Lecture 7
Diffusion

E5104 – Economics of Innovation

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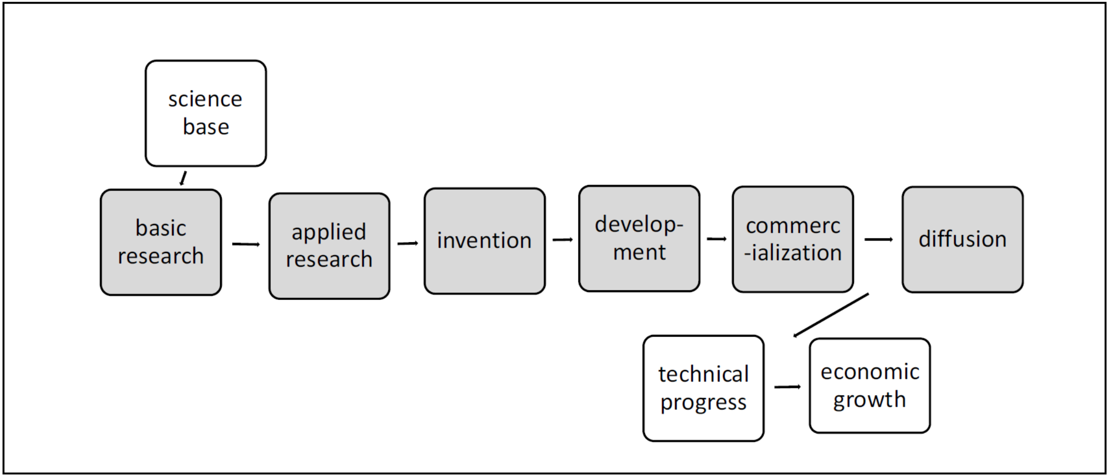
“in the history of diffusion of many innovations, one cannot help being struck by two characteristics of the diffusion process: its apparent overall slowness on the one hand, and the wide variations in the rates of acceptance of different inventions, on the other.” (Rosenberg, 1976, p. 191).

Linear Model of the Innovative Process

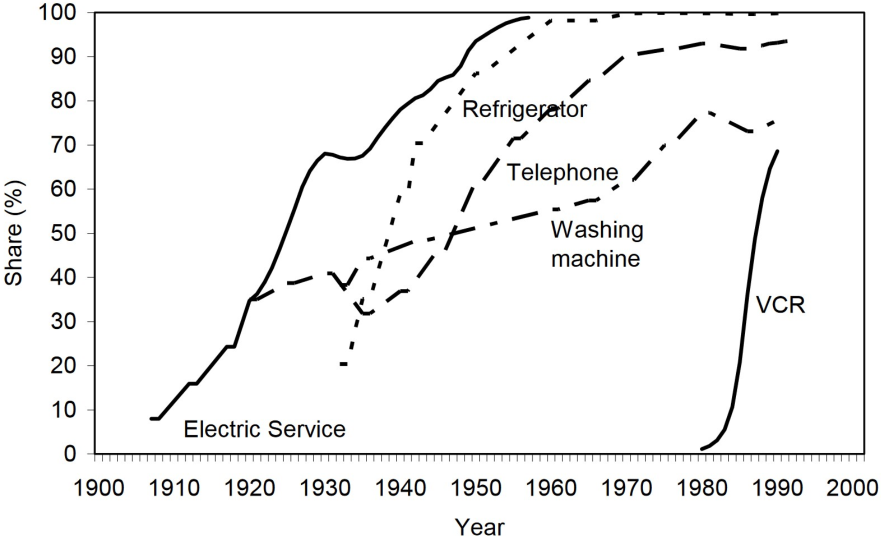


Source: Hall & Helmers (2022)

- **Diffusion**:
  - the process of spreading an innovation throughout the economy or the relevant set of potential users

- **(Technology) adoption**:
  - individual choice by economic agents to use a new innovation or technology

The S-Curve for Diffusion



Source: Hall & Helmers (2022); Federal Reserve Bank of Dallas

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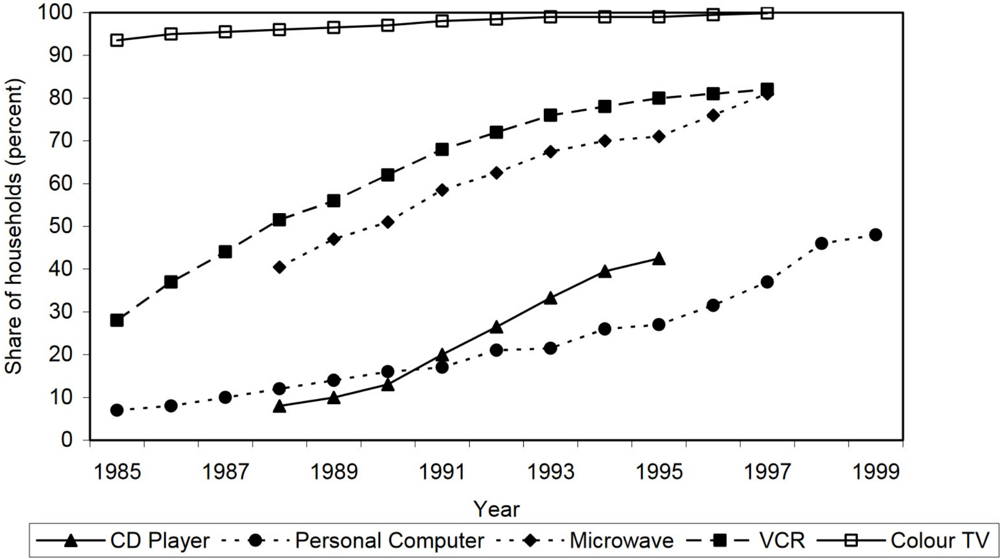
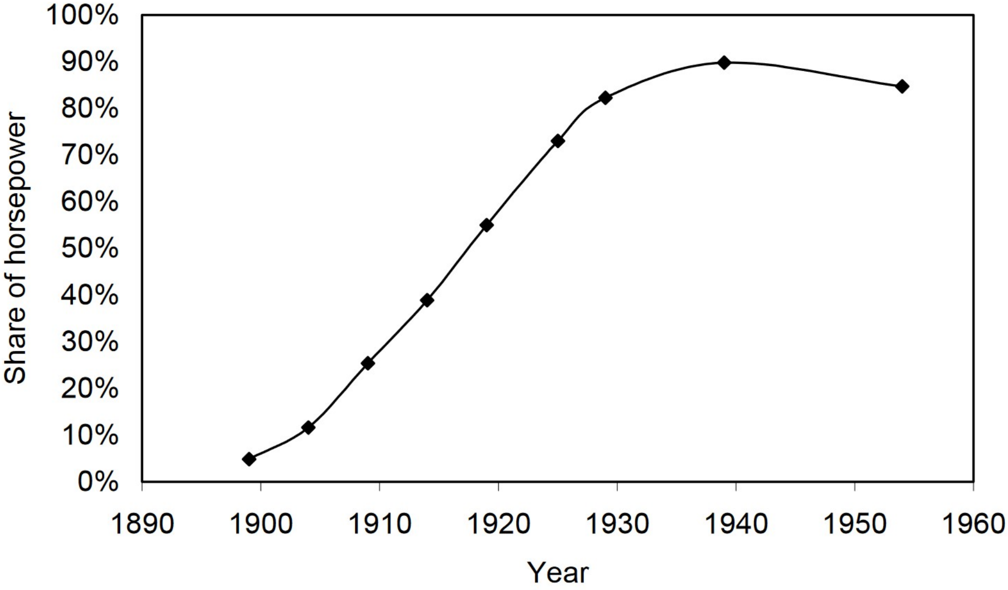


Source: Hall (2003)

The S-Curve for Diffusion



Source: Hall (2003)

The S-Curve for Diffusion

- Displaying the speed of diffusion of a particular technology in a population of potential adopters is often via an S-curve
- Curve shows the share of population of potential adopters that have adopted the new technology versus the time of introduction
- Two different types of models:
  1. benefits of the new technology vary across adopters
  2. an epidemic model of information spread among potential adopters

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Heterogeneous Adopters

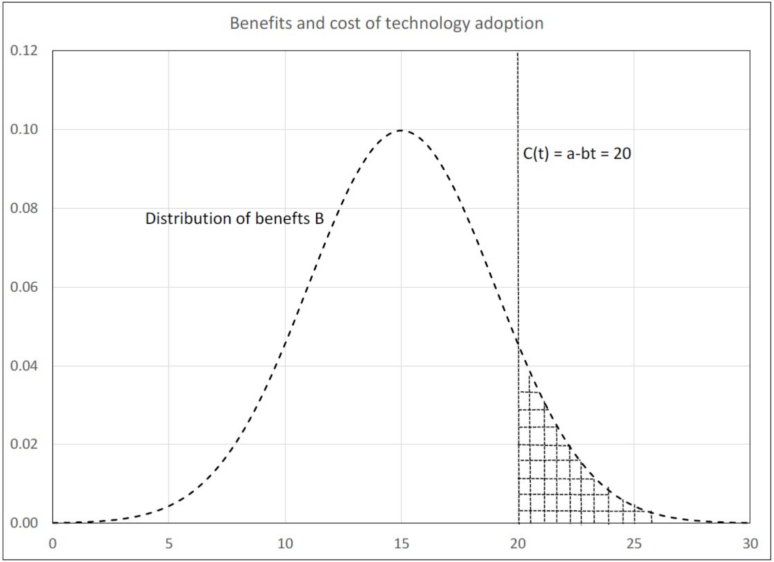
- Potential adopters receive benefits from adoption that vary (with unimodal distribution; e.g., bell curve)
- Costs of adoption decline monotonically over time and are the same for all potention adopters
- Individuals adopt when benefits are greater than the cost of adoption.
- This yields a curve where share of adopters is low at first (in the high-benefit tail), accelerates as center of distribution adopts and then slows down again (in the low-benefit tail)

Heterogeneous Adopters

- Suppose benefits B are normally distributed
- Costs decline at rate b: $C(t) = a - bt$
- At any time t: those who have adopted have been $B \geq a - bt$
- B is a random variable; share of those adopted is 1 minus the cumulative normal distribution evaluted at $B^* = a - bt$:

$$1 - \Phi(a - bt)$$

- $a - bt$ is monotonically decreasing in t, write share of adopters at any time t^* as $\Phi(t^*)$
- Implies an S-curve with shape of hte cumulative normal distribution
  - Works for unimodal distributions ($\rightarrow$ cumulative distribution)
  - Works with costs decreasing monotonically (not necessarily linear)



Source: Hall and Helmers (2022)

Epidemic Diffusion

- Epidemic model does not rely on heterogeneous adopter tastes (B)
- Adoption spreads throughout the population as potential adopters encounter past adopters
- Initiated by a small number of consumers who adopt early
- Assume N potential adopters; at any t, n_t have already adopted
- Those not adopted, $N - n_t$, encounters users and adopt with probability β times share of adopters.

Epidemic Diffusion

- Rate of change of adoption is

$$dn_t = \beta \left(\frac{n_t}{N} \right) (N - n_t)\, dt$$

or

$$\frac{dn_t}{N} = \beta \left(\frac{n_t}{N} \right) \left(\frac{N - n_t}{N} \right) dt$$

- Differential equation with solution

$$\frac{n_t}{N} = \frac{1}{1 + \exp(-(\alpha + \beta t))}$$

- RHS is version of a cumulative logistic function with

$$\alpha = \log \left(\frac{n_0}{N - n_0} \right)$$

and β describes dispersion of time of adoption (lower β, higher higher variance in time).

Factors Affecting Diffusion

Factors Affecting Diffusion

- Benefits
  - improvements over and closeness to potential substitute technologies
- Costs
  - price, costs of financing
  - costs of complements (e.g., electric cars need charging stations); larger firms might find it easier
- Need for complementarity technologies; lack will slow down diffusion
- Need for complementarity assets (can slow down diffusion)
  - e.g., reorganization of production (examples: computers/internet, electric motors in factories)
- Uncertainty
  - about the benefits and success of the new technology
  - about the uses to which the technology can be put (e.g., radio, laser)
- Market structure
  - related to effects of market structure on innovation

Factors: Regulatory and Institutional Environment

- Diffusion of LED bulbs encouraged by regulation restricting use of the incandescent light bulbs.
- Electric car diffusion encouraged by subsidies and fleet gas efficiency requirements
- Pollution or safety requirements an encourage new technologies
- But: safety regulation can slow down diffusion of new technologies (example, Dutch flute that was not warship-able)

Network Goods and Standards

Network Goods

- Technology whose value to one user depends on use by others
- They often require standards and coordination for the adoption to make them useful
- Two general classes
  - Direct networks:
    - Communication networks (telephone, fax, email, ...)
    - Value to a user depends on with whom they can communicate
  - Indirect networks:
    - Virtual networks created by “hardware/software” systems
    - Value depends on the number of other users because the existence of more users means more software available
- In the case of direct networks, the network externality is immediate and obvious

Examples for Indirect Networks (Hardware/Software)

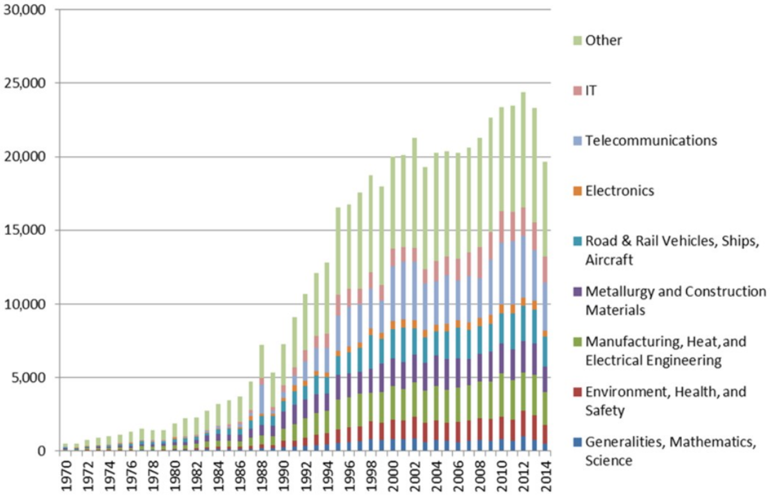
Hardware	Software (or "wetware")
Video/audio player	Video or audio tape, CD, DVD format
Voice activated home controller	Heating, locks, windows controlled
Computer	Operating system, applications software
Durable equipment including autos	Repairs and parts
Mobile telephone	3G, 5G, LTE, etc. standards
Language	Ability to speak it
Typewriter	Experience on the keyboard layout
ATM network	ATM card and bank account
POS terminal/merchant acceptance	Credit or debit cards accepted; method
Money (e.g., dollar, bitcoin, euro, etc.)	Places accepting this form of payment

Source: Hall and Helmers (2022)

Technological Standards

- Essential when different parts of a system must work together to produce useful output
- especially when there are many producers of elements of the system
- They have become increasingly important
  - 19th/20the century because of mass production
  - 20th/21st century because of internet and digital technologies
- Standards matter for diffusion
  - slow diffusion of electricity andnetworked computing
  - compatibility standards are required

Number of Standards Issued by Technology Field



Source: Baron and Spulber (2018)

Types of Standards (Specifications)

- a system of measurement (e.g., the metric system)
- particular measure (e.g., the gauge of a railway track, the size of a hose/faucet)
- functions that a particular item must perform (e.g., the features of a telephone)
- the way in which it must perform them (e.g. the layout of the computer keyboard as a way to communicate characters, the 5G standard for mobile telephones)
- input/output parameters (e.g., 110 volts versus 220 volts at the wall socket; the exact format of the digits your computer sends to a printer)

Types of Standards (Process)

- *de facto* (determined by the market):
  - **sponsored** – proprietary standards introduced by a single firm or by a joint venture between firms - examples: VHS or Betamax; Microsoft Windows.
  - **unsponsored** – those which arise naturally because of bandwagon effects - examples: driving on the right hand side of the road (from *de facto* to *de jure*)
- *de jure* (determined by government or committee):
  - **mandated** by government agencies for public goods reasons – examples: measurements from the DIN, National Bureau of Standards (U.S.)
  - due to **voluntary agreement** by a standards-setting organization – examples: ANSI (programming languages); ETSI (international telecommunications); IETF (internet architecture)

Network Externalities and Diffusion

- Networks, network platforms, and network standards have become very important to our understanding the diffusion of new technologies
- The choice to adopt a new network technology depends on the potential adopter's view of the likelihood of its success
  - preference for a particular network depends on the presence and identities of the other users
  - this creates network externalities
  - leads to increasing returns for the adopters of a network
- This feeds back to strategic behavior of firms (strong incentives to price low initially in order to build their market share)

Welfare and Network Competition

- Adoption rates for standards (technologies) can be too slow (excess inertia):
  - old technology has a large installed base and early adopters of the other bear too large a share of the switching costs.
  - new technology is unattractive with few users.
  - new technology's advantage is positive, but relatively small.
- Adoption rates might be too fast (excess momentum):
  - If users are heterogeneous, the first adopters are those who like the new technology and ignore their negative effects on the users of the old technology.
  - The network advantage is not that large so both technologies survive.s
  - The older technology has a small installed base, so switching costs are low.

Does the Better Tech Win? Standard Wars

- QWERTY/QWERTZ keyboard design (probably suboptimal layout)
- VHS vs. Betamax
- DVD vs. Blu-ray
- Historic: Thomas Edison’s favored direct current (DC) vs. George Westinghouse and Nikola Tesla’s alternating current (AC)

Modeling Competititing Networks/Standards

- Assume two technologies, *A* and *B*; two potential adopters *R* and *S*
- *R* prefer *A* and *S* prefer *B*
- Agents care about number of adopters
- Choices are made in sequence, one at a time

	Technology A	Technology B
R-agent	$a_R + rn_A$	$b_R + rn_B$
S-agent	$a_S + sn_A$	$b_S + sn_B$

- $a_R > b_R$ and $a_S < b_S$

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- $a_R > b_R$ and $a_S < b_S$

- R and S agents arrive in random sequence, say with 50% probability in each t
- Say, R agent is next to choose. Choose A if

$$a_R - b_R + r\left(n_A - n_B\right) \geq 0$$

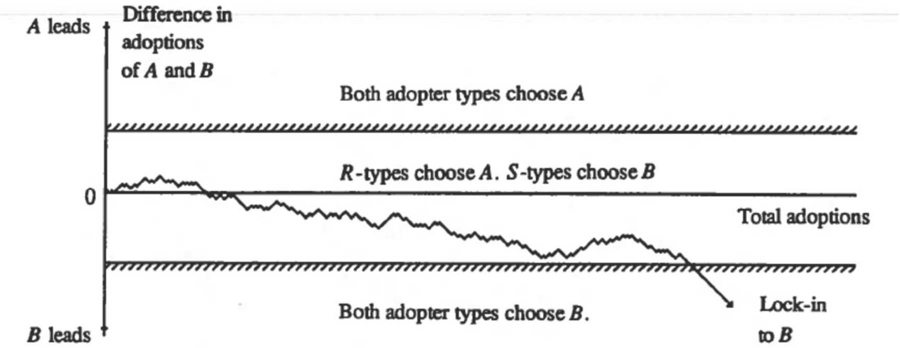
- Decision depends on relative number of A adopters (are there enough?)
- Note, if $r = s = 0$, then number of existing adopters does not matter, and in the long-run both technologies survive with 50% market share each
- Interesting case: increasing returns with $r > 0$ and $s > 0$.

- Define $n = n_A + n_B$ and $d_n = n_A - n_B$
- R chooses B (her second choice) if

$$d_n < \frac{b_R - a_R}{r} < 0$$

- Analogous expression for S
- Eventually a tipping point will be reached after which everyone will choose one of the two technology alternatives.
- Lock-in then happens because the advantage of the preferred technology is not enough to overcome the advantage of the large installed base
- Final outcome will depend on the arrival rates of agents with different preferences

Adoption/Lock-In With Increasing Returns



Source: Arthur (1989)

- More realism:
  - giving one technology a greater advantage than the other
  - add behavior of firms (pricing)
  - more-rational agents