Lecture # 17 – Theories of Diffusion

I. S-Shaped Diffusion Curves

- Key questions:
  - What is the rate of adoption and innovation?
  - What variables affect this rate?
  - How does policy affect diffusion?
- Early studies of diffusion
  - Early studies of diffusion focused on agricultural technologies.
  - The first studies were done by anthropologists and sociologists, not economists.
  - The diffusion traditions of various disciplines began to merge in the 1960s.
  - Ryan-Gross study of hybrid corn.
    - This was a sociology study.
    - Hybrid corn, introduced by Iowa State in 1928, had yields 15-20% higher than open pollinated corn.
    - It had been adopted by most Iowa farmers by 1940.
    - Ryan and Gross studied what factors influenced its adoption.
      - They found that communication between previous and potential adopters was important.
    - They found an S-shaped rate of adoption.
      - This result is still typical today.
  - S-shaped adoption curves
    - The S-shaped adoption curve is derived from a symmetric bell-shaped curve that describes the distribution of adopters over time.
    - Even today, most diffusion studies find a similar pattern.
  - Sociologists focus on the following reasons to explain the S-shaped curves:
    1. What is the relative advantage of the innovation over the existing technology?
    2. Is the technology compatible with potential adopters current way of doing things, and with current social norms?
    3. How complex is the technology?
    4. Trialability -- can the technology be tested?
    5. Observability -- how easy is it to evaluate the innovation after it has been tried?
  - Five categories of adopters:
    0. Innovators
    1. Early adopters
    2. Early majority
    3. Late majority
    4. Laggards

II. Examples

- Economists have added to the diffusion literature by examining individual differences in diffusion.
- Griliches' (1957) hybrid corn study
  - Griliches looked at the diffusion of hybrid corn both within regions (as did Ryan/Gross) and across regions.
  - Goal: to explain why individual adoption decisions vary:
    - The "acceptance problem" – what explains variation in adoption rates within a region.
    - The "availability problem" – what explained the timing of the development of hybrid corn for specific areas.
      - Separate breeds of hybrid corn needed to be invented for different regions.
  - Griliches did this by fitting an S-shaped logistic trend diffusion curve to data on the percentage of corn area planted with hybrid seed.
    - Define P as the percentage planted with hybrid seed
    - $P = K/(1 + e-(a + b*t))$
      - K = the ceiling, or equilibrium value
      - b = the rate of growth coefficient
      - a = constant of integration (positions curve on the time scale)
  - Key features of the curve:
    - Origin: the starting point. Griliches defines as date at which 10% of a region's corn was hybrid.
      - This is meant to indicate commercial availability of hybrid corn.
      - Average lag between technical availability and commercial availability was 2 years.
      - Agricultural stations did more work on hybrid corn in regions where corn was important (e.g. Iowa, Wisconsin). The date of origin is earlier here.
    - Slope: indicates the rate of acceptance
    - Ceiling: measures the percentage of acceptance when usage stabilizes
      - Interpretation: differences in rate of acceptance (slope) and level of acceptance (ceiling) can be explained by differences in how profitable it is to shift to hybrid corn.
- Diffusion of industrial technology
  - The standard S-shaped diffusion curve has also been found in studies of industrial technology diffusion.
  - Mansfield (1968) looked at factors influencing interfirm and intrafirm diffusion.
    - Looked of diffusion of 12 different technologies in 4 different industries.
  - Like Griliches, he found that key variables were:
    - Profitability

        - The proportion of firms already using the technology
- Example: diffusion of diesel locomotives in the railroad industry.
    - The first diesel locomotive made in the US was built in 1924. This was 11 years after the diesel locomotive was introduced in Europe.
        - Early diesels were slow, heavy, and had little power.
        - They were primarily used where smoke or fire was a concern.
    - In 1933, General Motors introduced an improved diesel.
    - By 1935, 50% of major American railroads had begun to use diesel.
        - Innovators tended to be large rail lines. They did not haul much coal.
        - Lines that hauled coal were reluctant to switch.
            - Coal was cheap for them.
            - They also did not want to alienate their major customers.
    - By 1940, most diesel engines were used for switching purposes.
        - Material shortages during WWII delayed adoption.
        - By end of WWII, about 10% of total locomotive stock was diesel.
    - Around this time, advantages of diesel became clear:
        - Due to engineering refinements, price per horsepower fell relative to steam engines.
        - Large savings possible by eliminating the need to service and repair steam locomotives.
        - As usage spread, uncertainties about performance and maintenance fell.
    - The rate of replacement (the switch to diesel) varied by railroad.
            - The transition from 10% to 90% replacement of steam by diesel took, on average, 9 years.
            - 20% of firms did this in 3 to 4 years.
            - 10% of firms, however, needed more than 14 years.
    - Mansfield used regression techniques to explain differences. Significant variables included:
        - Profitability of investing in diesel locomotive
        - Interfirm differences in size and liquidity
        - Differences in the starting date
    - Note as well that adoption often involves large fixed costs
        - Thus, firms often adopt when making big changes in the firms

- Text messaging
    - Text messaging has been adopted more slowly in the United States than in Europe or Japan.
    - Why?
        - Availability of substitutes
            - Because they must compete with cheap landline calls, the costs of cell phone calls are cheaper in the United States.
            - Similarly, free local calls enables inexpensive Internet service, so that instant messaging developed as an alternative to text messaging.
            - Hall provides other examples where substitutes matter, such as automatic washing machines
        - Technology standards
            - Less regulation in the U.S. led to the development of competing, but incompatible, standards for text messaging.
    - Note the importance of network effects
        - The value of text messaging depends on the number of other users.
        - This is true for many IT technologies.
        - Developing standards leads to faster diffusion.
            - But, as we discussed in class, should standards be set by the government or by industry?
- Multivariate processes
    - The preceding examples have been binary – one technology replaces another.
    - Often, diffusion is a multivariate process – several different technologies compete for market share over a period of time.
    - The Basic Oxygen furnace in steel presents an example
        - Experiments to use oxygen in the steel production process began in the mid-19th century.
        - However, largely because low-cost oxygen was unavailable, the idea was not widely applied until after WWII.
        - The first successful process was developed by Linz-Donawitz, an Austrian firm, in 1952.
        - Typically, the basic oxygen furnace is cheaper than open-hearth or electric furnaces.
            - The capital cost of an oxygen converter is about 1/2 that of open hearth.
            - However, oxygen converters are only effective if a blast furnace is nearby, since the oxygen converter must be charged with hot metal.
            - Less scrap metal is needed to charge the oxygen converter than other furnaces.
                - Thus, oxygen converters were adopted more quickly where scrap metal prices were high.

        - Country differences in adoption
            - Adopted quickly in Austria, where it was invented.
            - Also adopted quickly in Japan and Netherlands.
                - Both countries had rapidly expanding steel industries. They could add capacity without waiting until existing equipment needed to be replaced.
            - Adopted more slowly in France, Italy, and UK. US was in the middle.

III. Models of Diffusion

- Recent work on diffusion has focused on trying to explain the prevalence of the S-shaped diffusion curve.
- The epidemic model
    - The epidemic model considers information to be the key to diffusion.
    - As more people adopt the technology, information of it spreads quickly, leading to a period of rapid adoption.
        - The epidemic model models technology as a "contagious disease."
        - Adoption occurs as potential adopters learn about the new technology.
            - Adoption is slow at first, as few people (or firms) know about the technology.
            - The more people "infected" (that is, those that have adopted), the more likely others will also be "infected."
                - Thus, as information spreads, a period of rapid adoption follows.
    - Shortcoming
        - This model assumes that, once potential adopters learn of a technology, they will use it.
        - This model assumes the quality of the technology is the same over time.
    - Implications
        - Adoption includes a positive externality. The decision to adopt makes it more likely that others will also learn about the innovation.
        - This suggests that gradual diffusion is the result of a market failure.
        - It also suggests that, until market saturation is reached, the economy is in disequilibrium.
- Recent modifications focus on equilibrium.
    - These models assume there is perfect information on the technology, so that the epidemic model is not relevant.
    - Rather, there are differences among users that explain gradual diffusion.
        - Firms must pay a cost, c_t, to adopt the technology at any time t.
            - This price changes over time.
        - Each firm weighs the benefits of adoption at time t against the cost of adoption at time t.

        - As the costs or benefits of adoption change, the number of adopters changes.
- Implication:
    - Gradual diffusion is rational. It is the result of profit-maximizing behavior, rather than a market failure.
    - The *Economist* article "Lock and Key" is an example.
        - It suggests that lock-in is not a market failure, as suggested by the path dependence theory.
        - Rather, it is a rational result, because the cost of switching technologies is too high to justify only small benefits.
    - Types of equilibrium models:

1. Rank (or probit) models
    - Potential users differ in some important characteristic.
    - Thus, some firms benefit from adoption more than others do.
        - The earlier example of diesel for railroads that did or did not ship coal would be an example.
    - The net benefits can be ranked across firms.
        - Those with the highest ranks go first.
    - Examples of rank effects found to be important:
        - Firm size (generally a positive effect)
        - R&D expenditure
        - Market share
        - Market structure (ambiguous effect)
        - Input prices
            - Rose/Joskow (1990): utilities adopt fuel-saving technologies more quickly when fuel prices are high.
        - Characteristics of the technology
        - Government regulations
            - Rose/Joskow (1990) find that government-owned utilities are slower to adopt new technologies than privately-owned ones.
            - Hannan and McDowell (1984) find that banking and branch restrictions increased profitability of ATM machines.
2. Stock models
    - As the number of users of the new technology increases, the gross benefits from adoption decline.
    - Can be due to the effect of technology adoption on prices or due to prices in factor markets (supply effects).
3. Order models
    - The firm's position in the adoption order determines its gross return from adoption.

            - Early adopters typically get a higher gross return.
                - This suggests the first-mover advantage dominates the advantage of waiting for better technologies.
            - However, costs are important to get net return from adoption.
            - Thus, there is a tradeoff between first mover advantage versus higher early costs
    - Recent work combines equilibrium and epidemic models. These models are hazard models.
        - Hazard models combine a baseline epidemic diffusion curve with firm-specific variables to capture the effects above.
        - Firms adopt when the NPV of adoption is:
            - Positive, so that adoption is profitable, and
            - Higher than it would be if the firm waited until a later date to adopt
                - Thus, unlike the other models, there may be a benefit to waiting.
        - Allows the researcher to capture the magnitude of each effect.
            - Recent results suggest the firm-specific effects are more important.

IV. Diffusion of Energy Efficient Technologies

- In many cases, policy does not play an important role in diffusion decisions, which are primarily market-driven
- Energy efficiency provides an example where government policy does play an important role
    - Many studies find that both consumers and firms underinvest in energy efficiency, even when NPV is positive
    - Energy efficiency is often seen as a low cost way of reducing CO_2 emissions
    - This literature also offers an opportunity to consider lessons from behavioral economics on diffusion
- Is the energy efficiency gap real?
    - While engineering studies suggest more energy efficiency is possible, might there be rational reasons for not adopting?
        - Hidden costs
            - Administrative costs or time costs of installation
            - Decreased quality (e.g. lower lighting quality)
        - Consumer heterogeneity
            - Different preferences
                - Purchase a lower-efficient appliance if won’t use it much

                - A recent study finds conservatives are less likely to use high-efficient light bulbs
        - Uncertainty
            - Will energy prices fall in the future?
        - Rebound effect
            - Engineering estimates may overestimate potential savings
                - Assume perfect installation and maintenance
                - May ignore potential behavioral changes if energy use becomes cheaper

- Market failures
    - Nonetheless, there are several market failures that will lead to suboptimal investment in energy efficiency
    - Note that each has different policy solutions, so understanding which market failures matter is important, and is a question of ongoing research
        - Externalities
            - Some of the benefits of improved energy efficiency (e.g. reduced pollution) are benefits to society as a whole, rather than the potential adopter (not in article)
        - Imperfect information
            - Buyers and sellers may have different information about potential savings
        - Principal-agent
            - The person installing the technology might not be rewarded for doing so (e.g. landlord/tenant relationship)
        - Credit constraints
            - Investments often have high up–front costs
            - Will need to finance initial investment to reap future savings
        - Learning by using
            - Early users provide positive externality of their experience to future users
        - Regulatory failures
            - Electricity market regulation often means electricity not priced at marginal cost
            - Gillingham and Palmer suggest this is less important, since prices are often above efficient levels
- Recent work in behavioral economics suggests behavioral anomalies may also play a role
    - Behavioral economics combines psychology and economics, and notes cases where observed behavior differs from what traditional economic models predict
    - Systematic biases create a difference between <u>decision utility</u> and <u>experienced utility</u>.
        - Decision utility is the utility consumers maximize at the time of choice
        - Experienced utility is the utility consumers later realize as a result of a prior decision

        - Behavioral anomalies that lead to a difference between decision utility and experienced utility are <u>behavioral failures</u>
    - Note that if preferences are not stable over time, using consumer decisions to infer utility will lead to incorrect estimates
    - Nonstandard preferences: Preferences that violate standard neoclassical assumptions
        - Self-control problems
            - A behavioral failure
            - Appears as time-inconsistent preferences
                - People often take long-term view for distant outcomes, but use higher discount rates for the near future
        - Reference-dependent preferences
            - Consumer's utility depends on a reference point
            - For example, consumers exhibit loss aversion
                - Decline in utility from a loss is much larger than gain in utility from gaining similar income
                - Will this be more concerned with potential bad outcomes (e.g. what if I invest in energy efficiency and fuel prices fall) than in potential savings
            - Not necessarily a behavioral failure (decision utility might not differ from experienced utility)
    - Nonstandard beliefs
        - Systematically incorrect beliefs about the future
        - While people's beliefs about future energy prices may be wrong, it is not clear that they are systematically wrong
    - Nonstandard decision making
        - Decision processes that do not follow neoclassical assumptions
        - All could be behavioral failures
            - Limited attention
                - Follows from bounded rationality (Simon, 1955)
                    - Consumers simplify complex decisions by focusing on only a subset of available information
                - Salience matters here
                    - E.g. sales taxes added at register less salient than taxes added to list price
                    - Paying tolls vs. EZPass
                - Regarding energy efficiency, limited attention may be a reason consumers don't think much about fuel efficiency when buying a car
            - Framing of choices
                - Presentation of information affects choices
                - Important for properly designing energy efficiency labels

        - Suboptimal decision heuristics
            - Use of rules of thumb for decision making
                - E.g. favoring first name on ballot
            - Again, not directly studied in energy efficiency decisions

- Policies to promote energy efficiency
    - Understanding what failures need to be addressed (e.g. market failures, behavioral failures) is important
    - Market failures
        - Pigouvian tax
            - Addresses environmental externalities from energy usage
        - Subsidies are an alternative
            - However, by lowering costs, may have rebound effect
            - Also must consider costs of raising funds
        - Providing information
            - Product labeling is an example
        - Financing programs
            - Some communities fund energy efficient investments and let consumers pay it back through utility bills (e.g. from resulting savings)
    - Behavioral failures
        - Will information alone be enough?
            - Several studies find that providing information alone does not have a large impact
            - Houde (2013) finds that Energy Star labeling has positive net benefits, but also crowds out other energy-saving activity
        - Social norms
            - Information can also be used to change preferences
                - For example, providing information on the energy consumption of neighbors
                - Has been found to reduce energy consumption
                    - One study found the savings similar to what would happen if prices rose 11-20%
        - Energy efficiency standards may also be an option
            - Imposes the “correct” choice on a consumer
            - May be inappropriate for some in the case of heterogeneous preferences
    - Liberal paternalism (e.g. “Nudges”)
        - Give people freedom to make choices, but frame choices in ways to lead to good decisions)
            - For example, make energy efficiency a default option