Lecture # 5 -- Sources of Technological Change

I. What is Invention?

- Our goal over the next couple of classes is to consider what factors influence the inventive process.
  - We begin by looking at theories of invention and innovation
  - Once we describe how firms innovate, we can then ask what factors influence:
    - The level of innovative activity
    - The focus of innovative activity
- Note: Many economists distinguish between invention (the initial insight) and innovation (applying that insight to a marketable product).
  - This distinction was first made by Schumpeter.
    - Leads to the notion of "Creative Destruction" -- new ideas make old ones obsolete.
  - While Arthur's model focuses on invention, it also suggests links between the two processes.
- What is technology? That is, what are the inventions Arthur focuses on?
  - Arthur defines a *technology* as a means to fulfill a human purpose.
    - Could have a specific purpose (e.g. to power an airplane) or be more general (e.g. a computer)
  - The base concept or base principle of the technology:
    - The central idea or concept
      - E.g. ticks of a clock, reflection of radio waves => radar
  - The base idea must be exploited
    - The exploitation takes advantage of the base principle
    - A scientific principle by itself, Arthur argues, is not an invention.
    - Rather, it is the use of the principle or some purpose that makes a technology.
  - Technologies are put together (*combined*) from component parts
    - Technologies often have recursiveness
    - That is, the technology requires sub-components
      - It is an assembly of smaller technologies
- In his introduction, Arthur presents the cumulative synthesis approach was developed by Abbot P. Usher in the book *A History of Mechanical Inventions* (1929)
  - While he finds the model "frustratingly vague", Arthur's own model seems to owe much to Usher's original formulation.
  - Thus, we begin with a brief overview of his model, known as the <u>cumulative synthesis approach</u>.

- The cumulative synthesis approach proposes that major inventions emerge from the cumulative synthesis of relatively simple inventions, each of which requires an "act of insight."
  - Usher distinguishes "acts of insight" from "acts of skill"
    - "Acts of skill" are learned activities.
    - "Acts of insight" are unlearned activities that result in new organizations of prior knowledge and experience.
      - They may occur during the course of acts of skill.
- Four steps to individual invention:
  1. Perception of the problem
     - May be induced by economic forces
  2. Setting the stage
     - Elements necessary for the solution brought together through a configuration of events.
     - One necessary element is a person with the necessary skill in manipulating the other elements.
  3. The act of insight
     - The essential solution to the problem is found
     - This is an uncertain process.
     - Prediction is impossible.
  4. Critical revision
     - The new invention is redesigned to meet technical and economic requirements for successful adoption and diffusion.
- Note that smaller inventions may set the stage for a major invention.
- Most conscious effort occurs at steps (2) and (4).
  - The act of insight is influenced by setting the stage, but is harder to predict.
  - However, steps (2) and (4) can be accelerated when needed. Government policy is most likely to influence these two steps.
    - For example, research on energy in the 1970s, research on AIDs in the 1980s.
    - Not all research will be successful, but as more efforts are made, the likelihood of success increases.
  - Most resources are used in step (4).
    - For example, in the drug industry, 10-15% of resources typically go to steps (1)-(3), and the rest to step (4).
    - Critical revision often requires "acts of skill" rather than "acts of insight."
  - Note that market influences play a strong role in step (1).
- Moving to Arthur's article, Arthur focuses on invention, looking at the development of *radically new technologies*.

· What do we know about invention?
  - o Novel technologies shaped by social needs
    - § Similar to Usher's perception of the problem
  - o Respond to:

        - Economic opportunities
        - Perceived risk
        - Factor price changes
    - Cumulate with the growth of cultural and scientific knowledge
    - Can be catalyzed by the exchange of information within networks of colleagues
    - Invention is a process, not a single event
- What is invention?
    - Note, to begin, that Arthur focuses on radical inventions.
        - Compare to the *Economist* article discussing the many minor inventions made by firms.
        - How does Arthur distinguish between these?
            - Modified technology: changing purpose or components
                - E.g. using a computer for a different use, or changing the computer architecture
            - A significant invention changes the basic principle
                - Note that this rules out some major modifications, such as Watt's steam engine
                - "What differentiates invention is that the overall problem has not been satisfactorily solved before…" (p. 283)
    - "Invention is at bottom a linking of some purpose or need with an effect that can be exploited to satisfy it" (p. 282)
        - <u>Two steps</u>:
            - Search for a base principle
            - Translation of base principle into reality
- Developing the base concept
    - Arthur proposes two possibilities
        - Note that the first is very much like an "act of insight"
    - Process begins with a need
        - He gives the example of Britain needing faster airplanes after WWI
        - Economic need (e.g. a profitable market) may also be a starting point
    - The need becomes a problem
        - E.g. airplanes after WWI could be faster if flew higher
        - But at higher altitudes, reciprocating engines in use could not get sufficient oxygen.
        - Thus, a different engine principle was needed
    - What is being sought is not a new product, but a new principle
        - This is similar to Usher's act of insight
            - Arthur tries to add more structure to the process
            - However, identifying the base principle is still uncertain, and still leaves much work to be done.
        - Arthur argues that the principles are not "invented from nothing"
            - Rather, they are appropriated from things that already exist
            - What distinguishes Arthur's model of invention from "science"?
                - He focuses on use of *existing scientific principles* to solve the problem.

- The idea may come quickly (e.g. as an “act of insight”), but his examples use existing scientific knowledge.
  - § It seems Arthur distinguishes between applied and basic research, although he doesn’t explicitly say so.

- o Because the principles do not come from nowhere, the inventors in Arthur’s model must have knowledge of a broad set of scientific principles
  - § Does this differentiate Arthur’s model from Usher? Does this make the base concept also an “act of skill”?

- From principle to working technology
  - o Along the way, new problems needing new concepts may arise (“subproblems”)
  - o Arthur says that invention consists largely of solving subproblems (e.g. “development”)
    - § The various subproblems that needed solving to develop laser printers are a good example (p. 281)
    - § The principle was known, but how to make practical for commercialization required several new ideas
  - o This is where resources will be needed
    - § “Precisely focused effort” rather than a “conceptual breakthrough” needed (p. 282)
      - Solutions will be proposed. Some will fail, some will work.
    - § Once a prototype is developed, it becomes a candidate for commercialization
      - However, even more tweaking may be needed.
    - § Similar to Usher’s critical revision step.
- Is there a role for policy in Arthur’s model
  - o Some possibilities
    - § “National leadership in the creation of advanced technologies issues from long established knowings of how to work with particular novel phenomena and their associated functionalities. This necessary craft needs to be cultured slowly over decades in local settings with steady funding and encouragement. It is fed by universities; and it localizes because it tends to be shared at any time in any novel field of invention by small numbers of people confined to certain labs or particular regions.” (p. 285).
      - Suggests several policy roles:
        - o Education
        - o Support for university/lab research
        - o Technology transfer policies
    - § Arthur also notes this leadership doesn’t last forever.
      - Eventually knowledge leaks out, so that leadership needs to be constantly renewed.
    - § Other ideas:
      - Can government help with uncertainty and risk?
      - Can government determine the “need”? Should it do so?

- Is there anything else government can do to "set the stage"?

II. Who Does Research?

- Thus, in this section, we consider *who* is involved in the research process, and discuss the incentives that they face.
    - Note that different actors face different incentives, and will thus react to policies differently.
- Categorizing research (data presented today comes from the National Science Foundation's *Science and Engineering Indicators*, p. 14 of chapter 4)

1. Source of funds: who provides the funding?
    - In US (and most developed countries), industry is the largest source of R&D funding.
2. Performance: who does the research?
    - Not all R&D performed by the institution than funds it.
        - 37 % of federally-funded R&D done in industry or industry-administered FFRDCs.
        - Much of this is defense research.
        - Particularly true for universities. Just 28% of university *performed* R&D is funded by universities.
            - 58% of funding from federal government.
    - Link and Siegel note that most R&D is performed in the "US national innovation system."
        - Within this system, most R&D done in *research laboratories*.
        - However, as noted in one of the *Economist* articles, labs are becoming less important in business settings.
3. R&D by character of use
    - Corresponds to linear model of R&D developed by Vannevar Bush (in 1945 report to FDR: *Science – the Endless Frontier*)
        - Basic research => applied research =>technology development
    - <u>Basic research</u>: research whose objective is to gain more comprehensive knowledge or understanding of the subject under study, without specific applications in mind.
        - Advances knowledge, but has no specific, immediate commercial objectives.
    - <u>Applied research</u>: aimed at gaining the knowledge or understanding to meet a specific recognized need.
        - Oriented towards discovering new scientific knowledge with commercial objectives.
    - <u>Development</u>: systematic use of knowledge or understanding gained from research towards the production of useful products and/or processes.
    - Recent approaches acknowledge that the links are more complex.
        - Technology can lead to science.
        - Links between science and technology vary by field.
            - There is little division, for example, between leading edge biotechnology and modern biological science.

        - Nonetheless, data are still categorized as basic, applied, or development.
    - Different types of research done are by different groups
        - Basic:
            - 53% of basic research funded by government.
                - Just 21% by industry, since profits are less likely, and will not come for several years.
            - Over one-half of basic research (53.4%) performed by universities.
                - In a survey by Bozeman, 70% of university labs considered basic research a key mission.
                - Only 42% for government labs, and 11% for industry labs.
    - Applied and development more likely to be done by industry.
        - Industry funds 48% of applied research, and 78% of development.
        - Industry performs 90% of development research.
- What are the incentives faced by these research institutions?
    - Later in the course, we will discuss the incentives faced by public research institutions.
    - Today, we focus on the incentives faced by private firms.
    - The most important and visible output of a research laboratory is the information it creates, such as research papers and patents.
        - However, for a firm, getting a product to market is more important.
        - Consider the *Economist* article discussing how big firms have moved from a model where research is done in isolated labs to integrating research with the rest of the firm
    - To achieve economic viability, research institutions must generate new income streams.
        - How might these be different for different institutions?
            - Firms:
                - Goal is to create new products or processes
                - Firms respond to market incentives.
                    - Market conditions matter.
                - In more mature industries, innovation may come by devising new processes (e.g. "a better way")
                    - Examples include Dell, Wal-Mart.
                - Technology moves faster in emerging industry.
                    - Here, product innovations are more important.
            - For universities and government laboratories, developing new products is not the goal. We'll discuss more later in the semester.

- Large companies are using corporate labs less ("Out of the dusty labs": *Economist)*
    - With research done in labs, basic research was a luxury only large companies could afford
        - Basic research has a larger fixed cost
        - By internalizing the research, the firms prevents spillovers and internalizes the benefits.
    - What has changed?
        - Firms often acquire innovation via mergers/takeovers
        - There is less vertical integration than before
        - At the same time, the lines between basic/applied/development are becoming blurred
            - Big firms are doing more incremental research
            - Need to apply science to business
    - Why has this changed?
        - The article argues that getting basic research to product within firms was difficult.
        - Academics cannot do it on their own, as they have shorter time frames and are constantly searching for funding.
        - As innovations in software, rather than hardware, become more important, innovation becomes both cheaper and faster.
            - Thus, fixed costs are lower.
            - Bush's model assumes high fixed costs to basic research.
- R&D and firm size (we will discuss on Monday)
    - R&D and firms size is an example where distinguishing between levels of R&D and quality of R&D is important.
    - Most R&D is done by large firms
        - In US, over one-half by firms with over 10,000 employees
    - Small firms can be very innovative.
        - Often, they are innovative without doing their own R&D.
        - For example, rely on transfers from government labs or universities.
    - University spillovers are more important to small firms.
    - Small firms are more adept at absorbing external knowledge.
    - Compare to large firms
        - *The Economist's* "Big and clever" gives three reasons why large firms are again doing more R&D:
            - Growth clustered around ecosystems such as Apple's iPhone or Google's Android system
            - Globalization puts a premium on size to be able to compete
            - Many research challenges (e.g. health care, climate change) involve complex systems.
        - Advantages vary by industry.

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  - Consider the *Economist* articles. Existing firms focus on sustaining success.
    - Breakthrough innovations hard to come by.
    - As a result, many firms are cutting back on research laboratories.
  - Breakthrough innovations often come from smaller firms. Biotechnology is a good example.
    - Big firms “buy” research from startups.
  - Note here that there are many ways for firms to acquire new technology.
    - Create themselves
    - License from others
    - Purchase new capital with embodied technology
    - Acquire other firms
  - Over time, more focus has been on acquiring technology, rather than vertical integration in which basic and applied research are done in-house.
    - Firms with large research labs were usually monopolies (e.g. Bell Labs, IBM).
    - As these companies lost market power, basic research becomes less desirable.
      - Note that spillovers are an issue here. Basic research is more likely to have broad applications and leak out to competitors.