Lecture # 23 – Energy Technology Policy

I. Technological Change and the Environment: The Potential of New Technology

- How can further innovation help?
  - Possible solutions to the intermittency problem
    - Larger grids easier to balance
    - Demand-response strategies (e.g. "smart grid)
    - Energy storage: hydro or batteries
  - Energy Storage
    - Because wind and solar are intermittent sources, they cannot fully power the electric grid unless power can be stored
      - While costs are falling, energy storage is still expensive, so most renewable sources are not paired with energy storage
    - Energy Storage Techniques
      - Pumped hydro storage
        - Excess power used to pump water to a reservoir.
        - Currently lowest cost
        - Example: Denmark and Norway work in tandem to provide power.
          - When winds are favorable, Denmark exports wind energy to Norway. When not, Norway exports hydropower to Denmark.
          - Essentially, the hydropower not used when wind energy is exported is "stored" energy.
        - Globally, most energy storage today uses pumped hydro, but future expansion will be limited
          - Requires appropriate geography
          - Potential environmental effects of building new dams
      - Batteries
        - Most often use lithium-ion batteries
          - Short-duration (≈30 minutes, to smooth spikes in power grid)
          - Long-duration (for storing intermittent power for later use)
            - True long-term storage (beyond a few hours) is limited
        - Most commonly used energy storage in US
        - Costs have fallen dramatically since 2010
        - Barriers to battery development:
          - Safety concerns (e.g. overheating)
          - Patchwork of local regulations
          - New materials needed to get costs lower

- Zero-carbon options for processes that cannot run on electricity
  - Biofuels
    - Currently, this is the largest source of renewable energy
      - However, much of this is low-technology uses in developing countries. Presumably usage of these fuels will fall as countries grow.
      - Other fuels include things such as ethanol
    - Carbon released when burned is same as carbon absorbed as the plant grows
      - But requires energy to produce, so only zero-carbon if produced using zero-carbon energy
        - Corn ethanol in US averages only 39% lower CO_2 emissions than the gasoline it replaces
    - Is there enough farmland to grow the needed feedstocks *as well as supplying necessary food supply*?
  - Carbon capture and storage
    - Carbon is captured and stored underground or used in an industrial process
      - Can be done before combustion (removing carbon from fuel) or afterwards (removing from waste gases)
      - Currently used for enhanced oil recovery
    - Storage space is an issue
      - Oil & gas reservoirs, deep saline aquifers, and un-minable coal beds are options.
      - Must be stored in formations with impermeable cap rock to avoid leakage.
      - Eventually will dissolve in water.
      - Thus, safety has been a concern for some.
    - Because of economies of scale, only appropriate for large emitters, such as power plants
    - New technologies would remove CO2 from the air ("direct air capture"
      - These technologies are still very expensive
        - Require lots of energy: will that be carbon-free?
        - Occidental's example costs about $400/ton removed
      - As a result, firms are reluctant to invest in the technology
        - Occidental's plant would sell carbon credits to generate revenue
        - But high costs require a high carbon price to be viable

- Hydrogen
    - Obtained by splitting water into hydrogen and oxygen
        - However, this process is energy-intensive
        - Only makes sense in applications where electricity cannot be used directly
            - Examples include heavy duty transportation and industry
            - Already used in some industries, but with hydrogen produced using fossil fuels
    - Clean alternatives are more expensive
        - “Green” hydrogen uses renewable electricity as an energy source
        - “Blue” hydrogen uses fossil fuels combined with carbon capture and storage
        - U.S. subsides larger for green hydrogen
    - Infrastructure needed to deliver hydrogen
        - E.g. the challenge for heavy-duty trucking: both batteries or hydrogen fuel cells will require new networks

II. Technological Change and the Environment: Policy Options to Promote New Energy Sources

- While penetration of renewable energy sources is growing, achieving significant reductions in carbon emissions requires further development and deployment

- Innovation is needed to:
    - Reduce the cost of existing technologies
    - Develop new breakthrough technologies
    - Develop complementary technologies (e.g. grid management, energy storage) to better integrate intermittent renewables into transmission grids

- Thus, considering how policy can promote innovation on clean technologies is important
    - Innovation on many clean energy technologies peaked in the early 2010s. What explains the decline? Possibilities include:
        - Falling prices
        - The role of fracking
        - Weaker than expected regulations
        - Diminishing returns to research
        - Innovation worked
            - Related to diminishing returns
            - By 2017 solar PV costs had fallen below what experts had earlier predicted for the year 2030 (Nemet, 2019)
            - But similar trends observed for emerging technologies still needing improvements

- The process of technological change includes three steps:
  1) Invention – the birth of an idea
  2) Innovation – commercialization of an idea
  3) Diffusion – Adoption and utilization of the innovation

- Note that technological change is uncertain.
    - We don't know whether research will be successful, or which projects will be successful.
        - While some patents are worth billions of dollars, most have little commercial value.
        - This suggests that a diversified strategy is desirable.
    - "Picking winners" can be costly
        - E.g. synfuels in the 1970s.

- Technological change and the environment is complicated by the presence of multiple market failures.

- At all three stages, market forces provide insufficient incentives for the development and diffusion of environmentally friendly technologies
    - Environmental Externalities
        - Addressed by environmental policy (e.g. demand-pull policies)
    - Knowledge as a Public Good
        - New technologies must be made available to the public for the inventor to profit
            - When this happens, some or all of the knowledge that makes up the invention also becomes available to the public.
        - Public knowledge may lead to *knowledge spillovers*—additional innovations, or even to copies of the current innovations, that provide benefits to the public as a whole, but not to the innovator
        - Addressed by science and technology policy (e.g. *technology-push*)
- Implications of knowledge spillovers:
    - Underprovision of R&D.
        - Firms only care about the private returns. They invest in R&D until the marginal private rate of return equals the marginal cost. At this point, the marginal *social* rate of return will be higher than the marginal cost.
        - Thus, even if environmental externalities are corrected, there will still be insufficient R&D.
            - Studies typically find that the social returns to R&D are about 4X higher than the private returns to R&D.
    - Opportunity costs are important
            - This high social rate of return is true for *all* R&D, not just environmental R&D.
            - Thus, if we design policy to enhance environmental R&D, we must consider where those resources come from.
            - At least in the short-run, resources available to do R&D are inelastic.
                - Firms may face revenue constraints.
                - More importantly, R&D requires highly-skilled scientists and engineers.
    - Because of the public goods nature of knowledge, government policies are used to foster invention and innovation:
        - Intellectual property rights (e.g. patents, copyrights)
            - Give inventors a temporary monopoly, which enables them to capture more of the returns to their invention.
            - In return, the patent document makes the invention public.
                - As such, not every inventor chooses to patent an invention.
            - Because of the temporary monopoly, patents encourage innovation, but slow diffusion.
                - Concern over the high price of patented drugs, as compared to generic drugs, is an example.

- Government R&D funding
  - The government can provide research funding to firms and universities, or can perform research itself in government laboratories.
    - Many of the government laboratories are for the Department of Energy (DOE).
  - In 2023, the US government provided $172 billion of federal R&D funding (18% of total US R&D). Of that:
    - $44.2 b performed directly by govt.
    - $34.4 b performed by industry
    - $29.0 b performed by Federally Funded Research and Development Centers (FFRDCs)
    - $52.8 b performed by universities
    - $11.7 b performed by nonprofits
  - Government funding gives the government more control over the type of R&D done.
    - However, broader policies (e.g. supporting a range of options), are preferable to picking winners.
  - Government funding is particularly useful when spillovers are large.
    - For example, basic research that cannot be patented and/or embodied in a proprietary product.
  - Basic research can complement research done by firms.
    - For example, DOE labs often include public/private partnerships to help commercialize new technologies.
- Tax credits
  - Tax credits lower the cost of R&D for firms.
  - However, they give the government less control over the projects done.
    - Firms will still choose to do the most profitable projects first, so tax credits are unlikely to stimulate basic research.
- Prizes
  - Only paid out if a goal is met
  - If goal broadly defined, avoids “picking winners” among alternative solutions
  - Transfers risk from government to firms that do the R&D
  - If risk is significant, large prizes will be needed to get firms to take on this risk

- Because there are two market failures at work, policy needs to address both. Increased federal R&D spending address innovation market failures, but not environmental market failures.

- R&D policy can help lower the cost of climate policies
    - While R&D policy plays a role, it is not a substitute for environmental policy
    - R&D policy can help with the *development* of technologies, but not with the *diffusion* of technologies

A. Promoting Private Sector Innovation (Demand-Pull Policies)

- Key lessons on innovation and environmental policy
    - Innovation responds quickly to incentives
        - Newell *et al*. (1999) & Popp (2002) both find most of the response of R&D to higher energy prices occurs within 5 years
        - Responses to policy are even faster
    - Higher energy prices help encourage investment in alternatives, but they are not a substitute for environmental policy.
        - Energy efficiency innovations may cause a rebound effect
        - Higher energy prices also encourage the search for more fossil fuels. Some of these, such as oil sands, even produce more carbon emissions.
        - In contrast, policies addressing emissions change the relative price of fossil fuels, so that cleaner sources become more competitive
    - Which types of policy?
        - Economists tend to prefer market-based regulation over command-and-control options
            - Minimizes compliance costs
            - Provides greater incentives for innovation
                - Command-and-control regulation provides incentives to meet, but not exceed, standards (Popp, *JPAM*, 2003)
                - In contrast, market-based options provide rewards for continual improvement

- However, policy distinctions can be subtler
    - Technology neutral
        - Carbon tax
        - Cap-and-trade
        - Renewable Energy Certificates/Renewable Portfolio Standards
            - Many EU countries and US states have targets for a % of energy to be generated by renewable resources by a certain date.
            - In some cases, these are accompanied by other policies to help meet these targets.
            - Sometimes implemented using tradable certificates
                - Producers get a certificate for each unit of renewable energy supplied to the grid.
                - Customers or distributors must show that they use at least that percentage of renewable energy.
                    - They do this by purchasing permits.
                    - Since producers of renewable energy sell the permits, they are compensated for the extra cost of producing renewable energy.
                - Example of trade: wind plant uses all renewables, so could sell
    - Technology-specific
        - Feed-in tariffs
            - Some EU countries guarantee a higher price for electricity generated from renewable sources. This helps make these sources competitive with other fuels.
            - Examples include feed-in tariffs in Germany
            - Germany guarantees a price of 17.8 ¢/kWh for solar, about 11.5 ¢/kWh for wind
                - Had been as high as 55¢/kWh for solar
                - Ended in 2016, replaced with renewable auction

        - Renewable auctions
            - Set a target level of renewable energy investment
            - Allocate contracts to the lowest bidders
            - Many countries are using auctions to replace feed-in tariffs
        - Investment subsidies
            - Examples are tax credits for installation of solar panels, energy efficient appliances, etc.
            - U.S. has a 2.3¢/kWh production tax credit for wind and solar. Extended in 2015
                - Encourages wind production, since that is closest to being competitive
                - Uncertainty is an issue, since needs to be renewed frequently
        - Technology mandates
            - Examples
                - Phasing out fossil fuel powered vehicles
                - Mandating 10% biofuels in US gasoline
            - Technology mandates reduce consumer choice, and are usually considered less efficient
- Policies that let the market "pick winners" will focus research efforts on technologies closest to market (Johnstone *et al*. 2010)
    - Renewable energy mandates => wind innovation
    - Guaranteed prices (e.g. feed-in tariffs) => solar innovation
        - Consider, for example, solar energy in Germany
- However, policies that promote specific technologies may increase short-run compliance costs
    - Government R&D emerges as an option to support long-term research needs
    - Even if current technologies make large scale reductions costly, don't we want to provide incentives for some basic reductions now?
        - It will be costlier to do more later, as we will have missed low-cost options that are currently feasible.
    - Gradual phase-in is useful, as it gives time for the capital stock to turn over.
- Solutions?
    - Use government R&D to support long-term research needs (Acemoglu et al., *JPE* 2016)
    - Combine broad-based policies with limited subsidies for technologies furthest from market (Fischer *et al*., 2017)
        - Most effective if target other market failures

- The presence of other market failures informs policy choice
    - Capital market failures
        - Energy innovations take longer to get to market (Popp, *Res. Policy*, 2017)
        - Often have large fixed costs
        - Government support helps overcome funding hurdles
        - Policy examples:
            - DOE Loan Guarantee Program
            - US Dept. of Energy SBIR grants
                - Recipients 2X as likely to receive subsequent venture capital, produce more patents, & earn more revenue (Howell, *AER* 2017)
    - Path dependency
        - Two issues
            - Network effects: Developing charging infrastructure is necessary before consumers will purchase electric vehicles
            - The private sector won't develop charging infrastructure until there are enough electric vehicles on the road to make investment profitable
                - Early adopters of electric vehicles provide external benefits through network effects, justifying subsidies
        - Path dependent innovation: Existing knowledge matters
            - Prior success in fossil fuel research makes it more difficult for new technology to compete
    - Coordination market failures
        - Auto manufacturers and part suppliers compete in global markets. EV policy can help coordinate (Dugoua and Dumas *PNAS* 2024)
        - Technology standards help new firms enter smart grid innovation (Gregoire-Zawilski and Popp, *Research Policy*, 2024)
    - Learning-by-doing (LBD)
        - Experiences of early entrants provide lessons for future technology development
        - Justifies additional deployment policies (e.g. tax credits) if there are spillovers
        - Evidence is mixed
            - When learning exists, spillovers often small (Gillingham and Bollinger, *Mgmnt Sci*, 2021) or lessons from learning decay quickly (*JPAM*, 2012)
        - Fischer *et al*. (*JAERE*, 2017): R&D market failures more important than LBD, so R&D spending more effective than targeted deployment policies
    - Knowledge spillovers: are they different for energy?
        - Clean patents generate larger knowledge spillovers than the dirty technologies they replace (Dechezleprêtre et al., working paper 2017)

        - Gerarden (*Mgmnt Sci*, 2023): German solar subsidies => innovation that lowered costs. 86% of the benefits occurred outside Germany.
        - Enabling technologies more radical and more original (Popp *et al*., 2022)
        - Justifies increased government funding for clean energy R&D

B. The Role of the Public Sector (Technology-Push Policies)

- Innovation market failures require government support for R&D.
    - Federal R&D spending
        - Government funds particularly useful for basic research
        - Even for applied research, there are some end use technologies that serve a public good, and thus will not be pursued by private industry
            - Storage of nuclear waste
            - Testing repositories for carbon dioxide sequestration
            - Improving the electrical grid to manage intermittent flows from wind and solar
        - However, governments need to be aware of the potential of crowding out private research efforts. Thus, want to support research that the private sector won't do on its own.
        - Adjustment costs are important
            - Limits to how much we can spend on green R&D are likely to come not from the number of deserving projects, but rather from limits of the existing research infrastructure
            - US NIH experience is an example
                - Budget doubled between 1998-2003
                - Adjustment costs were high (including NIH administrative costs)
                - Funds were then cut
                    - Real NIH spending fell 6.6% from 2004 to 2004
                    - More competition for jobs among recent post-docs
                    - Researchers spend more time writing grants
        - Historically, energy R&D in the U.S. has focused on increasing energy supplies
            - Dramatic increases in the amount of recoverable resources have occurred
                - Fracking for natural gas is a good recent example.
            - Motivated by goals of energy security and lowering prices
            - Civilian nuclear energy was developed as a result of military R&D investments
                - Rapid growth occurred in 1970s, before Three Mile Island
                - High capital costs are also a concern

        - Nonetheless, research on nuclear continues
    - Wind energy research began in 1970s.
        - Leveled off in 1980s before growing again in 2000s
        - However, European investment has been greater
- Many early energy investments went to large scale projects that did not work out
    - Synfuels are a failed example from the 1970s
    - However, consider that uncertainty is a part of R&D
        - NRC study: While only a handful of DOE programs from 1978-2000 were successful, those that were had benefits high enough to justify the cost of the entire R&D portfolio
        - The successful projects were primarily energy efficiency (refrigerators, CFL)
        - Efforts to develop energy supplies were not successful ($6 billion costs vs. $3.4 billion benefits)
            - Focused on a narrow set of technologies, but funding continued for political reasons even after early failures
- The DOE's Advanced Research Projects Agency-Energy (ARPA-E) is an example of a government agency that has successfully promoted and managed high-risk, high-reward innovation
    - Requires research teams to set clear, measurable goals through various stages of research
    - Gives program directors the ability to terminate or redirect projects not achieving these predetermined milestones
        - Takes the decision to end funding out of the hands of politicians, making it easier to support more high-risk/high-reward projects

- Government funding can help new technologies overcome roadblocks to commercialization
    - A common concern among energy experts is the “Valley of Death”
        - Projects reach demonstration stage, but are not able to improve sufficiently to become commercialized
    - Raising private capital for clean energy technology can be difficult. Why?
        - Energy innovations take longer to get to market (Popp, *Res. Policy*, 2017)
            - Popp (*Research Policy* 2017) looks at citations between articles and patents
                - Probability of citation peaks 15 years after article publication
                - Longer than found in studies of other fields, suggesting that energy research takes longer to progress to a commercialized product
        - Often have large fixed costs
        - Difficulty with product differentiation may make large returns unlikely (van den Heuvel and Popp, *NBER WP*, 2022)
            - Tesla vs. solar panels
    - Government support can help overcome funding hurdles
        - US Dept. of Energy SBIR grant recipients 2X as likely to receive subsequent venture capital, produce more patents, & earn more revenue (Howell, *AER* 2017)
    - However, demand still matters
        - Early stage ARPA-E awards did not increase probability of exit (Goldstein *et al*., *Nature Energy*, 2020)
        - Changing policy expectations affect VC investment (van den Heuvel and Popp, *NBER WP*, 2022)

- Government funding can also new technologies overcome roadblocks to commercialization
  - Technology transfer increased after change in direction of energy R&D in the 1980s
    - Technology transfer slower when research is more basic or has national security implications
    - Patents that cite government patents (e.g. children) are most highly cited, suggesting technology transfer creates benefits (Popp 2006)
  - Research on renewable energy sources produced by government institutions has been particularly helpful moving alternative energy research to an applied stage (Popp, *Research Policy*, 2017)
    - Government articles not more likely to be cited by other articles, but are more likely to be cited by other patents

- How does government R&D aid commercialization?
  - Helps new energy technologies overcome roadblocks to commercialization (Mowrey et al., *Research Policy* 2010, Weyant, *EngEcon* 2011)
    - Large capital expenses leave a role for collaboration with the public sector to both provide support for initial project development and for demonstration projects
    - Advances in wind turbines were aided by U.S. Department of Energy-sponsored innovation on multiple turbine components
      - Funding complemented private sector efforts and allowed for feedback between public and private sector researchers

- What mix of policies should be used?
    - Simulations suggest the largest efficiency gains come from environmental policies, rather than R&D policies.
    - R&D policies help encourage research on alternative technologies, but they do not encourage diffusion.
        - Popp (2006) considers the long-run welfare gains from both an optimally designed carbon tax (one equating the marginal benefits of carbon reductions with the marginal costs of such reductions) and optimally designed R&D subsidies.
            - Combining both policies yields the largest welfare gain.
            - A policy using only the carbon tax achieves 95% of the welfare gains of the combined policy.
            - A policy using only the optimal R&D subsidy attains just 11% of the welfare gains of the combined policy.
        - Fischer and Newell (2008) compare policy options for reducing carbon emissions in the US electricity sector. In order of effectiveness, they find:
            - emissions price
            - emissions performance standard
            - fossil power tax
            - renewables share requirement
            - renewables subsidy
            - R&D subsidy
        - Fisher et al. (JAERE 2017)
            - R&D market failures more important than LBD
                - Thus, R&D spending more effective than targeted deployment policies
            - But, current policy favors deployment.