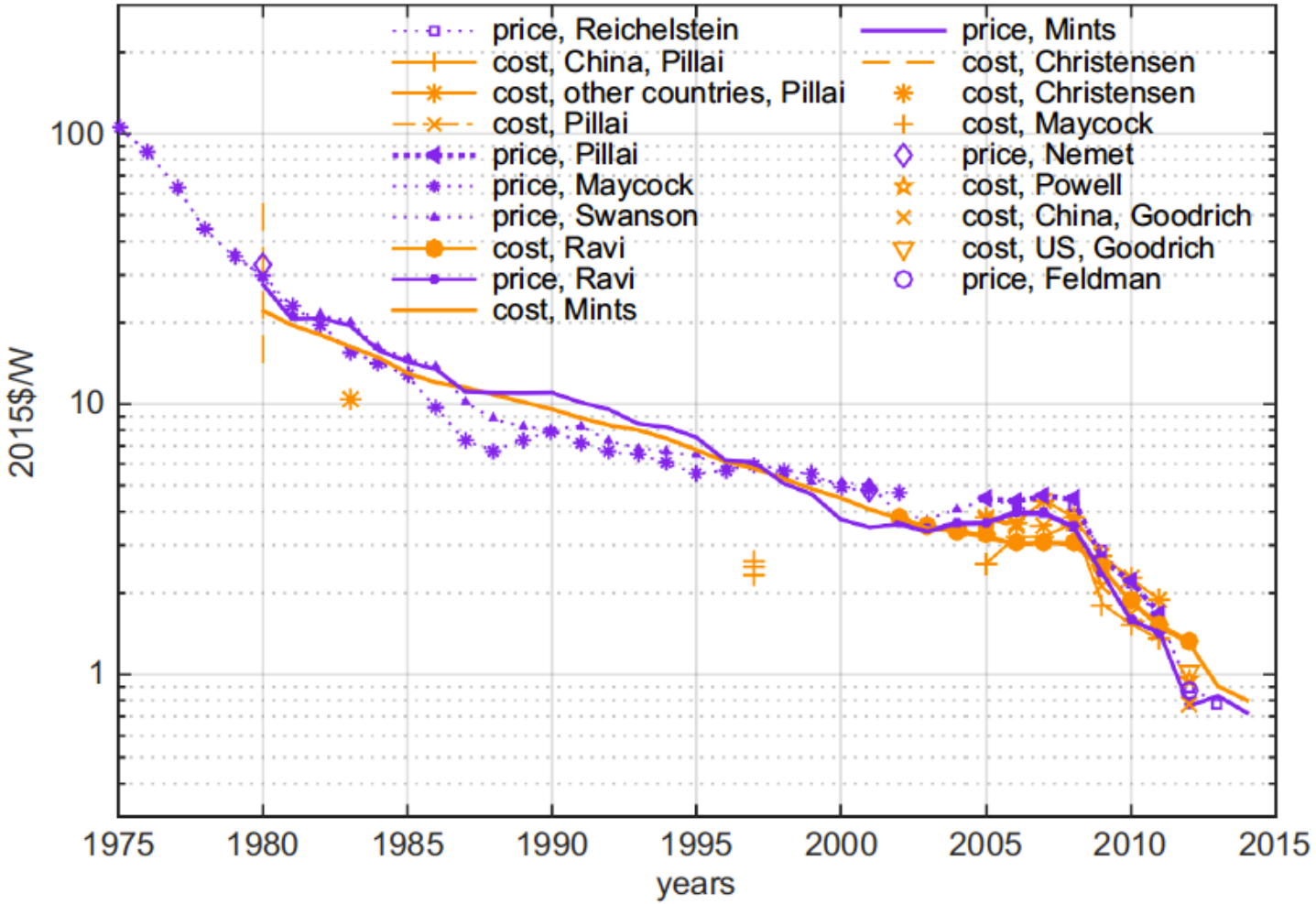
Drivers of cost reduction in photovoltaic modules and lessons for other technologies

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Photovoltaics modules cost decline



Kavlak, McNerney, Trancik, *Energy Policy* 2018.

Why did photovoltaics module costs fall?

Government policy drivers of PV modules' cost decline?

- 60% research and development funding and 30% market-stimulating policies?

or

- 30% research and development funding and 60% market-stimulating policies?

Most significant engineering driver of PV modules' cost decline?

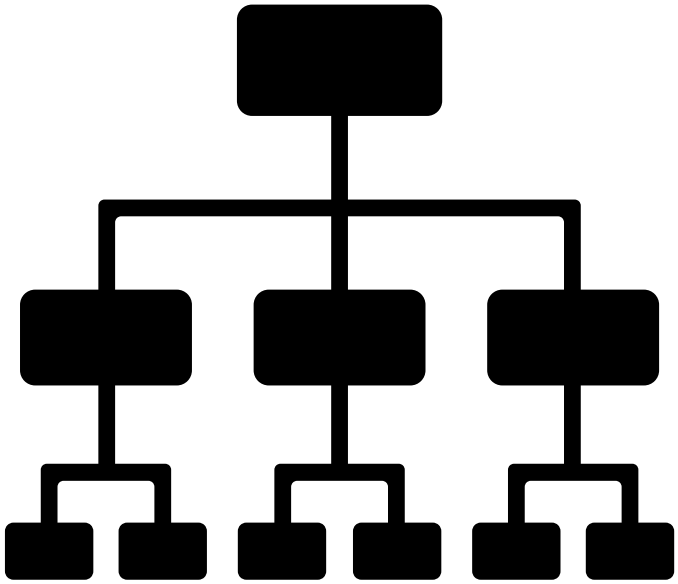
- Manufacturing yield
- Materials
- Module conversion efficiency
- Manufacturing scale

Conceptual model

Policies
(effects can be estimated)

High-level mechanisms
(effects can be estimated)

Low-level mechanisms
(measurable using
cost equation)



Quantitative model

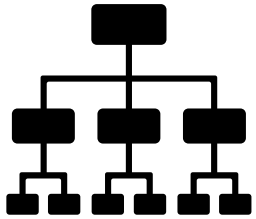
1. Cost equation

$$C(\mathbf{r}^t) = \sum_i c_i(\mathbf{r}^t)$$

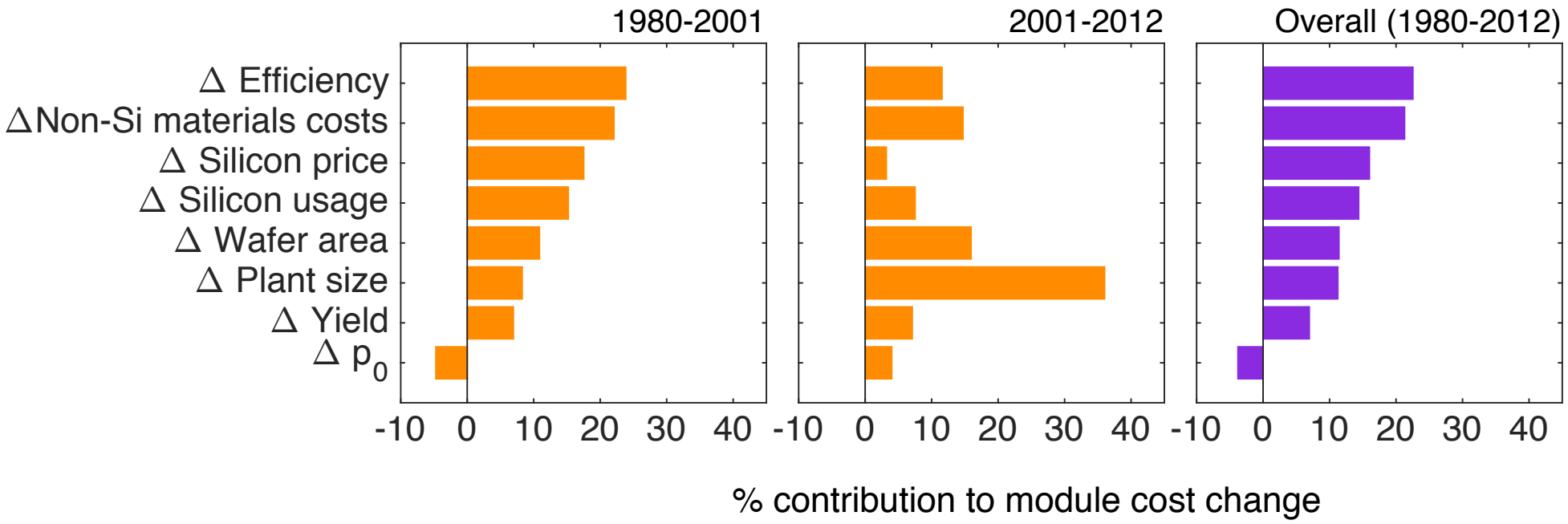
2. Cost change equations

$$(\Delta C_y)(t_1, t_2) \approx \sum_i \tilde{C}_i \ln\left(\frac{g_{iy}(r_{iy}^2)}{g_{iy}(r_{iy}^1)}\right)$$

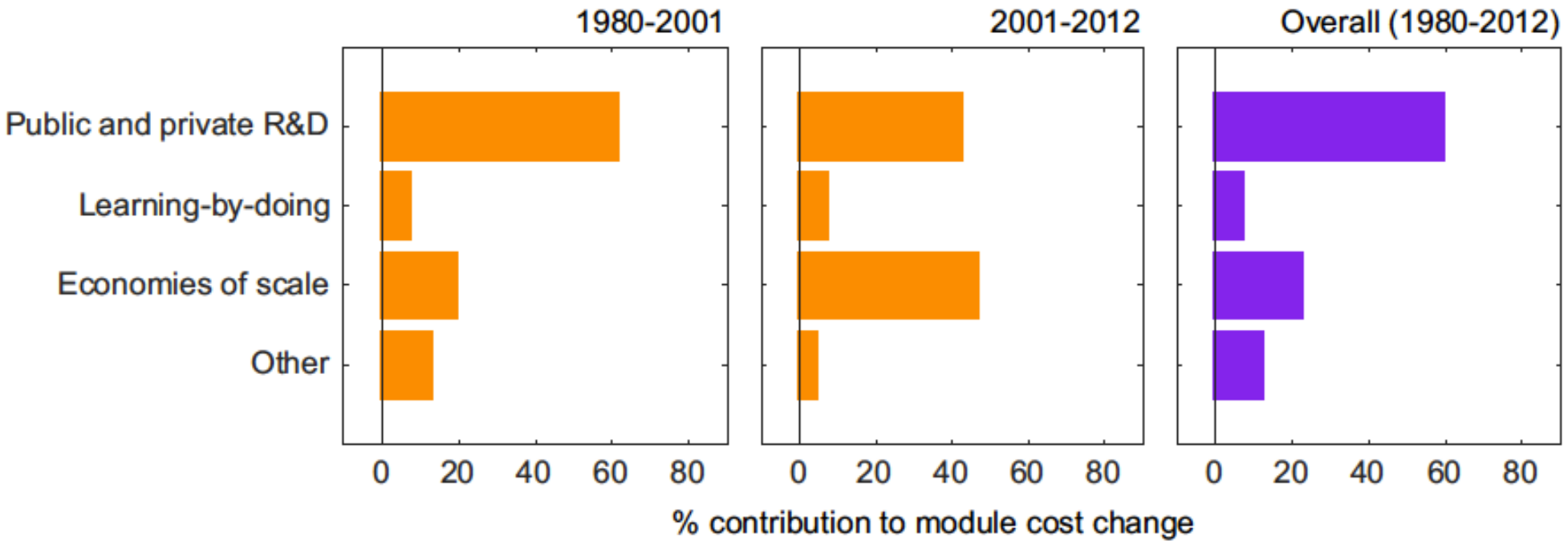
3. Assignment scheme



Low-level mechanisms of PV module cost reduction



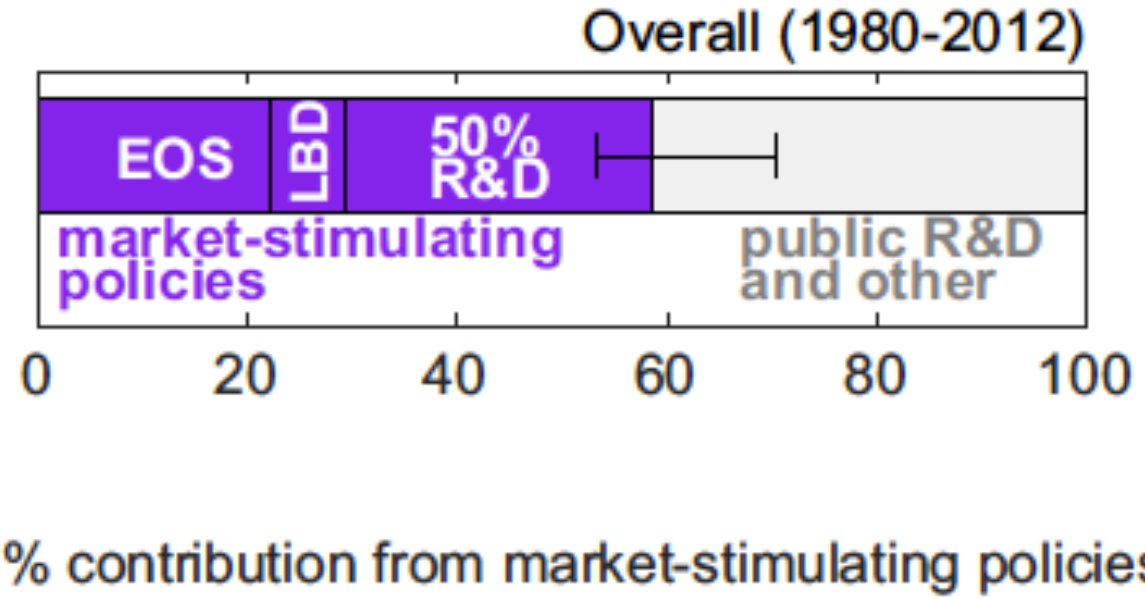
High-level mechanisms of PV module cost reduction



EOS=economies of scale

LBD=learning by doing

Government policy contributions to PV module cost reduction

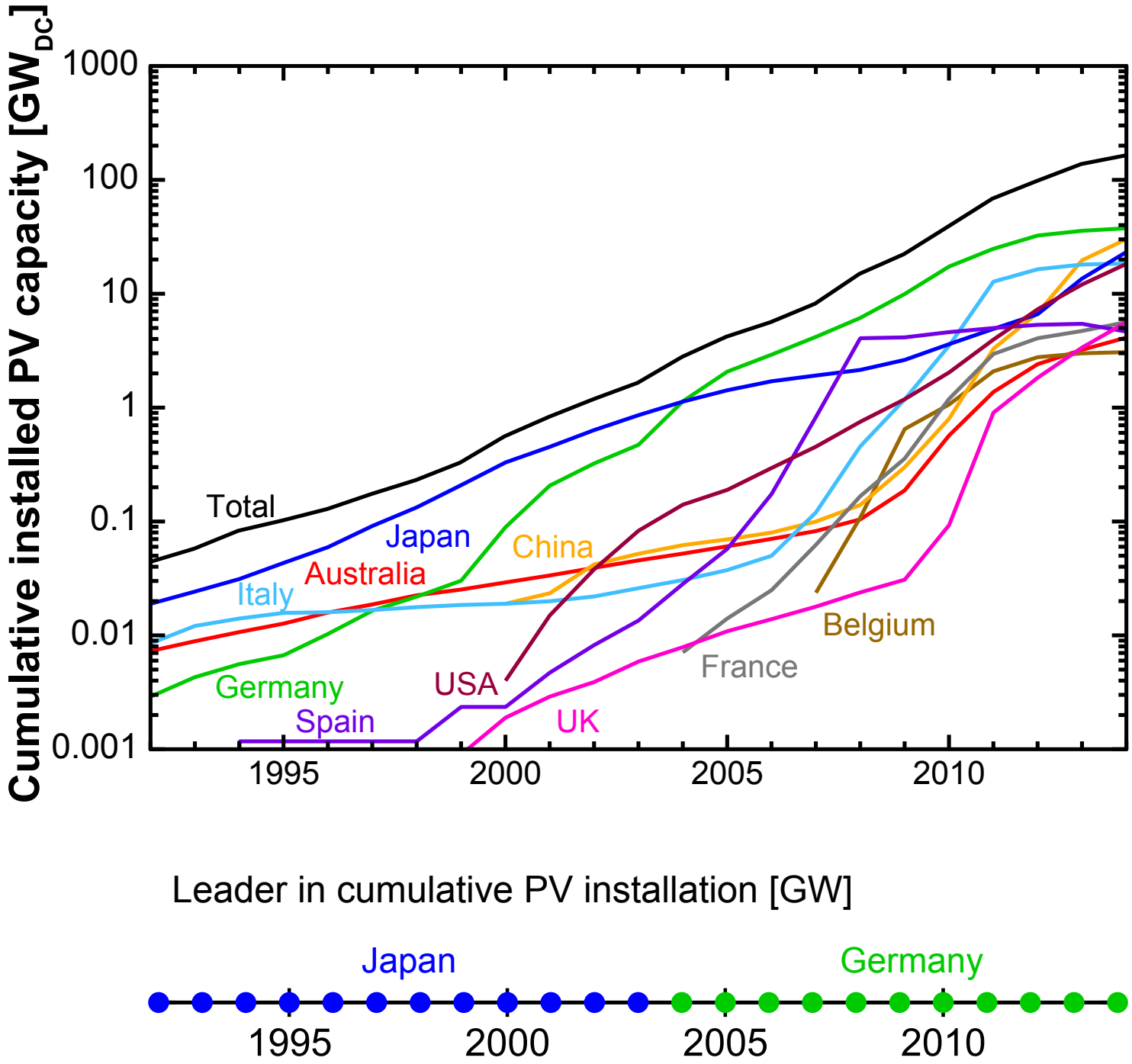


Government policy drivers of PV modules' cost decline?

- ~~60% research and development funding and 30% market-stimulating policies?~~

or

- 30% research and development funding and 60% market-stimulating policies?



Trancik, Brown, Jean, Kavlak, Klemun, Edwards, McNerney, Miotti, Mueller, Needell, Technical Report, 2015

Most significant engineering driver of PV modules' cost decline?

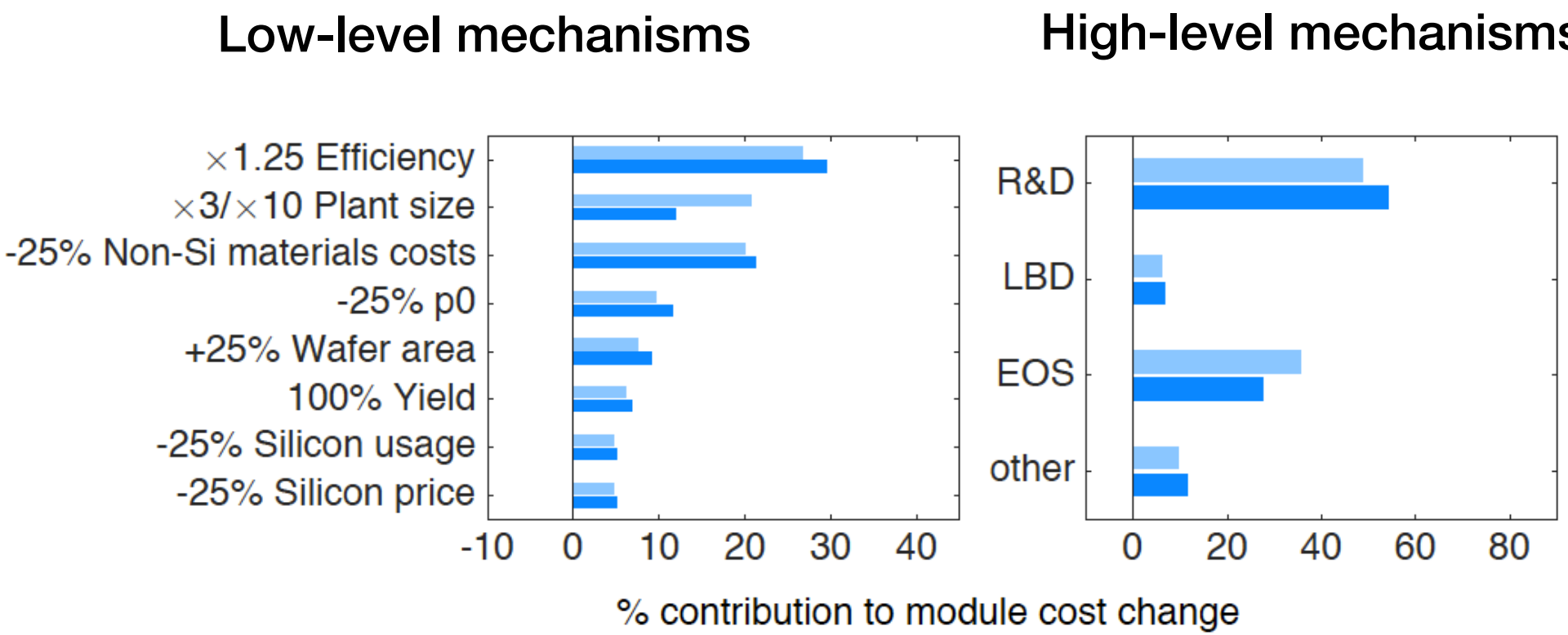
- ~~Manufacturing yield~~
- ~~Materials~~
- Module conversion efficiency
- ~~Manufacturing scale~~

Why did photovoltaics module costs fall?

- Efficiency, yield and other low-level mechanisms responsible (many possible knobs to turn)
- R&D and economies of scale dominant high-level mechanisms
- Market expansion policies played a critical role in reducing costs

Kavlak, McNerney, Trancik, *Energy Policy* 2018.

Prospective assessment of PV module cost reduction



EOS=economies of scale

LBD=learning by doing

Key takeaways (to inform policy decisions)

- Efficiency, yield and other low-level mechanisms responsible; Techs with many possible knobs to turn may show sustained improvement
- Policies supporting R&D drove important improvements; Models may help increase returns on investment
- R&D and economies of scale dominant high-level mechanisms; Prioritize both in setting company strategy and government policy
- Market expansion policies played a critical role in reducing costs; R&D alone may not achieve the same results

Methodological discussion

- Going ‘inside the black box’ identifies tech innovation drivers
- Tech features, strategies enabling innovation identifiable *ex ante*
- Method can be applied to many techs, metrics to:
  - Inform technology development efforts, investments, and government policy

Other technologies and recent findings

- Solar energy ‘soft’ costs:
  - Automation and standardization needed
  - New software in development
- Energy storage
  - Limits of Li-ion cost reduction potential
  - Models to inform flow battery and other tech development
- Nuclear fission, and others…

Acknowledgements

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