

Lecture # 22 –Alternative Energy Technologies

- *Policy question*: should households be rewarded for distributed generation
 - Distributed generation is producing electricity at the consumer site, such as with solar PV panels
 - Electricity generated reduces the consumer's bill, since they take less power off the grid
 - As a result, utilities have been lobbying to reduce solar incentives
 - Should they also be paid for any surplus power that they contribute to the grid (net metering)?
 - Pros:
 - Solar PV generates power at peak times, when it is more valuable
 - Concerns:
 - This doesn't reduce distribution costs
 - Some of the consumer's bill would have paid for these fixed costs
 - Consumers cannot control when the power goes on the grid
 - Over 40 states allow net metering
 - Since 2013, Hawaii, Nevada, Arizona, Maine, and Indiana have phased out net metering
 - How can policy address the costs of distribution?
 - Find new ways to value non-utility PV electric (NY)
 - Time of use rates that rise with demand (CA)
 - Encourages more investment in batteries
 - Fees for customers with solar panels on roofs (KS)

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)
 - 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 CO₂ 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 unminable 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
 - As a result, firms are reluctant to invest in the technology
 - Requires high carbon prices to be viable.

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
 - Until the past few years, energy R&D efforts have remained relatively flat since the 1970s
- 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.
 - Goolsbee (1998) finds that one of the chief beneficiaries of R&D tax subsidies are scientists and engineers, who receive larger wages when subsidies are increased.
 - In Popp (2004), I estimate that approximately one-half of the energy R&D spending that took place in the 1970s and 1980s came at the expense of other R&D.
 - 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 2019, the US government provided \$133.8 billion of federal R&D funding (21% of total US R&D). Of that:
 - \$39.8 billion performed directly by govt.
 - \$22.5 billion performed by Federally Funded Research and Development Centers (FFRDCs)
 - \$22.7 billion performed by industry
 - \$39.6 billion performed by universities
 - \$8.9 billion 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.
 - 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
 - Prices have been falling quickly
 - Suggests competition reduces costs
 - In Germany, lowest bids for onshore wind in 2016 were lower than market price of electricity, suggesting no subsidies needed
- 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
 - When might they compare favorably to other policies?
 - If the new technology (e.g. EV is an imperfect substitute for the old technology)
 - If it were a perfect substitute, no policy needed
 - If it is a poor substitute, forces consumers to choose a lesser technology
 - In between, the welfare losses can be only slightly worse than pricing mechanisms
 - Can help address network externalities
 - EV's need chargers, but chargers aren't profitable without EV's
 - May provide signals that encourage more R&D

- 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
 - 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

- Learning-by-doing (LBD)
 - Experiences of early entrants provide lessons for future technology development
 - Justifies additional deployment policies (e.g. tax credits)
 - But LBD effects are small (Nemet, *JPAM* 2012; Tang, *Energy Policy* 2018)
 - Nemet (*JPAM* 2012): LBD exists , but learning is subject to diminishing returns and decays quickly
 - Fischer *et al.* (*JAERE*, 2017): R&D market failures more important than LBD, so R&D spending more effective than targeted deployment policies
 - But current U.S. policies favor deployment
- 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)
 - 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
 - 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
 - Commercialization of research takes longer for energy
 - 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
 - Branstatter and Ogura (2005) find that patent citations to scientific publications peak about eight years after article publication
 - Finardi (2011) finds lags of just 3-4 years for nanotechnology

- 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.