Transition to Clean Energy Technologies

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- **Solar and wind** power **costs** declined by 85% and 45% in the last decade.
- Intermittency limits the substitutability between clean and dirty energy sources.
- *Macro climate models ignore the intermittency problem.*

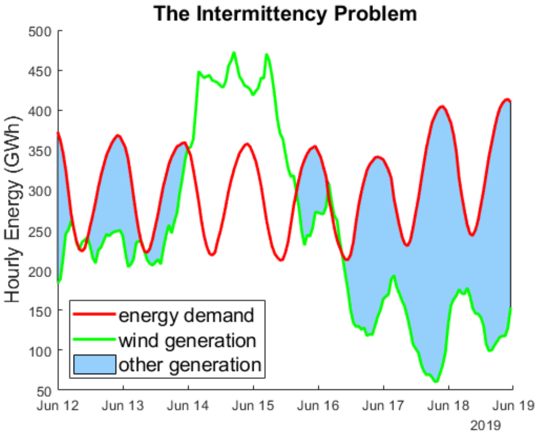

Figure: Country: US. Data Sources: Energy Information Administration (930 Data). Assumed wind capacity: 500GW.

Research questions

- Does the market have enough incentives to develop storage technologies to alleviate the intermittency problem?
- What are the optimal environmental policies in the presence of intermittency?
- What are the impacts of optimal and suboptimal policies on the energy market, innovation incentives, and welfare?

Methodology: *first macro climate model with intermittency*.

Quantitative Exercise: compare the *energy market equilibrium, innovation, and welfare* in the decentralized economy, in the optimal allocation, and with suboptimal policies (IRA in the US).

Literature

- **Macro Climate & Optimal Environmental Policies**

  Nordhaus (1993), Hassler and Krusell (2012), Golosov, Hassler, Krusell, Tsyvinski (2014), Acemoglu, Aghion, Bursztyn, Hemous (2012), Acemoglu, Aghion, Barrage, Hemous (2019), Acemoglu, Akcigit, Hanley and Kerr (2016), Hassler, Krusell, Olovsson, Reiter (2020)

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ρ: exogenous constant elasticity of substitution
- challenging empirical estimation
- key for optimal policies

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- **Directed Technical Change and the Environment**

  Acemoglu, Aghion, Bursztyn, & Hémous (2012), Acemoglu, Aghion, Barrage, Hemous (2019)

  → intermittency and storage technological change

Macro Climate Model with Intermittency and Innovation

Final Good Sector ⟷ Household

$$Y_t = (1 - D_t(S_t))A_t K_t^{\alpha} L_t^{1-\alpha-v} E_t^{v}$$

Output damages
S_t: *carbon stock*

Energy sector

- Dirty and clean energy producers
- Storage firms

Two choices:

- Capacity K_t^e ← R&D sector (DTC)

  (i.e., fossil fuel power plants, solar panels..)

- Hourly energy production e_{ht}

Time periods: within a period t (5 years) there is a continuum of hours, h $\in [0, 1]$.

Energy producers and Intermittency

- Finite number of heterogeneous producers indexed by fuel cost z
- **Producer choices:**
  - capacity $K_t^e(z)$ (i.e., fossil fuel power plants, solar panels..)
  - hourly energy production $e_{ht}(z)$
- **Producers costs**:
  - Capacity costs: $K_t^e(z)p_t(z)$
  - Hourly production costs: $\underbrace{e_{ht}(z)^\lambda}_{\text{O\&M}} + \underbrace{e_{ht}(z)z}_{\text{fuel}}$
- **Intermittency:** $\xi_h \in [0, 1]$.

$$e_{ht}(z) \leq \xi_h(z)K_t^e(z) \tag{1}$$

  - Clean producers: $z = 0$, $\xi_h(0) \in \{0, 1\} \rightarrow$ day and night
  - Dirty producers: $z > 0$, $\xi_h(z) = 1$

Aggregate Energy, Storage and Innovation

- The final good firm buys hourly energy e_{ht} from energy producers at the hourly energy price p^e_{ht} and aggregates it into **aggregate energy $\mathbf{E_t}$** by means of a Leontief production function, which results in the following aggregate energy demand

$$e_{ht} = q_h E_t \text{ for } h$$

- **Storage** can be used to transfer energy across hours.

- **Innovation**:
  - Scientists direct their innovation towards the clean, dirty, or storage technology: $s_{dt} + s_{ct} + s_{st} = 1$.
  - Innovation improves the quality of machines used to build energy producers' capacity. A successful scientist becomes the monopolist producing the machines she innovates on.

Results: Decentralized Economy

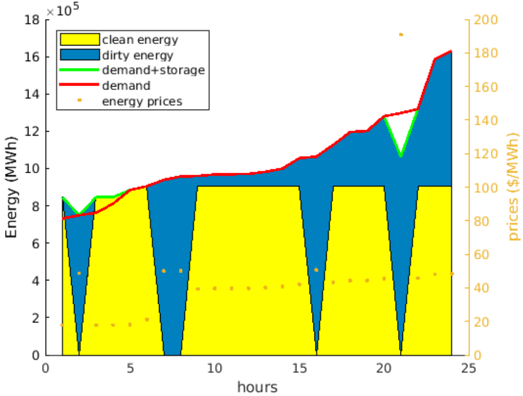


Figure: Energy Market in the Short Run (2020-2025)

The clean energy share in the short run reaches 67%.

Results: Decentralized Economy

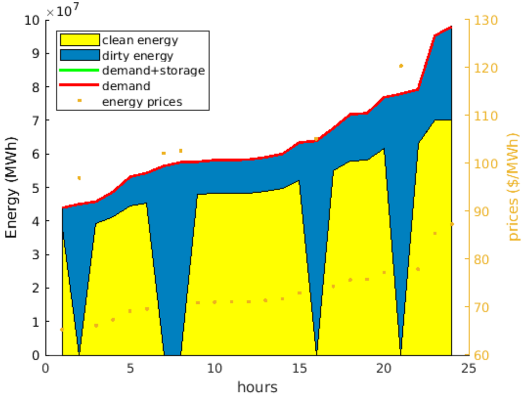


Figure: Energy Market in the Long Run (2020-2025)

The intermittency problem limits the clean energy share in the long run to around 60%.

Results: Decentralized Economy

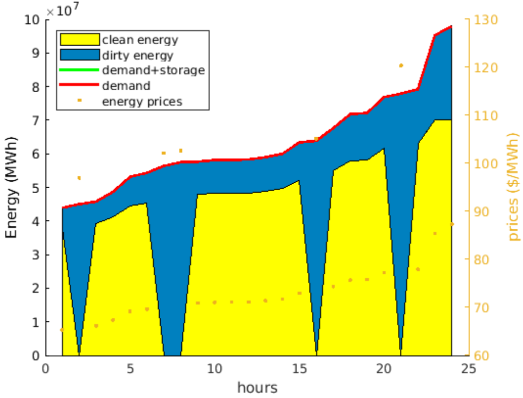


Figure: Energy Market in the Long Run (2205-2210)

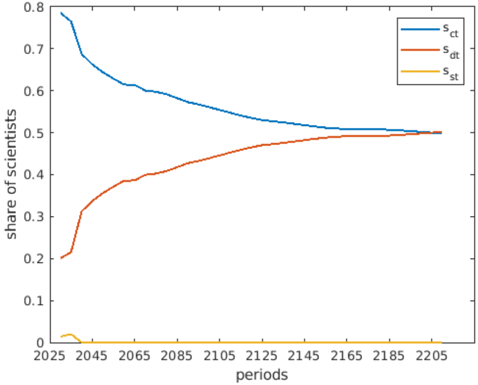
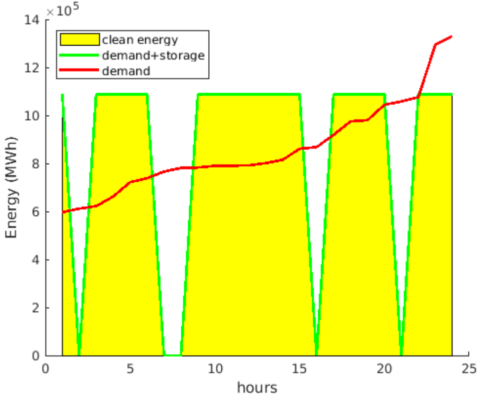


Figure: Innovation

In the long run, no innovation in storage technologies.

Results: Optimal Allocation



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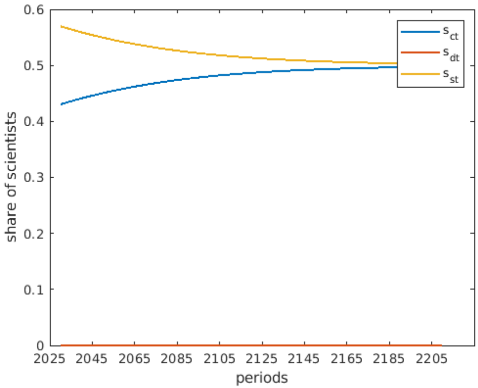


Figure: Innovation.

The Social Planner uses only clean energy and energy storage.

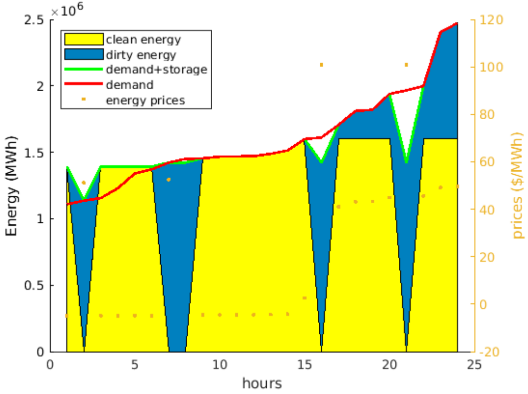
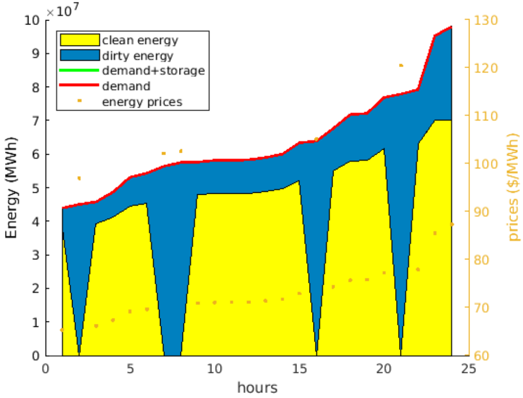


Figure: Energy Market in the Short Run (2020-2025)

The clean energy share increases from 67% in a scenario with no policy to 74% with IRA subsidies in the short run.

Suboptimal Policies: The IRA in the US



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Welfare effects:

- Moving from the CE to the SP allocation: +7%.
- Moving from the CE to the IRA subsidies allocation: +0.1%.

The storage technology is not developed. The intermittency problem limits the clean energy share.

Conclusion

This project: first macro climate model with intermittency and innovation in the energy sector.

- **Theoretical novelty**: micro-founded model of the energy sector, microdata from the electricity sector.
- **Key Results**:
  - *In the absence of policies*: intermittency limits the clean energy share, no storage innovation.
  - *Optimal allocation*: only clean energy and energy storage, faster transition than the existing literature.
  - *IRA subsidies* not enough to solve the intermittency problem.

Appendix: Carbon taxes