Economics 124/PP 190-5/290-5
Innovation and Technical Change

Diffusion of innovations (2)
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Outline

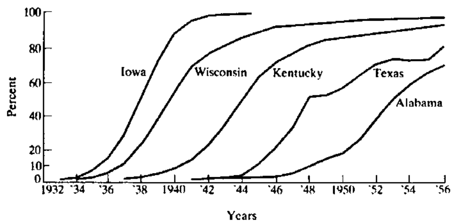
- Introduction – the s-curve
- Models
- Economic determinants of diffusion
- Factors affecting pace of diffusion
- Example: the dynamo and the computer

Next time: networks and standards

Factors affecting diffusion (1)

- Technology continually improving, so users wait for improved versions
  - Palm pilots; cell phones
  - Software and early adoption
- Technology has to be adapted to local conditions
  - Hybrid corn - geographic specialization

Percentage of total corn acreage planted with hybrid seed



Source: USDA, Agricultural Statistics, various years. Reprinted from Griliches, *Econometrica* (1957)

Factors affecting diffusion (2)

- users need to develop technical skills, which increases the costs of adoption, and may induce localization effects (learning curves)
  - E.g., learning to use a new computer or software
- development of skills in manufacturing the innovation and associated capital goods innovation takes time
  - Machine tools for manufacture of bicycles; sewing machines

Factors affecting diffusion (3)

- complementarities between new technology and other inputs, requiring joint adoption or reorganization
  - Railroads needed telegraph/block signaling/air brakes, etc.
  - New IT in U.S. firms required re-organization of the workplace; flattened management structure (Brynjolfsson)

Factors affecting diffusion (4)

- competition from old technologies, which are improving at the same time
  - E.g., wooden sailing ships in 1850-90; gas lamps in late 19th Century
- uncertainty/inability to anticipate the uses to which a new technology can be put
  - Recall examples from invention (laser, radio)
- institutional environment
  - e.g., slow diffusion of Dutch flute, speedy vessel invented in 1600s, due to piracy

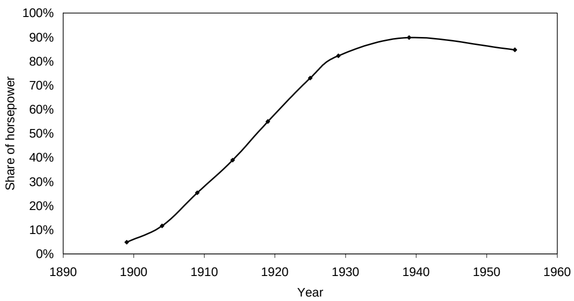
P. A. David on the dynamo

- Historical case of the electric dynamo as component of a general purpose technology – compared to present day computer diffusion
- Idea - need investment in complementary assets, such as the entire network, layout of factory, skills of workers, to take full advantage of the innovation

What is an electric dynamo?

- Now called an electric generator; converts mechanical energy to electrical using magnetism
  - 1832 - invented by Michael Faraday (UK) and Joseph Henry (US) independently
  - 1879 - Edison and Swann invent electric lamp
  - 1892 - first AC generator (US)
  - 1899 - electric light in 3% of US homes; 5% of factories
  - 1902 - five-megawatt turbine for Fisk St. Station, Chicago
  - 1920 - diffused only to 50% level in over twenty years
  - 1922 - Connecticut Valley Power Exchange (CONVEX) starts, pioneering interconnection between utilities

Diffusion of electric motors in the United States



The dynamo and the computer

- Nodal elements of a distribution/transmission network
- Compatibility standards required - a web of complementary technical relationships
- Extended trajectory of improvements to the technology during diffusion
- Diffusion slowed by lack of skills and by difficulty of appropriating returns to investments in improvements of the necessary capital goods (less true for computers)
- Slow diffusion and productivity slowdown
  - in US/UK during 1890-1913 (dynamo diffusion)
  - in US during 1970-1995 (computer diffusion)

The dynamo and the computer

- Both usher in a new techno-economic paradigm and therefore lead to productivity improvements only slowly as networks are built and factories are restructured to take advantage of the new technology
- Work by Brynjolfsson and others suggests that in the case of computer technology, a new organizational structure within the firm was also necessary to achieve the productivity benefits

Productivity measurement

Aggregate production function with technical progress *A(t)* and two inputs, capital *K(t)* and labor *L(t)*:

$$Q(t) = A(t)\, F[K(t),L(t)]$$

Q(t) is aggregate output (GDP) in year t

K(t) is a capital aggregate

L(t) is measured in person-hours or number of workers.

A(t) is the productivity level

- usually grows over time - more output for a given level of capital and labor

Productivity measurement

What is the growth of output as a function of the growth of labor and capital?

Differentiate output *Q(t)* with respect to time t. Use the chain rule.

$$\frac{dQ}{dt} = \frac{dA}{dt} F[K(t),L(t)] + A(t)\frac{dF[K(t),L(t)]}{dt}$$

$$\frac{dQ}{dt} = \frac{dA}{dt}\frac{Q(t)}{A(t)} + \frac{Q(t)}{F[K,L]}\left(\frac{dF(K,L)}{dK}\frac{dK}{dt} + \frac{dF[K,L]}{dL}\frac{dL}{dt}\right)$$

Productivity measurement

Express this in terms of growth rates: Divide by *Q(t)*. Multiply the second term by *K/K=1* and the third term by *L/L=1*.

$$\frac{1}{Q}\frac{dQ}{dt} = \frac{dA}{dt}\frac{1}{A(t)} + \frac{K(t)}{F[K,L]}\frac{dF(K,L)}{dK}\frac{1}{K(t)}\frac{dK}{dt} + \frac{L(t)}{F[K,L]}\frac{dF[K,L]}{dL}\frac{1}{L(t)}\frac{dL}{dt}$$

Digression: Logs and Growth Rates

The growth of X over a discrete interval of time (from 0 to 1) is equal to

$$\frac{X(1)-X(0)}{X(0)} = \frac{1}{X(0)}\frac{X(1)-X(0)}{(1-0)} = \frac{1}{X}\frac{\Delta X}{\Delta t}$$

As the interval of time becomes smaller and smaller, we can write this as a growth rate:

$$\frac{1}{X}\frac{\Delta X}{\Delta t} \rightarrow \frac{1}{X}\frac{dX}{dt} = \frac{d\log X}{dt}$$

Conclusion: the growth rate of a variable is approximately equal to its logarithmic derivative.

$$g_X = \frac{d\log X}{dt} = \frac{dX/dt}{X} = \frac{\dot{X}}{X}$$

Productivity measurement

Substituting growth rates G for the logarithmic derivatives:

$$G_Q = G_A + \frac{K(t)}{F[K,L]}\frac{dF(K,L)}{dK}G_K + \frac{L(t)}{F[K,L]}\frac{dF[K,L]}{dL}G_L$$

The quantities multiplying G_K and G_L are elasticities of output with respect to the two inputs, denoted by ε:

$$G_Q = G_A + \varepsilon_K G_K + \varepsilon_L G_L$$

Therefore output growth can be expressed as the sum of productivity growth (technical change) and the growth of inputs, weighted by their elasticities in the production function.

Digression: elasticities

The elasticity ε of Y with respect to X is defined by

$$\varepsilon_X = \frac{d\log Y}{d\log X} = \frac{X}{Y}\frac{dY}{dX} = \frac{dY/Y}{dX/X}$$

It is equal to the percent increase in Y associated with a percent increase in X, holding all other variables constant.

For example, ε_K describes how output increases when capital increases, holding labor input and technical change constant.

Growth accounting example

Aggregate US Data 1900-1949 (Solow, using CRS assumption to identify elasticities with shares):

$$G_A = G_Q - \varepsilon_K G_K - \varepsilon_L G_L$$

= 2.75% - (.35) 1.75% - (.65) 1.00%
= 2.75% - 0.61% - 0.65%
= 1.49%

Implication: slightly more than half of output growth is not explained by growth in capital and labor inputs. This quantity (G_A) is often called the "residual" or "total factor productivity growth."

Growth Accounting 1960-2001

	Growth rate	Growth due to			Growth rate
Period	of GDP	Capital	Labor	TFP (A)	of GDP/worker
1960-1970	4.0	0.8	1.2	1.9	2.2
1970-1980	2.7	0.9	1.5	0.2	0.4
1980-1990	3.5	1.5	1.3	0.6	1.7
1989-1995	2.5	1.2	1.0	0.3	1.5
1995-2001	4.2	2.1	1.1	1.0	2.7
Source: Jorgenson (2004)					

1980-2001: Capital contribution split between IT and non-IT:

- 0.5 to 1.0 from IT capital
- 1.1 from non-IT capital

Productivity measurement

Diffusion of major new systems associated with

- Unmeasured quality improvement from new commodities
- Bias toward expanding goods and services not well captured by national income accounts (e.g. lighting; transportation; faster service)
- Disembodied changes in the organization of production (e.g., continuous shift work; reduced middle management)

☐ Some *but not all* of this ends up in TFP