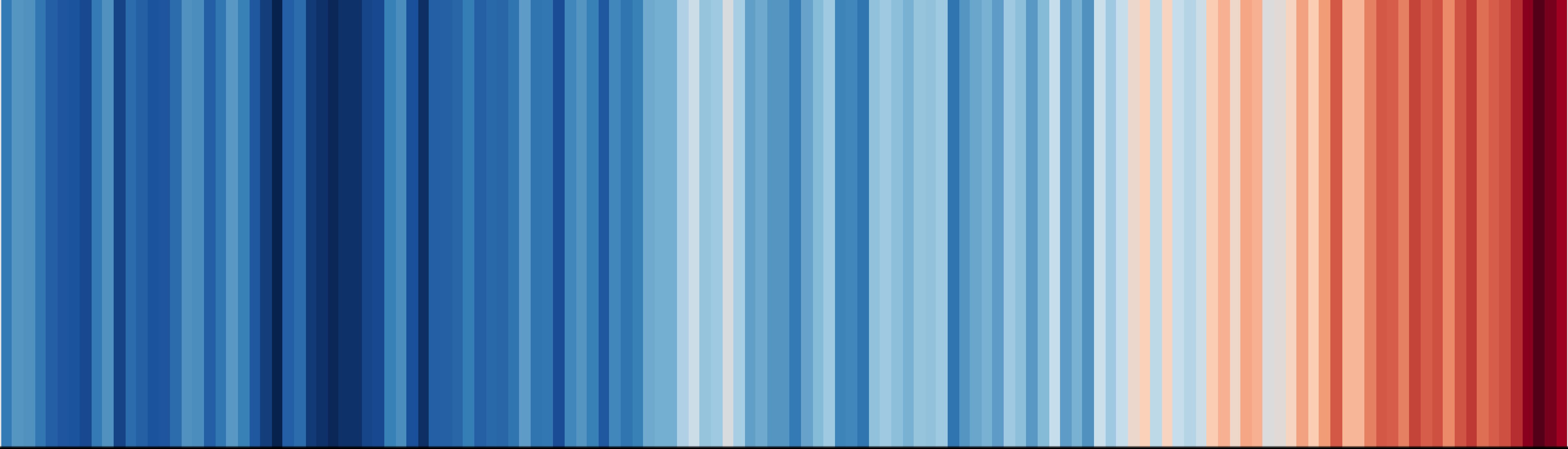

Quantifying the cost savings of global solar photovoltaic supply chains

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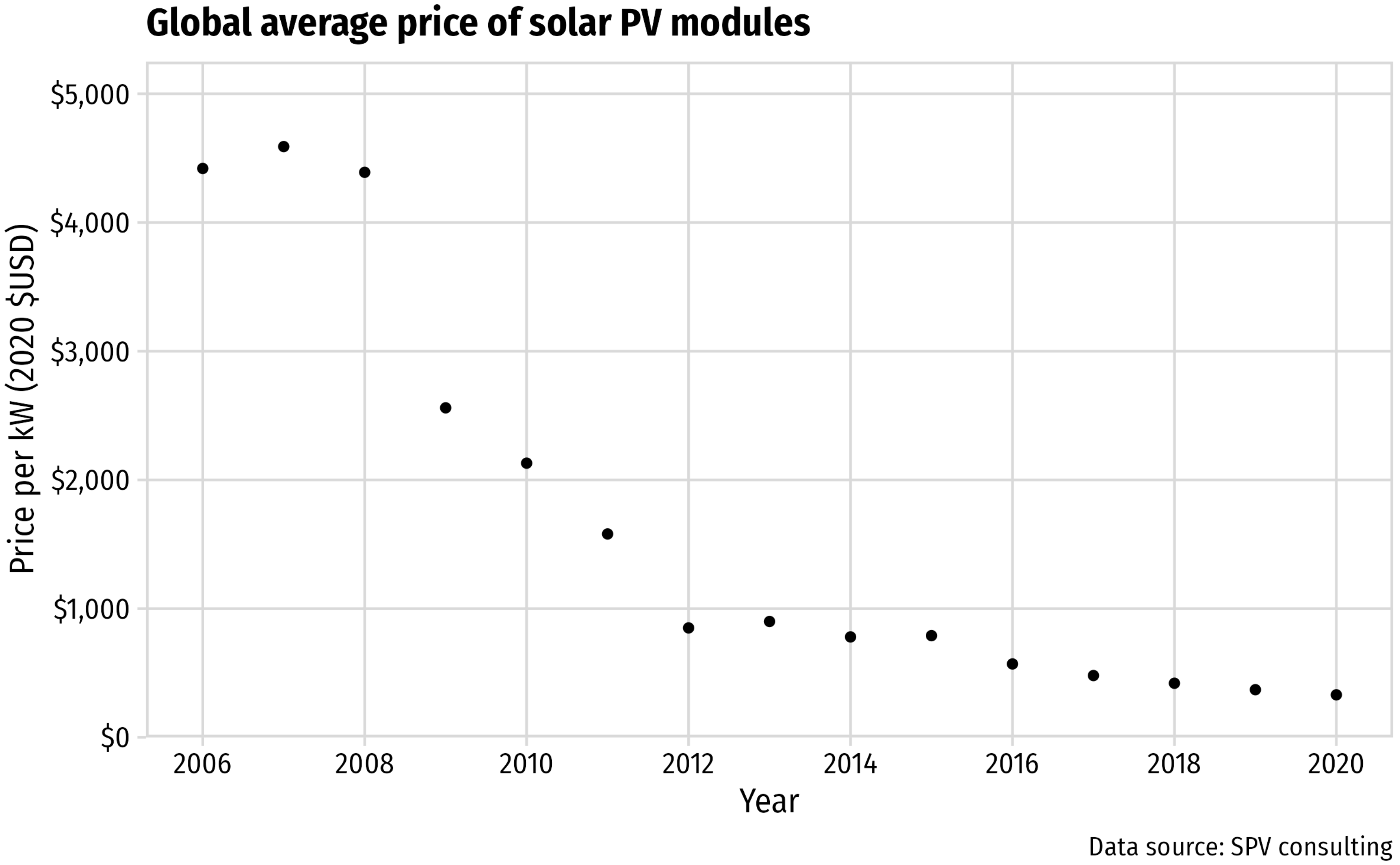
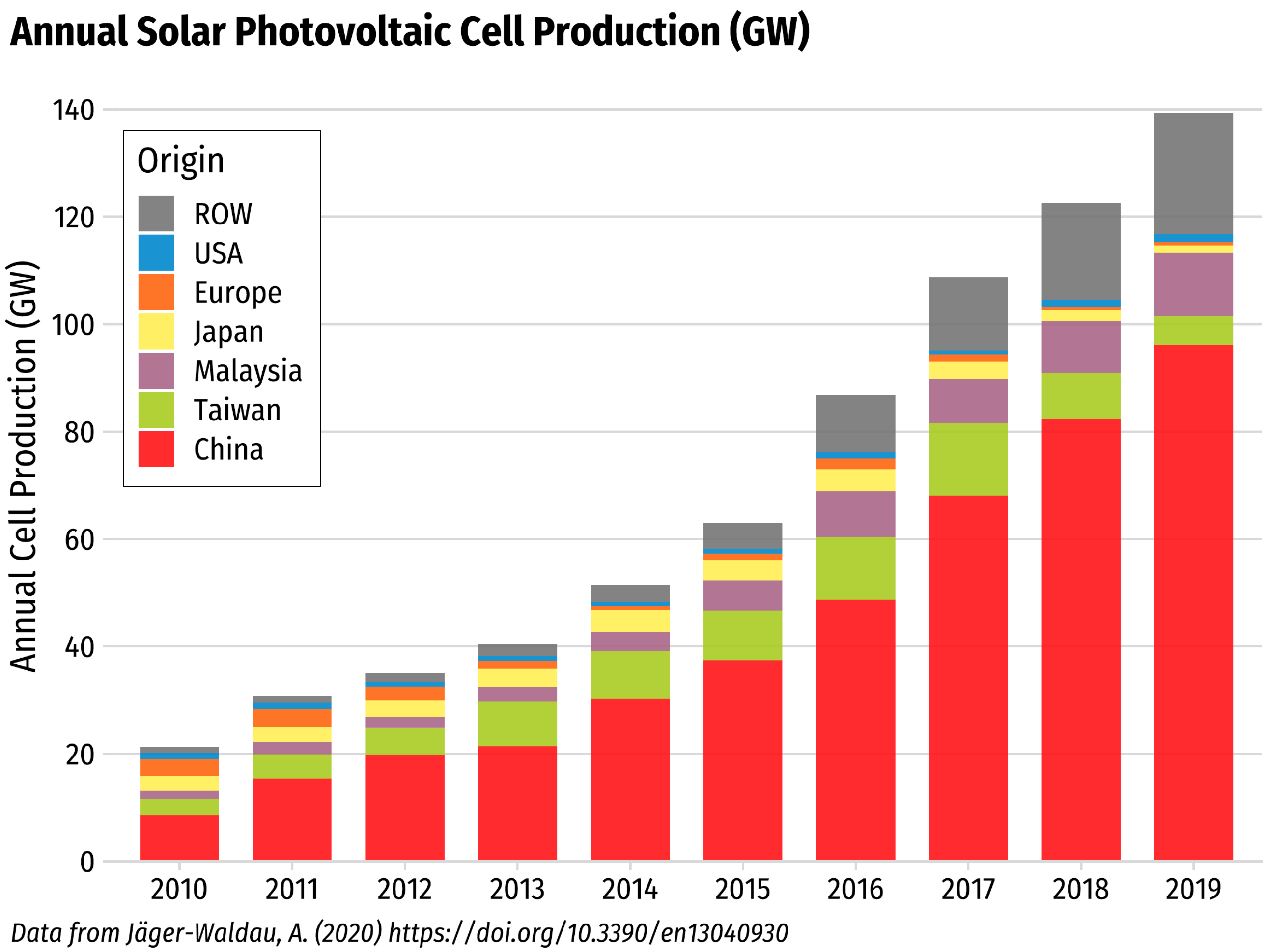
Gang He, Stonybrook University
Michael Davidson, UC San Diego

October 28, 2022

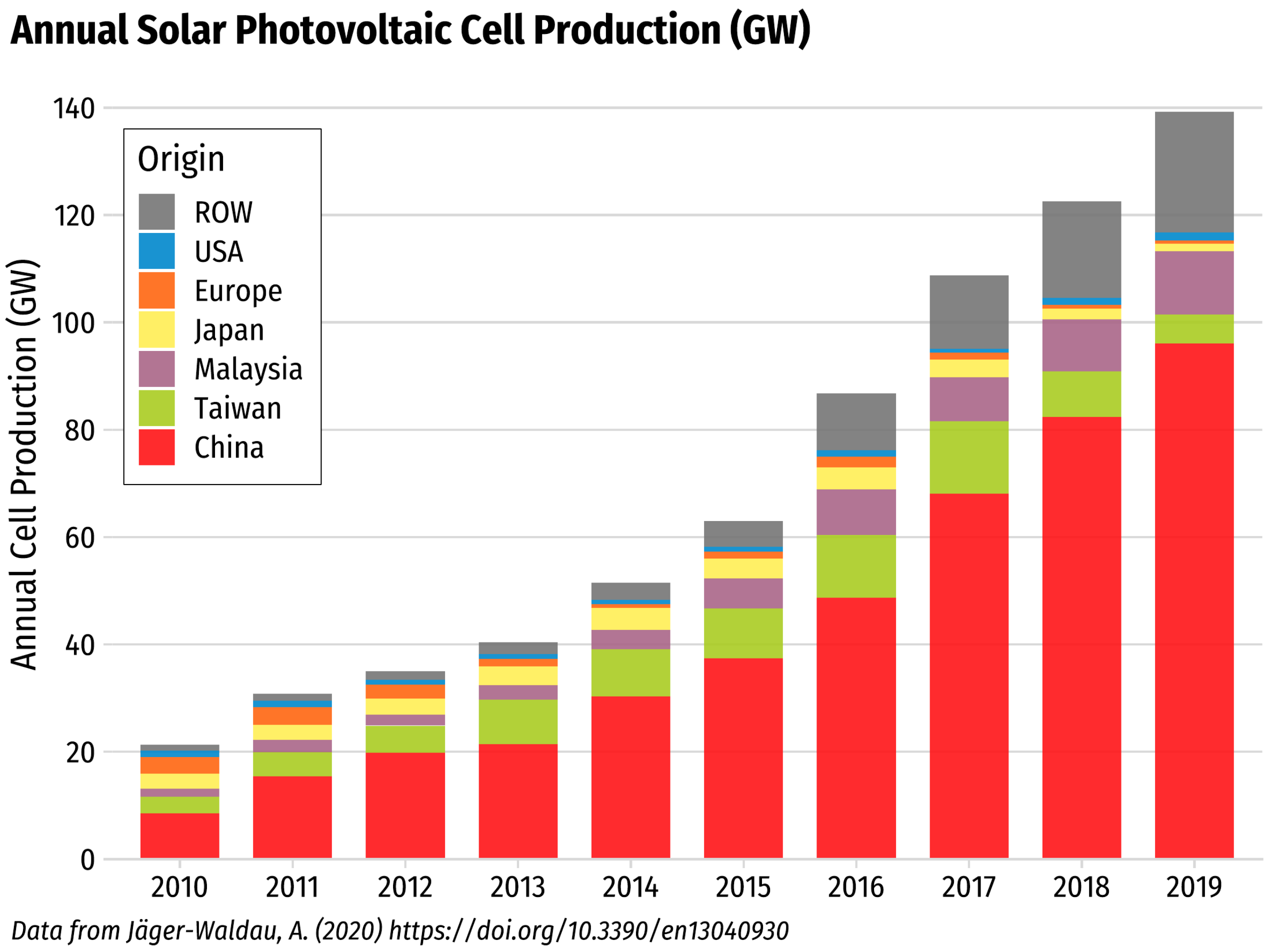
Between 2010 - 2020, global levelized cost of energy (LCOE) of utility-scale solar PV fell by 85%



China's "gift to the world"



China's "gift to the world"



China comprises ~70% of global PV manufacturing

Response:

- US and EU tariffs on imported Chinese PV panels
- June 2022: Biden invokes the Defense Production Act to accelerate US PV manufacturing

Same tensions in every low-carbon technology

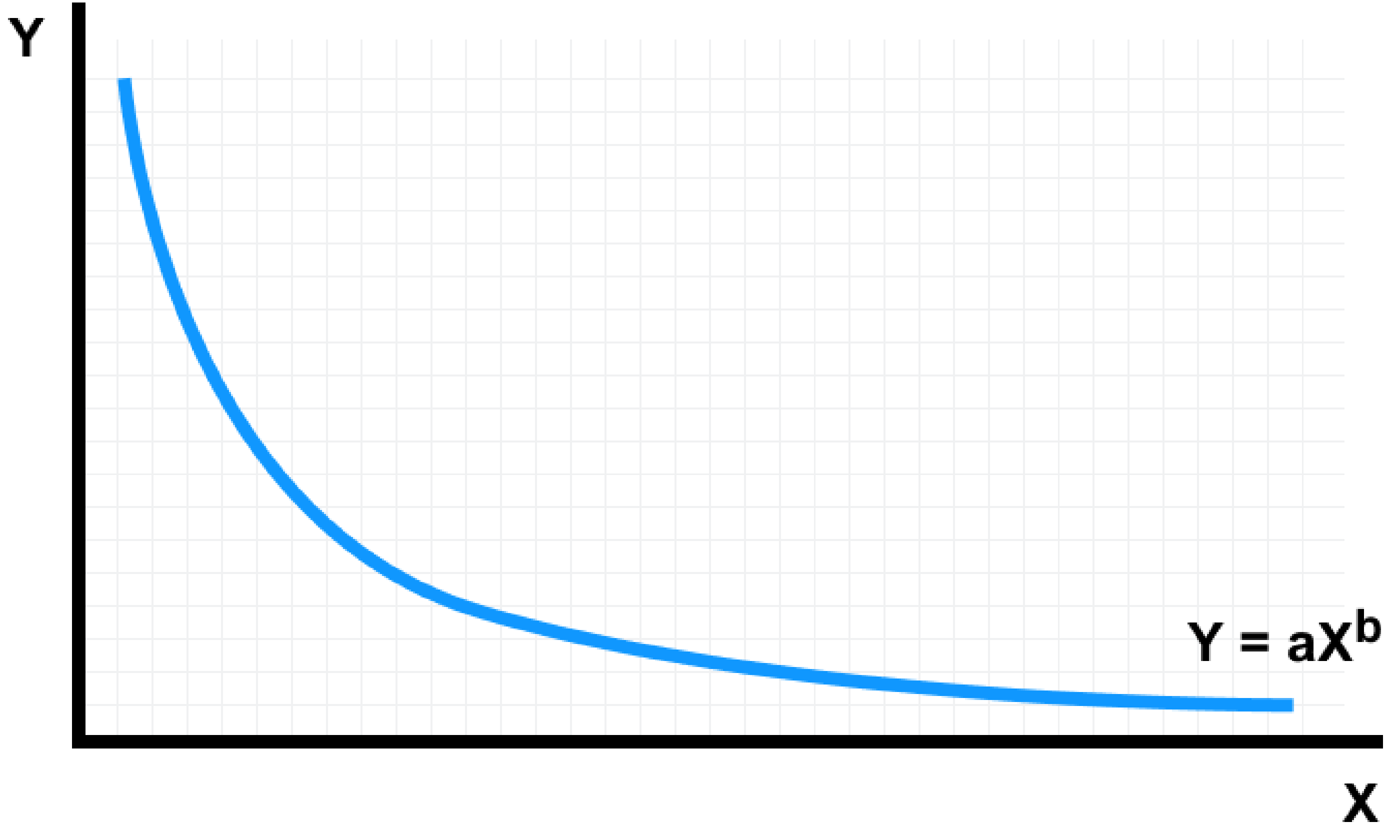
China is manufacturing leader in almost every sector

Technology	Scale
Solar Panels	From 1% to 70% (2001 - 2019)
Wind Turbines	1/3 of global supply (2020)
Electric Vehicles	51% of global sales (2021)
Lithium-ion Batteries	70% of global production (76% by 2025)
Nuclear Reactors	From 45 to 88 plants by 2030

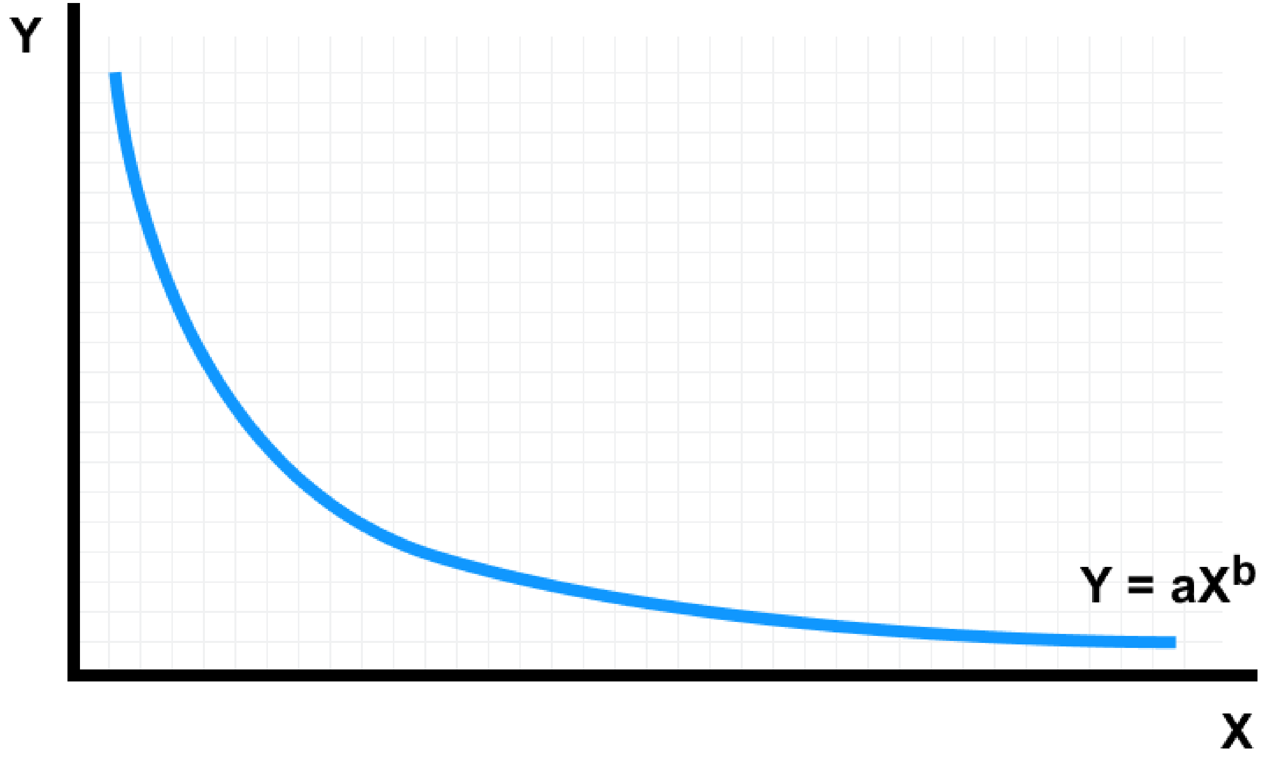
Title:
Quantifying the cost savings of global solar photovoltaic supply chains

Translation:
What's the cost of national versus global supply chains?

Learning curve model



Learning curve model



In context of solar PV:

- X: Cumulative installed cap.
- Y: = Price per kW

Log transformation:

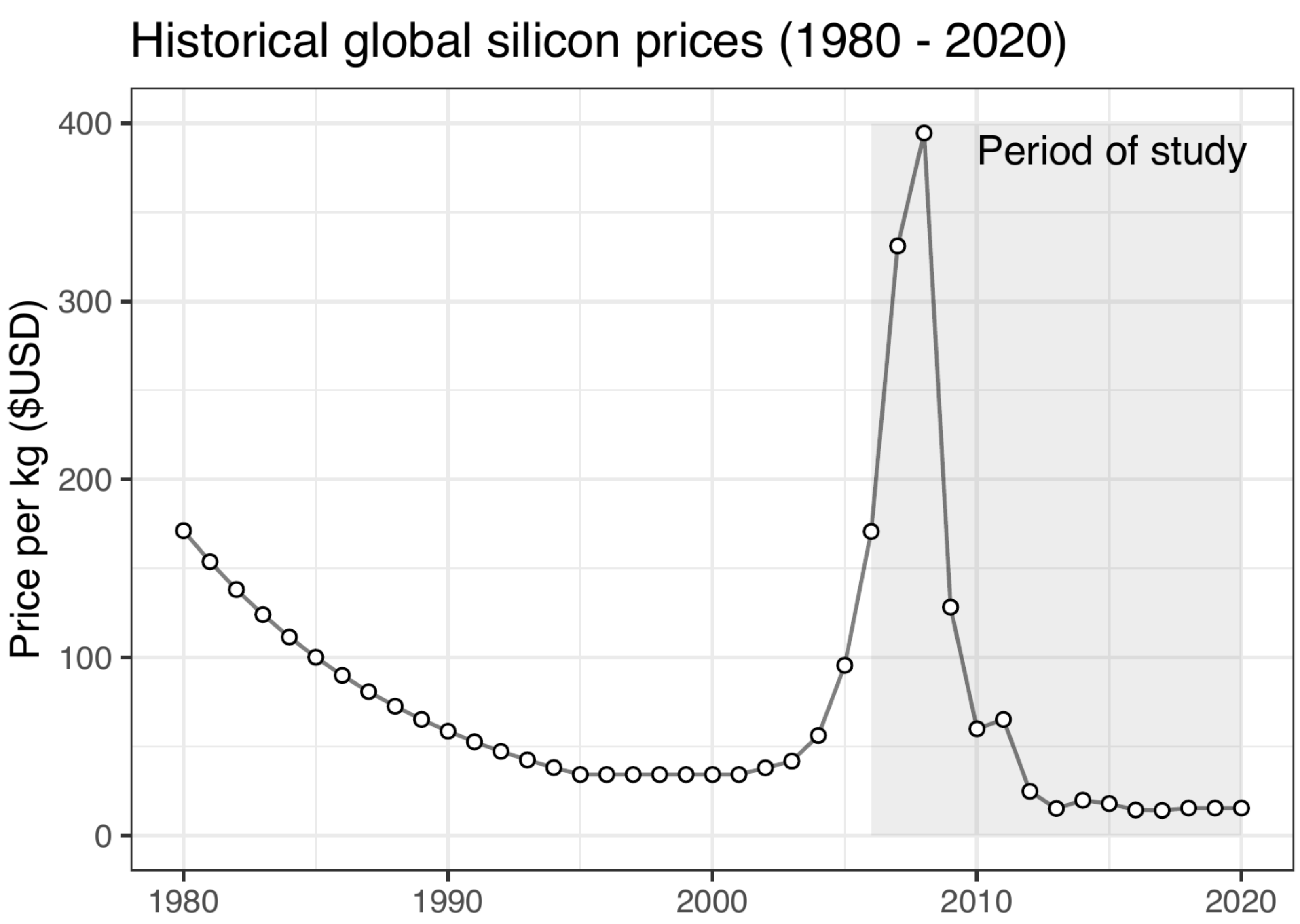
$$\ln Y = \ln a + b \ln X$$

Two-factor learning curve model:

$$\ln p_{it} = \ln \alpha_i + \beta_i \ln q_t + \gamma_i \ln \boldsymbol{s}_t + \varepsilon_{it}$$

price ($ / kW) = intercept + installed capacity + silicon price

for country *i* and year *t*



Data from Nemet, G. (2019) https://doi.org/10.4324/9780367136604

Two-factor learning curve model:

$$\ln p_{it} = \ln \alpha_i + \beta_i \ln q_t + \gamma_i \ln s_t + \varepsilon_{it}$$

Learning rate:

$$L_i = 1 - 2^{\beta_i}$$

Data Sources

Country	Data	Source
Global	Installed PV capacity and prices	International Renewable Energy Agency (IRENA)
U.S.	Installed capacity	Solar Energy Industries Association (SEIA)
U.S.	Module prices	Lawrence Berkeley National Laboratory (LBNL) & National Renewable Energy Laboratory (NREL)
China	Installed capacity & module prices	Energy Research Institute (ERI) & China Photovoltaic Industry Association
Germany	Installed capacity	IRENA
Germany	Module prices	Fraunhofer ISE50

All prices are in $2020 USD
(inflation adjustments from IMF, exchange rates from Federal Reserve Bank)

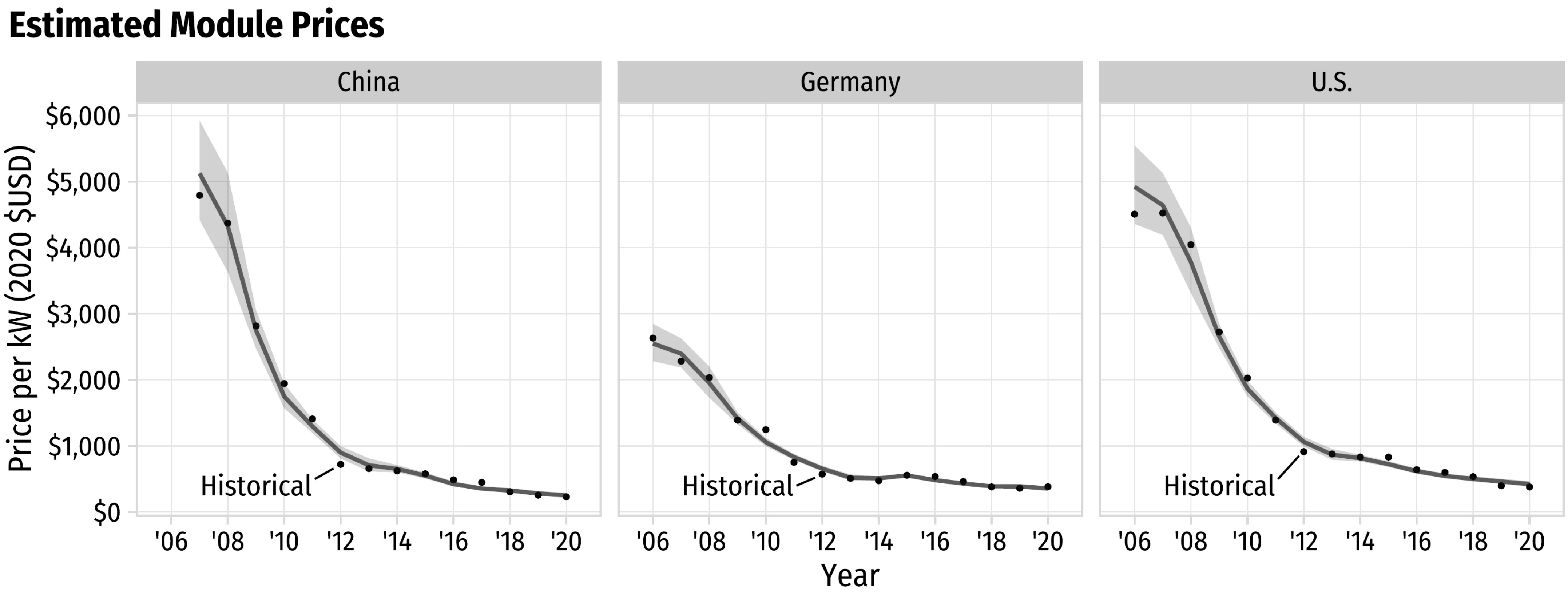
Model results

	United States	China	Germany
	Est. (Std. Err.)	Est. (Std. Err.)	Est. (Std. Err.)
(Intercept)	15 (1.04)***	18 (1.58)***	12 (0.96)***
log(cum_capacity_kw)	-0.44 (0.045)***	-0.57 (0.070)***	-0.33 (0.042)***
log(price_si)	0.15 (0.058)*	0.23 (0.079)	0.21 (0.054)

Learning rates: $L_i = 1 - 2^{\beta_i}$

- U.S.: 26%
- China: 33%
- Germany: 20%

U.S.: 26%; China: 33%; Germany: 20%



"National Markets" Counterfactual Scenario

Assumption: learning-related price decreases in country *i* in year *t* are derived from incrementally more nationally-installed PV capacity

$$q_t - q_{t-1} = (q_{it} - q_{it-1}) + (1 - \lambda_t)(q_{jt} - q_{jt-1})$$

$(q_{it} - q_{it-1})$: Amount installed in country *i*

$(q_{jt} - q_{jt-1})$: Amount installed in all other countries

$$q_t - q_{t-1} = (q_{it} - q_{it-1}) + (1 - \lambda_t)(q_{jt} - q_{jt-1})$$

Global markets

$$\lambda_t = 0$$

Capacity from all countries

$$(q_{it} - q_{it-1}) + (q_{jt} - q_{jt-1})$$

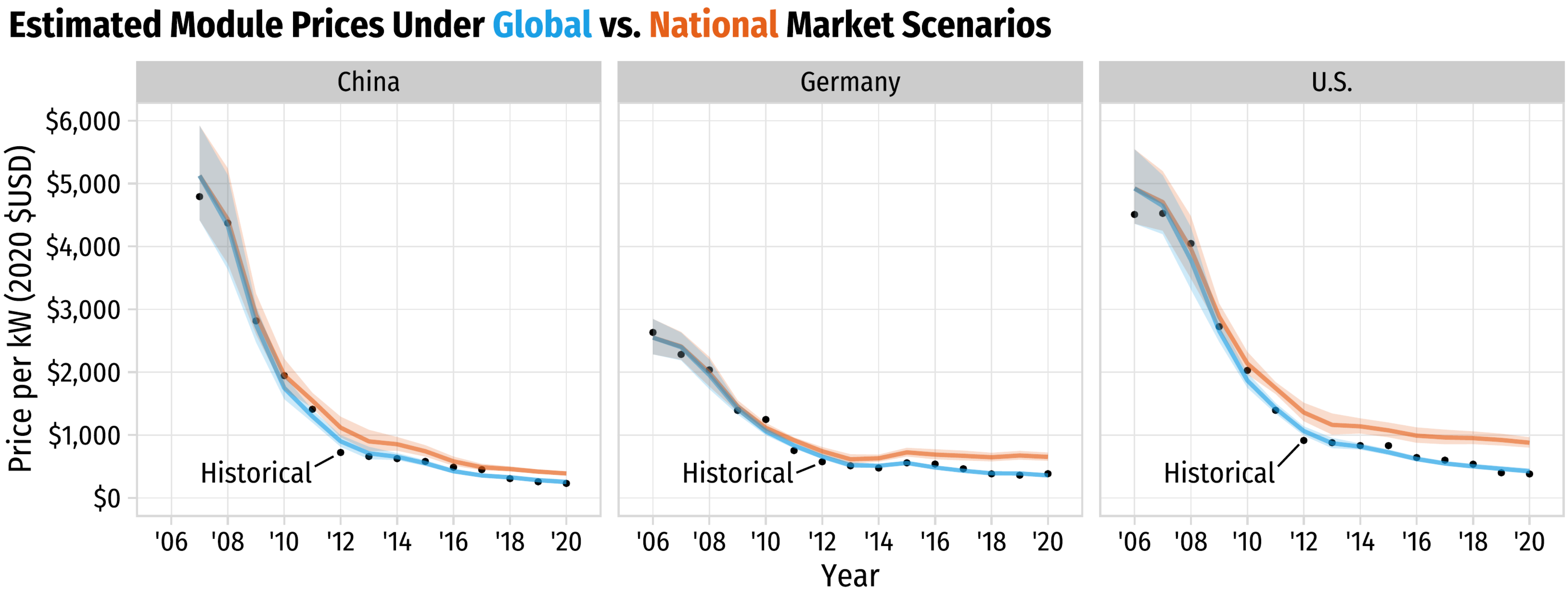
National markets

$$\lambda_t = 1$$

Capacity only from country *i*

$$(q_{it} - q_{it-1})$$

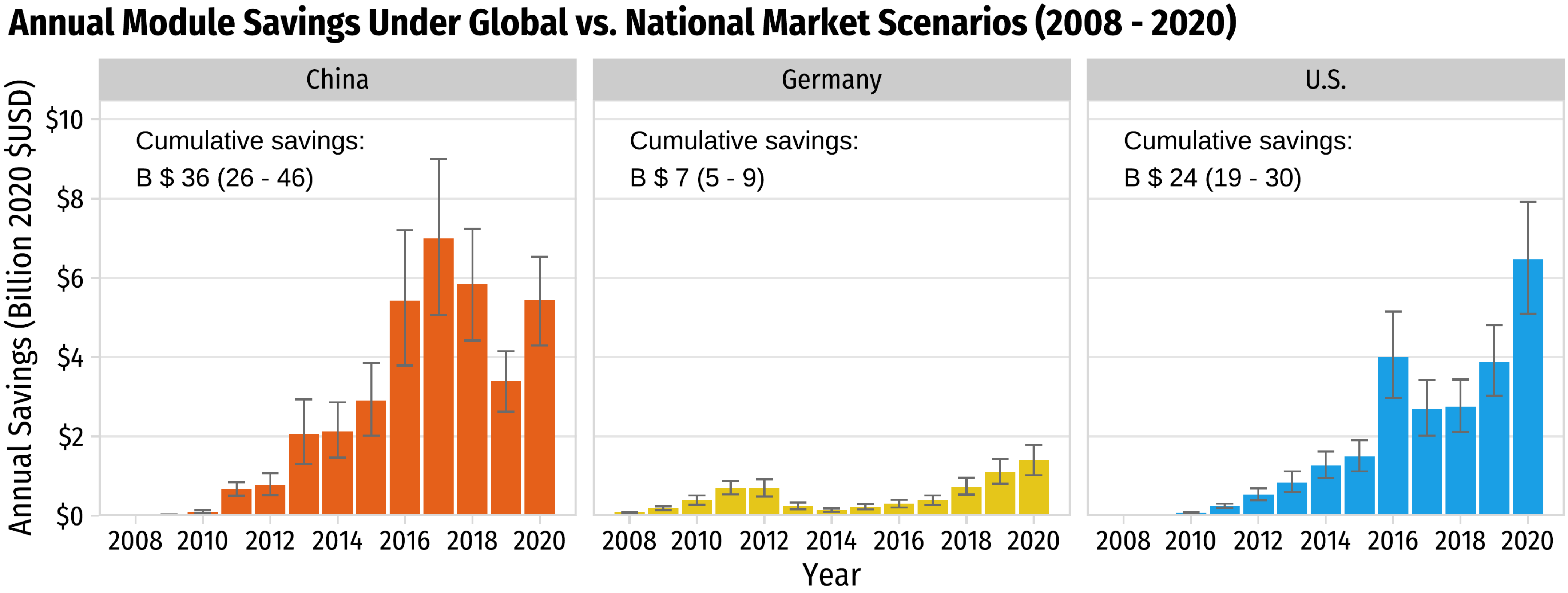
λ_t → 1 over 10-year period



Higher prices in 2020:

- 54% higher in China ($387 versus $250 per kW)
- 83% in higher Germany ($652 versus $357 per kW)
- 107% higher in the U.S. ($877 versus $424 per kW)

Total Savings: $67 billion ($50 - $84 billion)



Future projections

Two future projection scenarios out to 2030

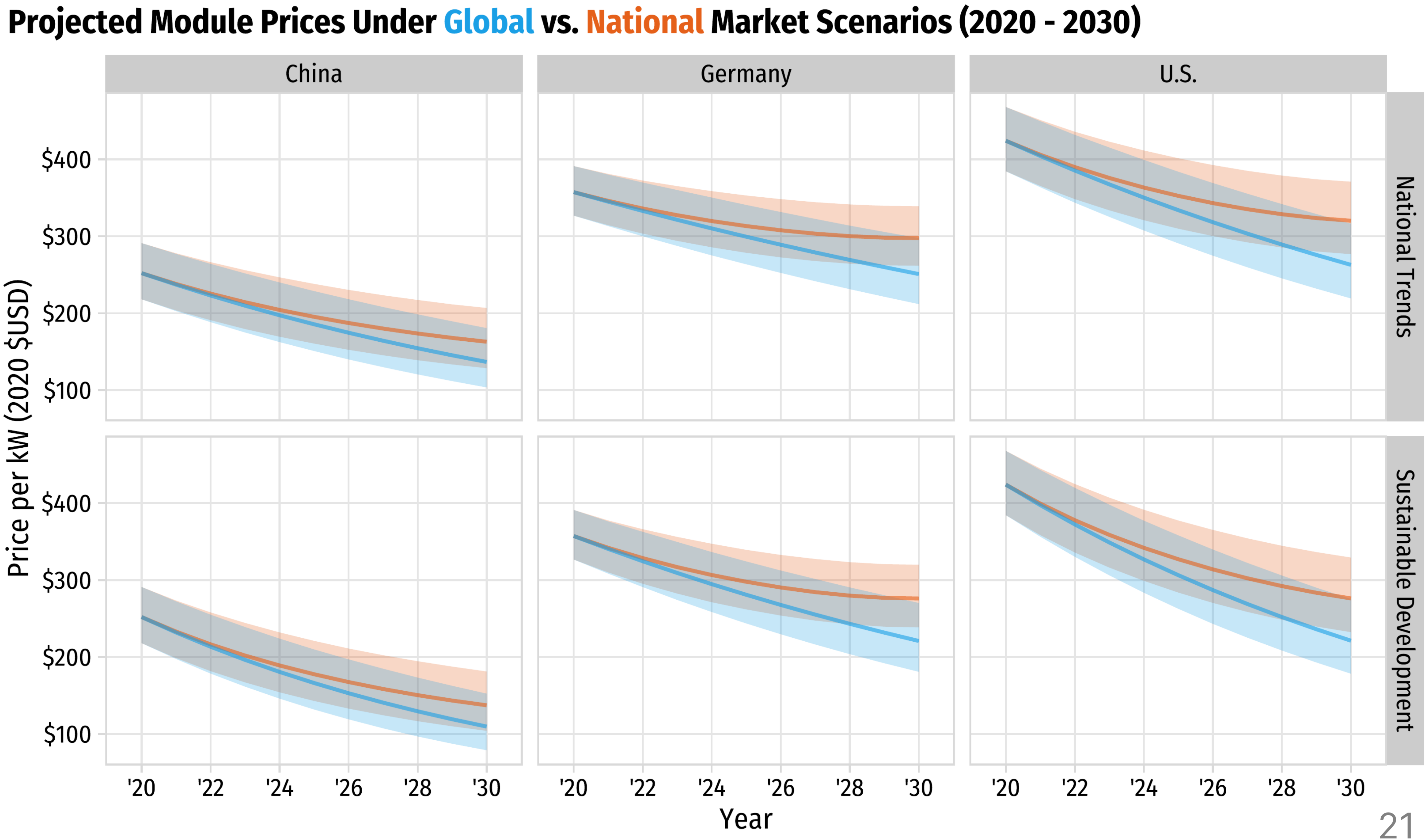
National Trends (NT)

Country	2030 Target (GW)	Implied CAGR
U.S.	295	12%
China	750	12%
Germany	103	7%
World	2,115	11%

Sustainable Development (SD)

Country	2030 Target (GW)	Implied CAGR
U.S.	628	21%
China	1,106	17%
Germany	147	11%
World	3,125	16%

(Sustainable Development Scenario in the 2020 IEA World Energy Outlook)



Projected Module Prices Under Global vs. National Market Scenarios (2020 - 2030)
China
Germany
U.S.
National Trends
Sustainable Development
Price per kW (2020 $USD)
$400
$300
$200
$100
'20
'22
'24
'26
'28
'30
Year

Higher prices in 2030

National Trends (NT)

~20% higher in each country

- China: $162 versus $135 per kW
- Germany: $298 versus $251 per kW
- U.S.: $320 versus $262 per kW

Sustainable Development (SD)

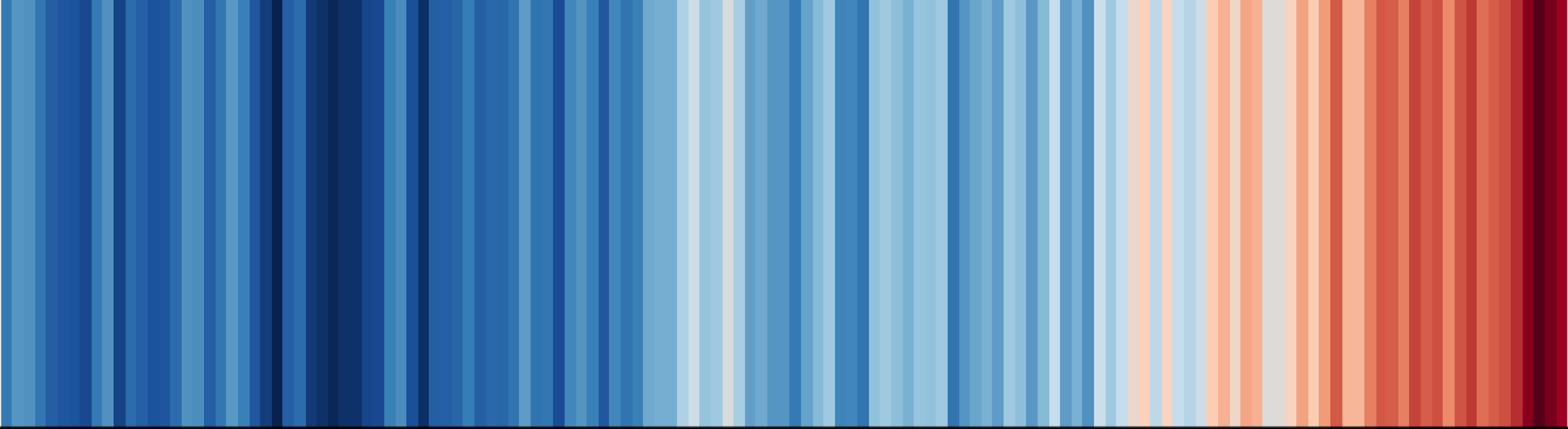
~25% higher in each country

- China: $136 versus $108 per kW
- Germany: $276 versus $221 per kW
- U.S.: $276 versus $221 per kW

For comparison, NREL's 2021 Annual Technology Baseline report predicts $170, $190, and $320 / kW by 2030 in advanced, moderate, and conservative improvement scenarios.

Sensitivity analysis app

https://jhelvy.shinyapps.io/solar-learning-2021/



Thanks!

Slides:

https://github.com/jhelvy/2022-isa-conf-solar

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Extra slides

Projected Annual Module Savings Under Global vs. National Market Scenarios (2020 - 2030)