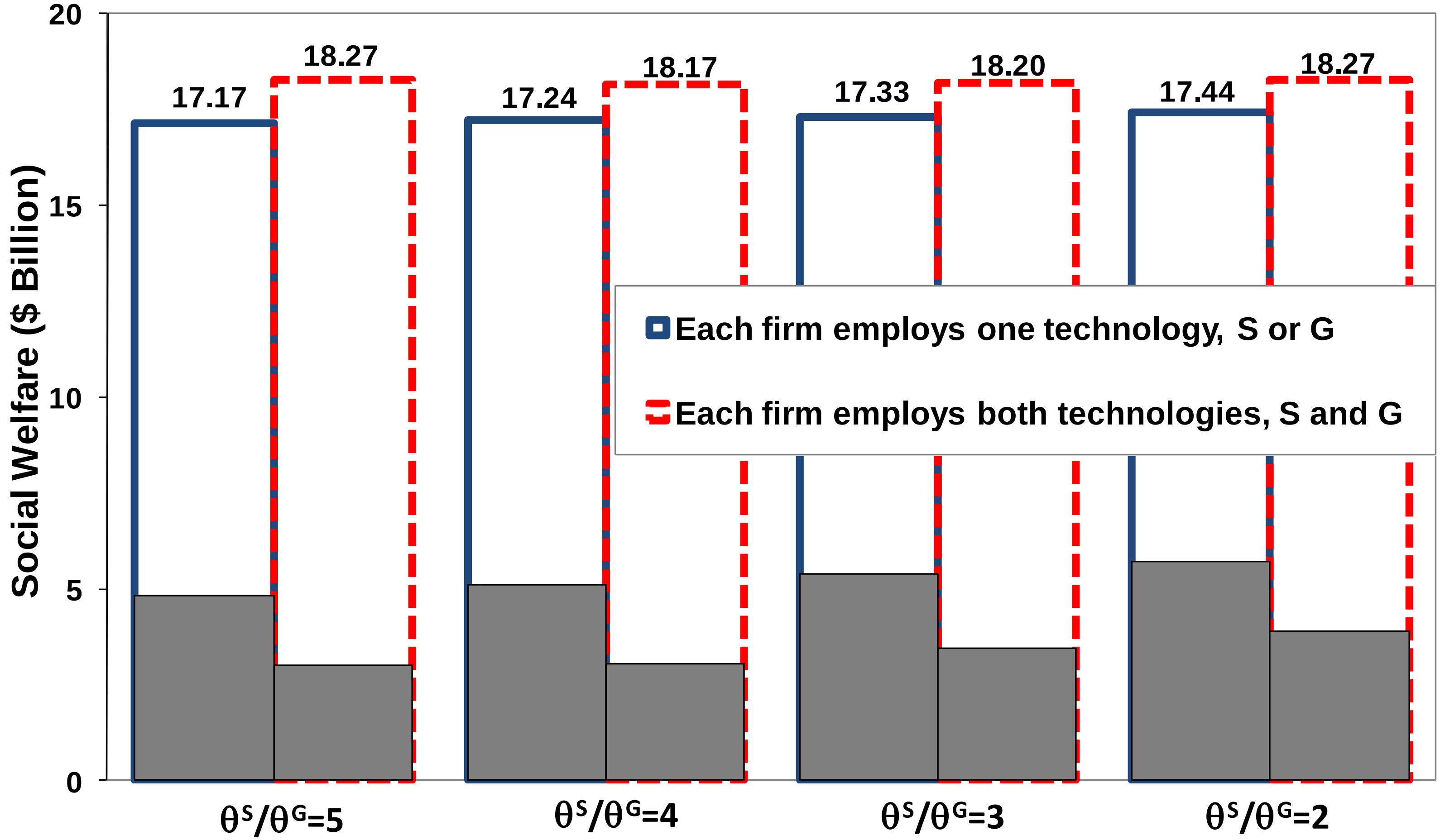
(sun is available 48% of the year; M = 5)



Profits of the PV-using firms (technology S) are depicted by the striped areas of the bars. Profits of the firms that employ CCGTs (technology G) are depicted by the white areas of the bars.

Social Welfare

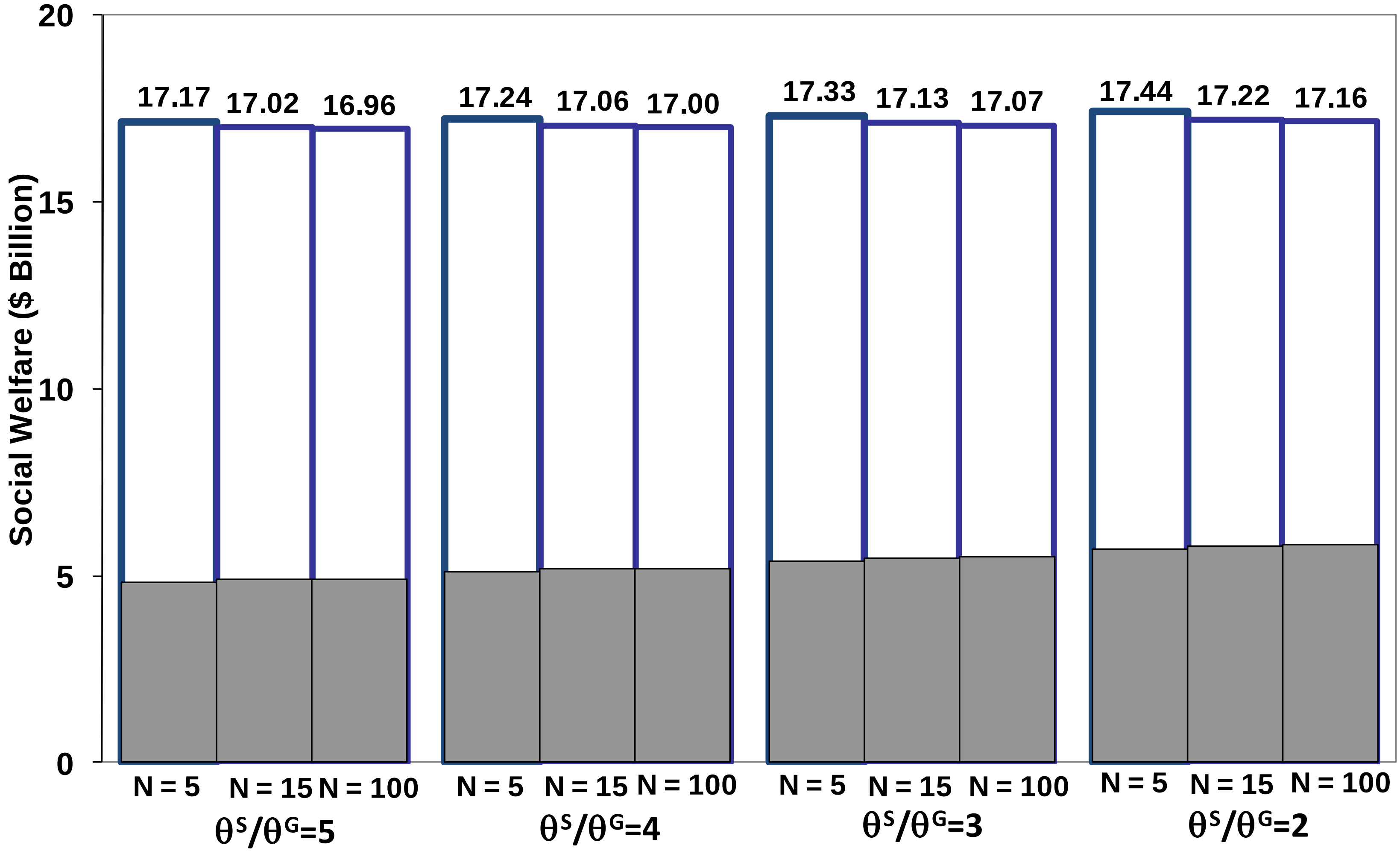
(sun is available 48% of the year)



Consumer surplus is depicted by the white area of the bars. Profits are depicted by the gray areas of the bars.

Social Welfare

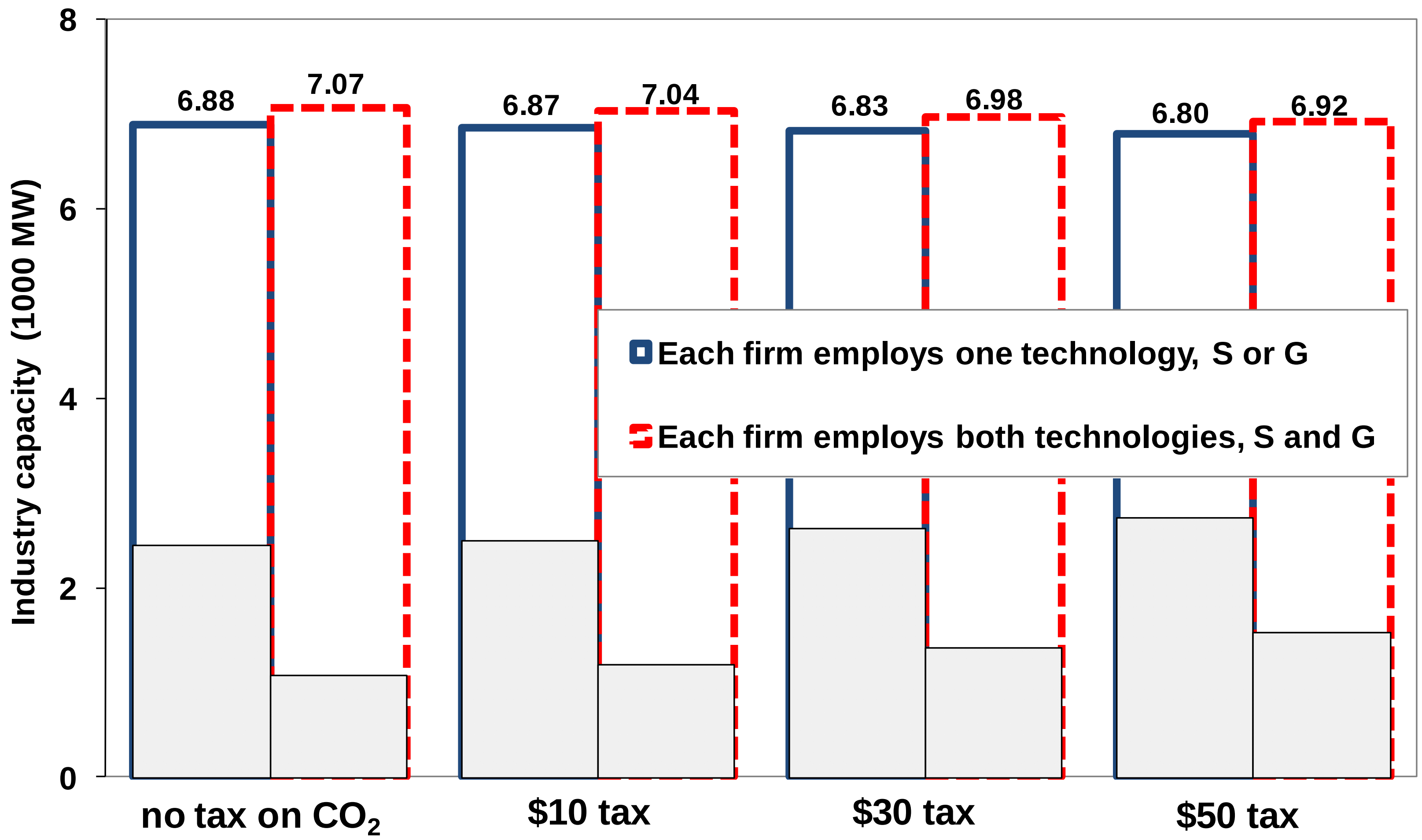
(sun is available 48% of the year; M = 5)



Consumer surplus is depicted by the white area of the bars. Profits are depicted by the gray areas of the bars.

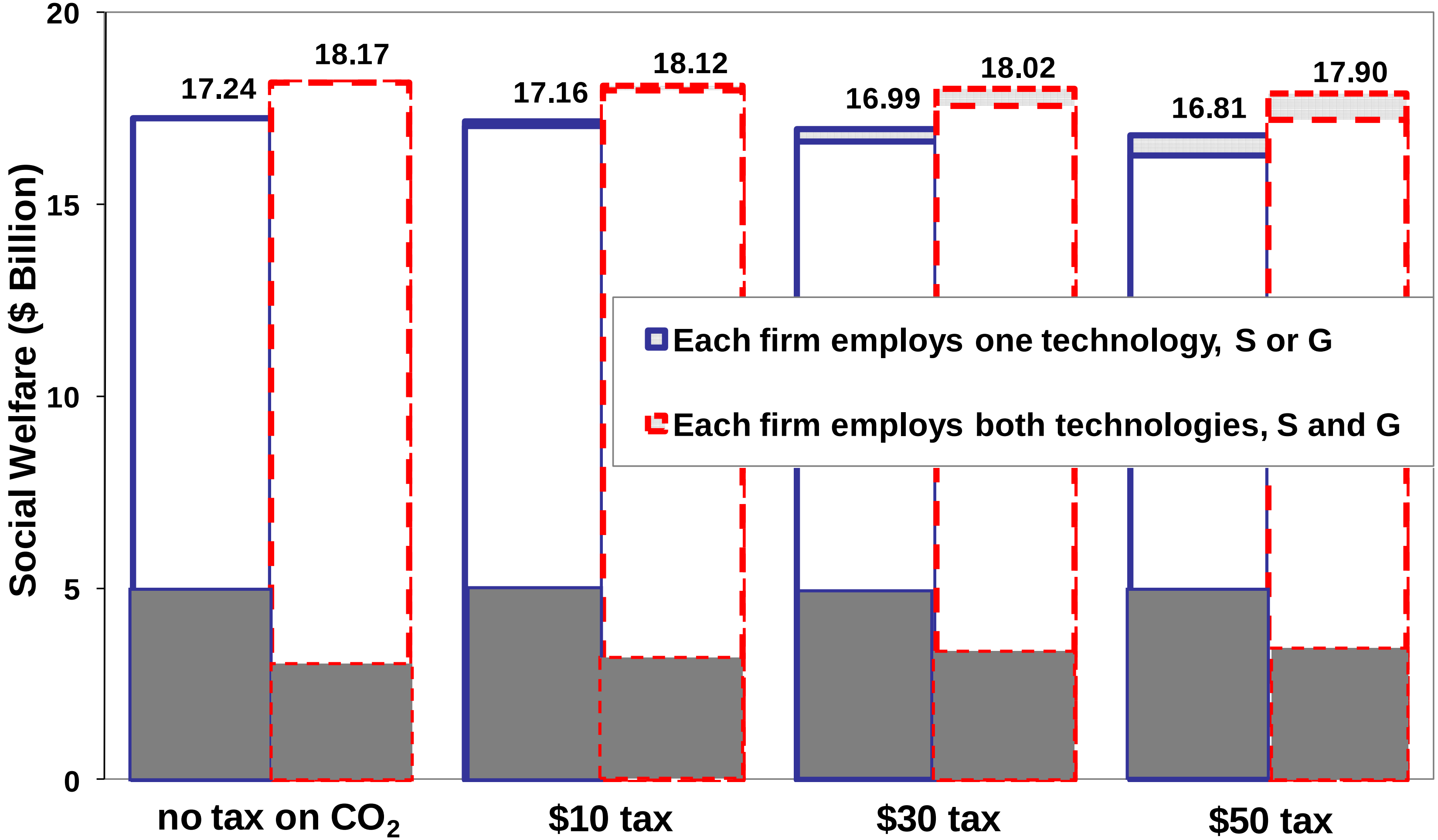
Industry capacity (tax on CO_2)

(sun is available 48% of the year)



Social Welfare (tax on CO_2)

(sun is available 48% of the year)



Industry profits are depicted by the gray area of the bars. Consumer surplus is depicted by the white area of the bars. Tax payments are depicted by the striped area of the bars.

Summary and main results

- **The share of PV in total capacity will be small in the near future and a CO_2 tax will likely have only a minor effect on PV capacity and production.**
- **The average electricity price will rise when PV adoption rises (due to the projected declining cost of PV capacity, as a result of technology improvements in PV production).**
- **Market structure [(1) Each firm can construct one generating technology; (2) each firm can construct both generating technologies] has a large effect on capacity mix and price volatility (When all producers use both technologies: average price is lower, electricity production is higher, Industry profits are smaller, social welfare is higher, the share of PV is smaller).**
- **Price volatility will rise and welfare will decline should the regulator introduce CO_2 taxes.**