Lecture # 26 – Innovation, Energy, and Climate Change

I. Innovation and Environmental Policy

- Technological change and the environment is complicated by the presence of multiple market failures.
    - Of course, market failures affect the process of technological change more generally.
        - However, technology policy alone will not suffice.
    - A second concern is environmental externalities.
        - Even if R&D markets functioned perfectly, firms will not have incentive to develop environmentally-friendly products if the costs of pollution are not internalized.
- Simulations suggest the largest efficiency gains come from environmental policies, rather than R&D policies.
    - Popp (*Climatic Change*, 2006) examines gains from carbon tax & R&D subsidies
        - Only using carbon tax => 95% of welfare gain of both
        - Only using R&D subsidy => 11% of welfare gain of both
    - R&D policies help encourage research on alternative technologies, but they do not encourage diffusion.
    - However, policies such as taxes and subsidies will encourage use of technologies closest to market (e.g. wind).
        - Direct government support plays a bigger role for technologies that aren't close to competing with traditional fuels.
    - Thus, both environmental policy and technology policy will be relevant.
- Knowledge market failures particularly relevant for energy and the environment
    - Incomplete information
        - Uncertainties for R&D are particularly large.
        - This makes raising capital to invest in projects difficult.
        - This may be a particular problem for projects with long term payoffs, such as basic research.
            - Also problematic for long-term environmental problems like climate change.
    - Adoption externalities
        - As discussed earlier this semester, these are particularly a problem for energy efficiency
            - People demand high returns (greater than 30%) to invest in energy efficiency.
                - Demand payback periods of 2-3 years
            - One issue is price
                - Energy is a small portion of the average household's budget
                - Energy efficiency is higher in counties with higher energy prices.

          - In the U.S., energy consumption in a state is about 7% lower for each cent/kWh by which electricity prices exceed the national average.
    - Learning by doing & learning by using
        - As firms or consumers gain experience with a product, costs may fall.
            - If this learning benefits others as well, there is a positive externality.
    - Principle-agent problems
        - E.g. do landlords have incentives to improve building efficiency if tenants pay their own energy bills? Do tenants have incentives to conserve if landlords pay the bills?
    - Lock-in
        - Switching to new technologies can be expensive
        - Thus, to adopt, the technology must not only be beneficial, but the benefits must justify the costs of switching.
            - Thus, slow diffusion of capital goods may be rational.
                - E.g. even if gas prices rise, you don't get rid of your current car right away

II. Where Does Our Energy Currently Come From?

- Most energy used in the US is consumed by industry and transportation.
- Of the 95.02 quads consumed in 20012, 77.99 were fossil fuels. Just 8.06 quads were renewable.
    - Of the renewables, most were hydropower and wood. 13% of renewables were wind, and 2% of renewables were solar.
    - Power generation is dominated by coal, nuclear and natural gas. In 2011:
        - 43% coal
        - 25% natural gas
        - 19% nuclear
- Worldwide, renewables make up 13% of total primary energy supply (TPES).
    - Most of this is combustible renewables and renewable waste, which makes up 9.7% of total primary energy supply.
    - Biomass is particularly important in developing countries. Thus, they have higher shares of renewable energy.
        - Share of renewables in TPES, 2011:
            - Africa 49.6%
            - Asia (except China) 25.7%
            - China 10.7%
            - Latin America 30.2%
            - Non-OECD Europe 3.5%
            - OECD 8.1%
            - Middle East 0.4%
    - Hydro is another 2.2%.
    - The remainder is geothermal, solar, wind, and oceans.

- The climate change problem
  - Electricity generation is the main source of carbon emissions (24.5% of carbon emissions globally), followed by deforestation (18%) and transportation (13.5%).
  - Potential mitigation targets frequently discussed
    - 550 ppm atmospheric CO_2
      - Emissions path:
        - Emissions begin to decline around 2020
        - Peak at 11 billion tons in 2040
        - Decline to 7 billion tons by 2100
        - BAU is about 20 billion tons
        - Gradual decline to 3 billion tons by 2200
      - Would lead to warming of about 3ºC above pre-industrial values
    - 450 ppm atmospheric CO_2
      - Advocated by those concerned that even moderate warming currently experienced (about 0.8oC) has already had effects
      - This would lead to warming of about 2ºC
      - Emissions path:
        - Emissions begin to decline around 2012
        - Peak at 9 billion tons in 2020
        - Decline to 3.5 billion tons by 2100
        - Decline to 2.5 billion tons by 2200

III. Alternative Energy Sources

- Note that we are not running out of energy. However, this does not mean that cheap energy will always be available.
- Rather, energy is a difficult issue for the following reasons
  1. Multiple economic, environmental, and security aims
     - Limiting costs increases usage (and emissions) and reduces funds for investment in infrastructure.
     - Increasing domestic supply unpopular if it involves drilling in environmentally-sensitive places.
     - Increasing supply via nuclear raises security concerns.
  2. All sources face some limitations
     - These are discussed in detail below.
  3. Large embodied capital investment and long turnover times of world's energy supply
     - Replacement cost of today's global supply system is $12 trillion
     - Typical turnover times are 30-40 years

- The potential and problems of energy sources
  - Conventional oil and gas
    - What is available?
    - Emissions are a concern
  - Coal, tar sands, oil shale
    - Usage increases carbon emissions
    - Coal has a high carbon content.
    - The process of extracting oil from tar sands is more energy intensive. For example, in the oil sands in Canada, the oil must be melted out of rocks. Because this requires more energy, more carbon is released
      - For example, a gallon of gasoline from tar sands releases 3x more carbon than a traditionally produced gallon.
    - Carbon capture and storage (a/k/a carbon sequestration)
      - Carbon is stored by injecting it into the ground
      - Space is an issue
        - Storing 60% of the CO_2 produced in the U.S. would fill all the space from oil consumed in the U.S.
    - Integrated gasification combined-cycle (IGCC) is a way to reduce CO_2 emissions from coal
      - Turns coal into a gas before burning
      - CO_2 is separated from hydrogen when gasified
        - CO_2 is stored, and hydrogen is used to generate electricity
        - Avoids the technical challenge of separating CO_2 from other flue gasses.
      - The technology is expensive. Needs a carbon price of at least $30/ton to be viable.
  - Nuclear
    - Safety and waste storage remain concerns
  - 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.
      - Is there enough farmland to grow the needed feedstocks as well as supplying necessary food supply?
      - Recent concerns over corn prices is an example here
    - Short term challenges
      - Supply of feedstocks
    - Medium term challenges

        - Developing new feedstocks and conversion methods.
    - Carbon content of biofuels depends on how produced
        - A project in Georgia uses waste from cut trees.
            - If the project receives credit for using material that would decompose anyway, the project could be carbon neutral.
        - In contrast, using corn as a feedstock uses fossil fuels in production.
        - Note how a CO_2 tax would affect the incentives for different types of feedstocks.
- Hydropower
    - Used for 16% of world electricity production.
    - Does not require technological breakthroughs.
    - However, political acceptance is an issue.
    - Small hydro is cost competitive
- Geothermal
    - Uses heat from the earth, which is captured as steam or used to heat water that is piped below the earth.
    - The technology is mature, but cost reductions are needed to make it competitive.
- Wind
    - Wind is now competitive in favorable locations.
        - Now about 5-8 cents/kWh
    - Issues for expansion:
        - Continued cost reductions
        - Understanding extreme wind conditions
        - Integrating wind turbines to the electric grid
        - Are there enough acceptable sites?
            - Good sites have sufficient wind or solar resources, are near where energy demanded (to avoid transmission losses) and are not ruled out politically.
- Solar
    - Solar is the most expensive of currently used renewable sources.
    - In addition to improving technology to lower cost, storage of solar energy is also an issue.
    - As with wind, are there enough acceptable sites?
    - Solar photovoltaics remain very expensive, but costs are falling
        - $20/W in 1970s
        - $2.70/W 2004
        - $1.37 - $2.27/W in 2011
    - Useful for modular locations (e.g. remote lighting, signs, etc.), but not for mainstream use.

            - Improved energy efficiency
                - Amount of energy required to produce output in industrialized economies has fallen since the 1970s
                - In the IEA's "greenest" energy projection, energy efficiency accounts for 2/3 of averted emissions
                - Many profitable measures currently exist
                    - Could earn average returns of 10-17%
                - Potential concern is the "rebound effect"
                    - Higher efficiency makes using energy cheaper
                    - Thus, demand for services increases
                        - For example, drive more when cars use less gasoline
                    - Two British studies suggest the rebound effect cancels out 26-37% of the gains from energy efficiency

IV. How to Get There: Policy Options

- 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.
- Because of externalities and long-term research needs, the government plays an important role in energy R&D
    - Represents roughly one-third of total US spending on energy R&D.
        - Role of private sector falling in the 2000s.
    - Energy companies tend to do less R&D per dollar of sales than high-tech industries
- Innovation market failures require government support for R&D.
    - Recall the types of support that could be used
        - 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.
                    - Without storage of energy, these will just be niche technologies.
        - 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.
            - Smaller firms won't participate if costs of research are high.

- They would need direct financial support.
- Could lead to wasted resources if several firms compete and duplicate efforts.
- Tax credits
  - Increase profitability of R&D
  - However, firms still do what is profitable.
    - Thus, needs to be accompanied by environmental policy to induce new energy R&D.

- 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
      - Denmark is a leader
- Many early energy investments went to large scale projects that did not materialize
  - 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
      - Funding continued for political reasons even after early failures
  - Another recent large scale failure is FutureGen
    - Began in 2003 to develop a near-zero emission coal fire power plant with carbon capture and storage
    - Was a partnership between US government and various power producers and electric utilities
    - Cancelled in 2008 due to cost concerns
    - Obama administration wanted to reinstate, but some major utilities pulled out
- During the Reagan administration, focus shifted to longer term orientation
  - Government R&D sponsored technologies not yet competitive
  - Other R&D left to the private sector

    - As a result, DOE R&D funding dropped by one-half
- Technology transfer is also important
    - 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
    - Popp (2006): Patents that cite government patents (e.g. children) are most highly cited, suggesting technology transfer creates benefits
- The role of markets and government policy
    - Energy prices are an important driver of innovation
        - Innovation falls when energy prices are low
            - Matters for both renewables and fossil fuels
            - Exploring for additional fossil fuels less profitable when prices are low.
- Regulatory structure matters as well
    - Electric utility R&D declined after deregulation
        - Deregulation led to uncertainty about future market conditions
        - Competition also made it more difficult for utilities to capture the benefit of R&D-induced cost savings
- Environmental policies can be classified into two main types
    - Market-based policies use market mechanisms to provide incentives to reduce externalities.
        - Examples include emission fees, energy taxes, and tradable permits.
    - Command and control policies dictate a specific level of environmental performance.
        - These provide less incentive for innovation, as there is no reward for exceeding the standard. In contrast, market policies provide continual rewards (e.g. lower taxes) for improvement.
- Economists tend to prefer market-based regulation over command-and-control options
    - Minimize compliance costs
    - Provide 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
    - Technology-specific

        - Feed-in tariffs
        - Investment subsidies
        - Biofuel mandates
    - Moreover, policies are often multi-dimensional
        - Technology requirements (e.g. biofuels mandate)
        - Performance requirements (e.g. removal efficiency for FGD)
        - Targets (e.g. renewable portfolio standards)
        - Tax incentives
- Types of policies used
    - Many policies designed to encourage alternative energy are very specific, rather than broad-based policies such as a carbon tax.
    - Renewable energy targets
        - Many EU countries and US states have targets for a percentage of energy that should be generated by renewable resources by a certain date.
        - In some countries, such as Australia and Japan, these are binding constraints.
            - E.g. all wholesalers must get 2% of their electricity from renewable sources.
        - In other cases, these are policy goals that are accompanied by other policies to help meet these targets.
    - Price guarantees
        - 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 55¢/kWh for solar, and 8.4¢/kWh for wind
    - Tradable green certificates
        - Used in Europe, Australia, Texas
        - The program begins with a target level for percentage of renewable energy use.
        - 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.
    - Investment subsidies
        - Examples are tax credits for installation of solar panels, energy efficient appliances, etc.
            - U.S. has a 1.9¢/kWh production tax credit
            - Encourages wind production, since that is closest to being competitive

        - Uncertainty is an issue, since the credits need to be renewed frequently
- Policy considerations
    - Even if current technologies make large scale reductions costly, do we want to provide incentives for some basic reductions now?
        - It will be more costly 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.
    - Environmental policies provide incentives for increased R&D.
        - Policies are needed to provide rewards for green innovation.
        - However, consider what types of R&D encouraged by these incentives.
        - Will projects with only long-term payoffs (e.g. solar PV) be encouraged?
    - Finally, note that 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 tar 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.
- 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.
    - However, policies such as taxes and subsidies will encourage use of technologies closest to market (e.g. wind).
        - Direct government support plays a bigger role for technologies that aren't close to competing with traditional fuels.

V. International Green Technology Transfer

We'll discuss this topic on Monday, but I'm putting the notes here to keep all the material on energy technology together.

- Technology transfer
    - Getting clean technologies to emerging economies is important
        - In 2010, 75% of the growth in CO_2 emissions came from non-OECD countries.
        - CO_2 emissions from non-OECD countries are projected to be nearly double of those from OECD countries by 2035
    - As we know, nearly all of the world's R&D is performed in the developed OECD economies

- As a result, their environmental policies usually shape the development of environmentally-friendly technologies
    - Most pollution control patents in developing countries come from developed country inventors
    - Dechezleprêtre *et al*. (2009) find that 2/3 of climate change innovations come from Japan, US, and Germany
        - Emerging economies accounted for 16.3% of climate-friendly innovations in 2003
        - The technologies most prevalent in these countries are cement manufacture, geothermal, and biomass technologies.
            - Cement manufacture and geothermal innovations take place mostly on a local scale, with less than 15% of these patents appearing in multiple countries.
            - This is consistent with the nature of these industries, which typically serve local markets and, in the case of geothermal, may face different technological needs depending upon local conditions.
            - Suggestive of the need for adaptive R&D to fit technologies to local conditions.
- While binding emissions constraints in developing countries will not be necessary to encourage the invention and innovation of green technologies, the key question is how to get these innovations to developing countries
    - Policy incentives are needed for the transfer of climate-friendly innovations
        - One exception is energy efficiency. Energy efficiency technologies will diffuse even without environmental policy in place, as they offer users the opportunity of cost savings.
        - However, diffusion may not be optimal, as social benefits of energy efficiency may be ignored by private investors (e.g. PMB < SMB)
    - These may come from the recipient countries (e.g. local policies) or from the source countries (e.g. Clean Development Mechanism)
        - The Clean Development Mechanism (CDM) enables developed country buyers to purchase credits for greenhouse gas reductions in developing countries
        - Currently, developing countries face no other reduction obligations
    - Low hanging fruit problem
        - Will CDM support the easiest projects, making it difficult for countries to do more on their own?
        - Technology transfer helps.
            - Dechezleprêtre *et al*. look at 644 CDM projects registered by the Executive Board of the UNFCCC.

                - They find that 279 projects, or 43%, involve technology transfer.
                    - Of these, 57 transfer equipment, 101 transfer knowledge, and 121 transfer both equipment and knowledge.
        - Adoption of environmental regulation follows standard diffusion curves
            - Over time, countries adopt environmental regulation at lower levels of per capita income
            - As pollution control technologies improve, the costs of adopting environmental regulation fall
                - Late adopters can learn from early adopters
                - Hilton (2001): countries phasing out leaded gasoline after 1979 completed the process five years faster than those going earlier
                - As a result, countries adopt regulation at earlier levels of development
                - International trade improves access to technology, leading to earlier adoption of regulation (Lovely/Popp 2011)
- Role of intellectual property
    - International agreements emphasize the need to transfer technology to developing countries
    - Suggest that the role of patents must be considered
        - The concern is that patents slow diffusion of green technology, and that this is bad for the global environment.
            - Because climate protection is a global public good, wide diffusion of climate-friendly innovations is desirable.
        - Compulsory licensing is one option, as proposed in a World Bank report (cited in OCTSD report, p. 5)
    - Most industrialized countries, however, disagree with this stance.
        - Rising power of China and India makes IPR more important
        - Consider the case study of wind in China and India
            - Licensing technology played an important role.
            - Thus, IPR can help facilitate technology transfer to emerging economies.
    - There has been little work directly studying the effect of intellectual property rights on technology transfer of eco-innovations
        - A Copenhagen Economics (2009) study on climate change concludes that IPR are not a barrier to the transfer of carbon emission-reducing technologies.
            - The high costs of these technologies are due more to the immaturity of the technologies, rather than IPR.
        - Barton (2007) suggests developing country policies such as tariffs on renewable energy technology and subsidies for fossil fuels do more to limit technology transfer of clean technologies than do IPR.

        - Few patents for green technologies filed in low-income countries.
            - Patents aren’t as important for green technology as they are for pharmaceuticals.
            - Technologies do compete with one another
- Policy options
    - Fast tracking green patents
        - In 2009, major patent offices put in place plans to “fast track” green patent applications.
        - Goal was to encourage diffusion by bringing products to market more quickly.
    - Eco-commons
        - Private companies place some green patents in the public domain.
        - Hall and Helmers (2013) find pledged patents protect environmentally friendly technologies and to be of similar value as the average patent in a pledging firm's patent portfolio but of lower value than other patents in their class
        - They find little evidence that the eco-commons increased diffusion.