Department of Mathematics Public Lecture

Department of Mathematics

The Diffusion of Social and Technological Innovations

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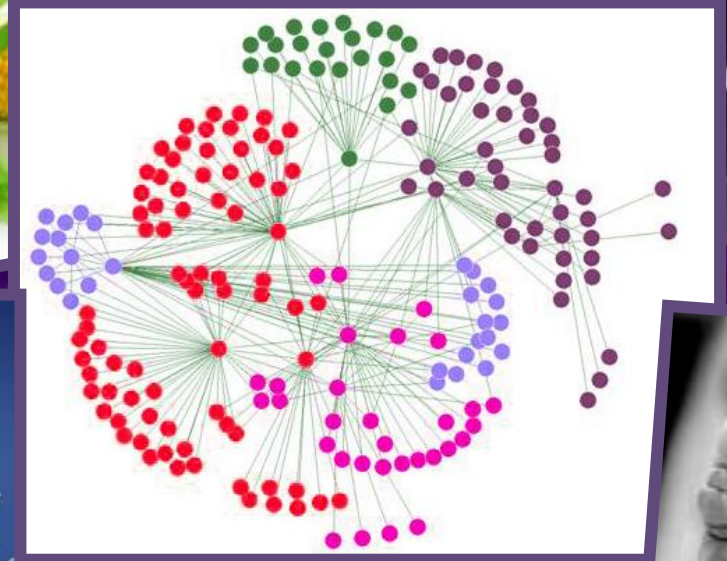


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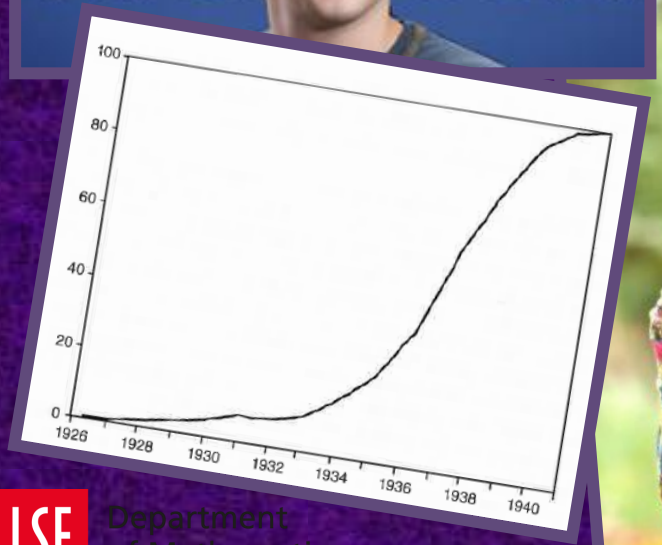

100
80
60
40
20
0
1926
1928
1930
1932
1934
1936
1938
1940

New technologies and improved ways of doing things are the key to economic development

- New crops & agricultural methods: tractors, hybrid corn
- New forms of medical treatment: antibiotics, stents
- New communication technologies: cellphones, social media
- Improvements in public health: boiling the drinking water, installing latrines, washing hands with antiseptic in hospitals.

Social innovations

- Forms of organization: limited liability company
- Financial contracts: insurance, forms of compensation
- Methods of accounting
- Microfinance
  - *Reversing dysfunctional social norms*
- Foot binding
- Duelling

- It is not enough to **discover** new and better ways of doing things: the discovery must gain acceptance by the population at large.
- Empirical work shows that this diffusion process is complex and can take a surprisingly long time.
- Sociologists and development economists have been at the forefront of this subject.

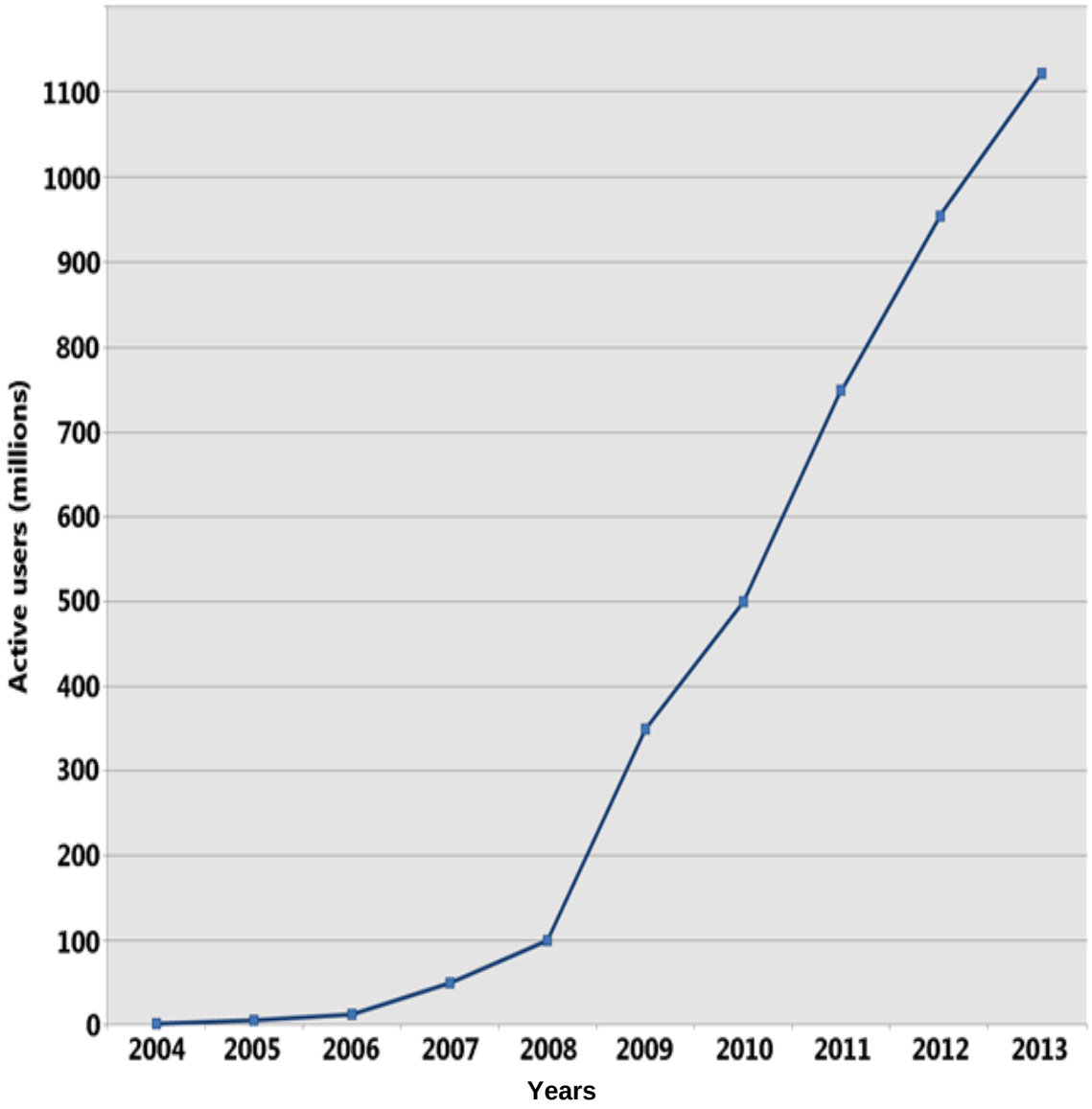
In this lecture I shall show how sociological and economic aspects of diffusion can be modelled using stochastic dynamical systems theory.

Factors inhibiting diffusion

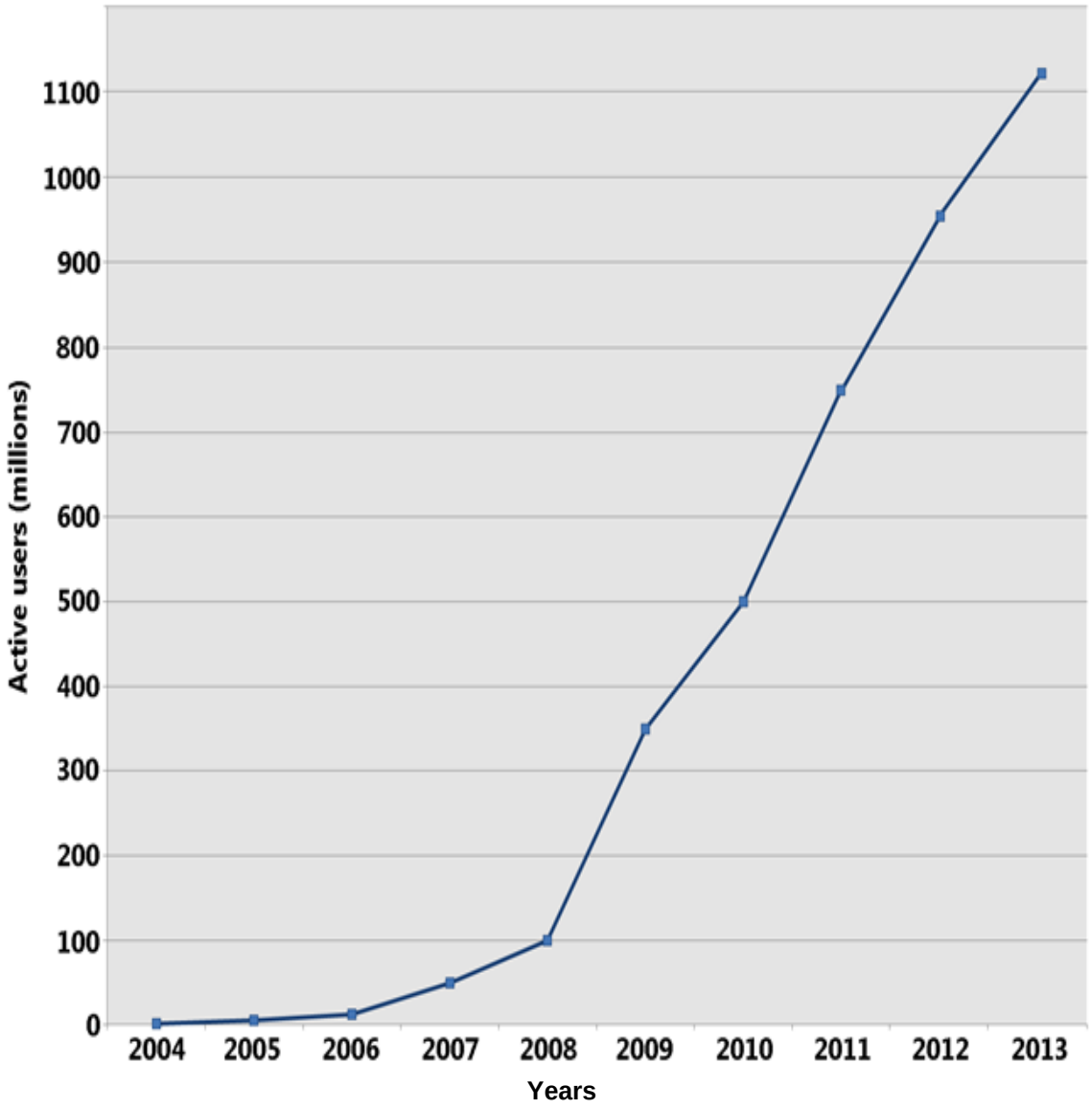
- **Inertia**: people are slow to act on new information.
- **Conservatism**: people are predisposed to be skeptical about the benefits of new ideas.
- **Uncertain benefits**: the link between the innovation and better outcomes is difficult to verify.
- **Norm violation**: new ideas may pose a threat to established beliefs and norms of behavior, and may be actively discouraged by non-adopters.

Factors propelling diffusion

Increasing returns. **The more people who adopt, the more valuable the innovation becomes for everyone**.


Active users (millions)
1100
1000
900
800
700
600
500
400
300
200
100
0
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Years

Millions of active Facebook users

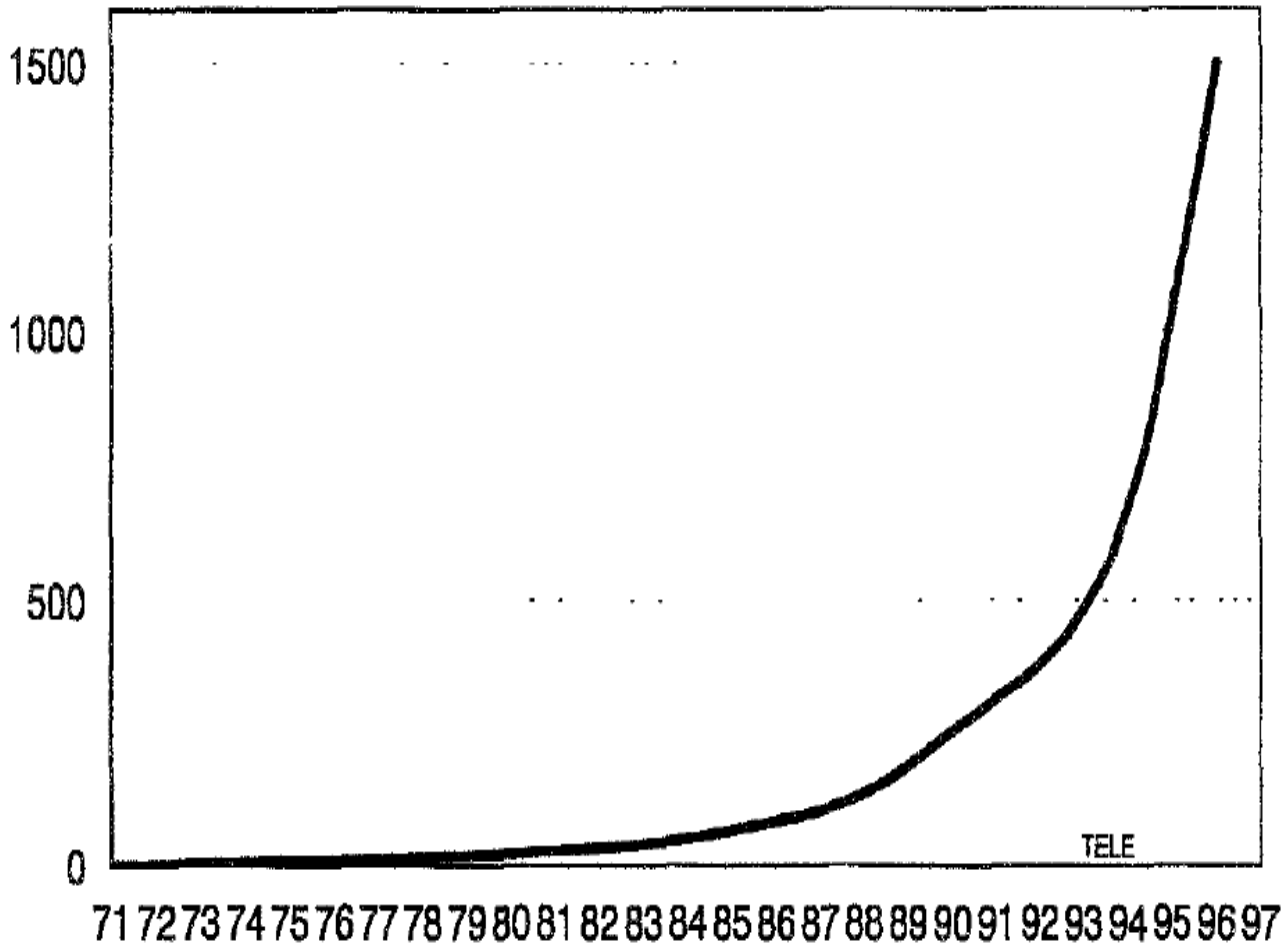


Factors propelling diffusion

Increasing returns. The more people who adopt, the more valuable the innovation becomes for everyone.

Improvement. **As an innovation is refined and improved over time, and production costs fall, more and more people find it worthwhile to adopt.**

Mobile phone users in Finland (thousands)



Source: Jaakkola et al. *Circuit Systems Signal Processing* 1998

Factors propelling diffusion

Increasing returns. The more people who adopt, the more valuable the innovation becomes for everyone.

Improvement. As an innovation is refined and improved over time, and production costs fall, more and more people find it worthwhile to adopt.

Learning. **As more people adopt, information accumulates that the innovation really is beneficial, leading still more people to adopt**.

Learning is especially important when benefits are uncertain

- Does boiled drinking water reduce the risk of disease?
- Does hybrid corn produce higher yields?
- Does paying an executive in stock options enhance corporate value?

Three case studies

I. The diffusion of hybrid corn among US farmers.

II. The diffusion of stock options as a form of executive compensation by US corporations.

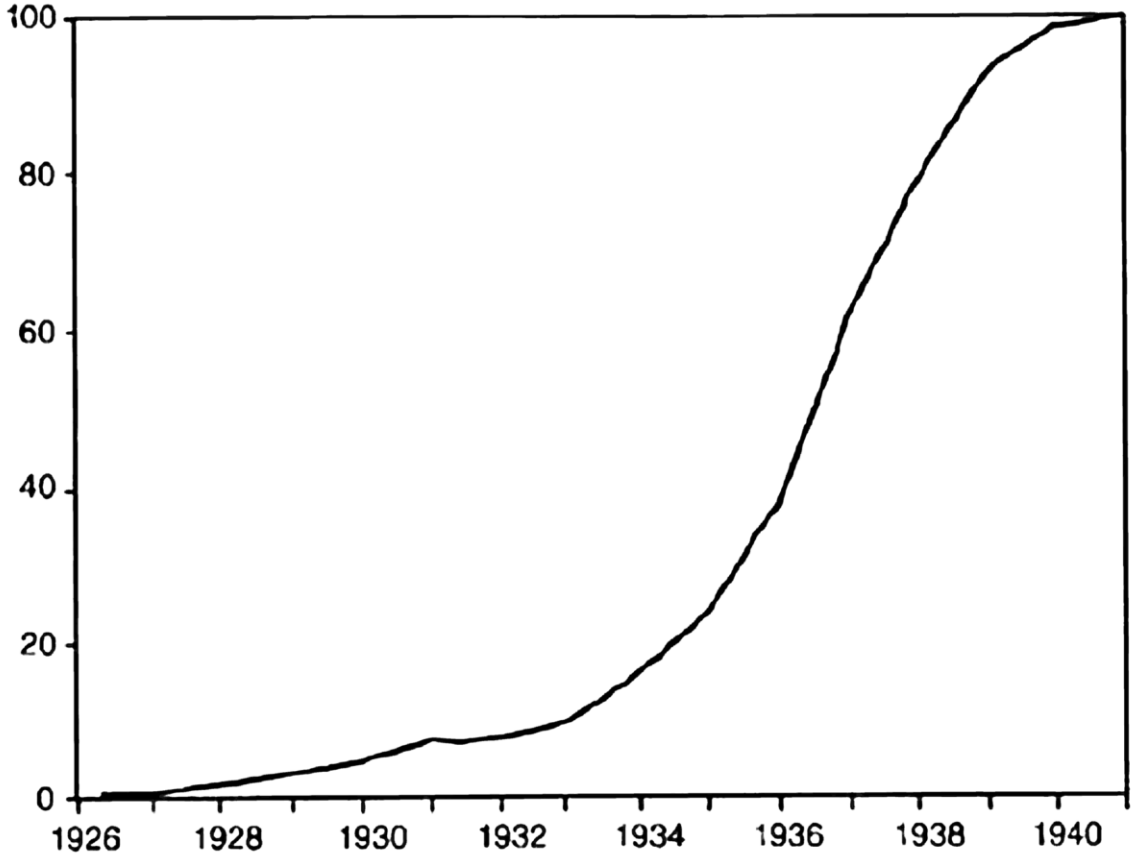
III. The diffusion of contraceptive practices in Kenya.

Case I. Hybrid corn in Midwestern US first introduced in the 1920s.

Adoption curve for hybrid corn: Iowa 1926-45

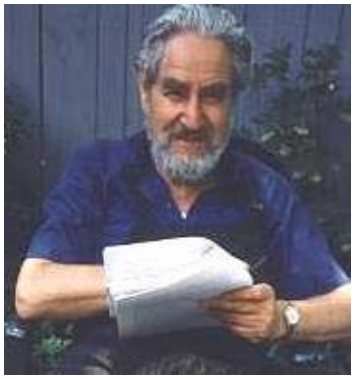
(Ryan and Gross, *Journal of Rural Sociology,* 1943)

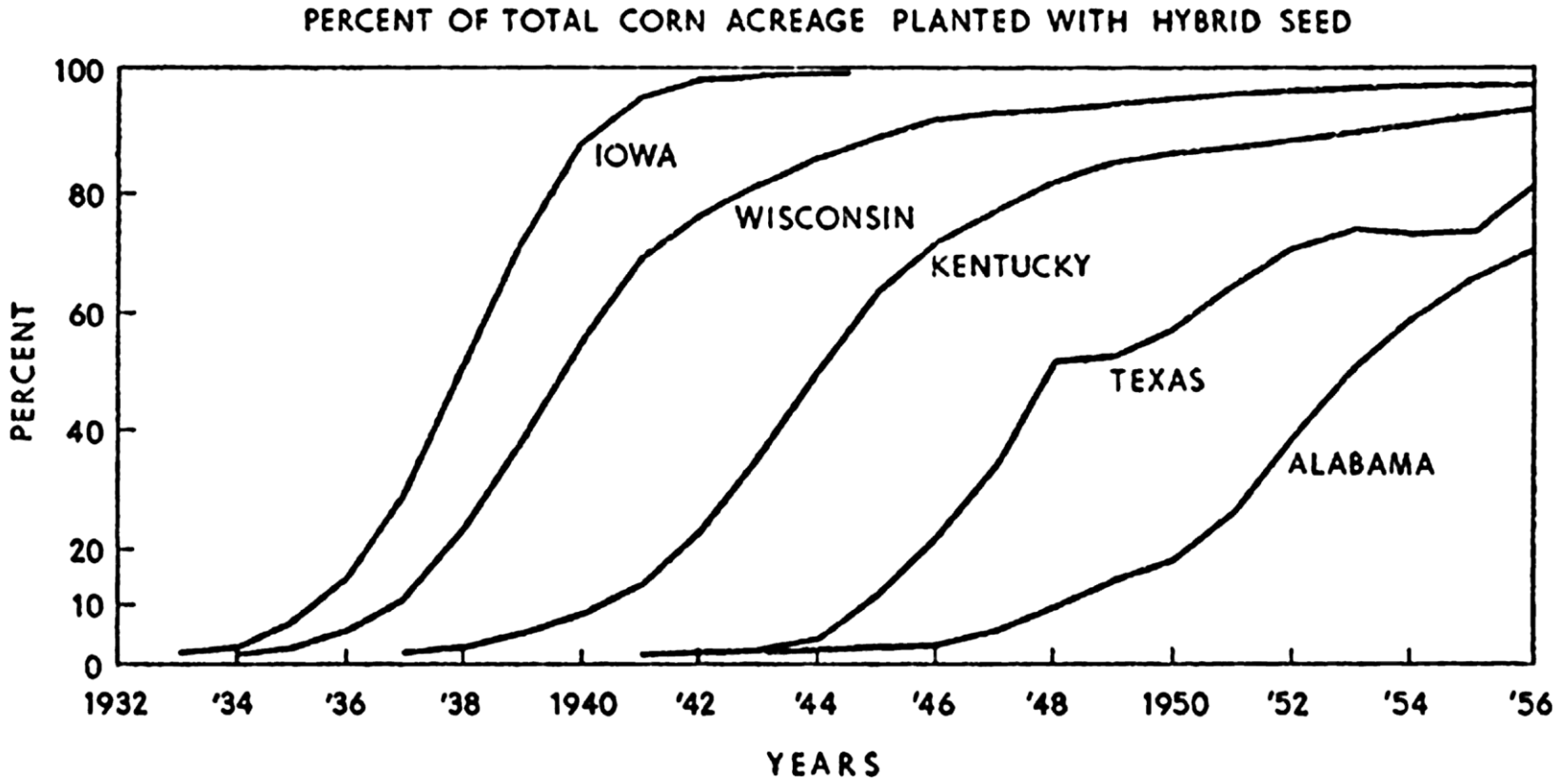
Adoption percentage



Years

Zvi Griliches (*Econometrica* 1957)





Contagion/bandwagon model

Let $p(t)$ = proportion of adopters at time t.

Rate of change

$$\dot{p}(t) = \lambda\, p(t)(1 - p(t)), \quad \lambda > 0$$

Solution is a logistic curve

$$p(t) = 1/(1 + \beta\lambda e^{-\lambda t}), \quad \beta > 0$$

- Griliches showed that in regions with better soils and higher productivity, farmers adopted at an earlier date and the rate of diffusion was faster.

- His thesis: *the rate of adoption was motivated by potential gains in profitability*.

Although profitability is important, many other factors also influence the rate of diffusion

- existing norms and customs
- receptivity to new ideas
- information campaigns
- learning from the experience of others

Learning from others

- In their 1943 study of rural communities, Ryan and Gross collected detailed survey about the timing and source of information about hybrid corn.
- They found that farmers attached more importance to experiences of others in their community than to claims by seed companies or agricultural extension agents.
- In other words they learned by observing outcomes from prior adopters.

The learning model

- Each agent has a **prior belief** about the expected benefits of the innovation compared to the status quo.
- Agents **observe outcomes** among prior adopters and update their prior beliefs accordingly.
- They adopt when the expected payoff gain from adoption exceeds the cost.

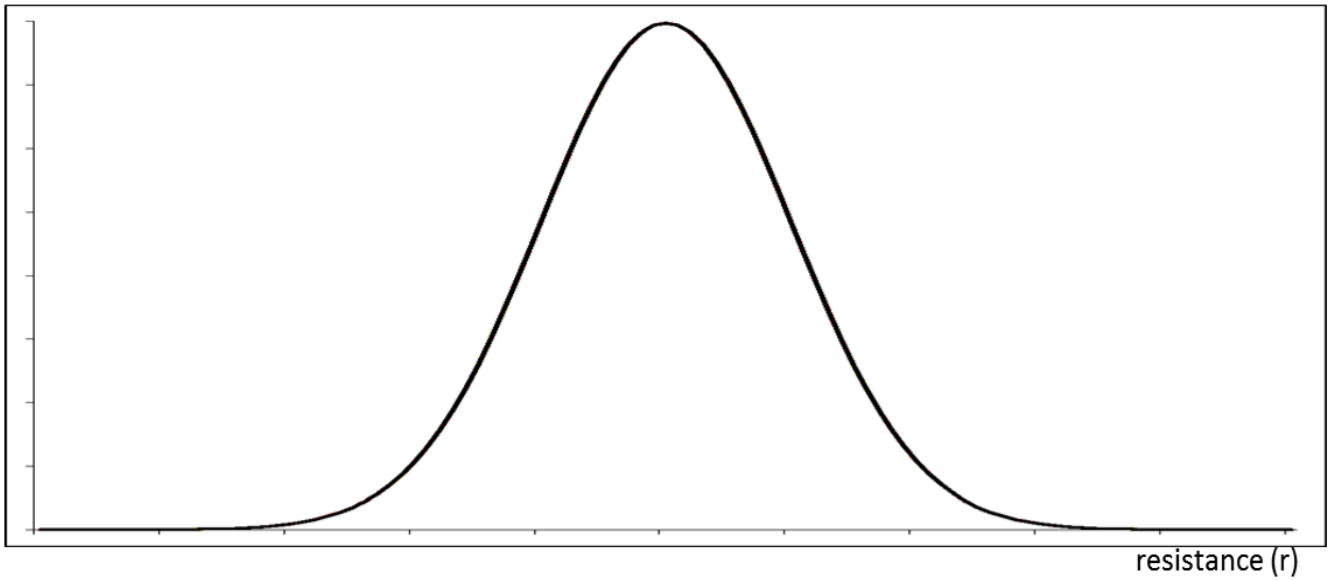
Information is generated by the cumulative experience of prior adopters. The total information available at time t is proportional to the *integral* of the adoption curve

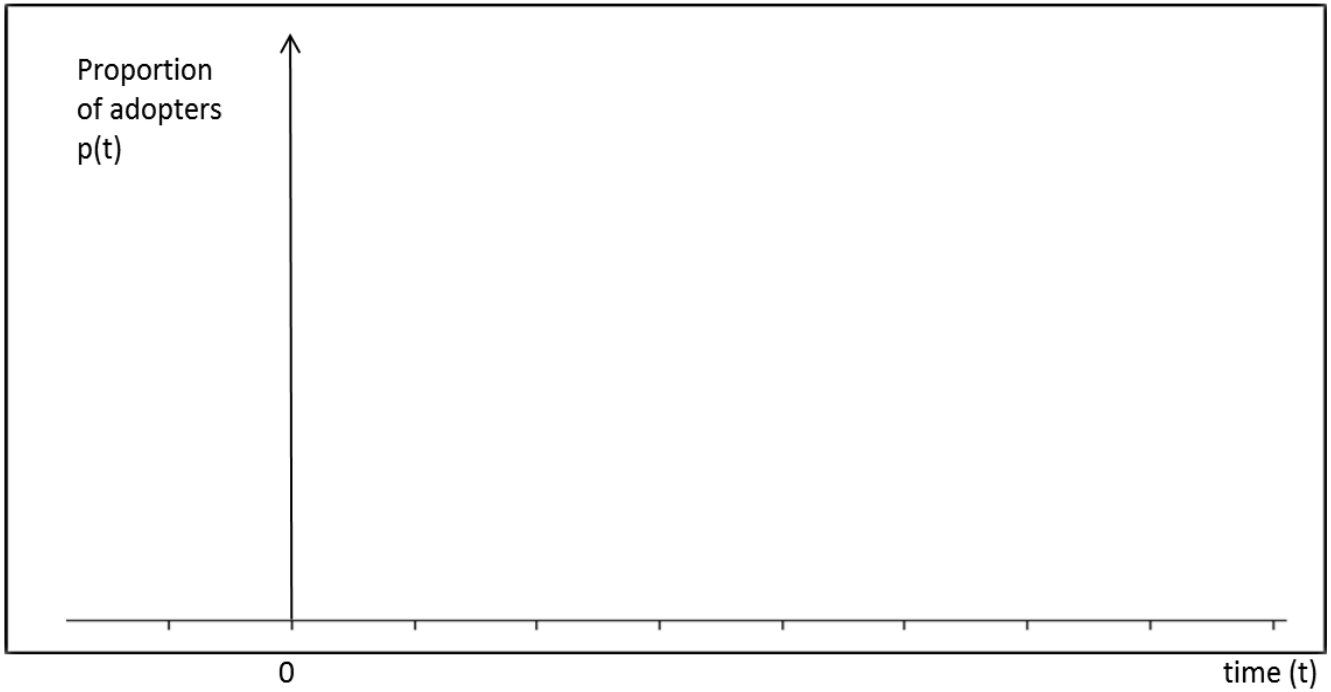
$$r(t) = \int_0^t p(s)ds$$

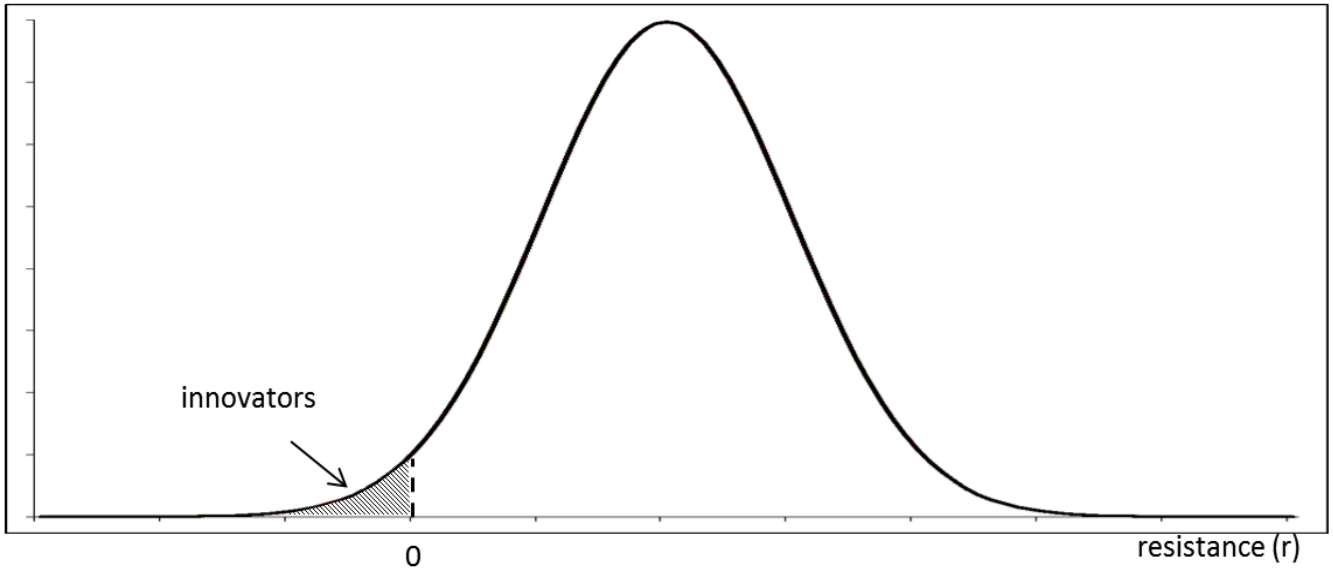
Let $F(r)$ be the cumulative distribution of *resistance* levels in the population due to conservatism, pessimistic beliefs, etc.

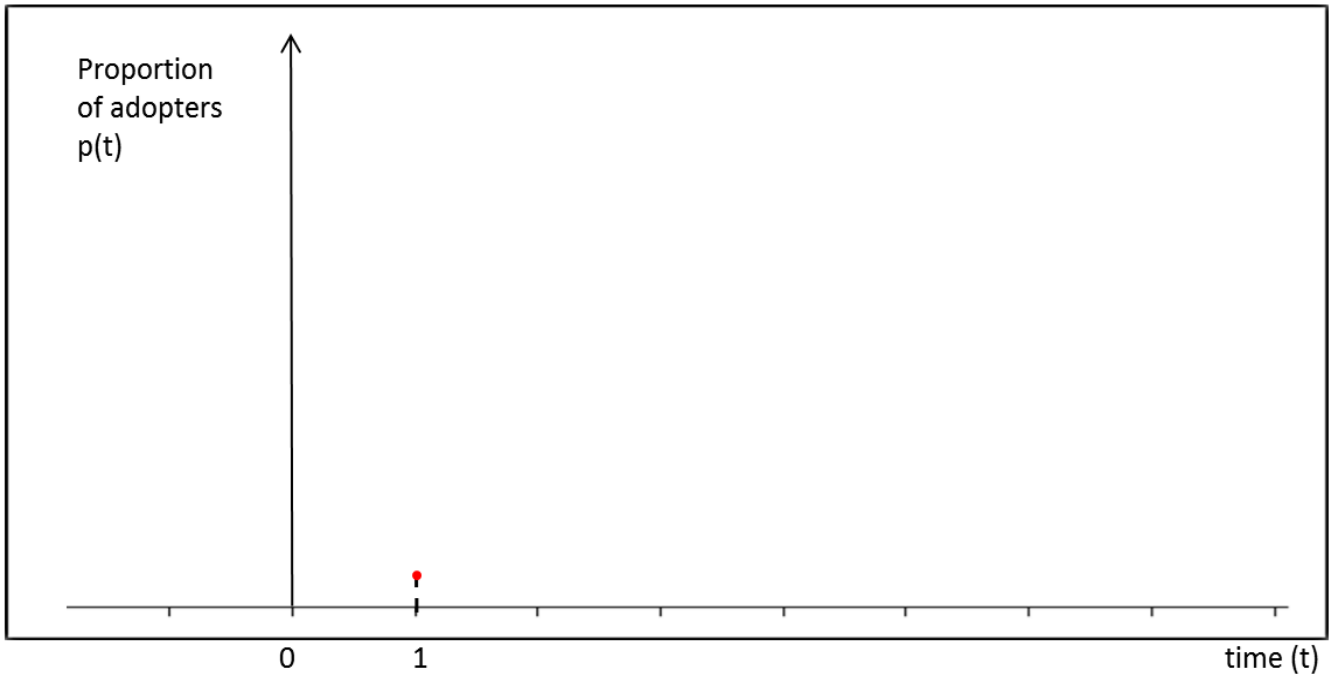
The dynamics are described by the differential equation

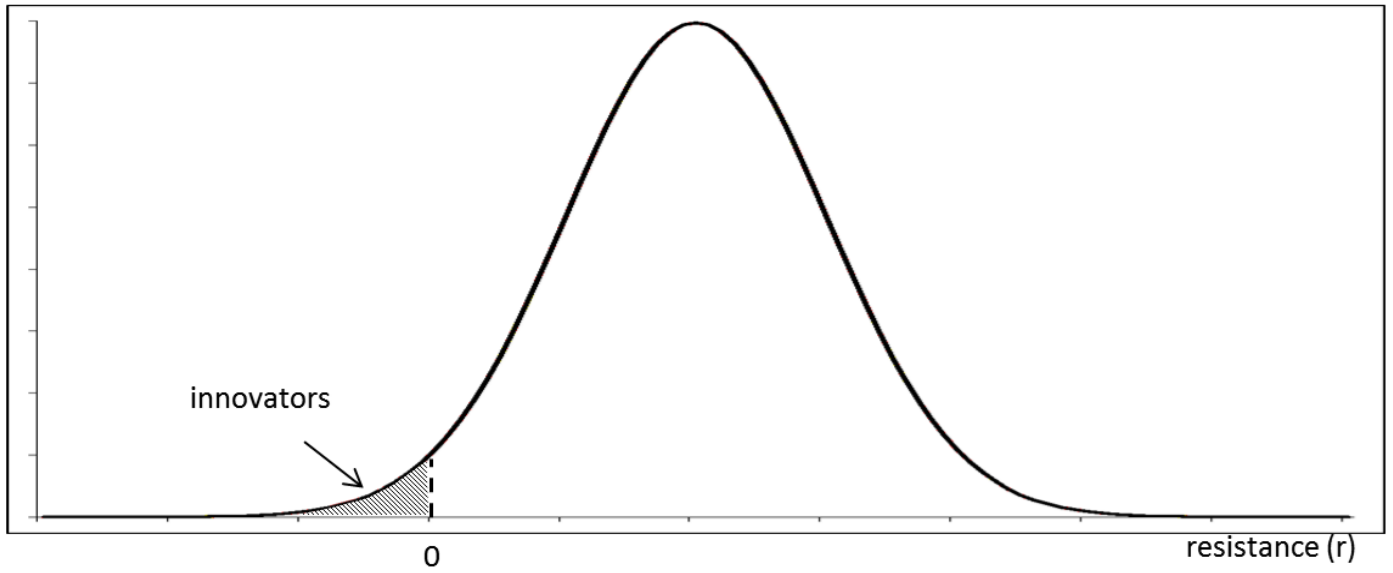
$$\dot{p}(t) = \lambda[F(\int_0^t p(s)ds) - p(t)], \lambda > 0$$

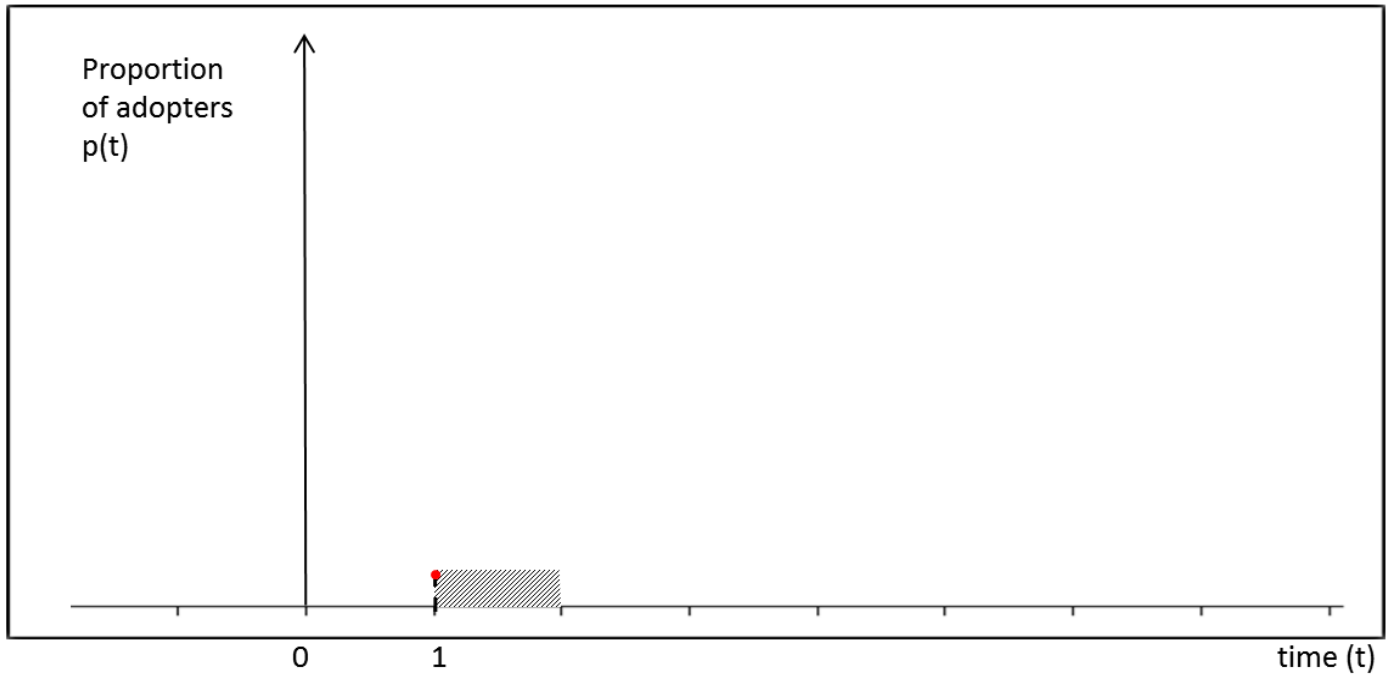

resistance (r)

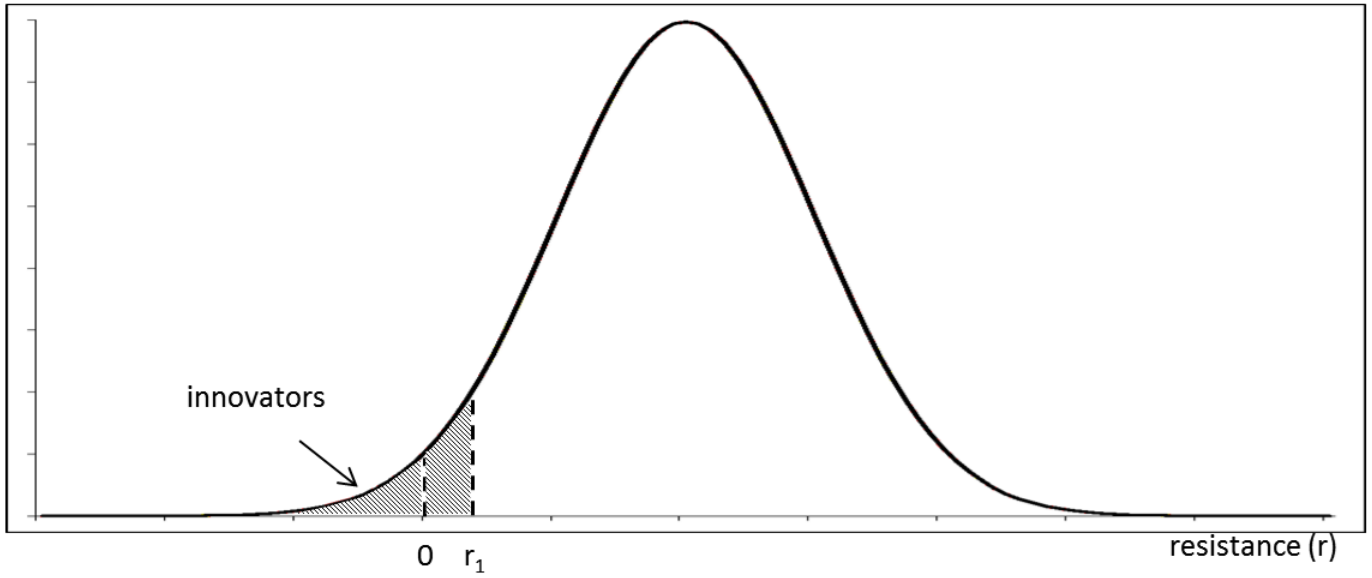

Proportion
of adopters
p(t)
0
time (t)

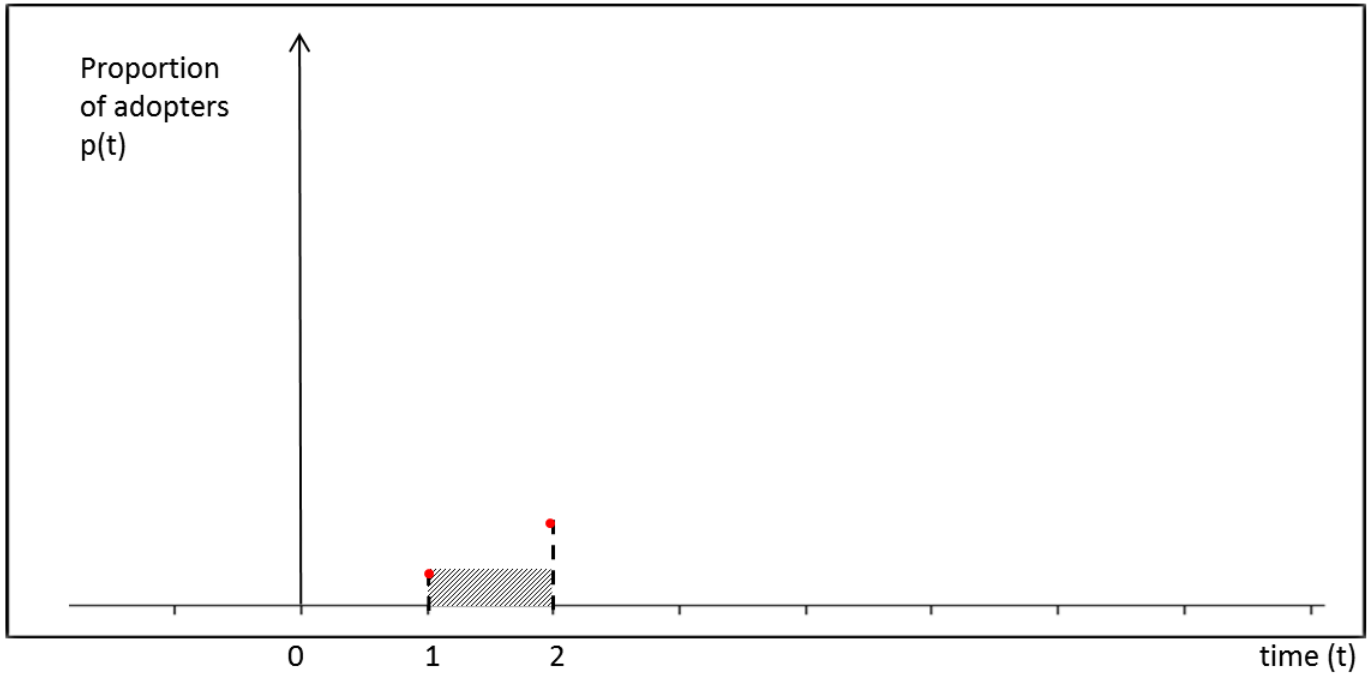

innovators
0
resistance (r)

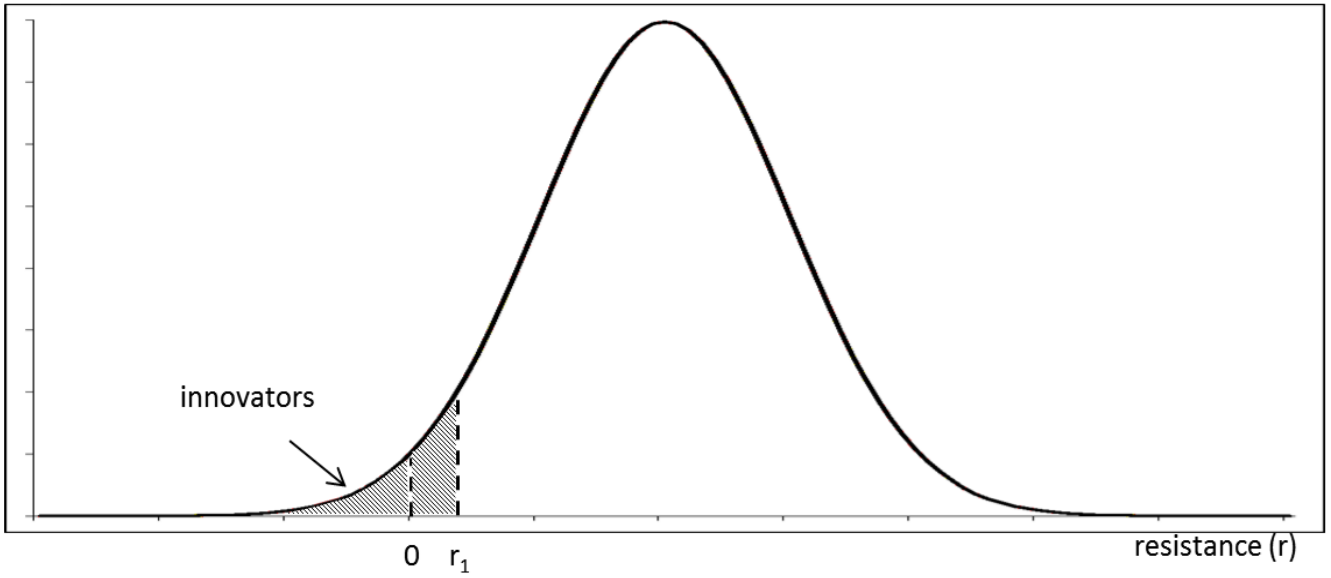

Proportion
of adopters
p(t)
0
1
time (t)

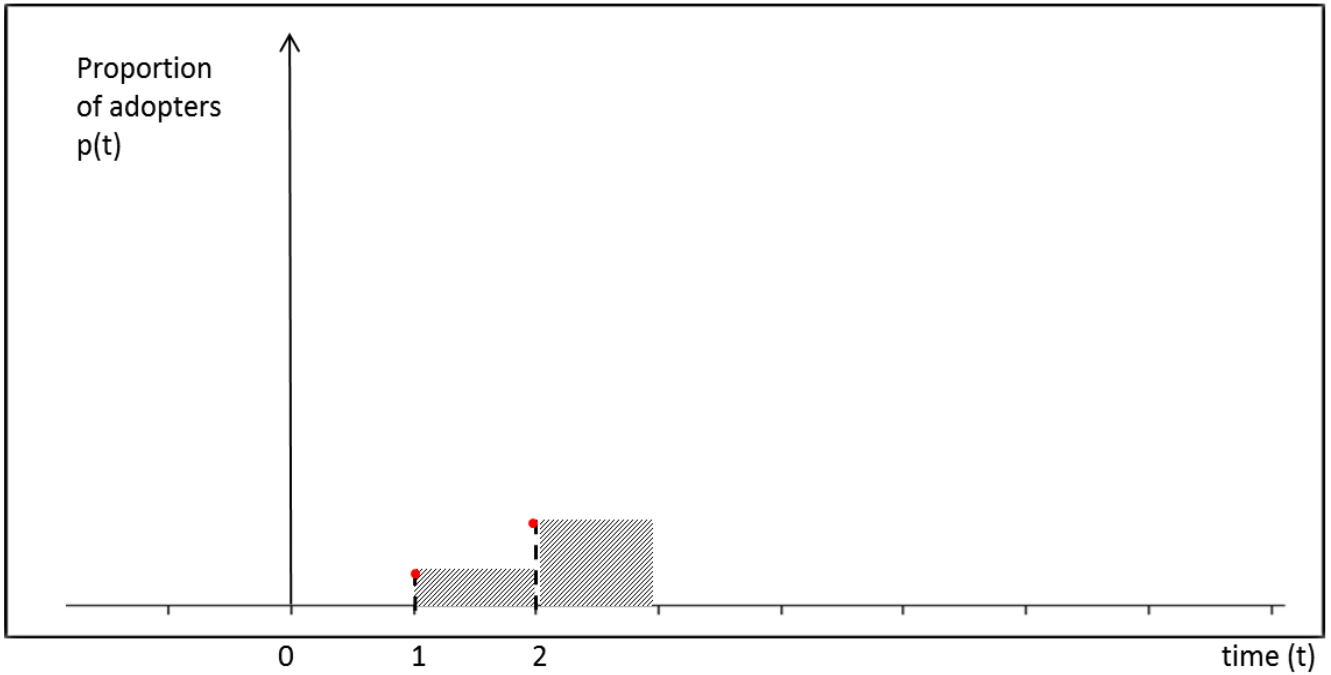

innovators
0
resistance (r)

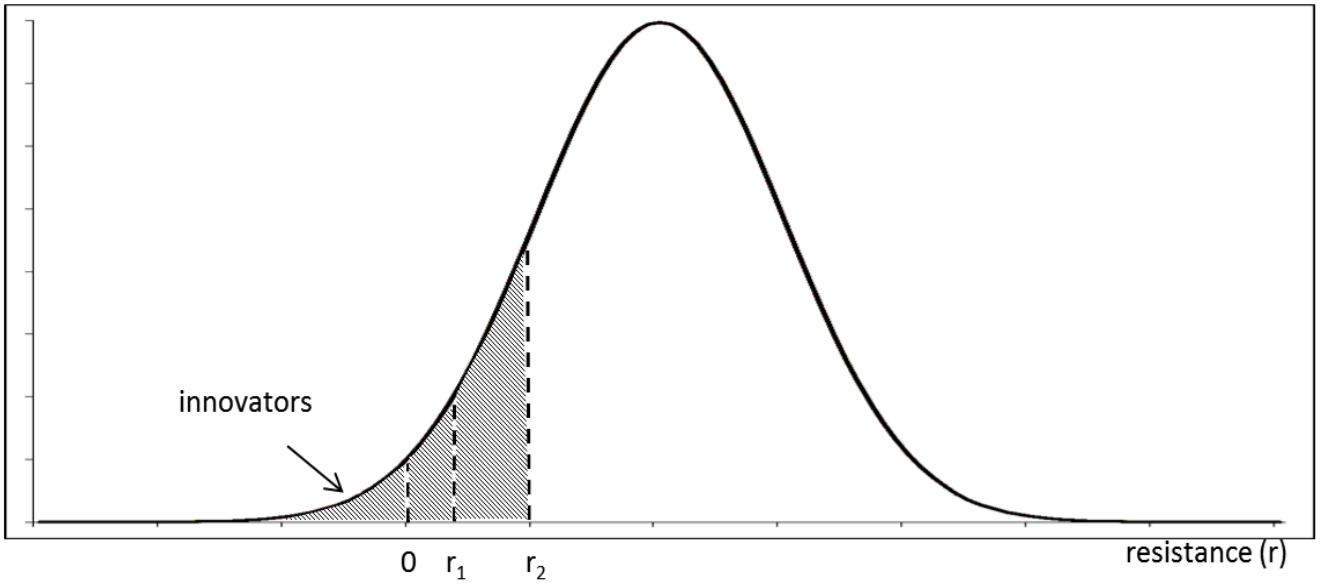

Proportion
of adopters
p(t)
0
1
time (t)

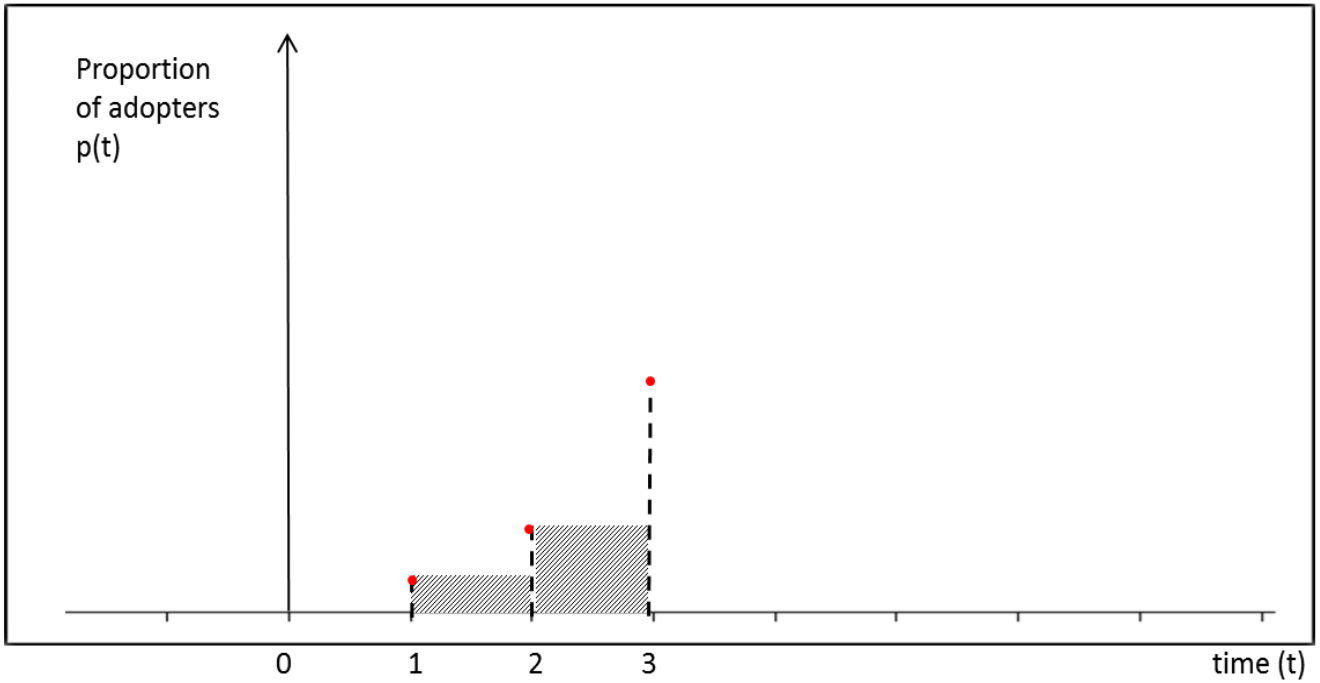

innovators
0
r_1
resistance (r)

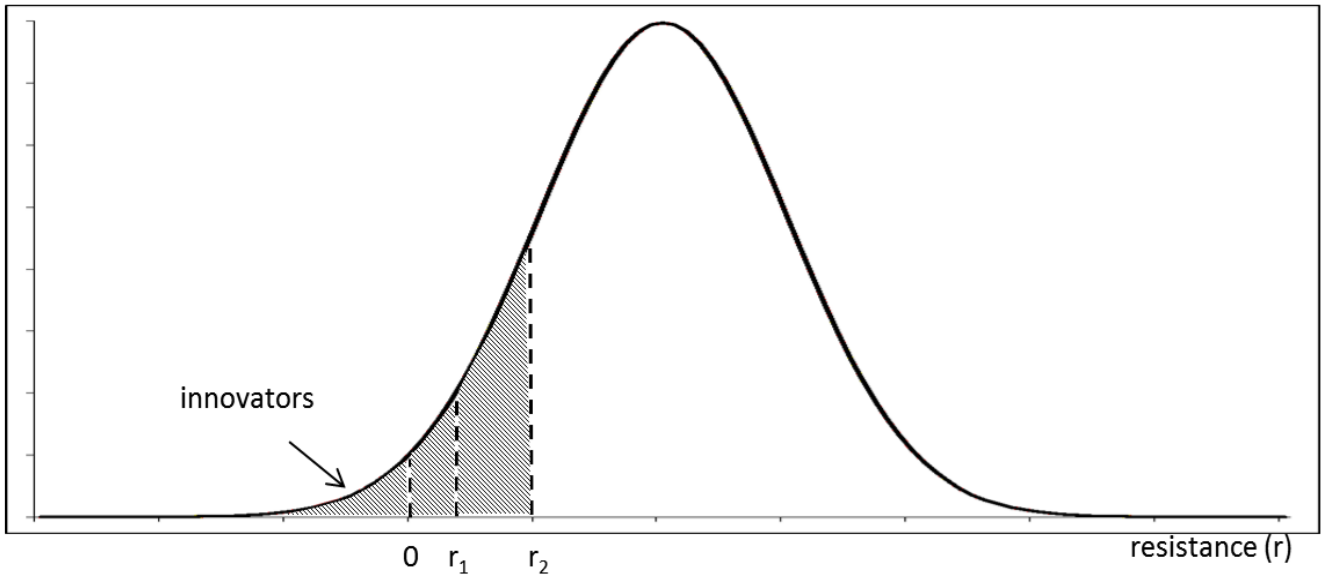

Proportion
of adopters
p(t)
0
1
2
time (t)

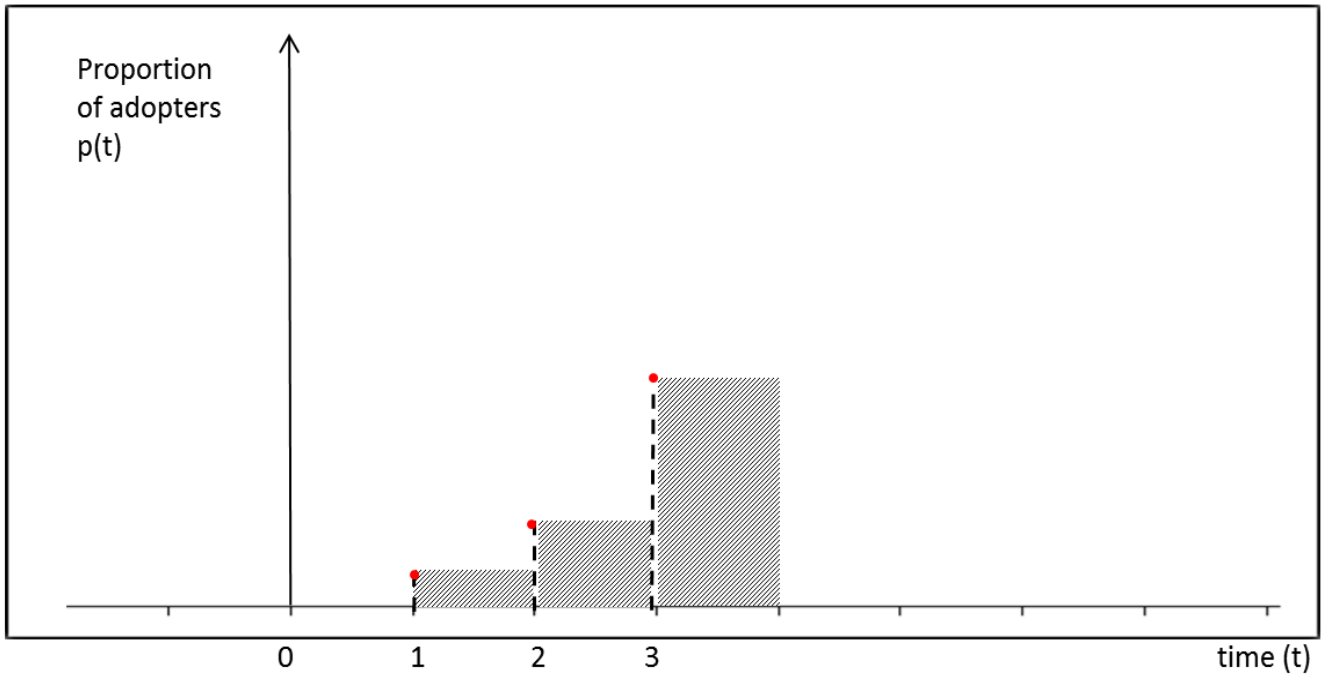

innovators
0
r_1
resistance (r)

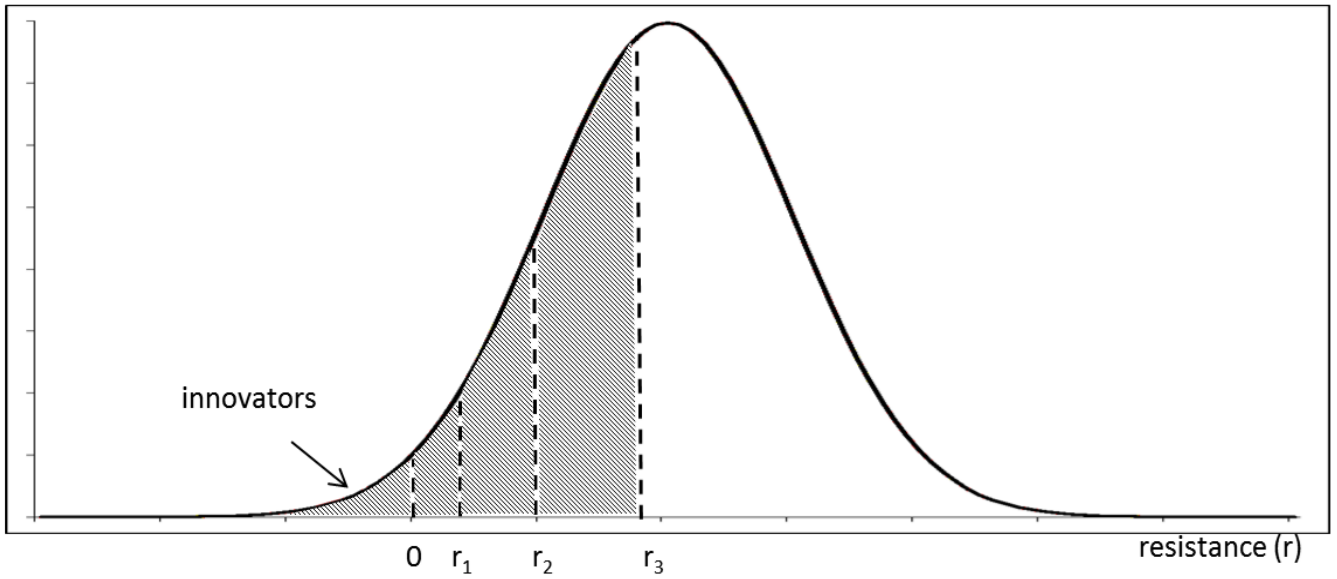

Proportion
of adopters
p(t)
0
1
2
time (t)

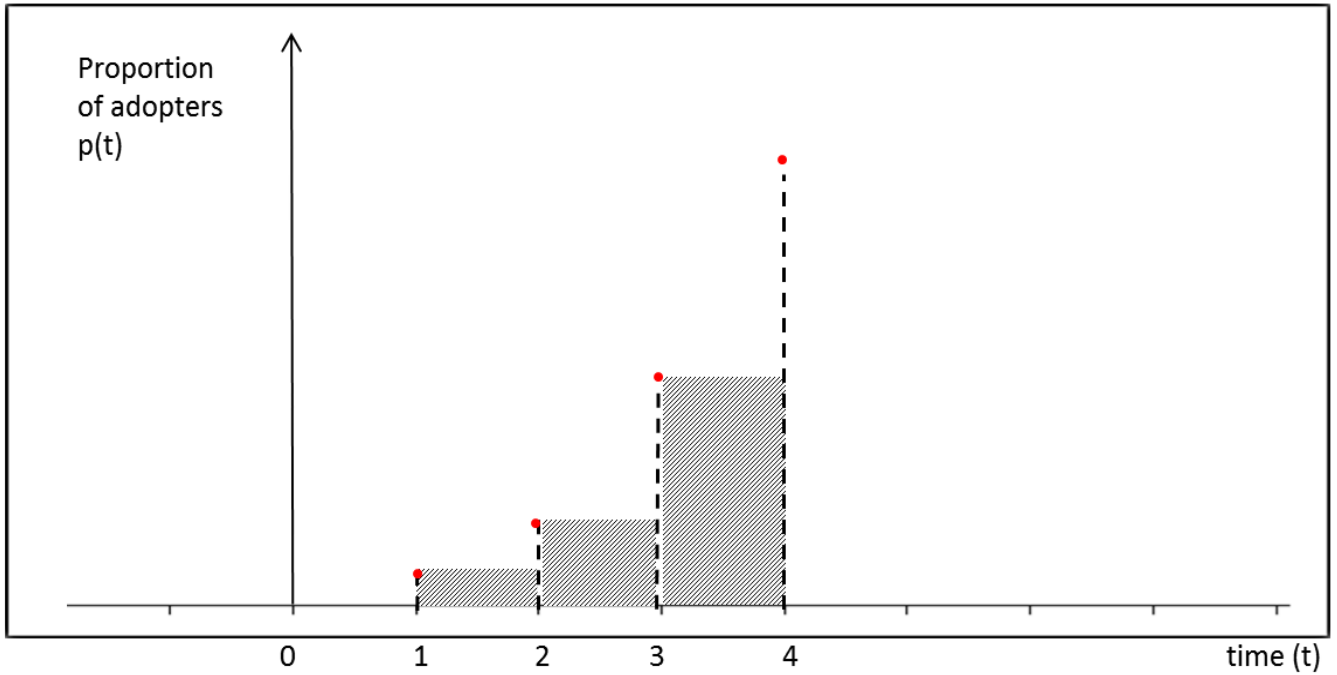

innovators
0
r_1
r_2
resistance (r)

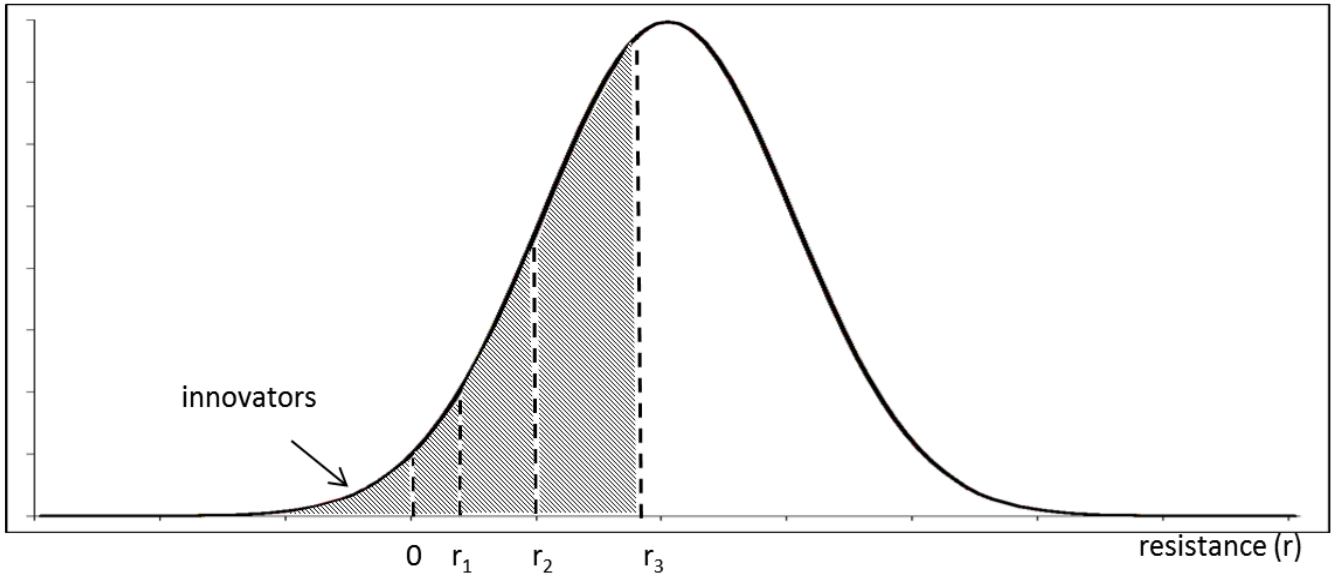

Proportion
of adopters
p(t)
0
1
2
3
time (t)

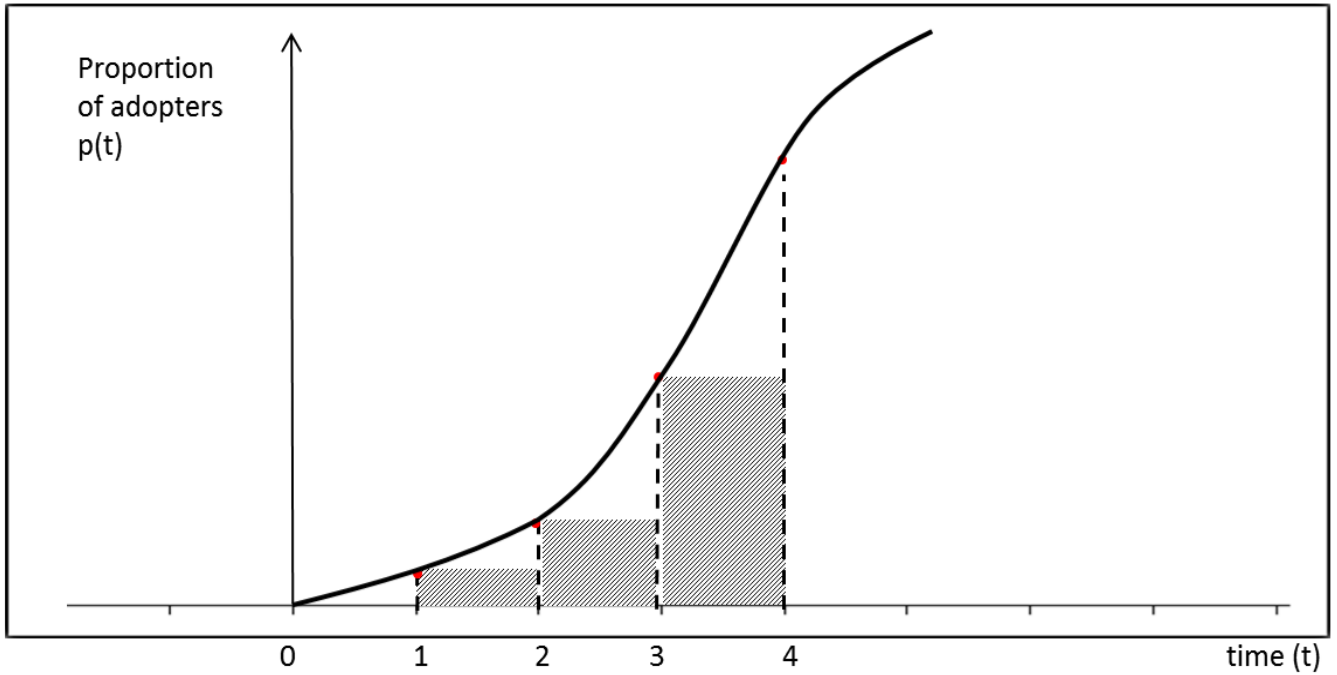

innovators
0
r_1
r_2
resistance (r)


Proportion
of adopters
p(t)
0
1
2
3
time (t)


innovators
0
r_1
r_2
r_3
resistance (r)

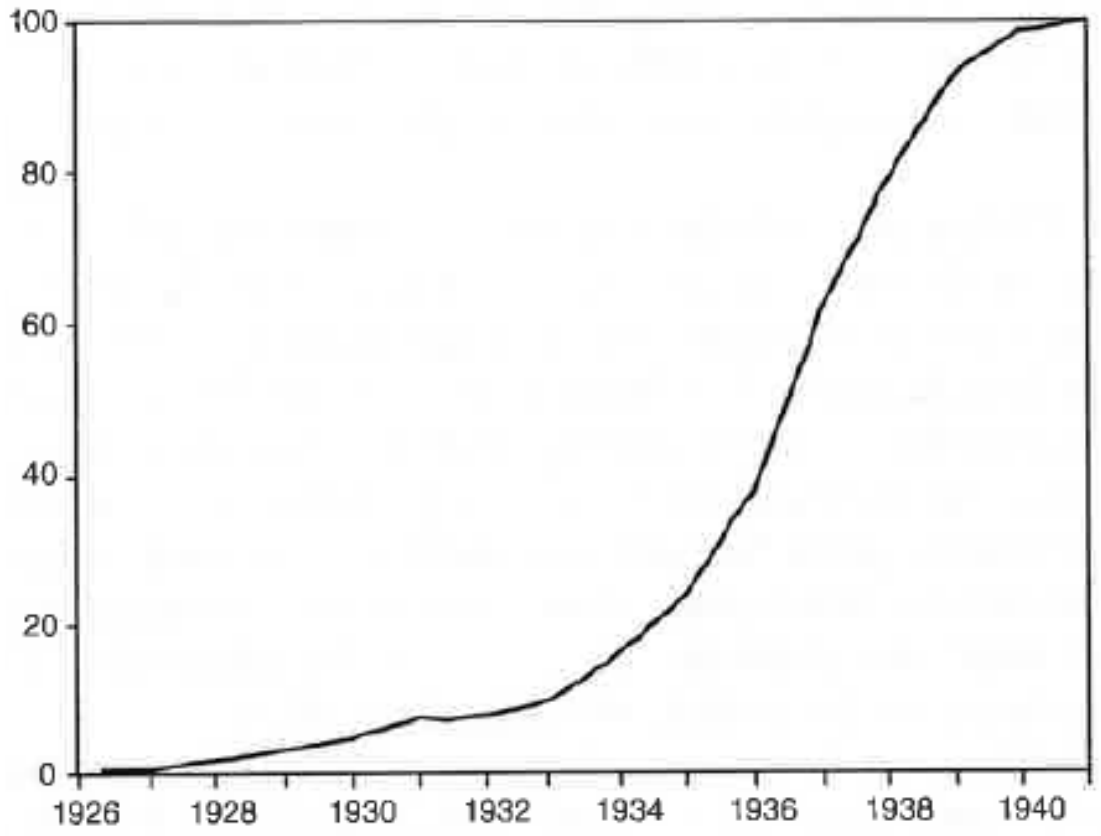

Proportion
of adopters
p(t)
0
1
2
3
4
time (t)


innovators
0
r_1
r_2
r_3
resistance (r)


Proportion
of adopters
p(t)
0
1
2
3
4
time (t)

The learning model fits the Ryan & Gross adoption data for hybrid corn much better than the contagion (logistic) model, which in fact can be statistically rejected.

Adoption percentage



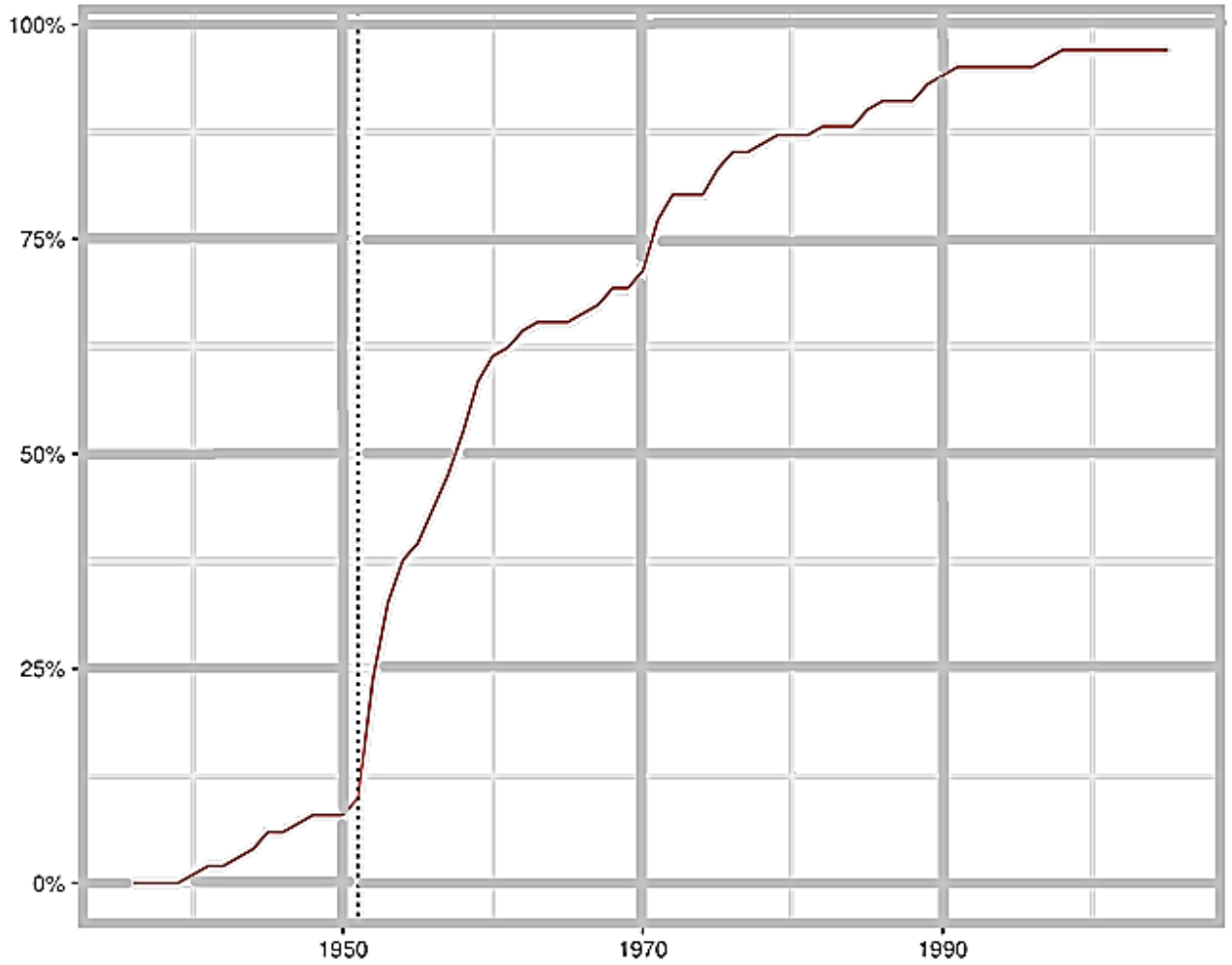
Years

Source: HPYoung, *American Economic Review* 2009

Case II. Stock options for corporate executives

Diffusion of Stock Options Among Large U.S. Corporations: 1936-2005

Adoption percentage



Source: Frydman & Saks, *Review of Financial Studies* 2010

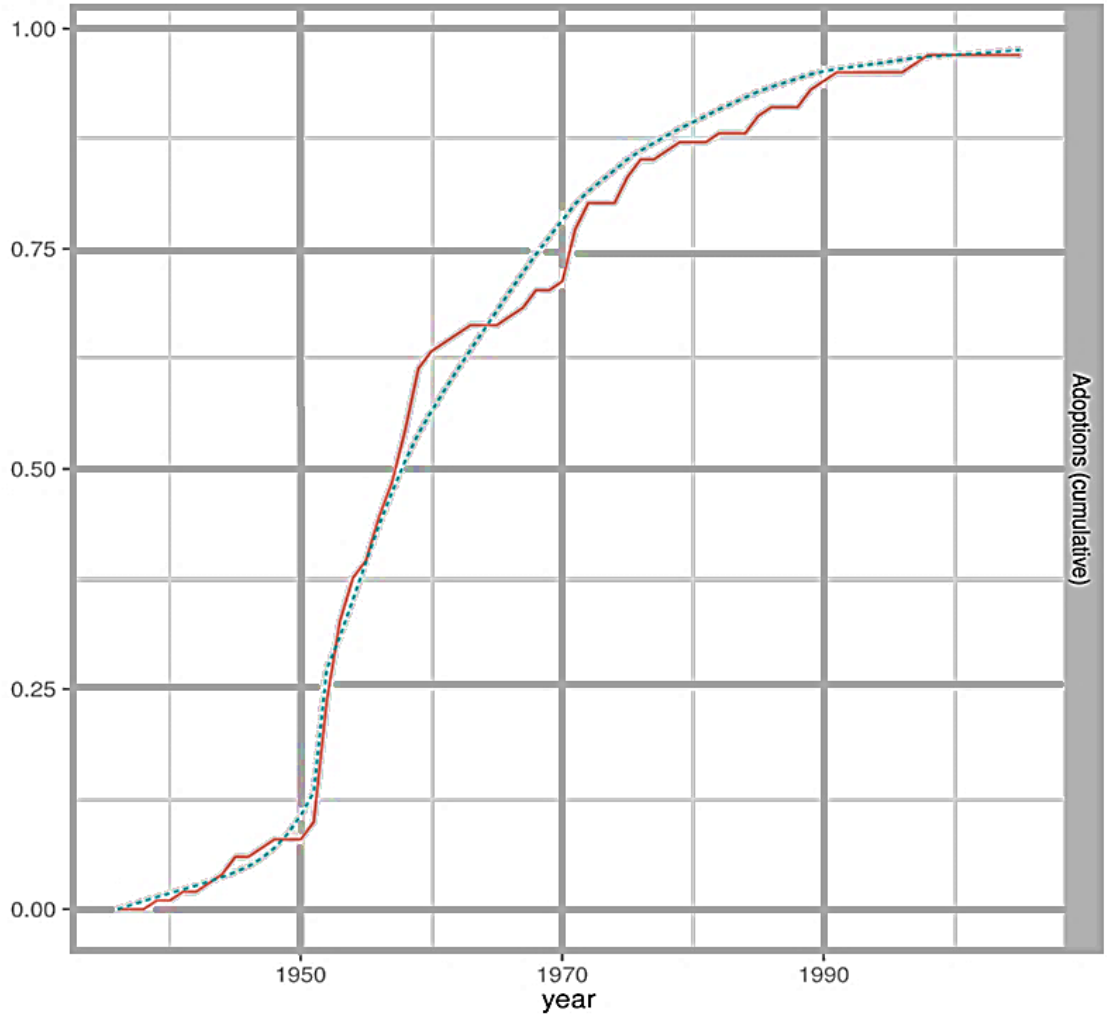
Qualitative features of the diffusion process

- Initially a long period of weak growth (1936-1950)
- Sudden growth spurt in early 1950s.
  - Triggered by a change in tax rates that gave very favorable treatment to options
- Tax changes only explain the spurt in 1951
  - It took another 20 years to reach 75%.

- **Observability of benefits:** firms can observe who adopted and how much the adopters' stock value increased relative to non-adopters.
- **Evidence of learning:** increases in the stock market value of prior adopters vs nonadopters leads to a higher rate of new adopters.
- **Learning from similar firms.** Effect is particularly strong among firms in the same industry.

Learning model fits the data very closely

Data = solid line, Fitted learning model = dotted line.

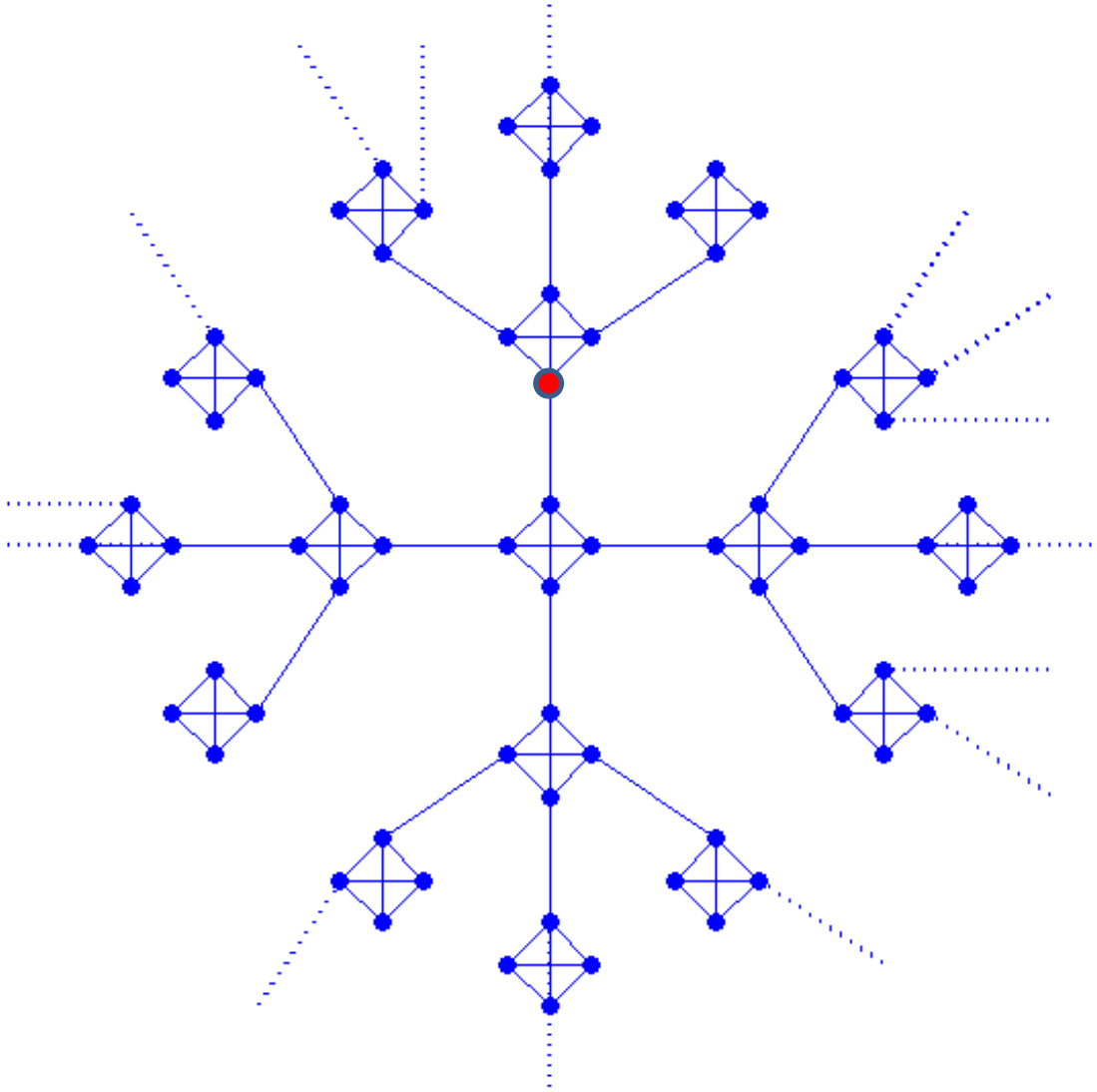


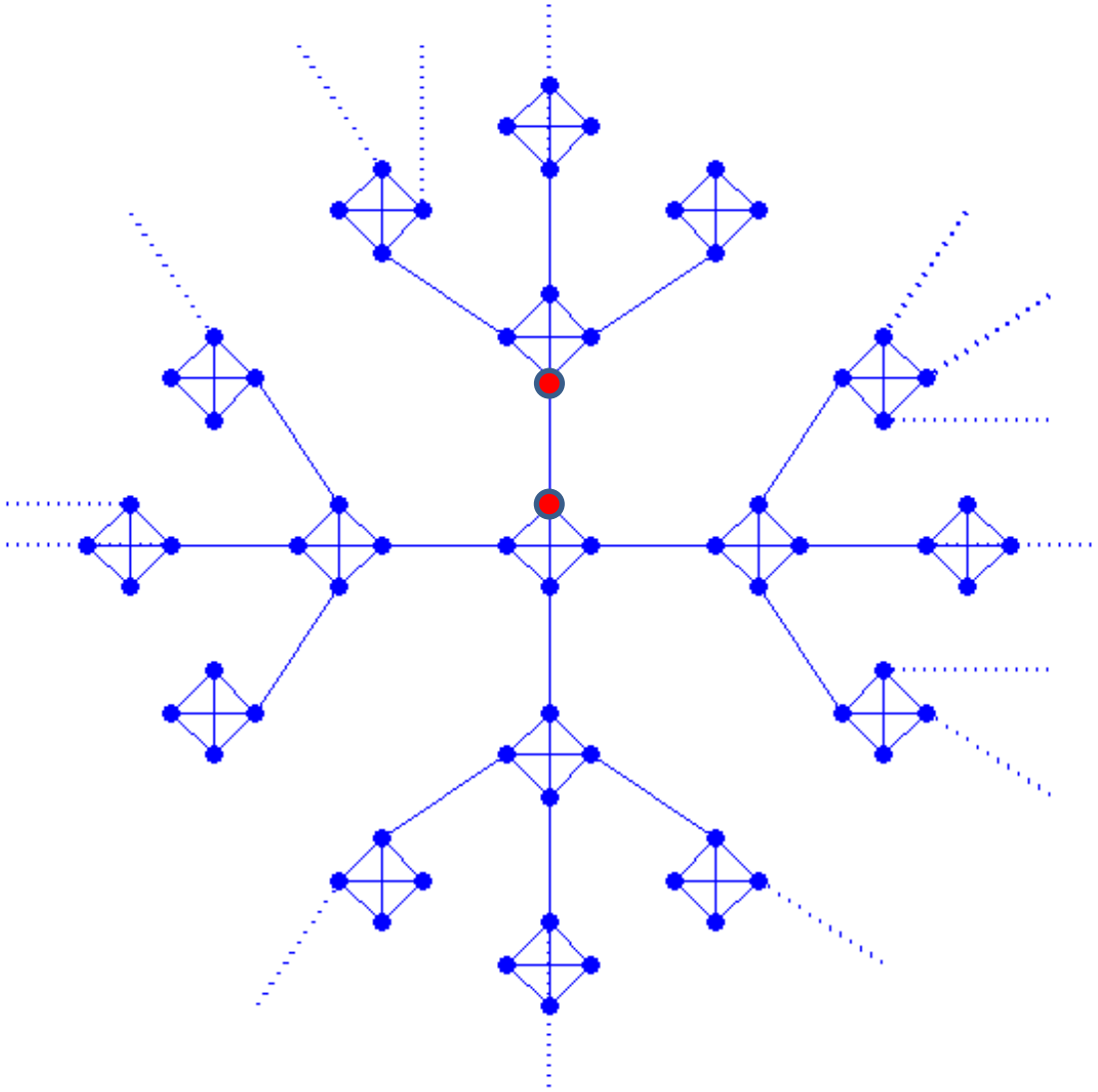
Source: Brown and Young, Oxford Economics Working Paper 777, 2016

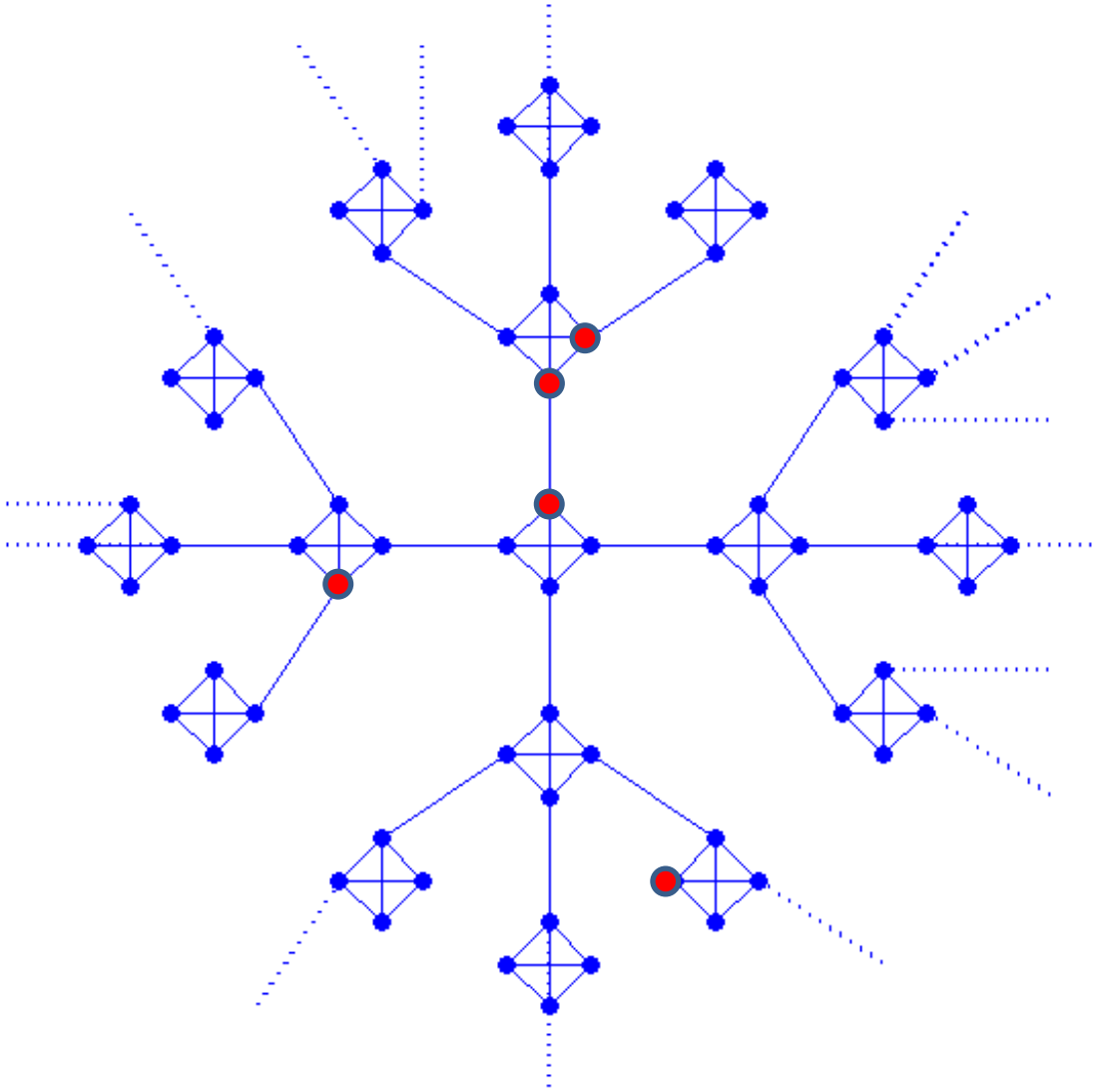
Network models of innovation diffusion

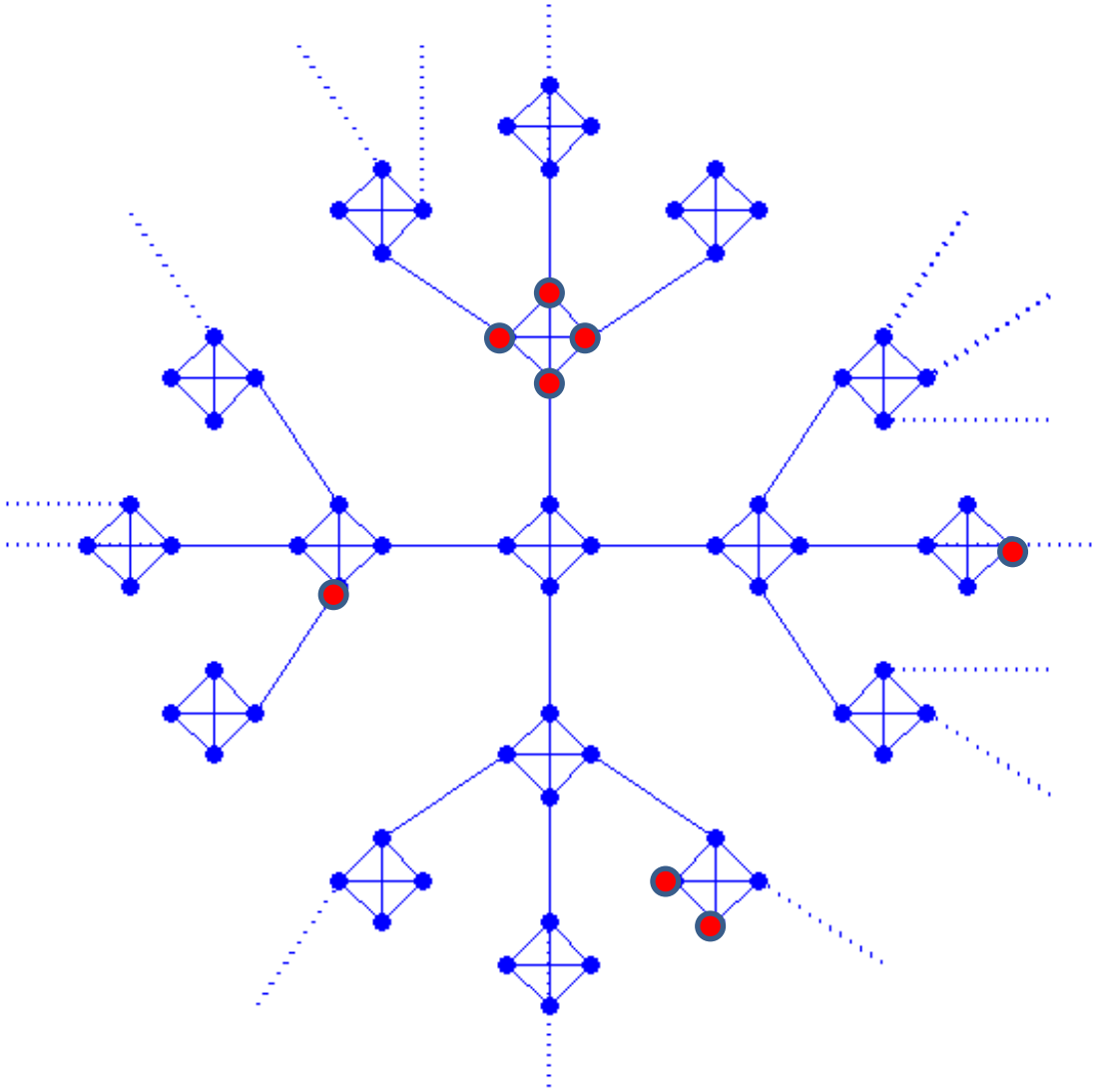
- Agents are embedded in a social network and obtain information from their neighbours.
- The probability of adopting depends on how many neighbours have already adopted and their position in the network.
- Theory of stochastic processes makes predictions about the rate of diffusion and the effect of network *topology*.

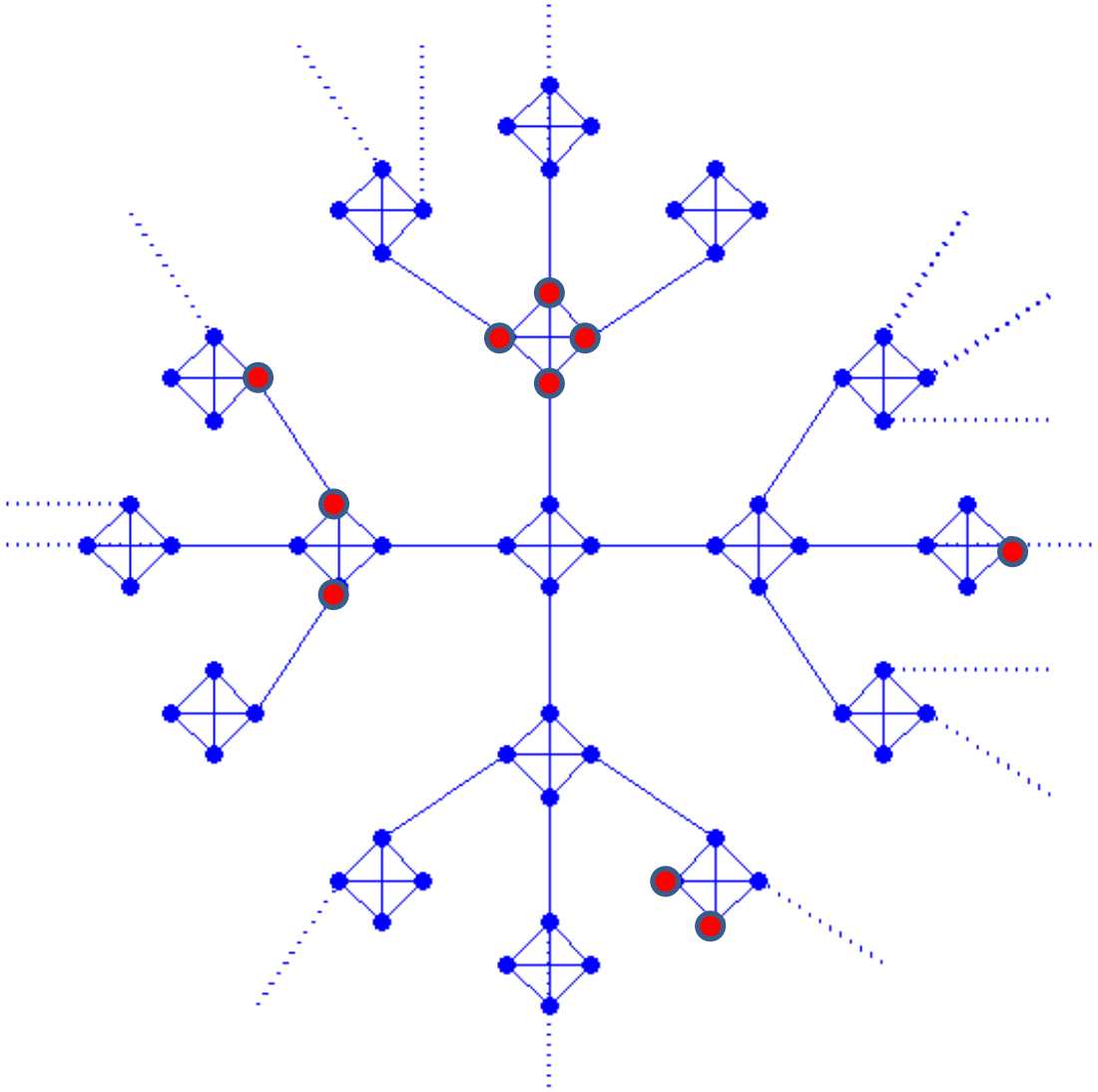
Young *Proc. Natl. Acad Sci*. 2011; Kreindler and Young, *Proc. Natl. Acad. Sci*. 2014.

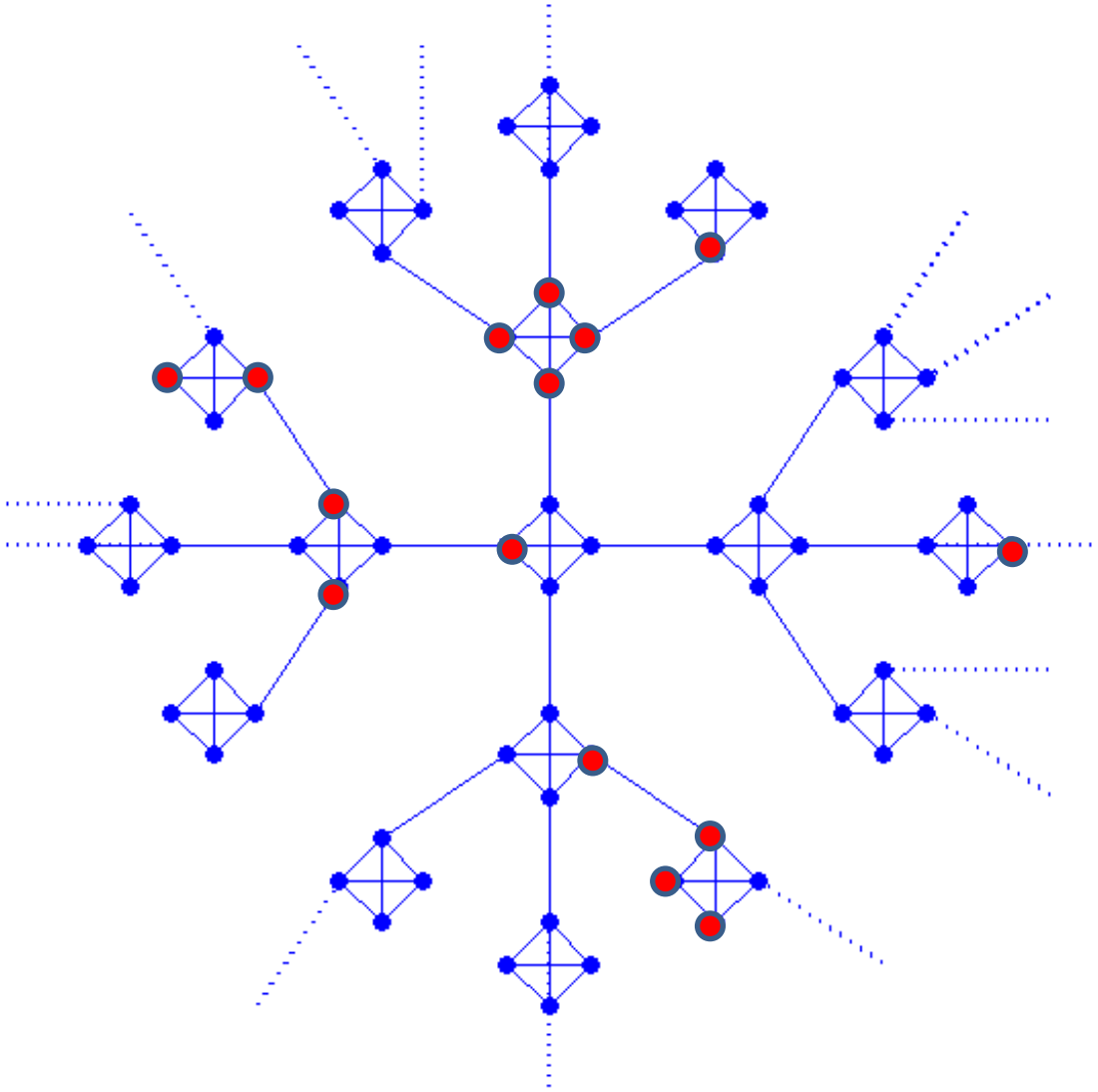












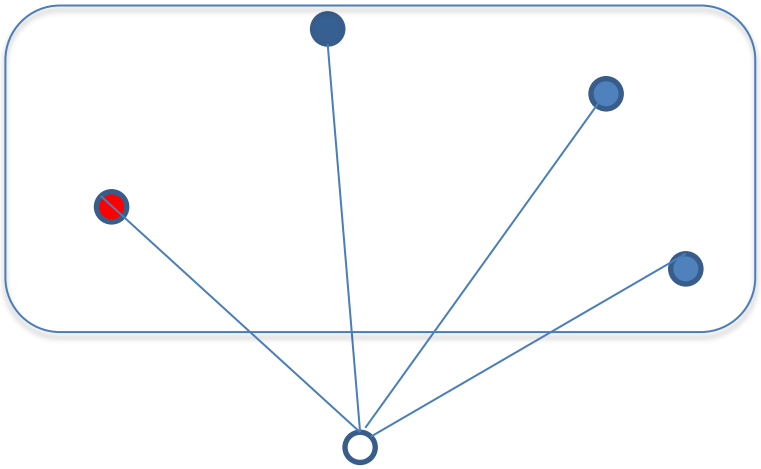
Case III: the diffusion of contraception

- **Social learning**: women learn about the potential benefits from the experience of prior adopters in their social network.

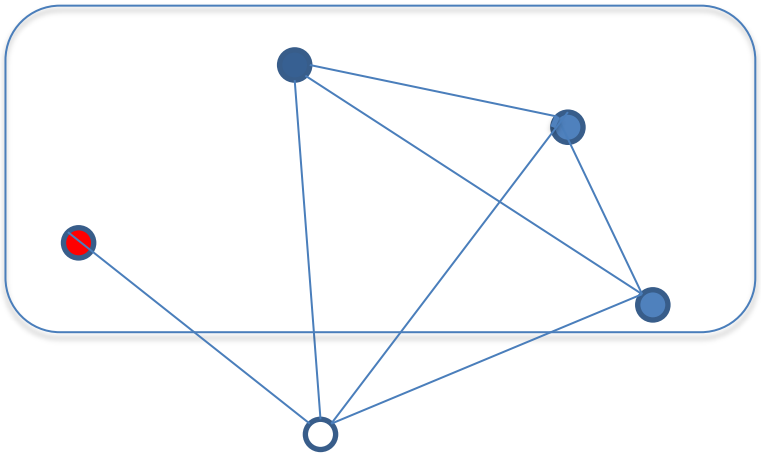
- **Social norms**: Early adopters are sanctioned by non-adopters if contraception goes against prevailing social norms.

Source*:* Kohler, Behrman & Watkins*, Demography 2001.*

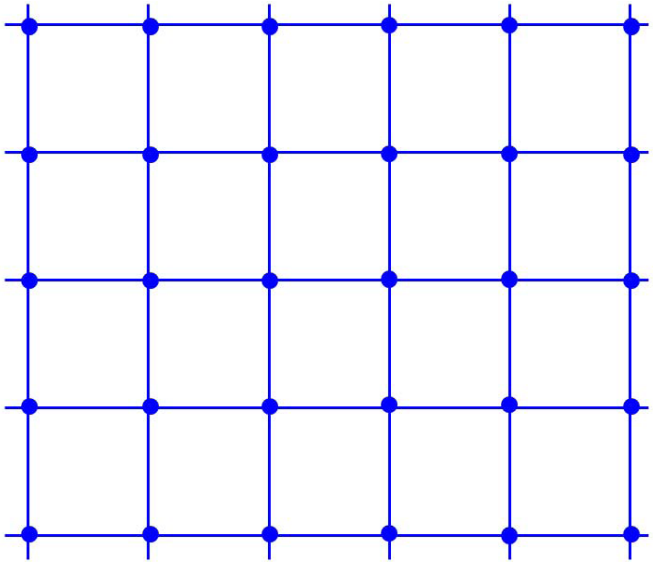
The **density** of an individual's neighbourhood is the number of links among her neighbours divided by the maximum possible number of links.



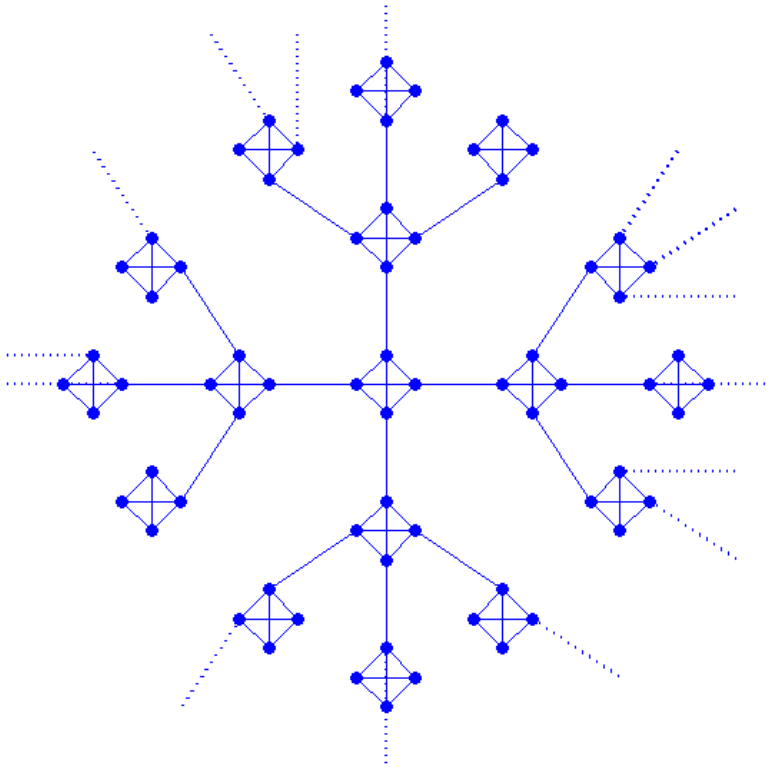
Density of neighbourhood = 0



Density of neighbourhood = 1/2



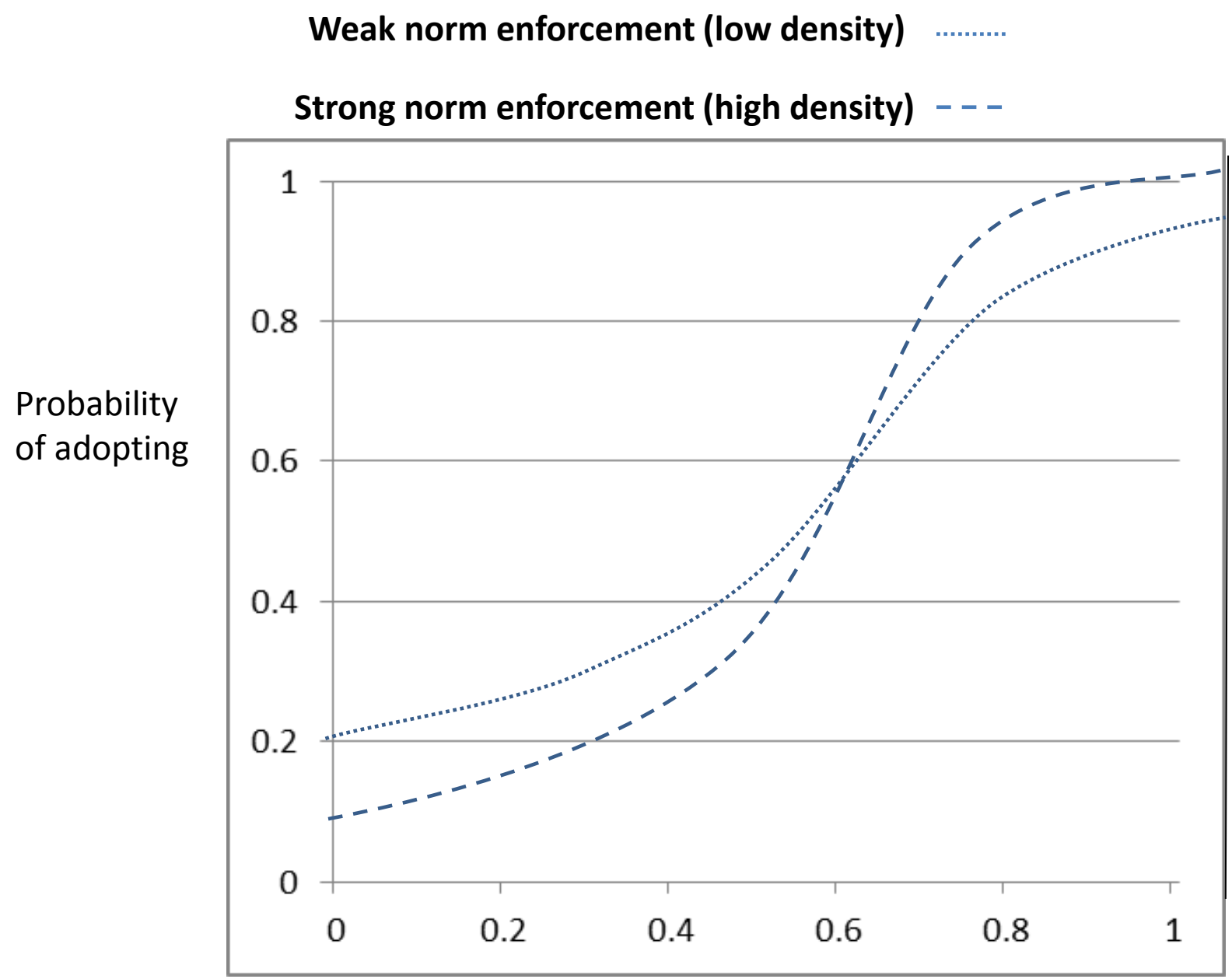
Neighbourhoods
have density 0



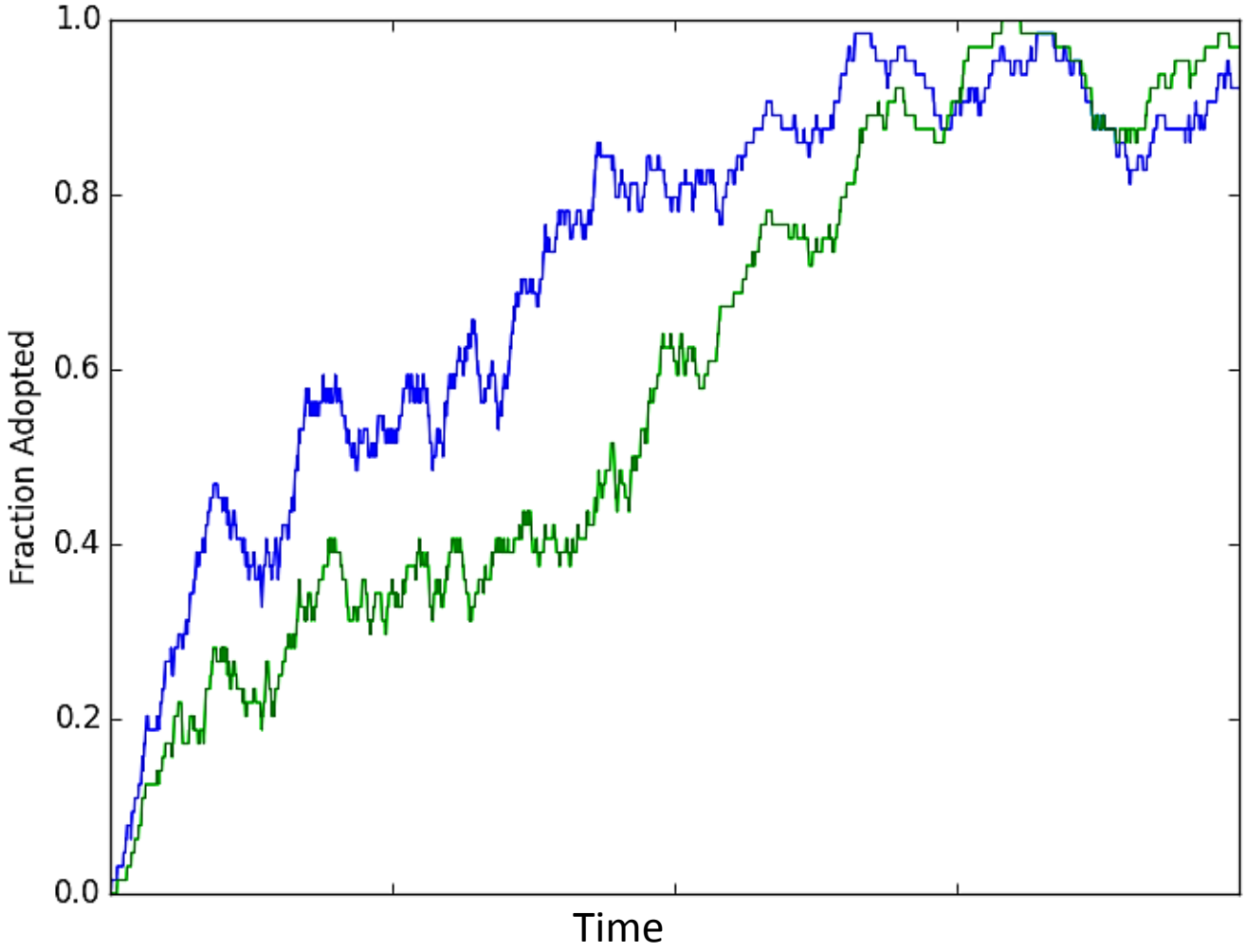
Neighbourhoods
have density 1/2

- *Hypothesis*: Locally dense networks are more effective at enforcing social norms but they provide no additional information compared to less dense networks.

- Initially local density retards diffusion but later on it speeds up diffusion as the innovation becomes established as the new norm.


Weak norm enforcement (low density)
Strong norm enforcement (high density)
Probability of adopting
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Proportion of adopters in neighbourhood

Stochastic diffusion curves: norms weak (blue) vs norms strong (green)



Policy interventions to speed up the diffusion process

I. *Disseminate information about the benefits.*

- In the US, local agricultural extension services played this role for hybrid corn (as did seed companies).
- In developing countries, family planning clinics play this role for contraception.
- Nevertheless adoption is often erratic and quite slow despite publicly disseminated information.

Policy interventions

II. *Provide subsidies for adopting the innovation.*

In the case of stock options, tax benefits jump started the process but it still took decades before they were in widespread use among US corporations.

Policy interventions

III. *Provide positive information to opinion leaders and/or those centrally located in the network*

- Currently being tried as a strategy for spreading information about microfinance in rural Indian villages (Banerjee et al., *Science* 2013)

Cautionary note: opinion leaders are sometimes the most resistant to change.

- Duelling was common in France until the late 19th century.
- There were numerous attempts to outlaw it but the practice persisted.
- The problem: leading social and political figures were the usual protagonists, and they risked losing their honour by backing reform.

(R. Hopton, *Pistols at Dawn: A History of Duelling* 2007)

Policy interventions

IV. *Coordinate a simultaneous shift in practices among a critical mass of interacting agents.*

- Instrumental in eliminating footbinding in China: "foot emancipation societies" were formed in which families contracted to marry their sons only to daughters who did not have bound feet.
- Currently being tried as a strategy for reducing female circumcision in sub-Saharan Africa.

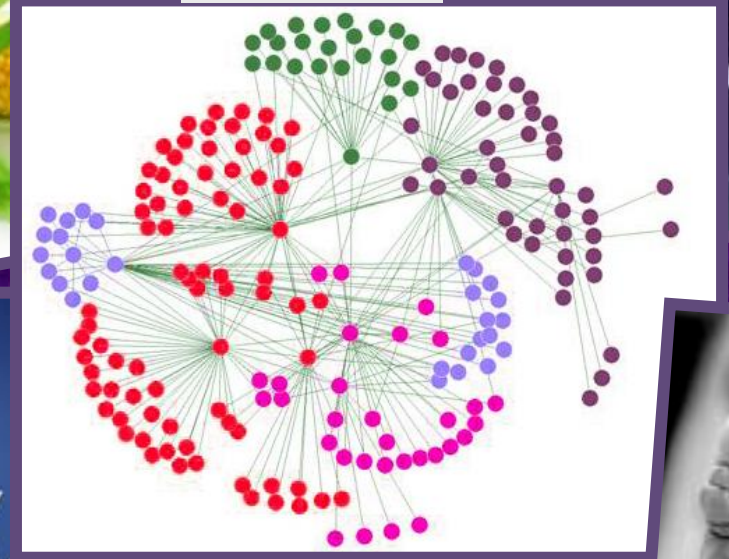
Mackie, *American Soc. Review* 1996; Mackie & Lejeune, *Innocenti Res. Centre, UNICEF* 2009.

Conclusions

- The diffusion of innovations is a complex process driven by sociological and economic factors.
- Learning, inertia, and social norms play a greater or lesser role depending on context.
- Learning is especially relevant when benefits are uncertain and can be estimated from the experience of others.

A combination of sociology, economics, and mathematics can increase our understanding of this complex and important phenomenon.

LSE Mathematics



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