What cost for photovoltaic modules in 2020? Lessons from experience curves

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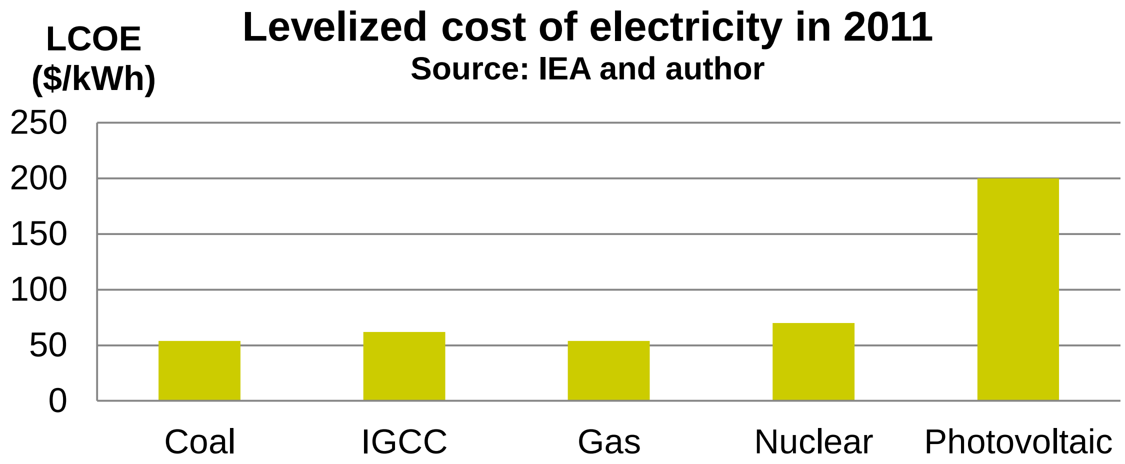
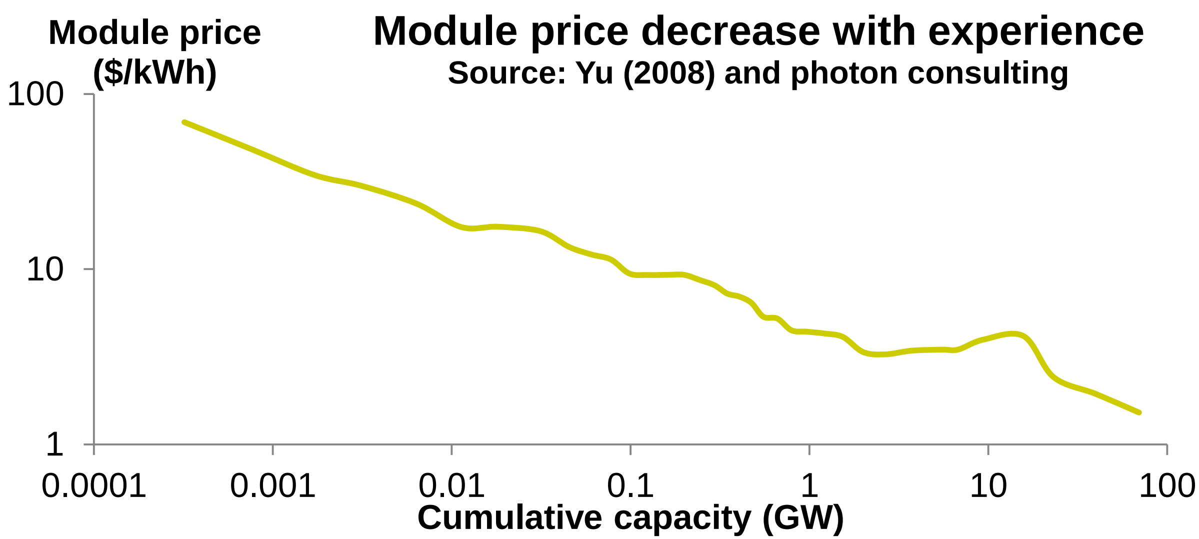
Importance of cost prediction for photovoltaic energy

- High cost today…



- …But future cost decrease through "learning by doing"

→Justifying development policy



The experience curve model

- One factor… $C = C_0 Exp^{-E}$
  - C : cost of one unit of output
  - C_0 : the cost of the first unit
  - Exp: experience (measured by cumulative output or another proxy)
  - $Learning\ rate = 1 - 2^{-E}$
- …Or multifactor $C = a\ Exp^{-E}\ X^{\alpha}\ Y^{\beta} \ldots$
- Regression equation:

$$\log(C) = \log(a) - E\log(Exp) + \alpha\log(X) + \beta\log(Y) + \varepsilon_t$$

Survey of experience curves applied to the PV industry

- 20 studies

- 17 with only experience as explanatory variable
  - Mostly on a global scale
  - Average learning rate of 20.2% on a global scale

- 3 with other variables: scale, R&D, silicon price, and silver price

Several variables can be included in the model

Purpose of the study

- Find the best specification of the model
  - Criterion: predictive power
- Use it to predict module cost until 2020
- Draw the implications for the cost of PV electricity

Consequence of the addition of an explanatory variable?

Two issues are important for the accuracy of the predictions:

- The predictability of the variable
- The consequence on the predictive power of the model
  - The addition avoids the omitted variable bias…
  - …but it can create multicollinearity increasing the variance

No clear answer → we test it empirically

Out of the sample evaluation of the different specifications

- Objective:
  - Evaluate the predictive power of the 16 different specifications = combination of explanatory variables:
    - Cumulative capacity: always included
    - Scale
    - R&D
    - Silicon price
    - Silver price

    (Scale, R&D, Silicon price, Silver price) } Possible additional explanatory variable → 16 combinations

- Data:
  - World average annual values from 1990 to 2011 for PV modules price, cumulative capacity, plant size, R&D knowledge stock, Silicon price, and Silver price

Out of the sample evaluation Methodology

- We estimate 192 models
  - 16 specifications
  - Estimated on 12 ten years periods: 1990 → 1999; 1991→2000, …

- Prediction after the estimation period until 2011

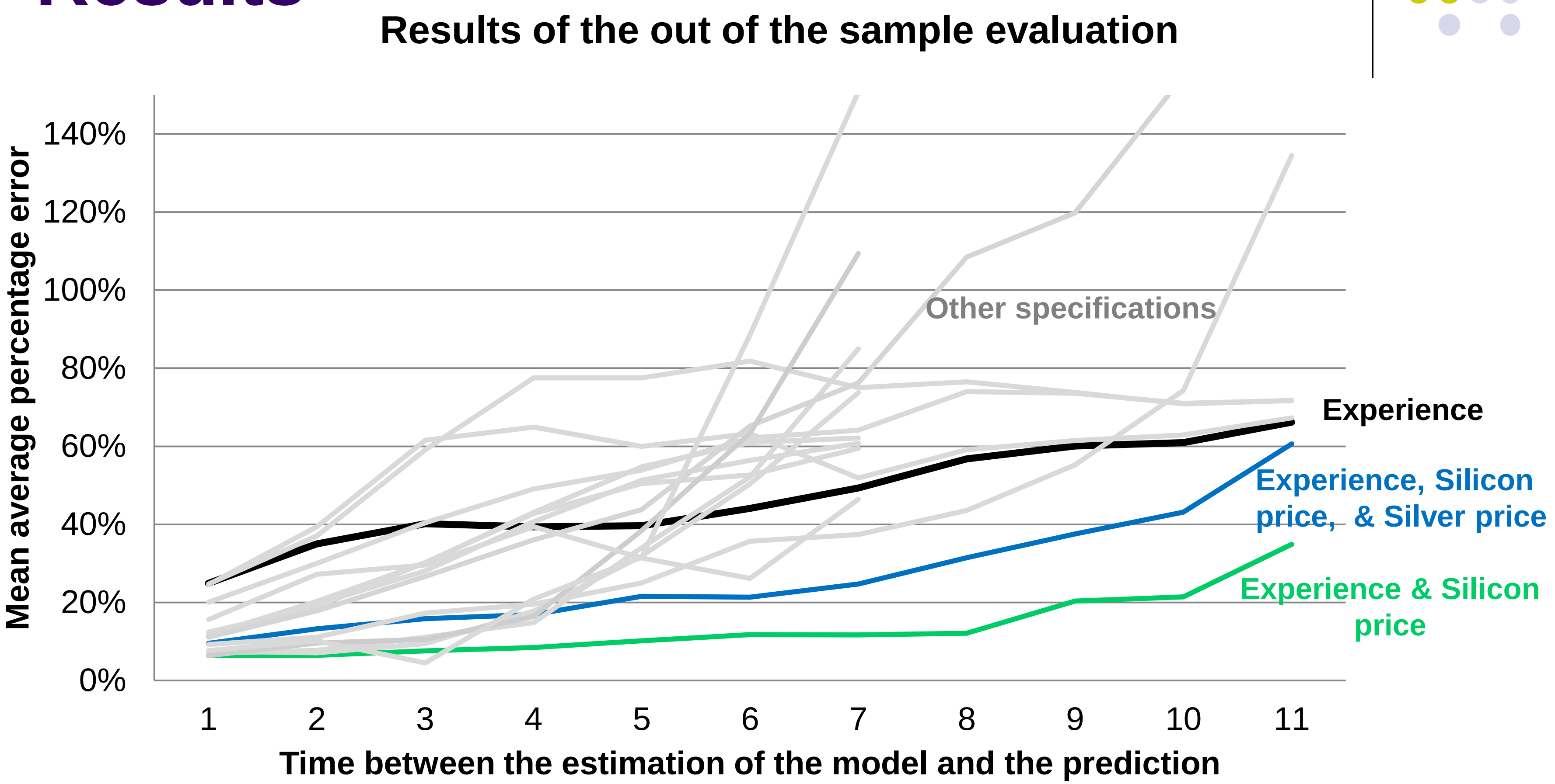
- Measurement of prediction accuracy based on the difference between the predicted $\hat{y}_i$ and the realized value y_i
- For each specification / time horizon, we compute the mean absolute percentage error (MAPE)

$$MAPE(t) = \frac{1}{n_t} * \sum_{i=1}^{n_t} \left| \frac{\hat{y}_i - y_i}{y_i} \right|$$

With t, the time horizon of the prediction,

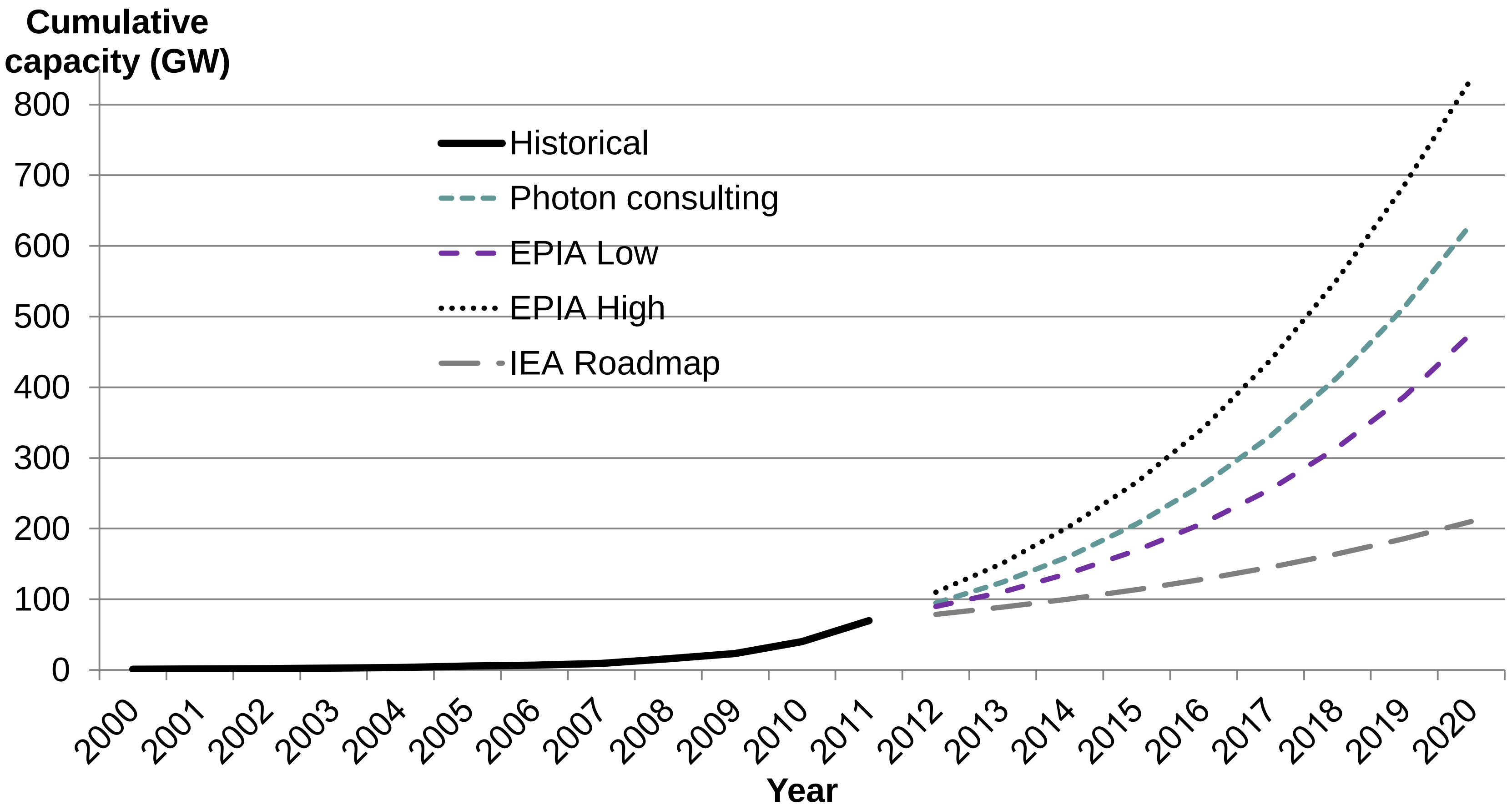
n_t the corresponding number of predictions at this time horizon

Out of the sample evaluation -Results



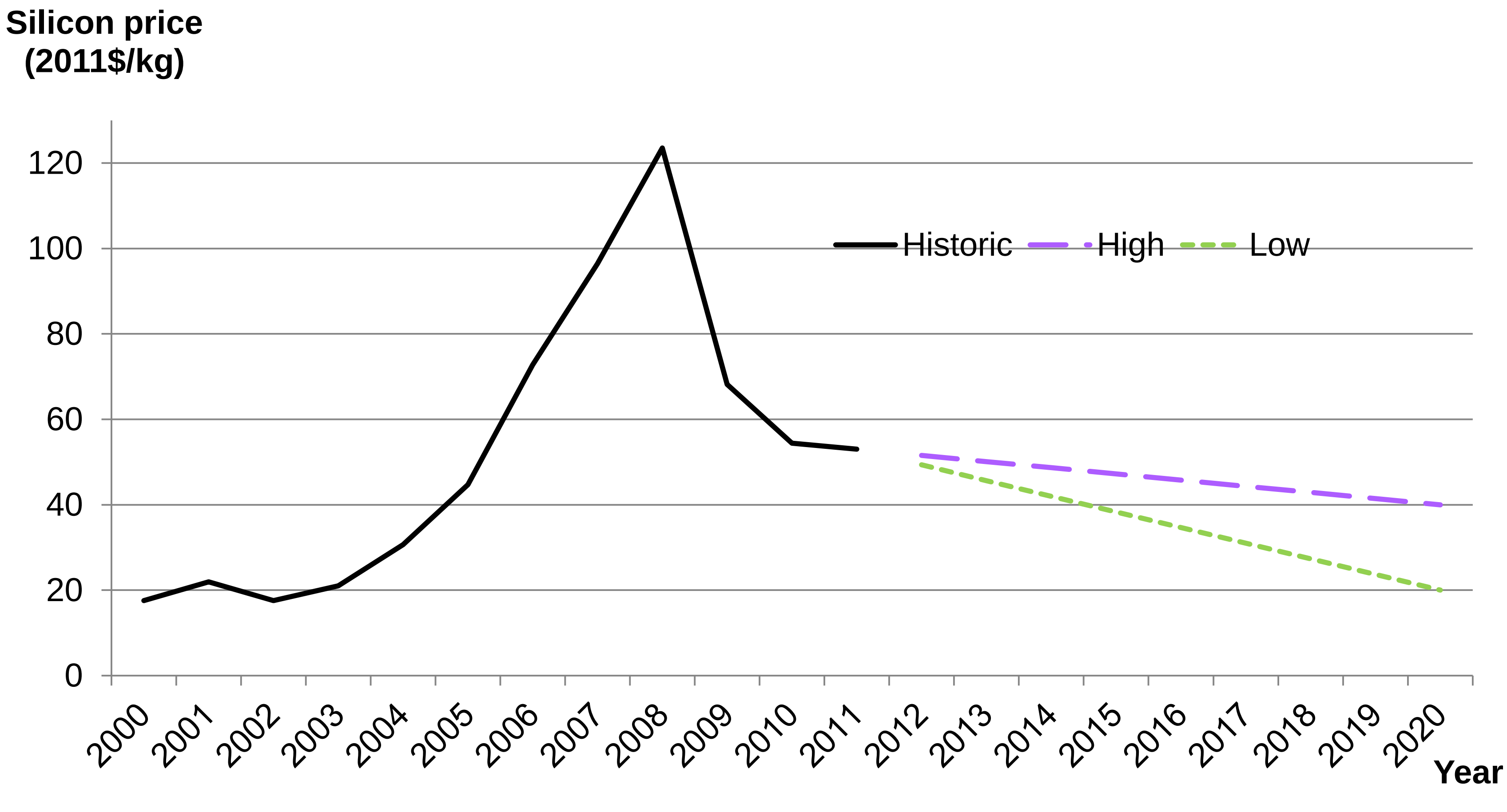
The specification with experience and silicon price has the best predictive power

Post 2011prediction of the dependent variables
- Cumulative capacity

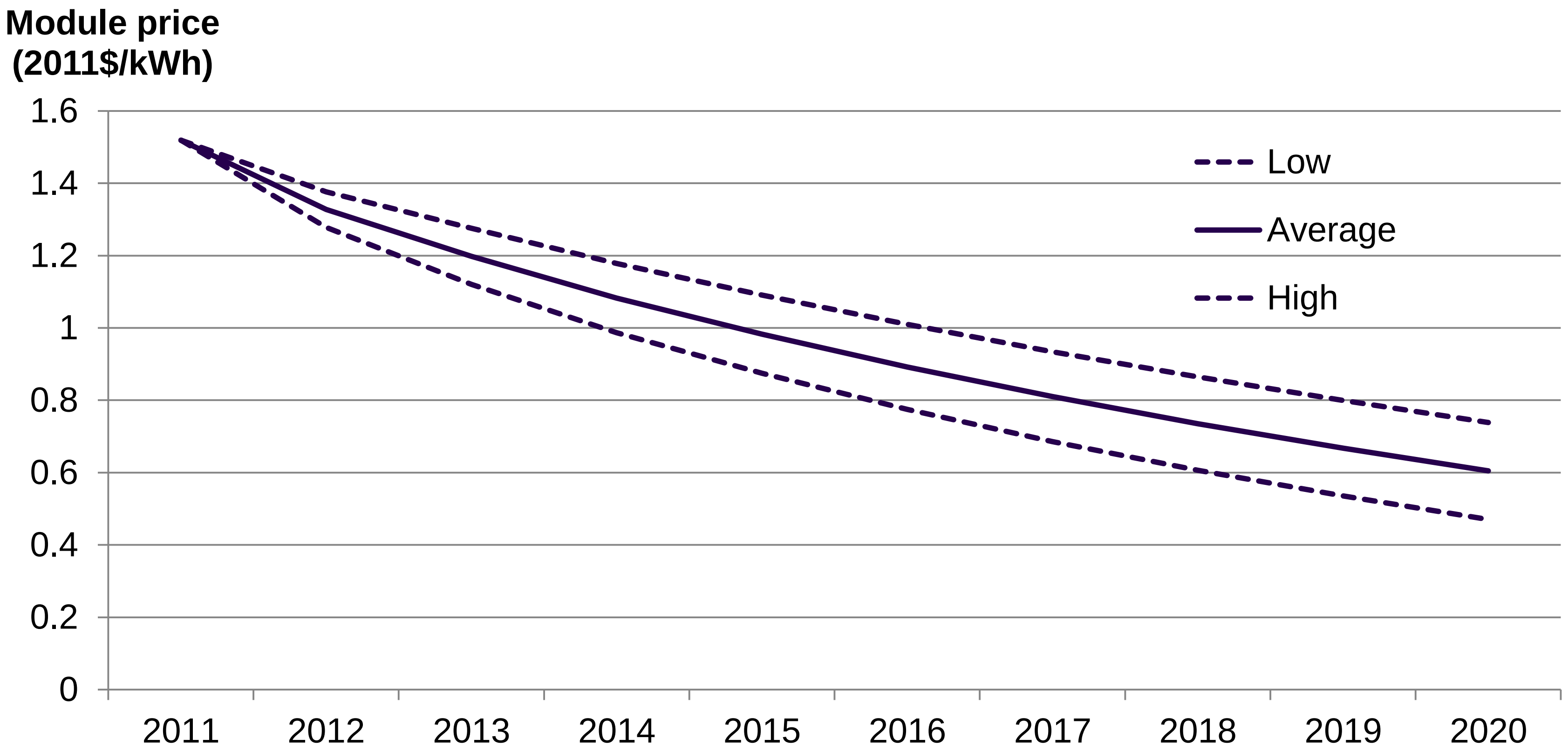


Highly dependent on policy decisions

Post 2011prediction of the dependent variables
-Silicon price



Results:
PV module price evolution until 2020



Module price of 0.60$/Wp in 2020 [0.47-0.74]

What PV electricity cost in 2020?

- The Levelized Cost Of Electricity (LCOE) in $/kWh
  - $$\text{LCOE} = \frac{\textit{Net present value (cost of the system+operation\&maintenance)}}{\textit{Net present value (electricity produced)}}$$
- depends on
  - The module price (about 40% of the total LCOE)
  - The lifetime of the project
  - The type of PV system (residential, commercial, utility)
  - The location (sunlight availability)
  - Etc…

It doesn't make sense to talk about on price of PV electricity

Grid parity

- Definition: When the LCOE of a PV system reaches the retail price of electricity (240$/MWh in Europe in 2011)
- Concern residential systems (replace electricity from the grid)

- Result:
  - Already reached in California and most of Spain,
  - We predict in Germany in 2013 where the electricity is expensive,
  - in 2017 in France…

- What means grid parity?
  - Doesn’t create the expected demand boom
  - Still long payback time

Competitiveness vith conventional technologies

- Definition: When the LCOE reaches the LCOE from conventional sources: about 70$/MWh
- Concerns utility systems (compete with power plants)

- Results:
  - In 2019/2020 in the sunniest places (south of Spain or Italy, California…)
  - Several years later in other countries

- Competitiveness with conventional technologies still miss the issue of integration

Conclusion

- The empirical evaluation suggests that the most accurate specification includes experience and silicon price as explanatory variables
- This model predicts a module price of 0.60$/kWh in 2011
  - Learning rate of 19.6%
- Competitiveness implications:
  - Grid parity is already a reality in regions with high sun availability and/or high electricity price
  - But competitiveness with conventional electricity production sources is still far (2019 in the sunniest places)
- Doesn't take into account other important aspects
  - Integration