Ray of Hope? China and the Rise of Solar Energy

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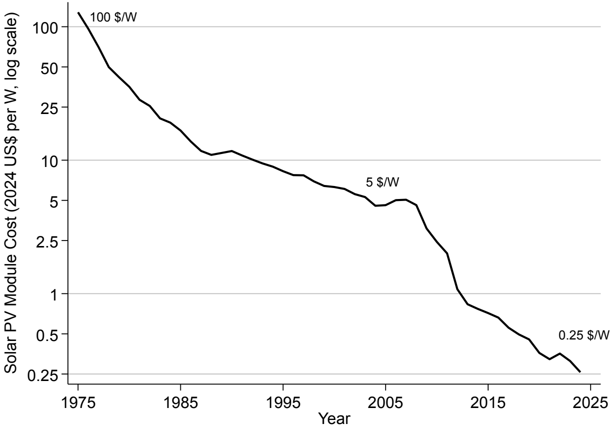
NBER SI: Productivity and Macroeconomics

Cost of solar has fallen dramatically

- Huge fall in cost relative to other energy sources and exceeding forecasts

Figure: Global average price of solar PV modules (in 2024 US$ per Watt)



Source: Our World in Data, LaFond et al. (2017) & IRENA Database

Chinese solar: A successful green industrial policy?

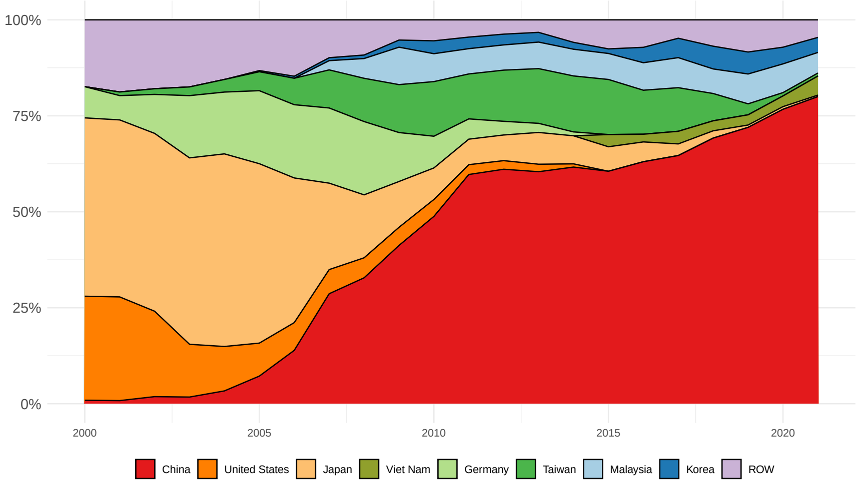
- Around 73% of global greenhouse gas emissions are attributed to the energy sector
- China embarked on mission to become world leader in solar energy

Research Questions

- How important was China's solar industrial policy in stimulating the industry?
- Did it raise Chinese welfare net of policy costs above & beyond environmental benefits?
  - If so, helps with political economy challenge with moving to net zero

China’s share of global solar production rose to exceed 80% in 2021

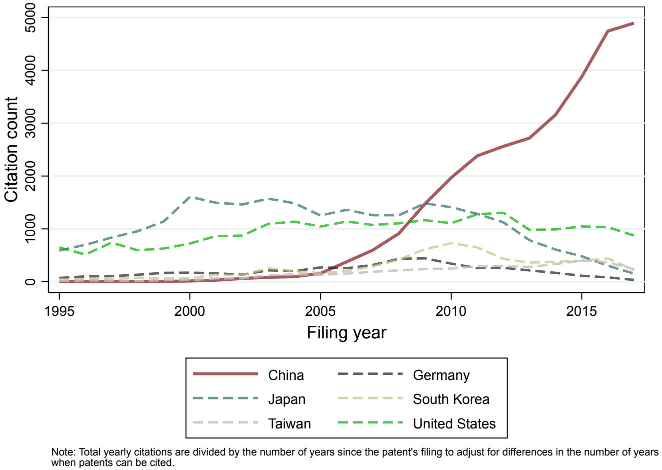
Figure: Share of Annual Solar Photovoltaics Cell Production in Leading Countries, 2000-2021



Source: International Energy Agency (IEA) & Earth Policy Institute

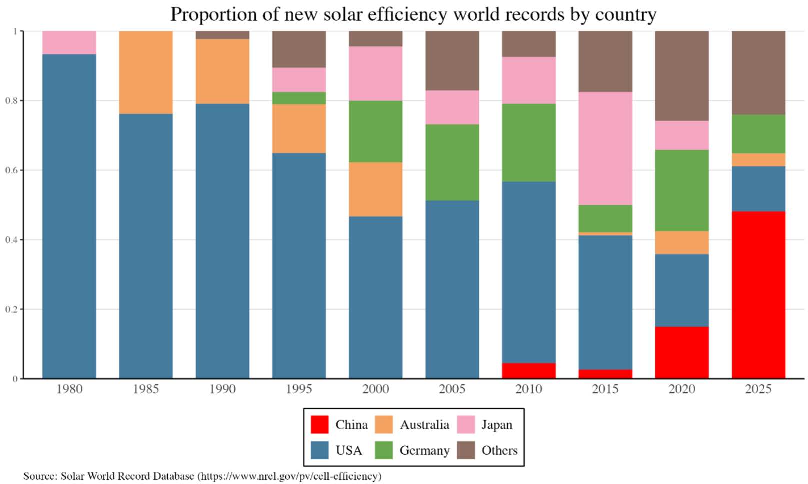
China is not just imitating: also innovating

Figure: Cite-weighted Chinese solar patents



Source: PATSTAT database: Patents by priority date in all patent offices.

China is innovating not just imitating: Technological Frontier



Note: Year refers to average over previous 5 years, so "2025" refers to competitions between 2021 and 2025, etc.

This paper: study impact of local subsidies on Chinese solar industry

- Retrieve policy text data from **PKULaw Database** and classify solar subsidies (cf. Juhasz et al., 2022; Wang & Yang, 2025)
  - Production, Innovation, and Demand/installation
- Gather rich new micro-data on universe of solar panel manufacturers in China
- Implement Synthetic DID approach (Arkhangelsky et al., 2021)
  - exploiting staggered introduction of city-level solar policies over time
- Develop & structurally estimate equilibrium model using moments from our data (e.g., local policy ATT effects). Analyze **economy-wide** counterfactuals & welfare

Preview of results

- **Innovation & production subsidies** generate city-wide increases in solar industry
  - **innovation**
  - Number of firms, production, revenues, exports, productivity

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  - Panels can be sourced from other Chinese cities
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- **Extensions:** Cross-city "business stealing" dominated by positive spillovers; placebos on non-solar patents & GDP; some effects via learning by-doing; etc.
- Quantitative model implies 40-50% of solar price drop & growth of Chinese solar output & innovation due to policies
- Aggregate model implies net gains for Chinese citizens: **$1.65** per **$1** of subsidy (& double this when adding social cost of carbon).
  - But an innovation heavy policy mix would have been more cost effective

Outline

Background & Data

Local Impact of Solar Subsidies

Model & Quantification

Solar industrial policy was led by local governments

- Industry accounts suggest important role of local government
  (Ball et al. 2017; Chen, 2016)
- City governments have significant policy autonomy
  - Text of policy documents makes this clear
- City governments have budget to implement meaningful industrial policies
  (Bai, Hsieh, and Song, 2019)
- Local bureaucrats have strong incentives to promote growth
  (e.g. career concerns (Jia et al. 2015; Li and Zhou, 2005))

We measure solar industrial policy using the PKULaw database

- Extract solar policies from database of all laws, regulations, and policies in China
- Identify financial subsidies based on text (with quantitative information)
- Distinguish subsidy policies into 3 types: (i) Demand (ii) Production & (iii) Innovation
- For each policy we observe implementing authority and date

Examples of policy text in the PKULaw database

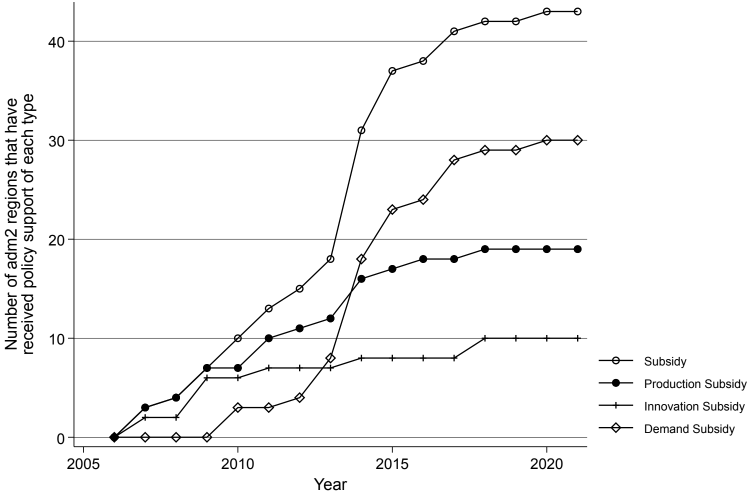
Table: City-level solar policies

Type of policy	Number	Example
Subsidy	78	
1. Production subsidy	27	*"The cost of a new solar production line built in Hefei will be subsidized by 12% (2018)"*
2. Innovation subsidy	12	*"Firms will be awarded 10,000 RMB if they earn provincial level R&D center certification (Guilin, 2011)"*
3. Demand subsidy	61	*"1 RMB per watt for the electricity generated by solar projects installed in Beijing (2010)"*

Source: Own analysis using PKULaw data

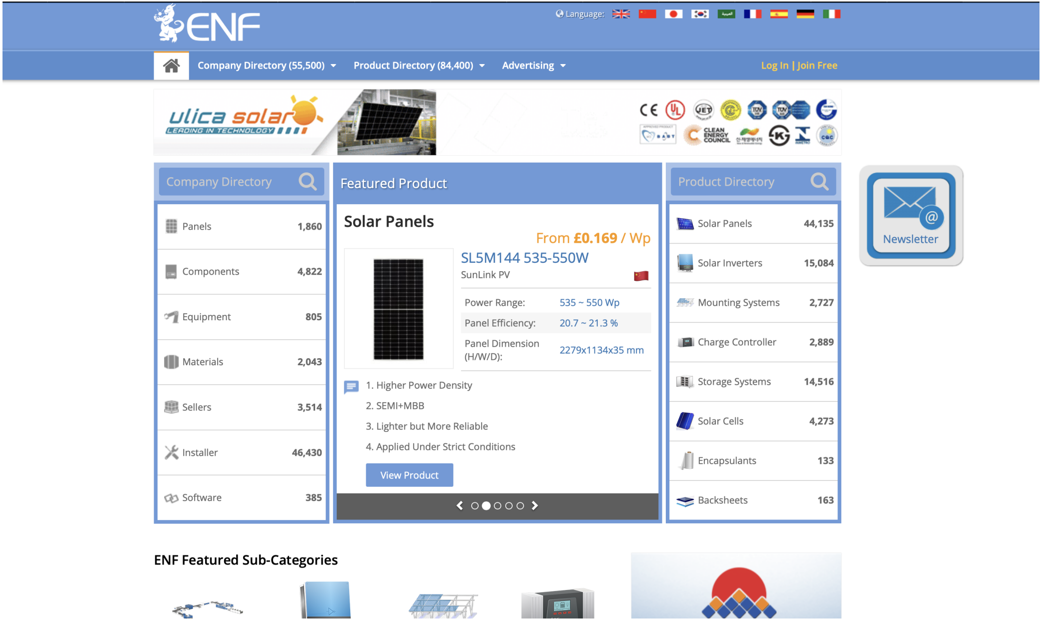
Time series of policy support

Figure: Number of cities treated with supply & demand subsidies



We study the outcomes of solar panel manufacturers

- We define the solar industry as the set of firms who produce solar panels
- Sample from **ENF Solar**, the largest online solar directory worldwide


ENF
Language:
Company Directory (55,500)
Product Directory (84,400)
Advertising
Log In | Join Free
ulica solar
LEADING IN TECHNOLOGY
CLEAN ENERGY COUNCIL
Company Directory
Panels 1,860
Components 4,822
Equipment 805
Materials 2,043
Sellers 3,514
Installer 46,430
Software 385
Featured Product
Solar Panels
From £0.169 / Wp
SL5M144 535-550W
SunLink PV
Power Range: 535 ~ 550 Wp
Panel Efficiency: 20.7 ~ 21.3 %
Panel Dimension (H/W/D): 2279x1134x35 mm
1. Higher Power Density
2. SEMI+MBB
3. Lighter but More Reliable
4. Applied Under Strict Conditions
View Product
Product Directory
Solar Panels 44,135
Solar Inverters 15,084
Mounting Systems 2,727
Charge Controller 2,889
Storage Systems 14,516
Solar Cells 4,273
Encapsulants 133
Backsheets 163
Newsletter
ENF Featured Sub-Categories

We study the outcomes of solar panel manufacturers

- We define the solar industry as the set of firms who produce solar panels
- Sample from **ENF Solar**, the largest online solar directory worldwide
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  - Cross-referencing aggregate statistics suggests we capture the whole industry
  - Match ENF register with administrative data on innovation, revenues, and exports

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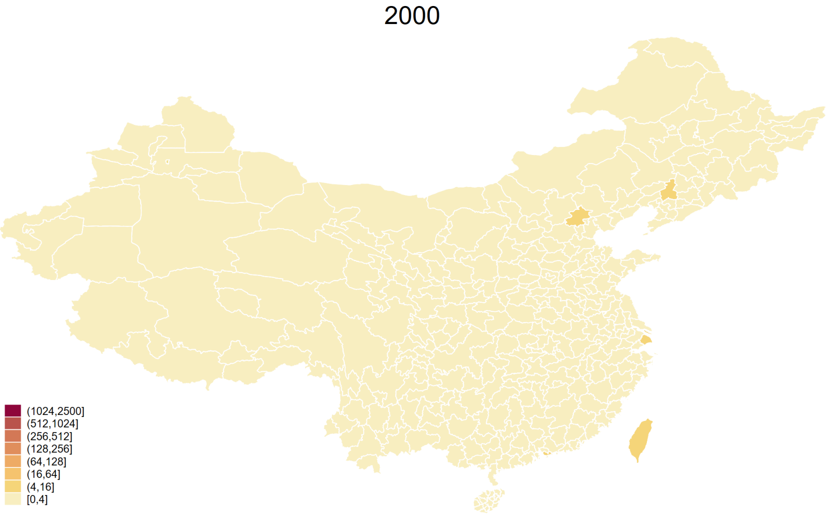
- Aggregate firm data at **city-year level**

1. **Innovation**: All patents filed by solar firms in city-year (text, citations, etc.)
2. **Revenues**: Total revenues (and employment, capital, etc.)
3. **Production capacity**: Total MWh capacity of all solar panels manufactured
4. **Firm count**: Number of solar firms
5. **Exports**: Total Exports (values, volume, etc.)

Our analysis compares city-level policies & industry outcomes

Patent counts and any subsidy



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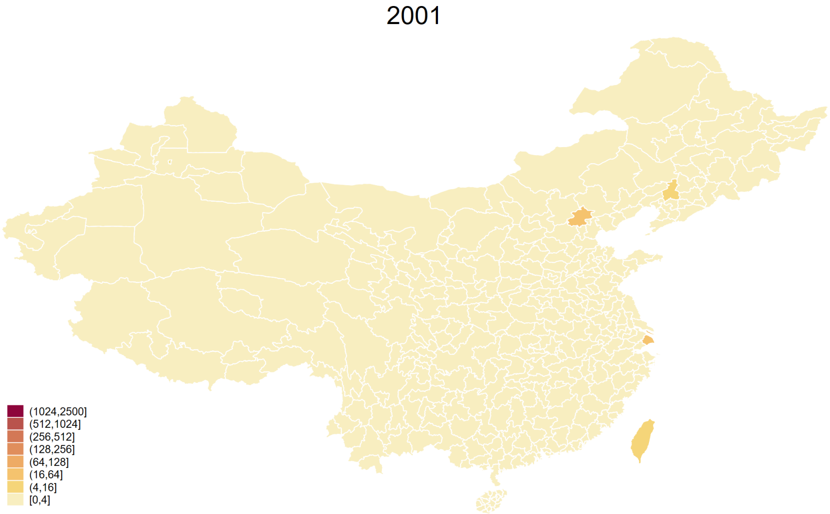

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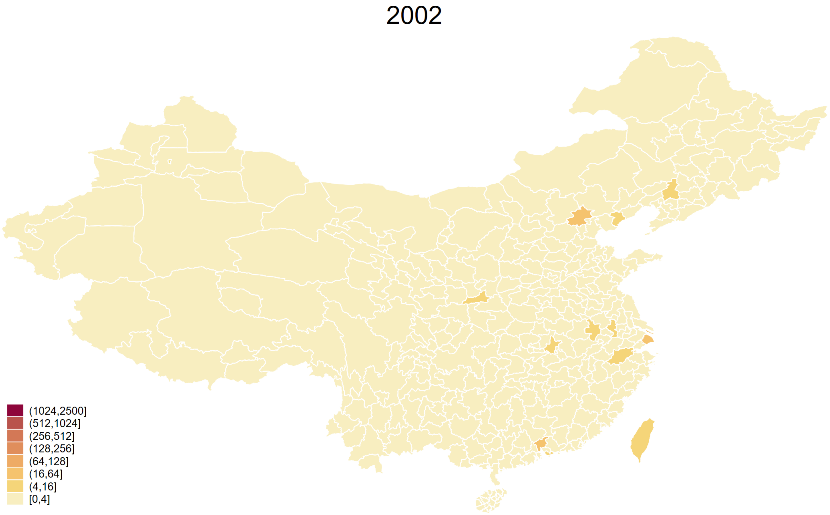

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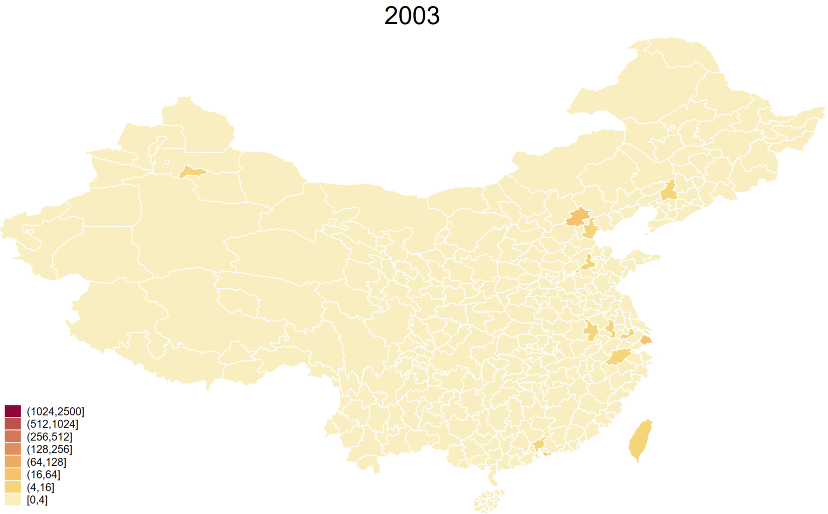

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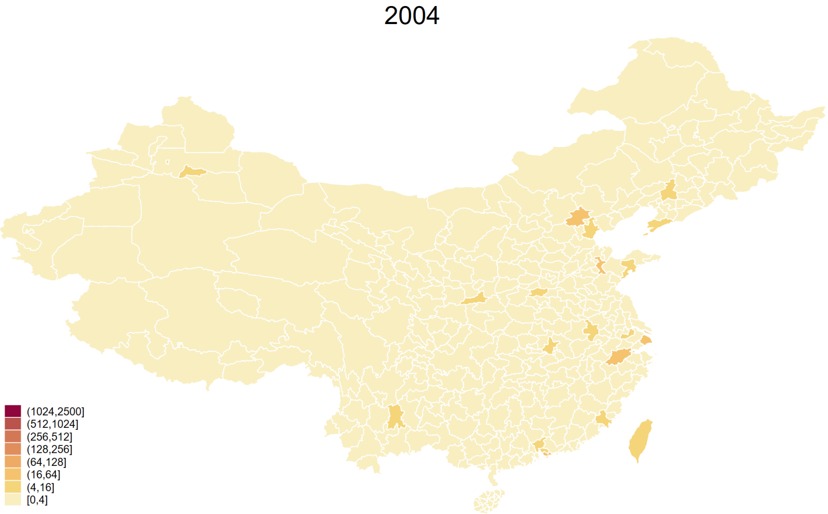

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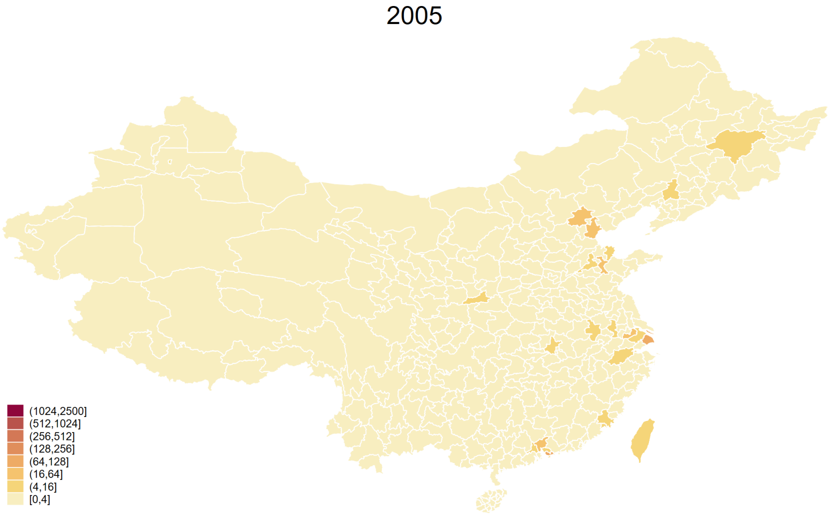

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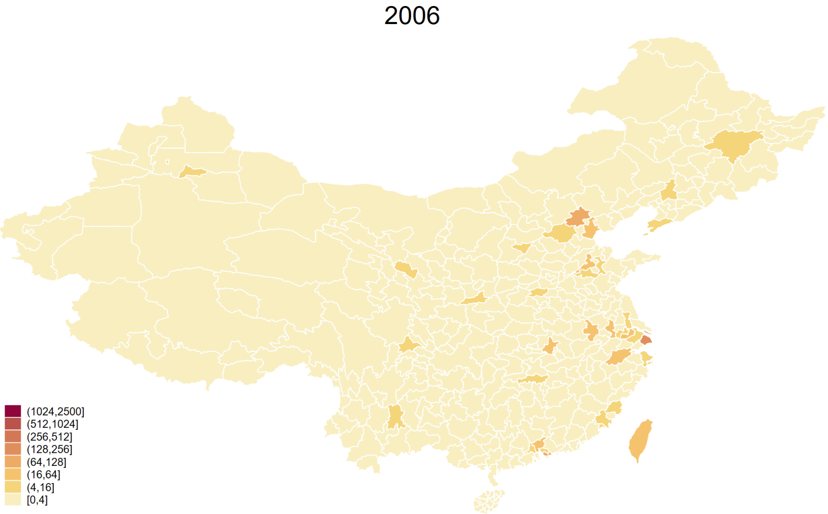

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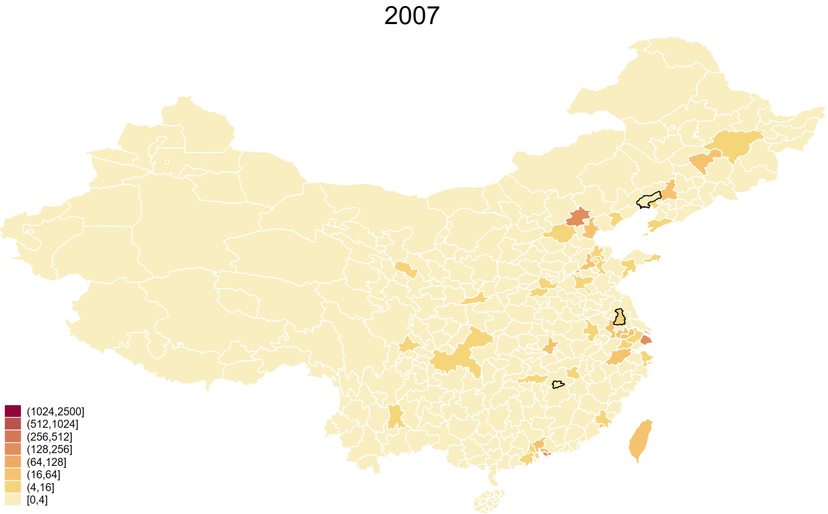

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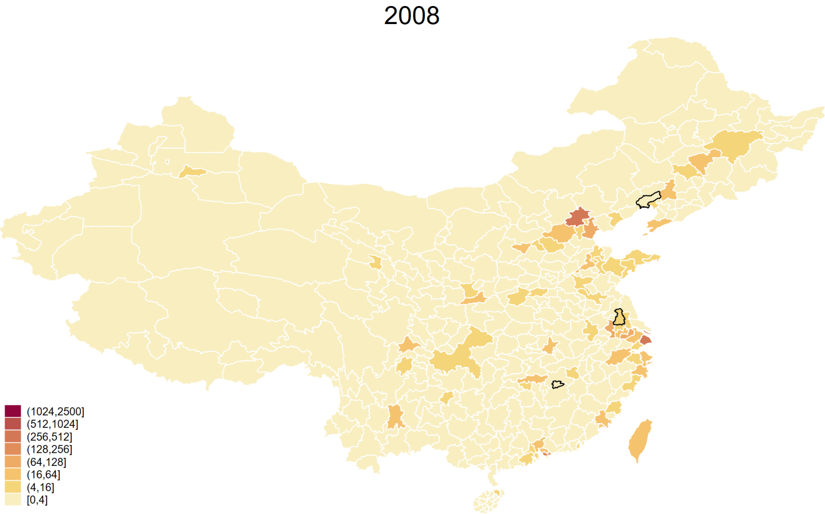

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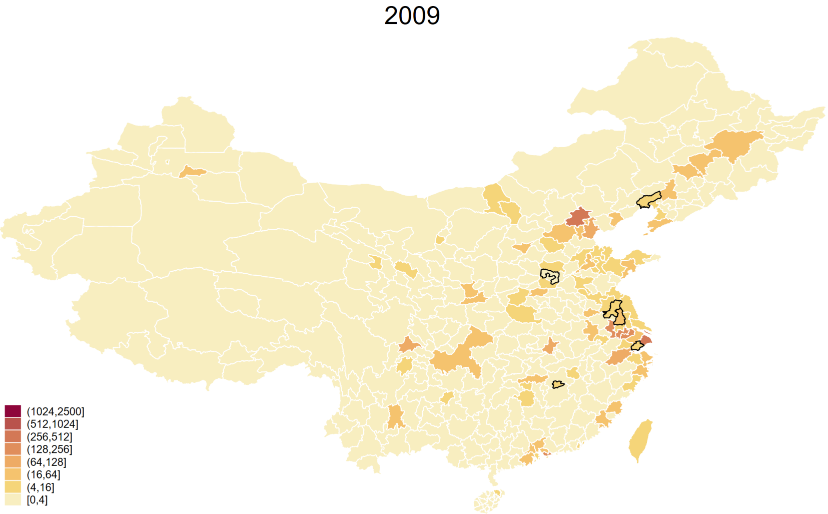

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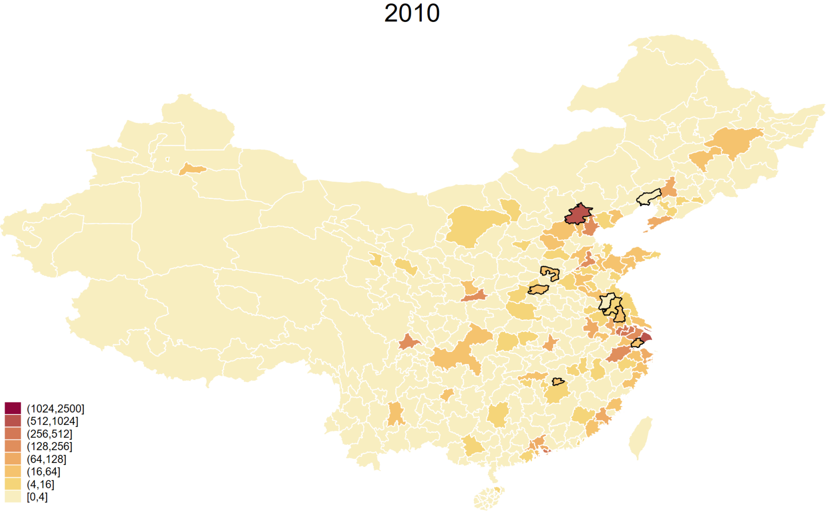

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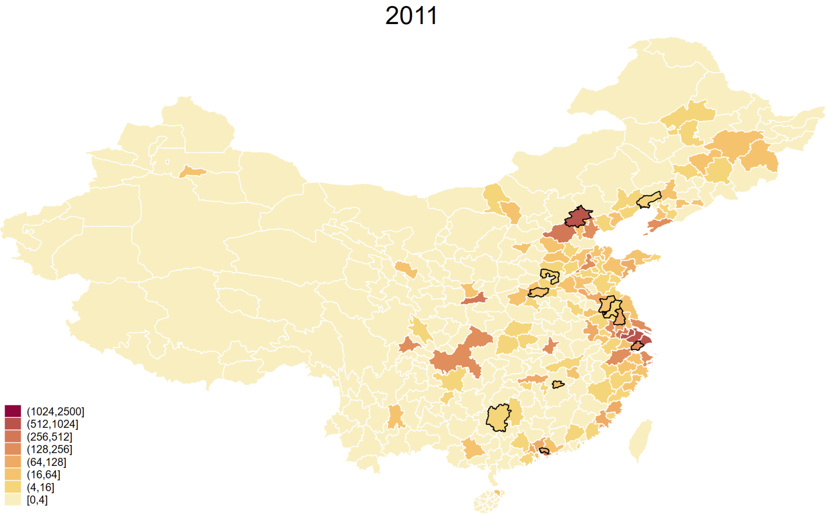

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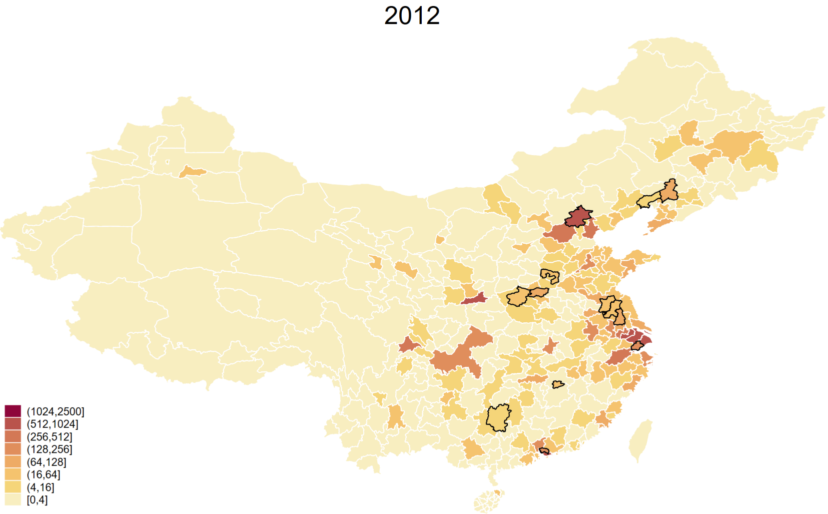

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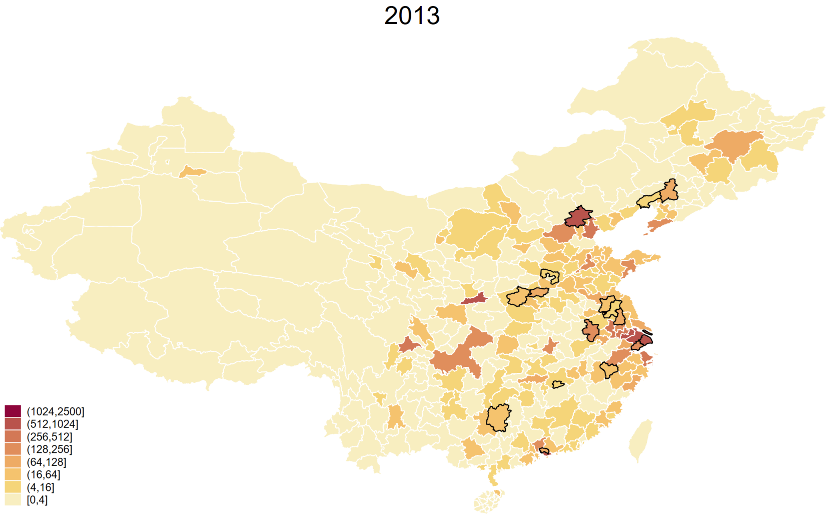

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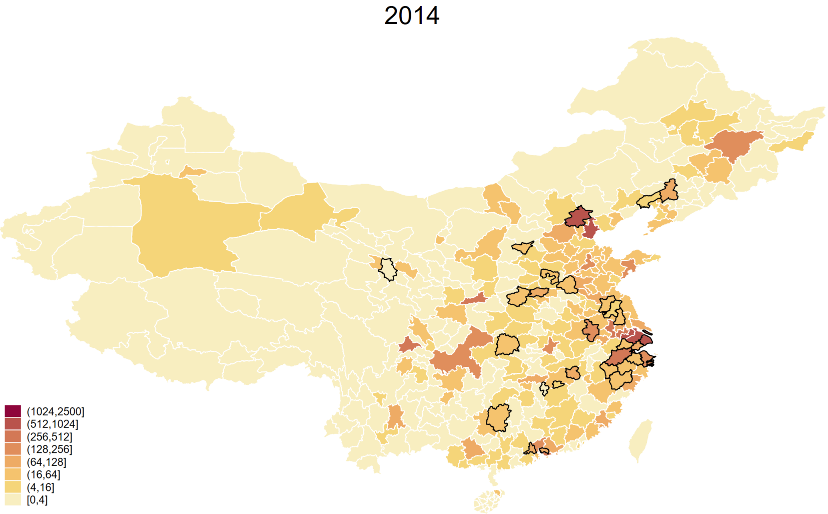

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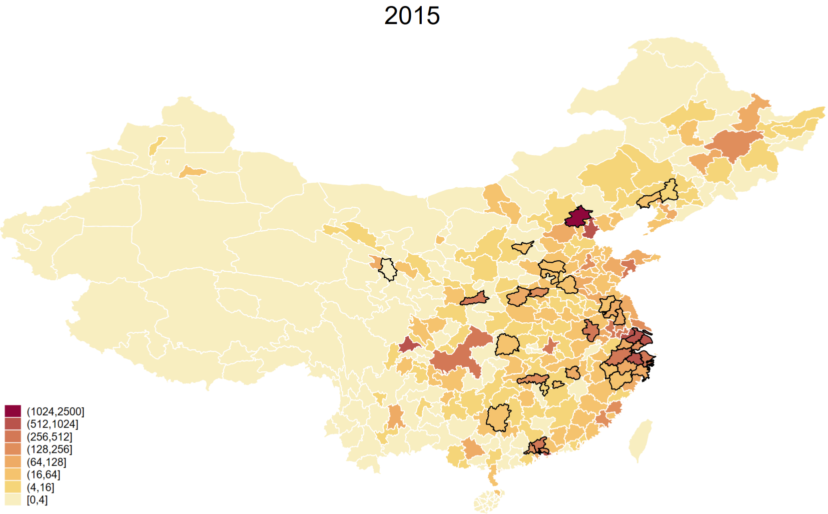

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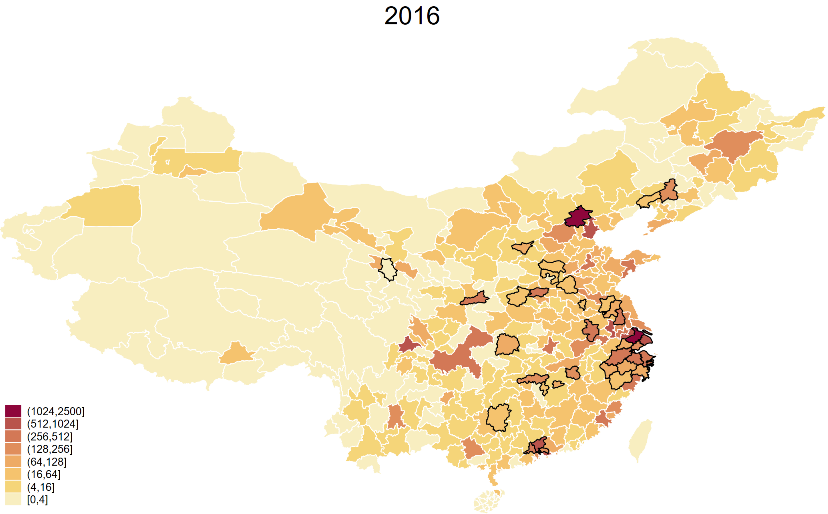

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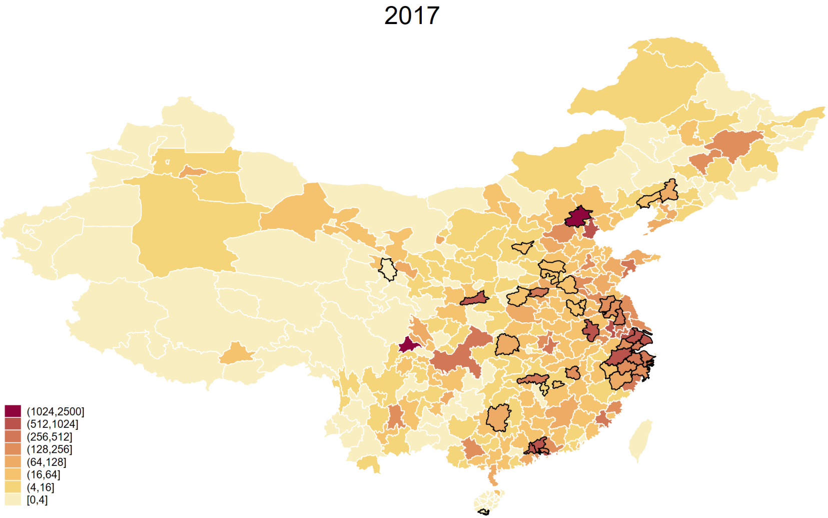

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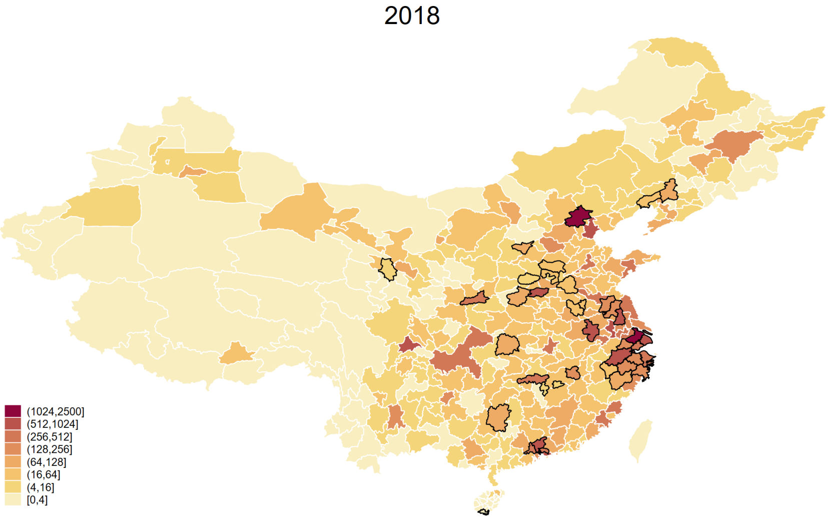

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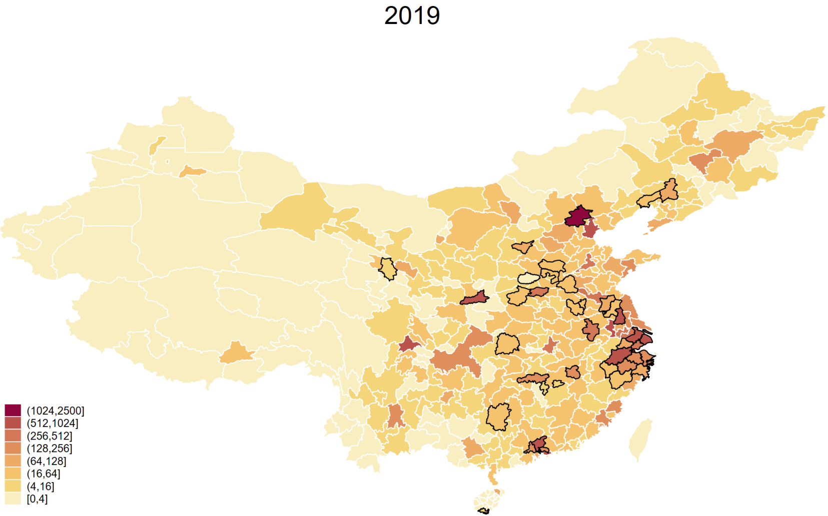

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Outline

Background & Data

Local Impact of Solar Subsidies

Model & Quantification

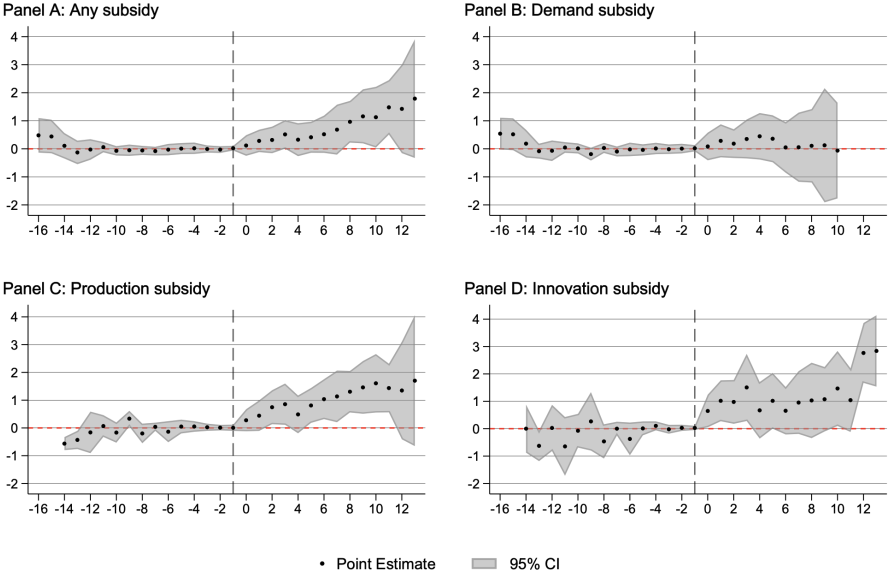
Empirical Strategy

- Local effectiveness of solar industrial policy

- Challenges in evaluating industrial policy:
  - Allocation of solar industrial subsidies to a firm is highly non-random
  - So focus on introduction of city level subsidies
  - These are staggered over time, starting in 2007 (encouraged by Eleventh Five Year Plan)
  - Some mild pre-trends for some outcomes.

- We follow the **synthetic-difference-in-differences (SDID)** methodology
  (Arkhangelsky et al 2021)
  1. Construct synthetic control group such that pre-trends are approximately parallel
  2. Compute treatment effect using diff-in-diff between treatment and synthetic control

Results: Patents



Results: Patents

Table: Patent Counts (Aggregate ATT)

	Any subsidy	*Demand subsidy*	*Production subsidy*	*Innovation subsidy*
All patents	0.496**	0.236	0.871***	1.060***
	(0.200)	(0.275)	(0.227)	(0.367)
Observations	6,086	6,086	6,086	6,086

Notes: * 0.1 ** 0.05 *** 0.01. SDID on 358 cities 2004-2020. Outcome is IHS of patent count by solar firms in city-year pair (level av. = 13.1). SE cluster bootstrapped b

Levels

Positive results across a wide range of solar industry outcomes

Innovation

- Average increase in patents of 64%
- Holds for citation-weighted patents (quality adjustment)
- Holds for patents reflecting learning-by-doing improvements in patent abstract

Additional industry outcomes

- Same pattern in event studies for firm counts, revenue, capacity, exports

Pollution

- Only demand subsidies have significant negative effect

Positive spillovers outweigh business stealing

- SDID using adjacent-city policies

Spillovers results

Table: Positive spillovers outweigh business stealing

	(1) All patents	(2) Firm count	(3) Revenue	(4) Panel capacity	(5) Solar export value
Any subsidy in an adjacent city	0.373*** (0.096)	0.099 (0.055)	0.617*** (0.199)	0.385 (0.263)	1.099** (0.491)
Observations	5,049	5,049	5,049	3,210	3,861

Notes: * 0.1 ** 0.05 *** 0.01.

Overview of further extensions & robustness

- Productivity
- Placebos on GDP, non-solar patents, etc.
- Adding controls to SDID (GDP, population, income, tax revenue, ...)
- Using a common synthetic control based on multiple outcomes
- Total solar patents (including universities, non-solar firms, etc.)
- Adjustment based on factory locations
- SDID robust to compositional changes
- Results in levels, etc. (e.g. Chen and Roth, 2022)

Outline

A model of electricity generation using manufactured inputs

- **Goal of the model**

> 1. Comparative statics for local and national impact of place-based subsidies
> 2. Quantifiable framework for recovering subsidies
> 3. Analysing aggregate effects, counterfactuals, and welfare

- Heterogeneous manufacturing firms under monopolistic competition
- Many (N) Chinese City-regions (plus 'Rest of World') with different productivities
- Representative consumer in each region demands electricity services
- Local "Grid Planner" builds clean (solar) and dirty (coal) power plants
- Manufacturers' decisions: **entry, exit, production, and technology upgrading**
- Aggregate knowledge spillovers in solar manufacturing

Model quantification

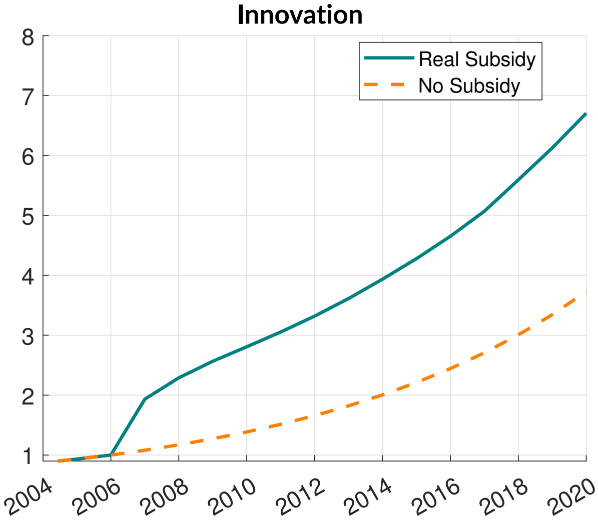
1. **Calibration**
   - Using our firm-level panel data:
     - Productivity gain from innovation
     - Knowledge Spillovers
     - Shape of productivity distribution
   - From literature: transport costs (Egger et al., 2023); energy substitution elasticities (Jo, 2025; Shapiro & Walker, 2018)

2. **Model inversion** using pre-policy data (2004-06)
   - Production & Innovation fixed costs
   - Entry costs sunk costs & city-specific productivities

3. **Minimum distance** (adding data from 2007 onwards)
   - Subsidy magnitudes (matching revenue and innovation ATTs)

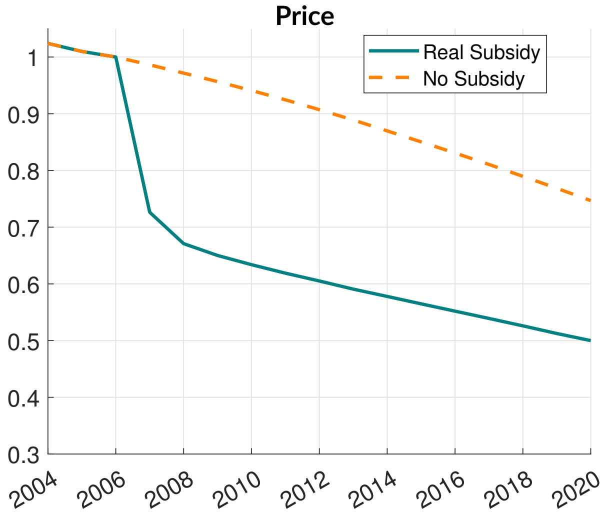
Counterfactuals without subsidies

Industrial policies explain about half of increase in Chinese innovation



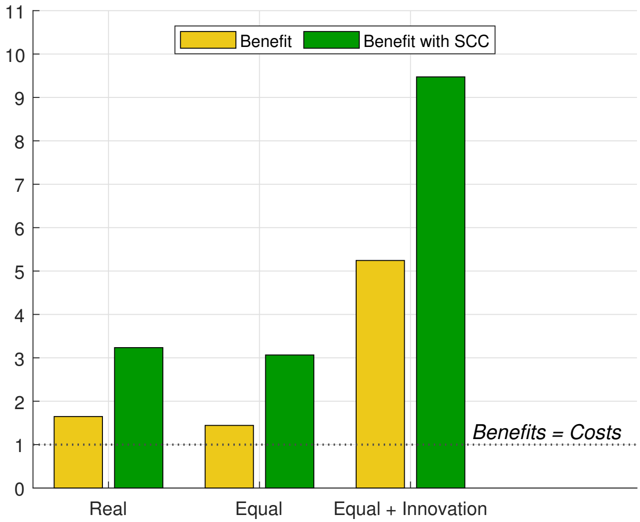
Counterfactuals without subsidies

Industrial policies explain about half of fall in solar prices



Modelling Counterfactuals: Social Benefit-Cost Ratios

Including Social Cost of Carbon (SCC) doubles the benefits



Conclusions

- New & comprehensive database on Chinese solar industry & policies
- Production & innovation subsidies effective at stimulating local solar industry: patenting & production
- Structurally quantified equilibrium model shows effects persist at aggregate level
  - Policy explains about half of change in innovation, revenue and prices
- Benefits to China 65% larger than subsidy costs (double if inc. social cost of carbon)
  - But focus on innovation subsidies would have been even more effective
- Next steps: Impact on rest of world; Use framework for other industries; understanding demand policy effects