Strategic investment in renewable energy under technological change

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Motivations

- The renewable energy is underinvested
  - cellulosic ethanol in 2014
    - target: 1.75 billion gallons
    - actual: less than 1 million
- A key reason: existing technology is not cost competitive enough in this sector
  - cellulosic ethanol: $4 -$5/gallon

Motivations

- Government technology policy is necessary to promote investment in the renewable energy sector
  - technology-push: government R&D spending
    - target on new innovative technology or big improvements of existing technology through R&D efforts
  - demand-pull: subsidy, mandate, investment share
    - target on the use of existing technology, trigger learning by doing (including the scale of economies)

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Research Questions

- What are the impacts of different types of technology policies on firms' optimal investment strategy in the renewable energy sector?
  - technology-push or demand-pull
- Breakthrough Energy Coalition
  - Bill Gates, Mark Zuckerberg and more than 20 billionaires
  - 20 countries pledge to double government investment in clean energy innovation

Research Questions

- What is most needed now is money for accelerated deployment and project financing of technologies that are now market-ready (DOE, 2015)
- The accelerated deployment created economies of scale and brought technologies rapidly down the learning curve
  - solar, wind, batteries, and LED lighting

Contributions

- Most existing literature focuses on R&D-based improvements or learning-by-doing for existing technologies (Löschel & Otto, 2009)
  - Similar effects, different policy efficiencies
- The cost savings from the policy-induced improvement of existing technologies may not reveal a firm's real incentive to invest

Contributions

- Firms anticipate the irreversible investment in future technologies that are currently unavailable
  - solar photovoltaics (PV) (Baker et al.,2009)
    - silicon wafer cells, 36 cents/kWh
    - organic cells in 10 years, 5 cents/kWh
    - multi-junction cells in 20 years, 2.9 cents/kWh
- Government R&D spending most targets on the basic research to develop innovative technologies that are not available yet

The model

- An upstream R&D industry that delivers a sequence of technological “innovations” stochastically with efficiency u and probability λ
  - silicon cells, organic cells, multi-junction cells
- When each innovation arrives, a sequence of engineering “refinements” is triggered to complement the innovation efficiency w, probability μ
  - improvements on the inverter’s conversion efficiency

The model

- Firm's anticipations regrading technology
  - $E(\lambda) = f_{In}(I_{RD}) + \varepsilon_{IN}$ $E(u) = g_{In}(I_{RD}) + \epsilon_{IN}$
  - $E(\mu) = f_{RE}(I_{RD}) + \varepsilon_{RE}$ $E(w) = g_{RE}(I_{RE}) + \epsilon_{RE}$
    - f and g: the innovation and refinement production function, increasing function
    - I_{RD} : government R&D spending
    - ε, ϵ: common errors in the anticipation
    - positive: optimism on future technology
    - negative: pessimistic opinion on future technology
    - affected by the policy signal and the technology information sent by the government

The model

- After investment
  - triggering learning curve at $e^{-\gamma q}$
    - learning speed γ and capacity q
- Production cost: $C_t(q_t) = aq_t^2 + s\theta_t q_t$
  - θ_t is a function of all technology parameters
- Perfectly competitive market: the price P
  - subsidy: $P + \chi$
- Establish investment cost Bq
  - investment share: $Bq(1 - \phi)$

The model

- Optimal solution: Investment scale q^* and timing θ^*
- $\frac{P+\chi}{\rho} - \frac{\left(\frac{P+\chi-aq^*}{\rho} - B(1-\phi)\right)\beta q^* \gamma e^{-\gamma q^*}}{\rho - e^{-\gamma q^*} + 1 + w\mu} = \frac{aq^*(2-\beta)}{\rho} + B(1-\phi)$
- $\theta^* =$

$$\underbrace{\frac{1}{s}\left(\left(\rho - e^{-\gamma q^*} + 1 + w\mu\right)\right)}_{\text{prospect effect}} \underbrace{\frac{\beta}{\beta - 1}}_{\text{lag effect}} \underbrace{\left(\frac{P+\chi-aq^*}{\rho} - B(1-\phi)\right)}_{\text{scale effect}}$$

Result

- **Proposition 1.** A sufficiently large government R&D spending delays the investment but increases the investment scale
  – waiting for the technology breakthrough
  – choosing a larger investment scale under the more advanced technology

Result

- **Proposition 2.** A sufficiently optimistic policy signal and technology information delays the investment but increases the investment scale
  – ambitious targets or optimistic estimation of technology progress
  – the firm deferring its investment may never see the promised technology arrive
  – the exaggeration of its real cost-efficiency results in a great profit loss after the production

Result

- **Proposition 3.** A demand pull policy accelerates the investment and increases the investment scale
  - improves the profitability of using existing technologies
  - the shadow value of learning

Conclusions

- Any technology policy will stimulate a larger investment scale
- Large public R&D spending provides strong incentives to wait
- Subsidy and investment share stimulate an early investment and trigger learning-by-doing
- Policymakers should be more cautious in R&D spending and projecting future technology efficiency, and be careful not to let investors become complacent by deferring investments and just waiting for the advanced technology

Future research

- Social welfare impact
- What is the optimal policy portfolio?
- Questions?