Erasmus University Rotterdam
Department of Applied Economics
Dr. Philipp Koellinger

Economics of Innovation

Lecture 5 –
Diffusion of innovation

http://www.economics-of-innovation.com

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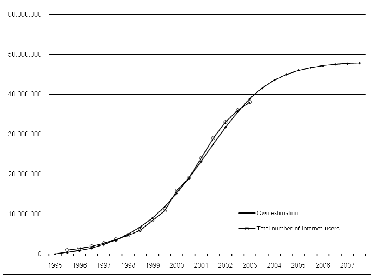
Number of Internet users in Germany



Sources: Koellinger, Statistisches Bundesamt, Nielsen NetRatings, GfK Online Monitor

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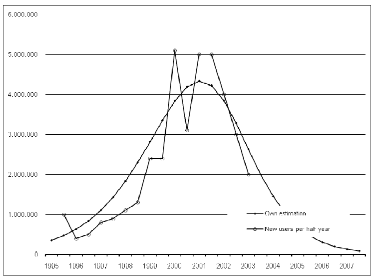
Number of new Internet users per half year in Germany



Sources: Koellinger, Statistisches Bundesamt, Nielsen NetRatings, GfK Online Monitor

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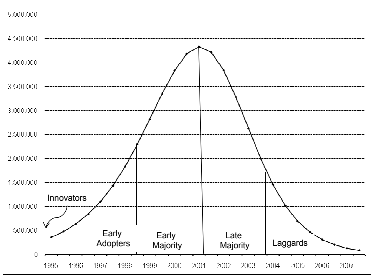
Adopter categories



Categories according to Rogers (1962, 2003) : *Diffusion of Innovations.*

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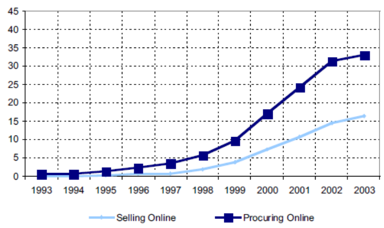
E-commerce diffusions in European firms

Exhibit 1-5: Diffusion of e-commerce in EU companies, 1993-2003

Computed based on questions on the starting time of online selling / procurement activities.



In % of enterprises. Base: Survey 2003, 7 sectors, companies selling / purchasing online

Source: *e-Business W@tch* (2003)

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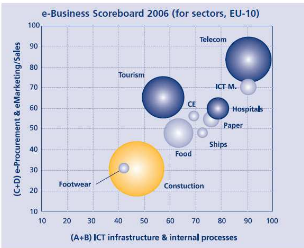
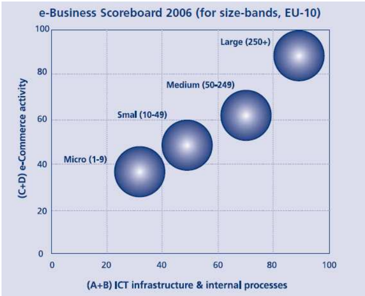
Sector differences in adoption



The Scoreboard consists of 16 component indicators, grouped in four categories (see p. 79). In this presentation, the x-axis comprises the categories A and B, and the y-axis the categories C and D. The underlying survey data have been weighted by employment, thus emphasizing the activity of larger firms. The size of the bubbles is indicative for the relative size of a sector (by employment). Data for hospitals are not 100% comparable, as for some business indicators proxies had to be used.

Source: *e-Business W@tch* 2006

Size-class differences in adoption



Source: *e-Business W@tch* 2006

Regional differences in adoption

3. Companies placing orders to suppliers online (%)

	Food	ICT manuf.	Tourism	Construction	Telecom
Belgium	57	70		48	87
Denmark	83		77	87	99
Estonia			73	63	67
Greece	54		45	43	
Ireland	52	71	55	45	
Cyprus	33		52	36	
Latvia		62	35	52	53
Lithuania		60		49	70
Luxembourg			57	53	
Malta			53	62	
Austria	61		72	68	
Portugal	30		29		
Slovenia			43	36	
Slovakia			36	34	40
Sweden		91	81		81
Bulgaria	38		21	40	
Romania	44		51	48	71
Turkey		70			63
Norway			85	74	
EU-10	**54**	**72**	**60**	**53**	**78**

Source: *e-Business W@tch* 2006

Empirical regularities

- Diffusion of new production technologies and products takes time
- Diffusion rates differ across industries, size-classes and regions
- Similar S-shaped diffusion patterns are typically found for all kinds of innovation
  - Diffusion starts slow, then accelerates up to some maximum
  - Slow down after maximum until market saturation is reached
- As technologies mature, they tend to exhibit falling prices and rising quality / performance

Questions addressed by diffusion theory

- Why don't innovations gain immediate usage in the market if they are useful and beneficial?
- Where does this S-shape come from?
- What are the factors influencing the speed of diffusion and the market potential of an innovation?
- Is everyone profiting from the diffusion process to the same extent?

- Our focus is on new production technologies
  - Firms are the customers

Different theoretical approaches

- Epidemic models
  - Spread of information among potential customers over time
- Rank effects models
  - Different expected benefits and adoption costs among potential customers
- Stock effects models
  - Strategic aspects for identical firms in one market: Given a particular price of the new technologies, it can be profit maximizing if not all firms adopt the new technology
- Order effects models (not covered here)
  - Early adopters might have sustainable excess returns that cannot be replicated or extinguished by late adopters

Epidemic effects - 1

- Similarity to spread of infectious diseases ('epidemic')
  - In equilibrium, N firms would adopt new technology
  - Only a few firms might originally know about the new technology
  - As other firms make contact with early adopters, they get informed and adopt as well ('infection')
  - Diffusion process is viewed as adjustment towards equilibrium
- Variables:
  - N potential adopters
  - $M(t)$ cumulative number of users in period t
  - $\delta M(t)/N$ number of users a potential adopter makes contact with in period t
  - q is probability that contact will lead to adoption

Epidemic effects - 2

- Number of new adopters in period *t*:

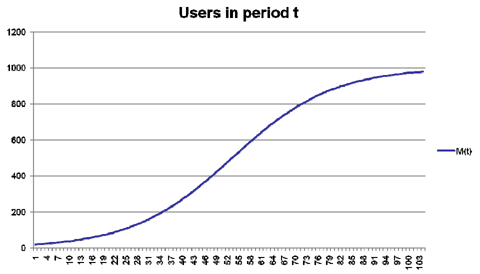
$$\frac{dM(t)}{dt} = \frac{\delta q M(t)}{N}\{N - M(t)\}$$

- Solving with respect to *M(t)*:

$$M(t) = \frac{N}{1+\exp(-p-\delta q t)}$$

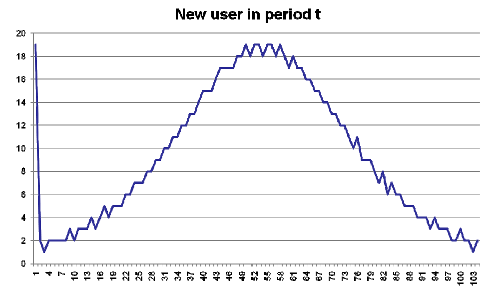
- …where *p* is the starting date of the diffusion process, i.e. intercept term
- This is the standard logistic function! Nice…

Example



Parameters: N = 1000; p = -4; q = 0,25; δ = 0.3

Example



Parameters: N = 1000; p = -4; q = 0,25; δ = 0.3

Rank effects - 1

- Assumptions
  - Perfect knowledge about innovation
  - Heterogeneous population – different expected benefits from adoption
  - Falling prices per quality unit of technology over time
- Market for new technology is in equilibrium throughout the diffusion process
  - Firms make individually optimal investment decisions
- Variables
  - *V(t,t)* expected gross benefit of adoption in period *t*; adoption in *t*
  - *c(t)* cost of adoption in period *t*
  - *M(t)* = *m(t)***N* number of user in *t* as share of population *N*

Rank effects – 2

- Relevant dimension of firm heterogeneity include:
  - Location (country, city…)
  - Sector
  - Size class
  - Previous investments (e.g. related or unrelated technologies)
  - Complementary inputs (e.g. R&D, human capital)
  - Organizational structure, -culture, and –intelligence
  - Risk taking propensity of managers and their openness to technological change
- As a result, firms can have different expected net benefits from adoption of the same technology

Investment decision: Rank effects – 3

- Present value of new technology is the discounted future cash flow of additional profits due to new technology:

$$V(t,t) = \int_{\tau=t}^{\infty} \Pi(\tau,t)\exp(-r\tau)d\tau$$

  - t is time of adoption
  - τ is point in time
  - r is discount rate
- Net present value:

$$NV(t,t) = V(t,t) - P(t)$$

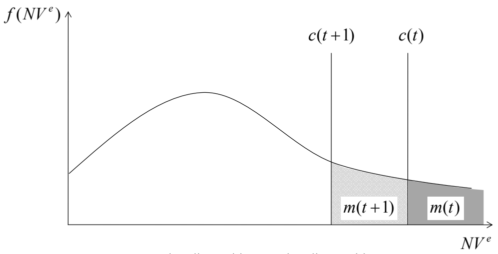
- If prices and benefits are constant over time, invest if:

$$NV(t,t) \geq 0$$

Investment decision: Rank effects – 4

- If prices and benefits may change over time, firms have to form expectations and optimize timing of adoption:
  - Waiting may be more beneficial than adopting immediately
  - Adoption in *t* requires not only $NV^e(t,t) \geq 0$, but also that $NV^e(t,t) > NV^e(t+i,t+i) \quad \forall i$
  - In other words, it must also not be profitable to postpone adoption because of expected falling prices or rising net benefits in the future

Diffusion over time: Rank effects – 5



$$c(t+1) < c(t) \rightarrow m(t+1) > m(t)$$

Source: Stoneman (2002)

Stock effects – 1

- Assumptions
  - Perfect knowledge about innovation
  - No risk
  - Homogeneous population of firms competing against each other in the same output market
  - No entry or exit, no learning-by-doing, no other scarce production factors
  - Falling prices per quality unit of technology over time
- Market for new technology is in equilibrium throughout the diffusion process
  - Firms make individually optimal investment decisions, given the investment decision of their rivals (game theoretical equilibrium)

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Stock effects – 2

- Crucial for understanding:
  - For each firm adopting the new cost reducing technology, it will be optimal to expand production.
  - Demand function remains constant. Hence, any expansion of production will lower the equilibrium market price.
  - Both firms with the new or the old technology can only charge this equilibrium price.
  - Hence, technology adoption of rivals cuts into the profit line of firms that have not yet adopted.
  - Nevertheless, if new technology becomes sufficiently better or cheaper over time, it will not be optimal for all firms to adopt immediately.
  - Trade-off between these two factors leads to diffusion path…

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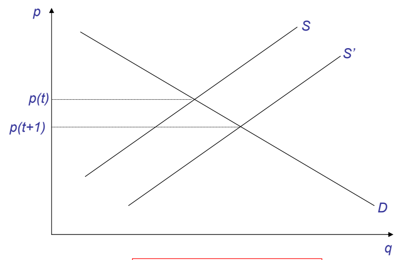
Output market changes: Stock effects – 3



$M(t+1) > M(t) \rightarrow p(t+1) < p(t)$

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Variables: Stock effects – 4

- $p(t)$ equilibrium market price at t
- $M(t)$ number of users of new technology at t
- c_0 marginal cost of old technology
- c_1 marginal cost of new technology
- $q_0(t)$ output of firm with old technology at t
- $q_1(t)$ output of firm with new technology at t
- $\Pi_0(t)$ annual profit with old technology at t
- $\Pi_1(t)$ annual profit with new technology at t
- $V_0(t,t)$ present value of profit streams with old technology
- $V_1(t,t)$ present value of profit streams with new technology
- r discount rate
- $C(t)$ purchasing cost of technology at t

Payoffs: Stock effects – 5

- Profits with old and new technology:
  $\Pi_0(t) = (p(t) - c_0)q_0(t)$
  $\Pi_1(t) = (p(t) - c_1)q_1(t)$
- If new technology is superior to old technology:
  $c_1 < c_0 \text{ and } q_1 > q_0 \rightarrow \Pi_1 > \Pi_0$
  - Profit advantage of firms using new technology
- For simplicity, assume the technology has infinite life and firms have myopic expectations. Present values:

$$V_1(t,t) = \int_{\tau=t}^{\infty} \Pi_1(\tau,t)\exp(-r\tau)d\tau; \quad V_0(t,t) = \int_{\tau=t}^{\infty} \Pi_0(\tau,t)\exp(-r\tau)d\tau$$

Investment decision: Stock effects – 6

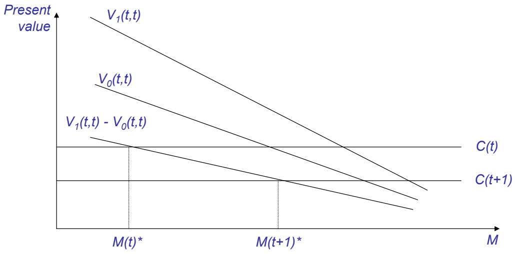
- Difference between payoff streams (under myopic expectations):

$$V_1(t,t) - V_0(t,t) = \frac{\Pi_1(M(t)) - \Pi_0(M(t))}{r}$$

- Investment rule:

$$V_1(t,t) - V_0(t,t) = \frac{\Pi_1(M(t)) - \Pi_0(M(t))}{r} > C(t)$$

Profit gains: Stock effects – 7



Source: Stoneman (2002)

Characteristics of equilibrium: Stock effects – 8

- Firms are *ex ante* identical. If *C* falls deep enough, all firms will adopt, they will be identical *ex post* as well.
- During the diffusion process, firms are heterogeneous with respect to technology adoption and profits.
- Early adopters have the highest profit gains over time.
- Yet, it is not clear who these firms will be:
  - *N* pure strategy equilibria
  - Coordination problem

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Extensions

- Order effects
- Supply side
- Coordination issues
- Risk and uncertainty
  - Behavioral biases of decision makers
    - Prior gains and losses
    - Biased perceptions
- Diffusion of multiple, related technologies
- Diffusion policy

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Some empirical evidence

- Usually very strong influence of rank effects
  - Firm size (+ for many technologies)
  - Sector
  - Country
  - Previous investments in complementary technologies & resources
  - Organizational characteristics
- Also evidence for epidemic effects
- Only weak evidence for stock and order effects
- Policies intended to speed up diffusion seem to be rather ineffective