Simulation Innovation: a Node

Simulation In Innovation: What models of innovation generation, diffusion and impact can teach us

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Acknowledgements

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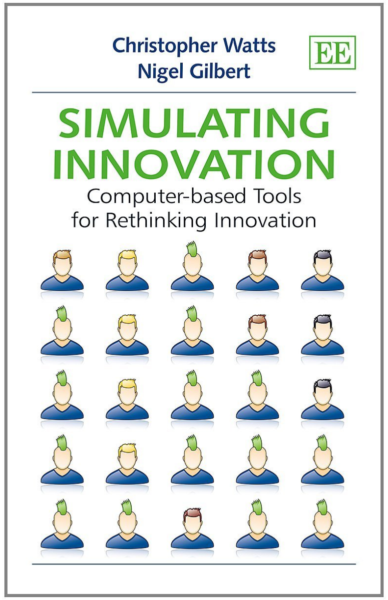
- Christopher Watts is a member of Ludwig-Maximilians University, Munich

The book



- This paper draws upon the book

  Watts, Christopher & Nigel Gilbert (2014) “Simulating Innovation: Computer-based Tools for Rethinking Innovation”. Edward Elgar Publishing: Cheltenham, UK.

- See the website to download models

  http://www.simian.ac.uk/resources/models/simulating-innovation

- What’s it about?
  - A critical survey of simulation models in innovation studies: (1) complexity science, (2) diffusion models, (3) social networks, path dependence, herds and fads, (4) organisational learning, (5) scientific publication, (6) ANT & SCOT, adopting & adapting, innovation as constraint satisfaction, (7) technological evolution, innovation networks

Today's contents

- Why simulate innovation (using ABMs)?
  - Explain stylised facts and patterns in terms of micro-level generative mechanisms
- How not to simulate innovation
  - It's not about forecasting single numbers
  - It's not about the diffusion of some new thing
- Some examples (3 today)
  - Collective learning model, Percolation model, Hypercycles model
- Key themes
  - Collective intelligence as heuristic search, Representation of innovation, Input structures, Output structures, Networks as inputs and outputs

WHY
SIMULATE INNOVATION?

Tools for thinking

- Models are *tools for thinking*
- They focus our attention on particular things
  - Phenomena they will explain
  - Causal mechanisms which they represent
- They may divert attention from other things
  - E.g. Pre-crisis economics
    - Mainstream, neo-classical economics focuses on market equilibria
      - Crises and crashes are not supposed to happen
    - Humans and organisations are assumed to be “rational agents”
      - Selfish optimisers, with perfect information and instantaneous ability to choose
    - Analysis is easiest if every agent is identical
      - So ignore inequality

Tools for rethinking economics

- We need better tools for economics
  - Psychologically realistic decision making
  - Agents motivated by more than money
    - Input from psychology, sociology, cognitive science
  - Heterogeneous agents
  - Role of social networks, not free markets
  - Non-linear inputs
  - Non-equilibrium outcomes
  - Etc.

- Tools for evolutionary economics
  - And neo-keynesian, behavioural, marxist…

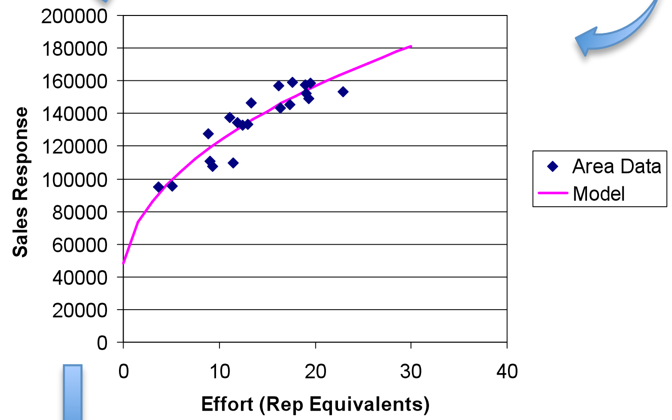
Agent-based simulation models as the tool?

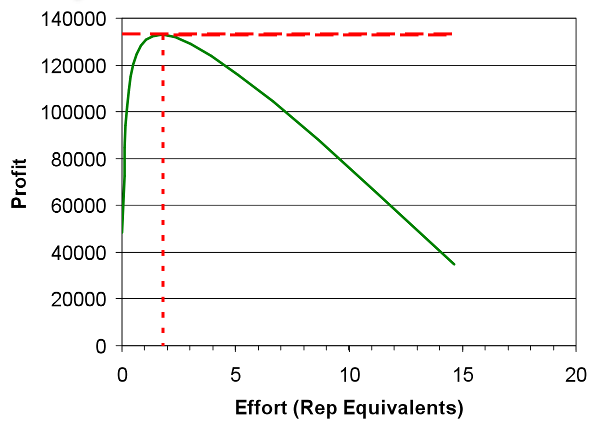
- What ABMs offer
  - Heterogeneous agents
  - In social networks of interdependencies
  - Random variation in behaviour
  - Adapting to dynamic (co-adapting) environments
  - Bounded (rational?), heuristic decision making using limited information
  - Generate emergent phenomena

Modelling for Business Analysts

1. Get historical, quantitative data
    - Effort: How many calls the sales reps made in each area
    - Response: How many sales were obtained in each area
2. Get mathematical model
    - Making a few theoretical assumptions
3. Fit model to data
4. Interpret model for client
    - “If X is your effort, you will get $Y in response.”
    - “X will cost you Z.”
5. Make recommendations
    - “Choose X = 2 to maximise profit.”
6. Boost client’s sales(?), justify your fee, …

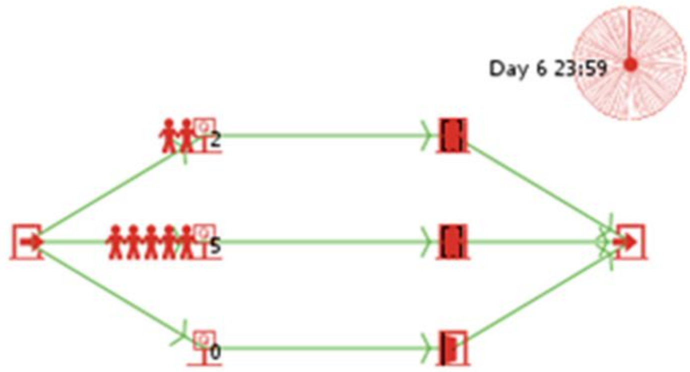
$$S = \lambda + \frac{\Delta \times \chi^{\gamma}}{\rho + \chi^{\gamma}}$$

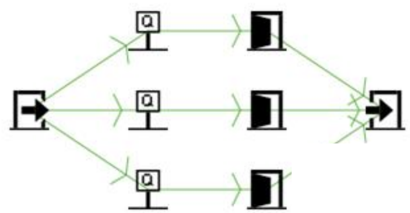


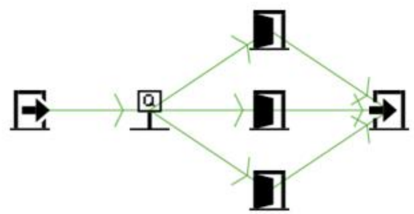


Simulation models in Operations Research

- "Simulation" in O.R. means discrete-event simulation
- Typically used for representing queueing systems
  - Customers waiting for service in supermarket, post office
  - Patients waiting for operation
  - Cars waiting for traffic lights
- How many servers do I need?
  - Waiting bad for customers, therefore bad for business
  - Servers cost money
- How should I structure my queues?
  - 1 queue for n servers, or n queues for n servers?







Pattern-oriented modelling

- In *Social Simulation* we rarely make quantitative forecasts
- Rather we connect **social mechanisms** to the **patterns** that emerge from them
  - Qualitative outcomes, not forecasts of single numbers
  - We link micro to macro
    - But without the hard maths. and the dodgy behavioural assumptions
- We provide *plausible* explanations
  - Not *probable* ones
    - Unlike statistical modelling
  - Not *deterministic* ones
    - Unlike mathematical deduction
  - Not *necessary* ones
    - Unlike Kantian philosophy

Why simulate innovation?

- Bridge the micro-macro gap
  - There are various stylised facts concerning innovation
  - Models of micro-level social mechanisms may be able to generate these macro-level facts
    - Pattern-oriented modelling
- Demonstrate a sufficient cause for the pattern
  - Although alternative explanations may exist
- Demonstrate when emergence is and is not likely to occur
  - Network structures, behavioural practices, environmental dynamics

Why not other research methods?

- Complexity
  - Heterogeneous agents with multiple mechanisms may have non-trivial, emergent phenomena, e.g. auto-catalysis
  - Hard for quantitative and mathematical approaches to reproduce this
- Experimentation
  - Practical, ethical reasons prevent experimentation and answering what-if hypotheticals
  - Qualitative studies struggle to obtain the scale needed to explain macro-level patterns

What do we mean by innovation?

- Ideas, practices, beliefs, technologies, processes, roles, structures, organisations… that are
  - **New**, novel, newly invented, created, emerged or introduced
  - **Useful**, valuable, practical, having an important effect
- Most of the models are highly abstract!
  - Though their authors may have had particular case studies in mind, and even (occasionally) some empirical data
    - E.g. the SKIN model

HOW NOT TO SIMULATE INNOVATION?

The linear model of innovation

- Three distinct phases identified
  - **Innovation**, **Invention** or **Introduction** of innovative thing, product, practice, technology, etc.
  - **Diffusion** of the innovation
  - **Impact** of the diffusion
    - On adopters, inventors, suppliers, other technologies and services

Critique of the linear model of innovation

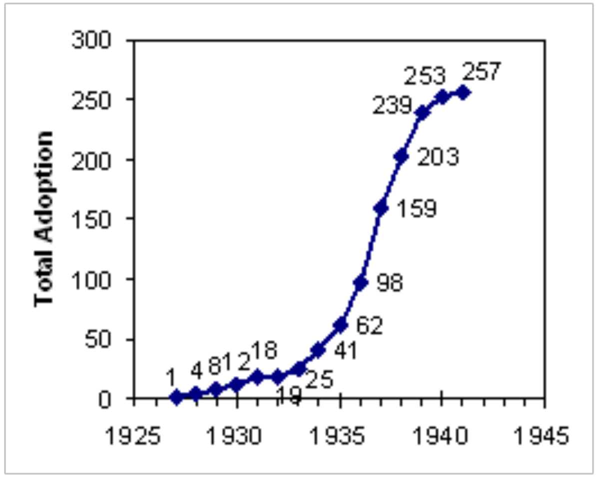
- Should we separate the phases?
  - The origins or generation of innovation is often left a mystery
  - Once launched, an innovative product may be reinterpreted, reapplied, modified by its users
    - "To adopt is to adapt" (Akrich et al.)
    - The innovation is not fixed over time, nor identical to all potential adopters
  - Innovations' impact may include affecting the chances of their further adaptation and diffusion, and the generation of new innovations
    - E.g. Our desire for compatibility in information technology leads to positive feedback loops, increasing returns to scale, market lock-in on inferior designs

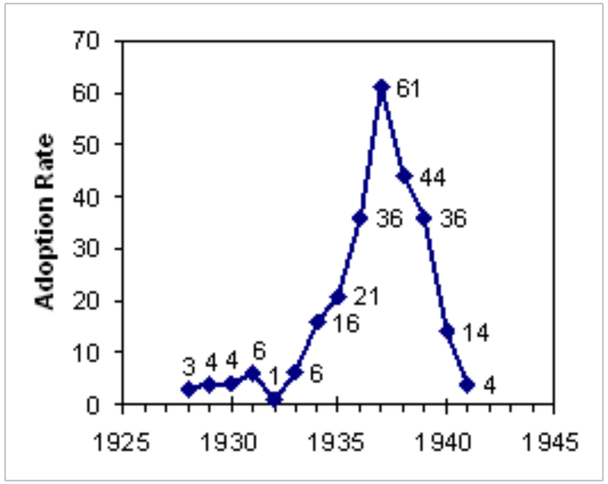
Webs of technologies & practices

- Innovative technologies do not diffuse in a vacuum; they have competing, dependent and supporting products and services
- Creative destruction:
  - New technologies can destroy whole webs of interdependent technologies, practices & roles, while enabling new webs to form
    - The automobile rendered obsolete the horse, the cart, the haymaker, the blacksmith, etc.
    - The automobile needed petrol stations, tarmac roads, mechanics, etc.
    - The automobile made possible roadtrips, drive-in cinemas, out-of-town shopping malls, mega-churches, etc.

The diffusion curve

- Ryan & Gross (1943) data on adoption of hybrid seed corn among Mid-west farmers
  - Total adoption to date followed an S-curve
  - Adoption rate rose to a peak then declined
- Focus on
  - Take-off point
  - Point of peak rate
  - Market saturation level





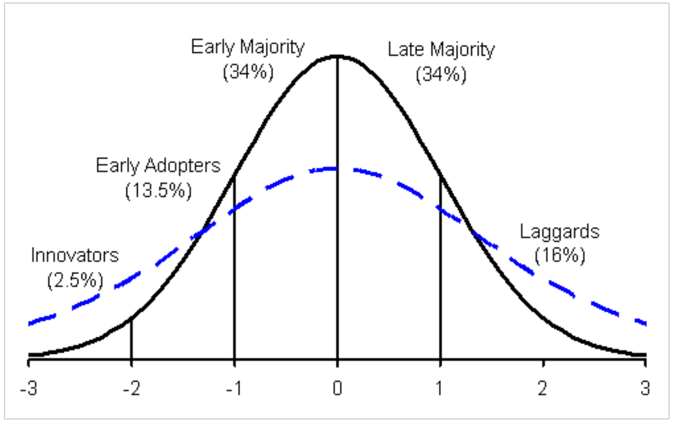
Rival models for the diffusion of innovations

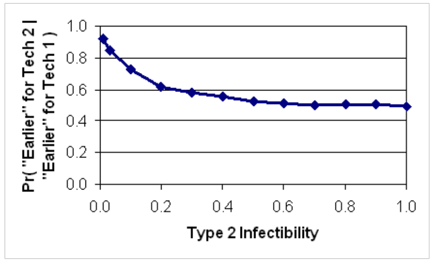
- **Epidemic model**
  - Innovations spread like an infectious disease
    - Word-of-mouth advertising
    - Imitating the neighbours
- Preferred explanation for sociologists
- Focus on
  - structure of **social networks**
  - who are the hubs in the net
  - charismatic super-persuaders
  - **communication** practices

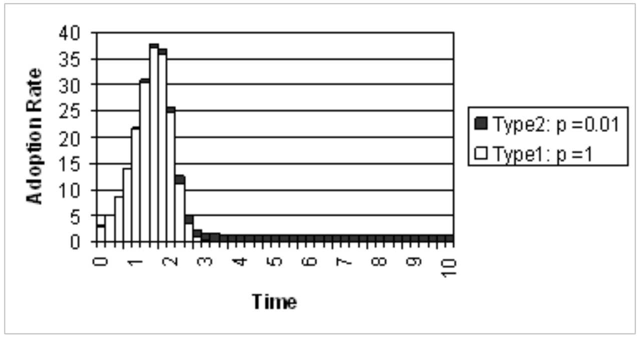
- **Probit model**
  - Heterogeneous agents repeatedly reconsider decision to adopt in changing environment
- Preferred explanation for economists
- Focus on
  - Decision makers' attributes
    - Size, wealth, knowledge, capabilities
  - Changing socio-economic context
    - Market price, economic confidence, public experience of the innovation

The two explanations can be incompatible

- Rogers (1958) categorised adopters by when they adopted:
  - innovators; early adopters; early majority; late majority; laggards
- Rogers (2003, ch.7) identified relations between these categories and socio-economic and personality attributes of adopters
- The simplest epidemic model (the S-I model) is not compatible with this diversity in adopter attributes
  - *Either* adopter attributes will give too little information about future adoption to be useful
  - *Or* the adoption rate curve will be skewed, not symmetrical
  - The adoption rate curve (from the logistic function) has a different shape from a normal distribution for attributes
    - They have different mathematics



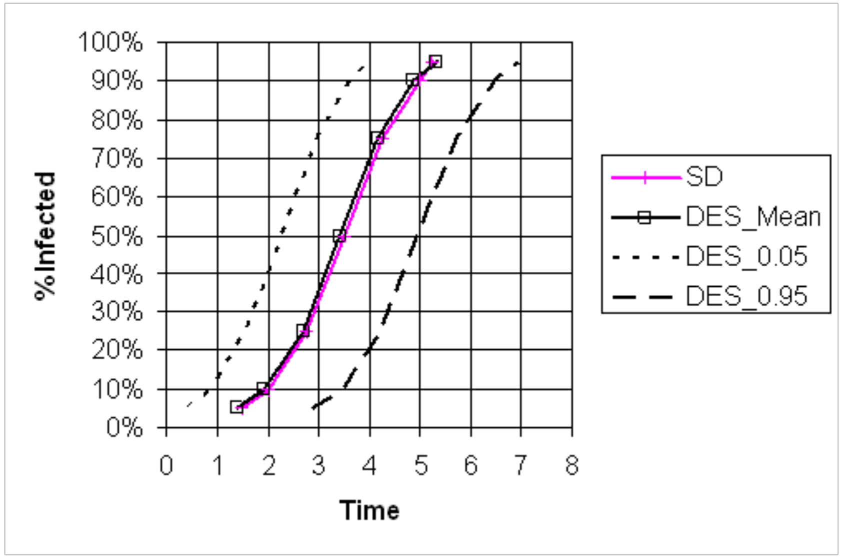


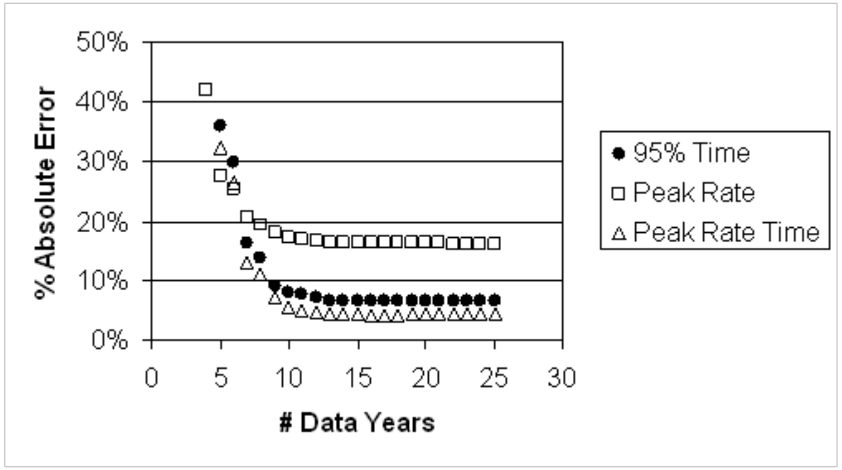


Forecasting adoption will rarely be useful

- Models that omit random variation will produce expensive errors

- Models fit to time-series data will
  - *either* have too little data and **make expensive mistakes** about how many will eventually adopt
  - *or* require too much data and provide accurate **forecasts too late** to be of use
    - The peak adoption will have already occurred





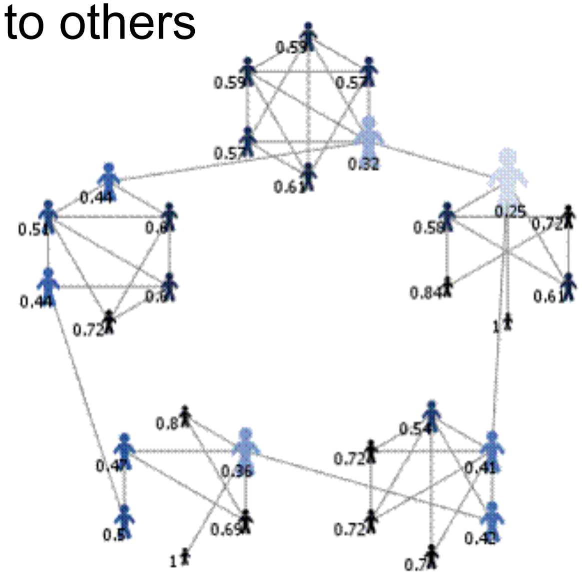
Rethinking innovation: it's complex

- More focus on networks of interdependencies among diverse parts
- More focus on generation, adaptation and reinterpretation of innovations
- More focus on dynamic context of adoption
- More focus on chance events leading to later lock-in
  - Less focus on the attributes of the winners

NETWORKS & INNOVATION

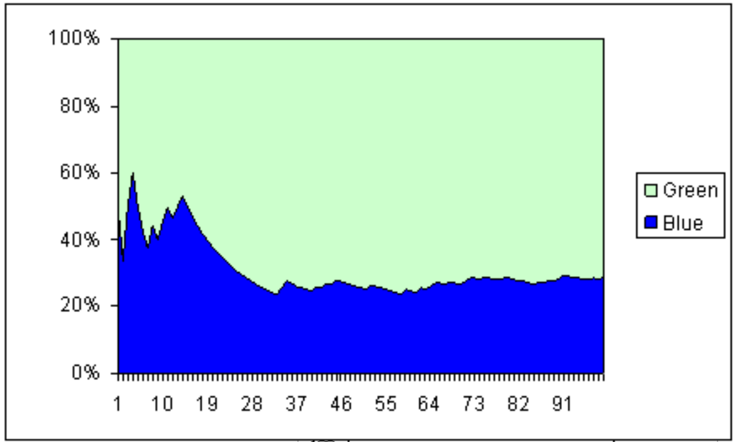
Diffusion in a social network

- If individuals are influenced in adoption by their friends, neighbours and colleagues, network structures become important
- Who is the best person to start diffusion?
  - Target the hub, the one with shortest paths to others or the bridge between groups?
  - This varies with network structure

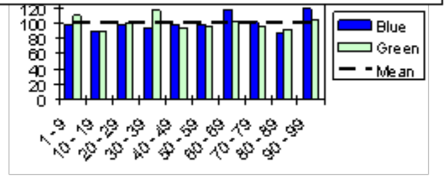


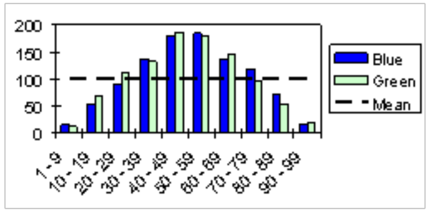
Competing diffusions

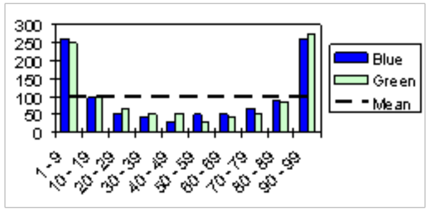
- How does network structure affect the outcome of competing diffusions?
  - E.g. the relative numbers of adopters of two technologies, “Blue” and “Green”
- Path dependency: Early adoption decisions affect the chances of later adoption decisions



- Network structure affects the distribution of possible outcomes:
  - 0% Blue:100% Green, 10%:90%, 50%:50% etc.
  - In random networks, all outcomes are equally likely
  - In regular networks, a 50:50 balance is the most likely
    - the fairest network?
  - In tree structures, winner often takes all

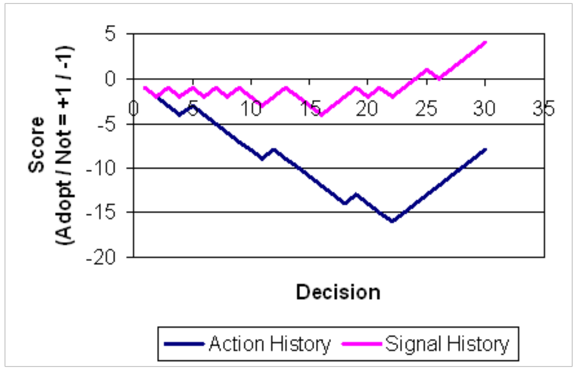


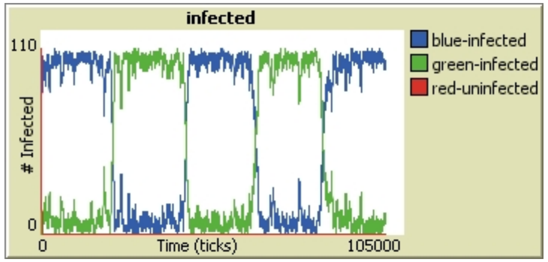


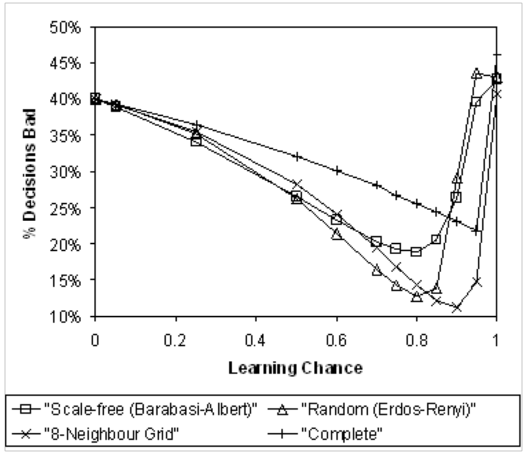


Social learning

- If adopters have only weak ability to judge the value of adopting, can they improve this by imitating others?
- **Information cascades**: after the first few adoption decisions, a cascade of copycat adoptions occurs
  - Herd behaviour
- Rational agents should factor this in: agents adopting as a herd do not provide extra information about the innovation
- But decisions that surprisingly buck the trend may reflect new information
  - Mavericks who ignore the trend can benefit the collective
- Network structures affect how often we need to learn from others and how often make our own judgment







SOME SIMULATION MODELS

Simulation models of innovation

- **L&F:** Lazer, D., & Friedman, A. (2007). The network structure of exploration and exploitation. Administrative Science Quarterly, 52(4), 667-694.
- **Percolation:** Silverberg, G., & Verspagen, B. (2005). A percolation model of innovation in complex technology spaces. Journal of Economic Dynamics & Control, 29(1-2), 225-244. doi: 10.1016/j.jedc.2003.05.005
- **Hypercycles:** Padgett, J. F., Lee, D., & Collier, N. (2003). Economic production as chemistry. Industrial and Corporate Change, 12(4), 843-877. doi: 10.1093/icc/12.4.843
- **A&P:** Arthur, W. B., & Polak, W. (2006). The evolution of technology within a simple computer model. Complexity, 11(5), 23-31. doi: 10.1002/cplx.20130
- **CJZ:** Cowan, R., Jonard, N., & Zimmermann, J. B. (2007). Bilateral collaboration and the emergence of innovation networks. Management Science, 53(7), 1051-1067. doi: 10.1287/mnsc.1060.0618
- **SKIN:** Gilbert, N., Ahrweiler, P., & Pyka, A. (2007). Learning in innovation networks: Some simulation experiments. Physica a-Statistical Mechanics and Its Applications, 378(1), 100-109. doi: 10.1016/j.physa.2006.11.050

- More references available in the book

Questions for comparing models

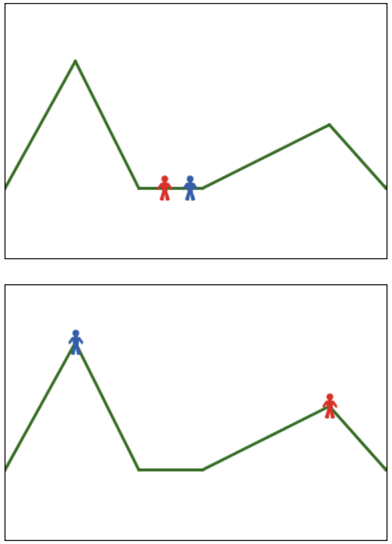
- What is the innovation?
  - e.g. new idea, belief, combination, theory, product, process, sequence, organisation, structure…
- How is it represented in the model?
  - Bit string, Transformation rule, Vector position in state space, Network of agents...
- What input structures are assumed?
  - Social networks, Fitness landscapes, Environment, Desired functions…
- What patterns emerge?
  - Growth curves, Frequency distributions, Networks…

Three types of example

1. Models of organisational learning
   - Innovation as collective problem solving
2. Models of technological evolution
   - Innovation among interdependent technologies
3. Models of emergent, novel organisation
   - Emergent networks and other structures from individual actors' activities

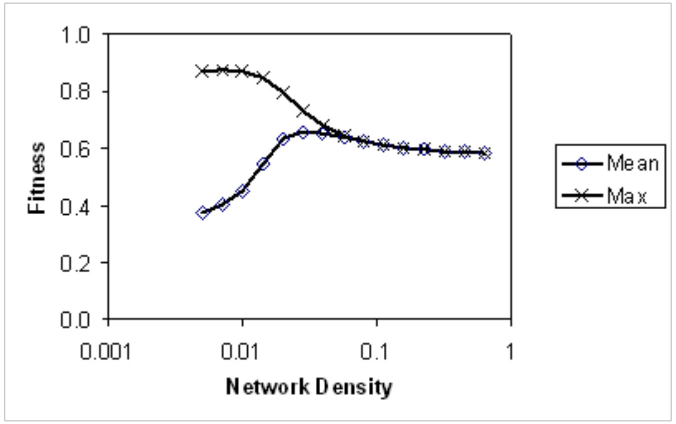
Type 1: Explore & exploit: Models of organisational learning

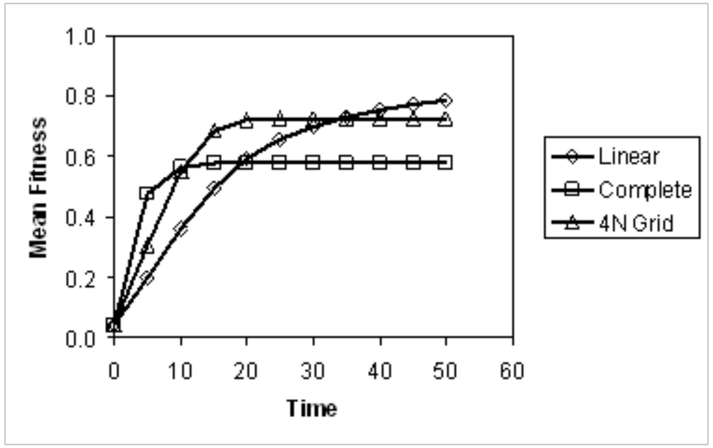
- Individuals in a firm seek new, better combinations of routine practices
  - “Better” is assumed to be common to all; every employee is motivated by the same objective or goal
- They use heuristics, routine innovation practices, to search for these combinations:
  - Trial-and-error experimentation
  - Learning from others
- Aim for a balance between **exploration** of new combinations and **exploitation** of ones already found
- If sharing ideas, avoid groupthink and **premature convergence** on inferior solutions



Lazer & Friedman's model of collective learning

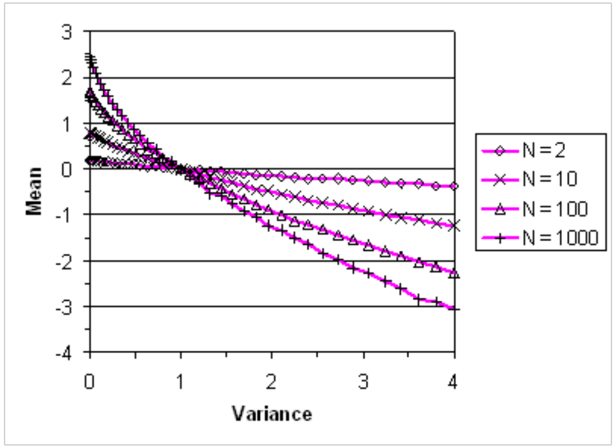
- Object: bit string representing combination of binary beliefs
  - Knowledge increases through agents' use of trial-and-error and learning-from-others heuristics
- Input structures:
  - Fitness landscape (Kauffman's NK)
  - Social network for agents
- Output structure: Fitness improvement curve
- Problems solving performance varies with
  - Relative frequency of different innovation practices
  - Social network structure among problem solvers

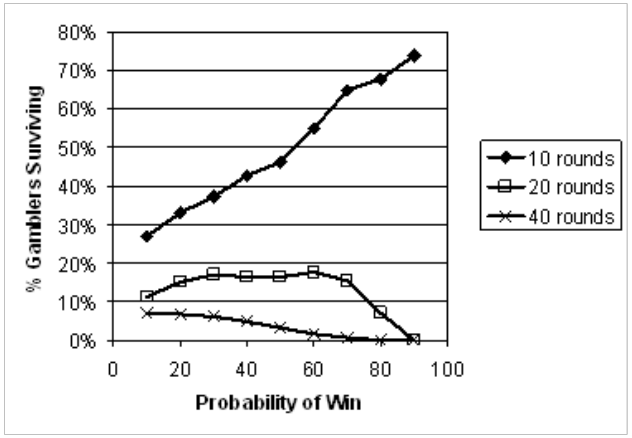




Refocusing organisational learning

- Most models assume individuals seek solutions to the same problem
  - The firm's goal, e.g. the firm's profits
- Most models investigate what produces the best expected, or average, fitness
  - But individuals are often rewarded for their individual successes
  - If winner takes all, it may be more rational to take risks, adopt innovation practices with more variance in success
- Given fixed resources and gambles with negative expected payoffs, individual survival may be longer if you prefer high-risk, high-payoff activities





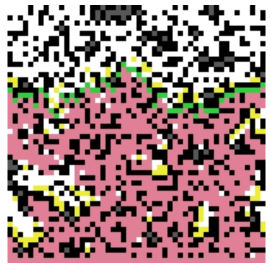
Type 2: Models of technological evolution

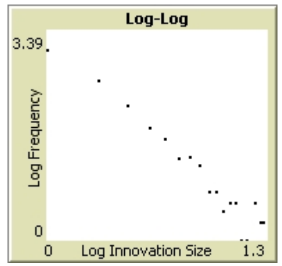
- Innovations make possible further innovations
- Innovations render previous ones obsolete
- The size, or importance, of an innovation may be defined in terms of its effect on other innovations

- What is the distribution of changes?
  - Periods of small, incremental changes, punctuated with brief periods of revolution
  - Scale-free: changes occur on all scales
- It becomes hard to forecast which will be the most important innovations, and who will be their inventors

Silverberg & Verspagen's Percolation model of technological evolution

- Object: technologies in technology space are nodes in grid; R&D leads to percolation
  - Highest node is state of the art
  - Innovations are jumps in state of the art
- Input structure: grid structure
- Output structure: scale-free frequency distribution of innovation sizes





Arthur & Polak's model of technological evolution

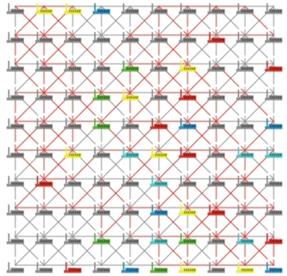
- Object: logic circuit composed of NAND gates
  - Knowledge: set of circuit designs, each composed of other members
- Input structure: evaluate using list of desired logic functions
  - New designs may replace older ones because satisfy more functions or cheaper/simpler
  - Innovation size: the number of technological designs rendered obsolete and replaced
- Output structure: scale-free frequency distribution of technology replacement sizes

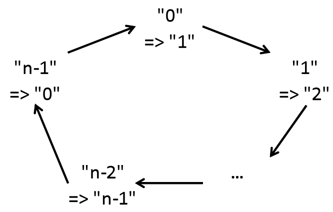
Type 3: The emergence of novel organisation

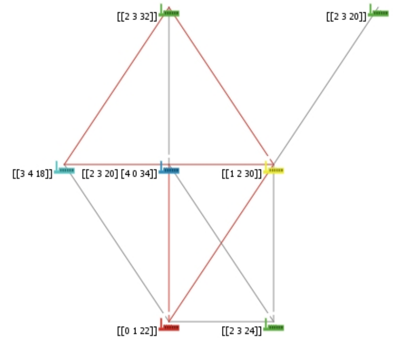
- Not innovation as new *combinations* of things, but the emergence of new things
- New products are part of webs of supporting practices and technologies
- Under what circumstances can new network structures emerge without complicated processes of design?
  - Self-organising: individual actors create the structure through their activities
- What structural properties will the emergent networks have?
  - Self-maintaining: the structure determines the continued success of particular roles for the actors

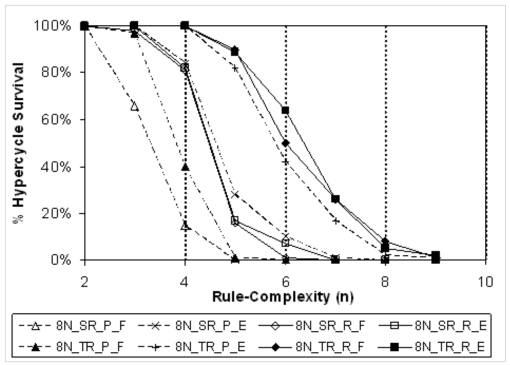
Padgett's hypercycles model of economic production

- Object: production rules (Given a "0", turn it into a "1")
  - Knowledge: firms increase their stocks of rules through learning-by-doing
- Input structure: heterogeneous firms organised in a social network
  - Firms transfer their output products to neighbours to use
- Output structure: self-organised, self-maintaining network of firms with rules
  - A novel object
  - Think about the emergence of organisations and markets, life, etc.









CJZ's model of emergent innovation networks (Cowan, Jonnard & Zimmermann 2007)

- Object: quantities of knowledge represented in several dimensions
  - Collaboration produces increases in quantities
    - Cobb-Douglas production function
- Input structure: none specified
- Output structure: social networks

SKIN model (Ahrweiler, Gilbert, Pyka, Simulating Knowledge dynamics in Innovation Networks)

- Objects: vectors (kenes) used for producing other vectors; recipe (innovation hypothesis) for doing this
  - Knowledge: firms fund R&D, trade expertise on market, form alliances (innovation networks)
- Input structures?
  - kenes are just maths
  - Firms could have network structure
- Outputs: scale-free distribution in innovation network size

WHAT WE LEARNT

There are a lot more models than this!

- If I had a euro for every paper containing a diffusion model…

- The book might not cover your favourite models in innovation studies
  - So ask: What, if anything, would other models add to the features in the paper's or book's models?

- How would you apply a model to a *real* case or pattern?

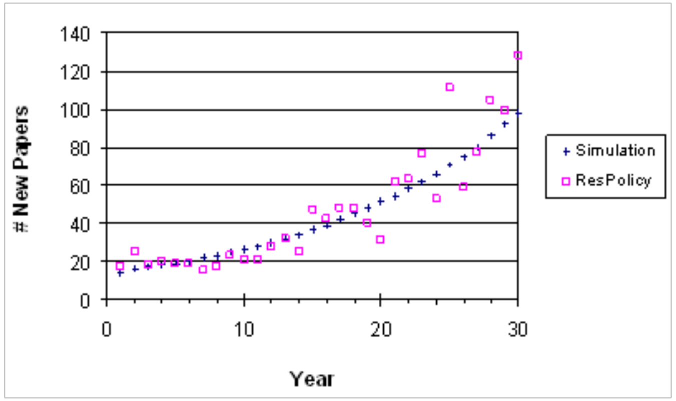
Key themes

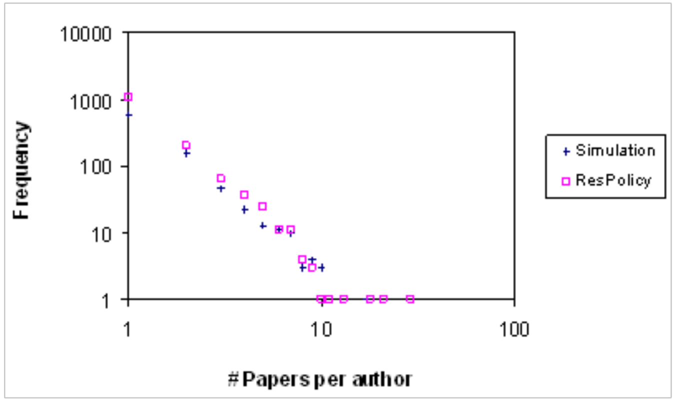
- Innovation is the product of collective effort
  - Human agents can solve problems collectively using simple routine search practices, that as individuals they would be unlikely to solve on their own
  - Some organisational structures and practices are better than others for generating innovation

- Innovation is usually recombination of existing parts
  - Innovation can be reinterpretation of existing technology
    - Tracing new trajectories in technology space
    - Exaptive bootstrapping (Villani et al.)
- New objects can emerge as self-maintaining / auto-catalytic structures

Problem: Combining mechanisms

- Real human agents belong to multiple networks at any one time and engage in multiple practices
- Combining micro-level mechanisms might mean they no longer generate the desired patterns
  - Our model of academic publication produced realistic growth curves and frequency distributions
  - Then we added the concept of authors engaging in heuristic search for better combinations of ideas
    - As seen in models of organisational learning
  - Suddenly it became much harder to calibrate a model!





Model replication is possible

Model	Attempted?	Did it work?	Causes
L&F's Learning	Yes	Perfect	Easy model, Uses NK fitness, Good variance reduction
S&V's Percolation	Yes	Nearly perfect	Easy model / clear description
Padgett's hypercycles	Yes	Nearly perfect	Multiple papers
A&P's Tech. Evolution	No	-	Big computer X lots of time
CJZ's innovation networks	Yes	No!	They "deleted" their original code

Download models from the website

- Our own models
- Our replications of classic models

  www.simian.ac.uk

- And don't forget to look out for the book!

  Watts, Christopher & Nigel Gilbert (2014) "Simulating Innovation: Computer-based Tools for Rethinking Innovation". Edward Elgar Publishing: Cheltenham, UK.

STYLISED FACTS ABOUT INNOVATION

Stylised facts

- Patterns found in quantitative data
  - Academic publication data
  - Social and firm network structures
  - Technological change

- These are regularities that social science needs to explain
- Which methods can do it?

Innovation is progressive, as learning or problem solving

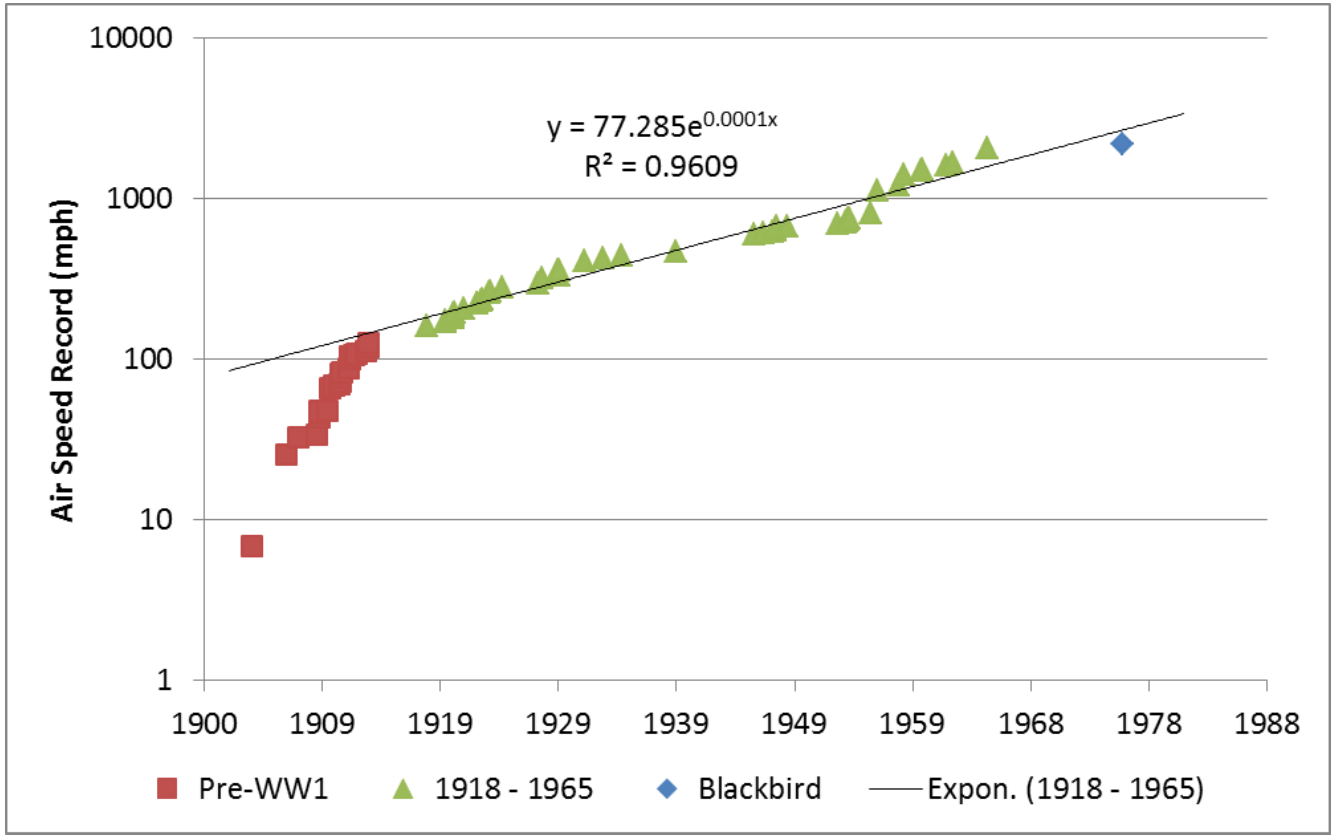
- While searching for what goes well with what, ever better solutions to problems are found over time
- Older solutions are rendered obsolete and replaced

- Diminishing returns to search effort?
  - As you approach the optimal or peak solution

Quantitative innovation & trajectories

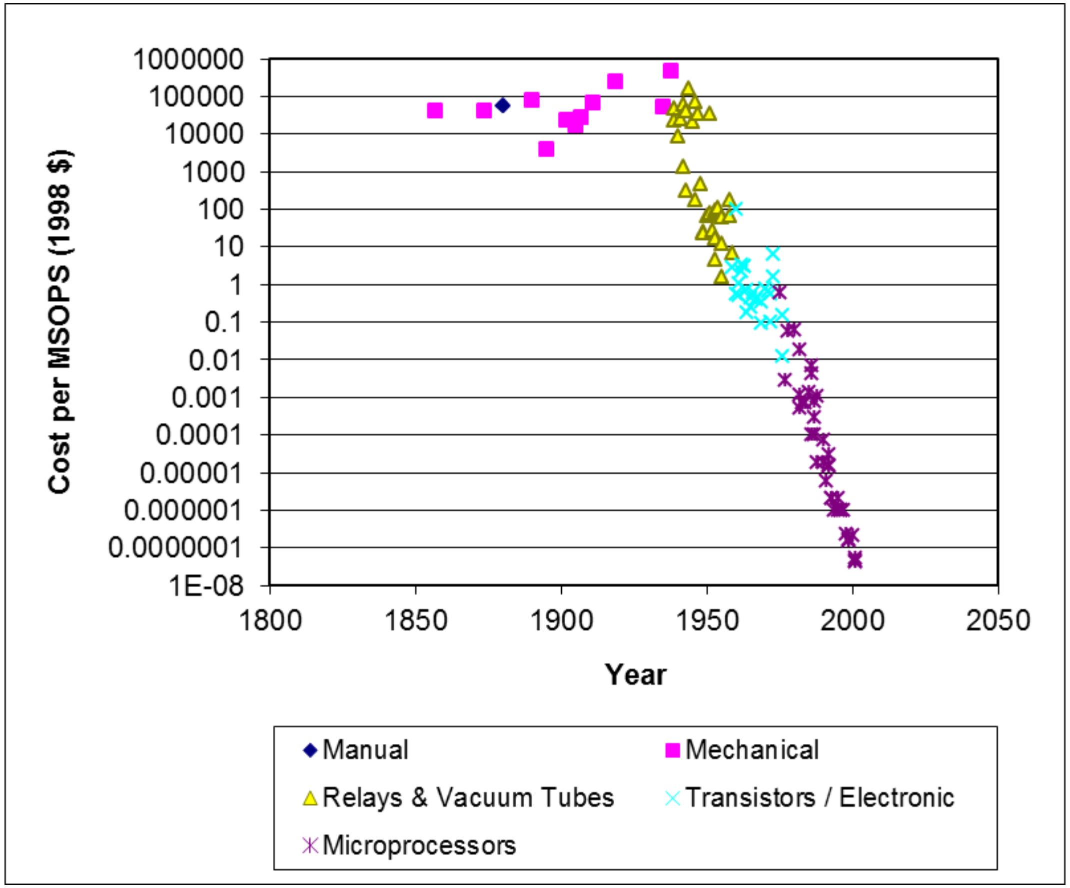
- Many technologies display quantitative improvements over time in quality
  - Better, faster, cheaper
  - At a constant rate, e.g. Moore's law
- Even when there are changes in component technologies or innovators
  - Vacuum tubes, transistors, silicon chips
  - France, Britain, USSR, USA
- Trajectories in technology space?

Air speed records



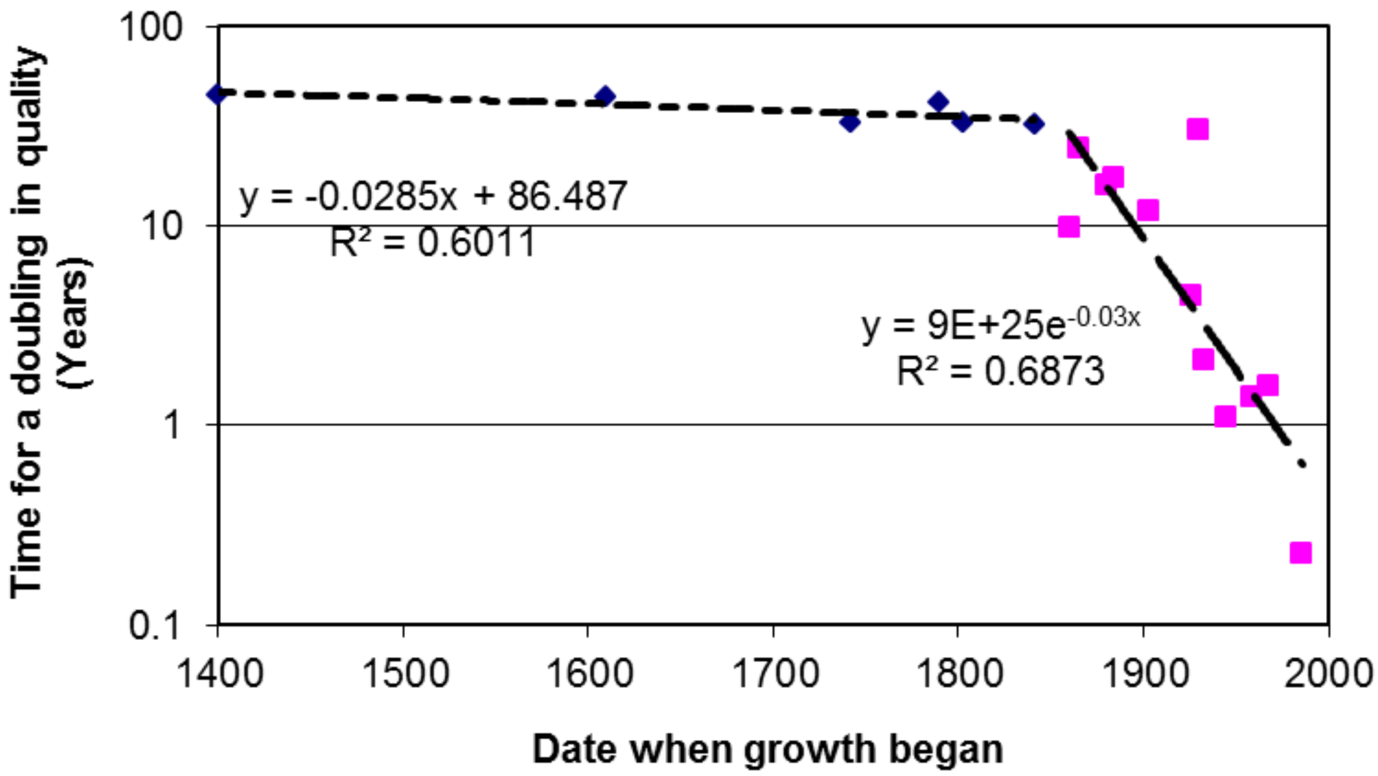
- http://en.wikipedia.org/wiki/Airspeed_record

Computing cost



- Nordhaus, W. D. (2007). Two centuries of productivity growth in computing. *Journal of Economic History*, 67(1), 128-159.

Innovation in the innovation rate



- Lienhard (2006), p. 129
  - Quality-doubling times for various technologies, different choices of quality
  - What happened around 1840?

Qualitative innovation: new things and structures emerge

- The number of goods available increases over time
- Beinhocker, 2007, pp. 456-457:
  - A human being 10000 years ago had 100s of goods available
  - In a US city today there are 10^10 barcodes for things

- Explain in terms of *exaptive bootstrapping* (Villani et al. 2007)?

Scale-free distribution in “innovation size”

- Financial value: Innovators make money (sometimes)
- Use: Innovations are components for later innovations
- Use / Attention: Innovations are cited
  - Citation frequency distributions
- Effect: Innovations cause disruptions, obsolescence, bankruptcies
  - Schumpeter’s “perennial gale of creative destruction”

Distinct types of innovation?

- Incremental and radical…
- …and architectural and modular

Social network structure

- Networks of
  - people, firms, regions, etc.
  - academics, papers, topics,…
  - patents, authors, holders, institutions, places, …
- Produce SNA metrics, science maps
- Incorporate dynamics, endogeneity
  - Networks produce and are produced by innovations
  - Coadaptation