Innovation and Structural Change in Complex Evolutionary Systems

Part I

Innovation: Evidence & Basic Principles

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Aim for the next four days

Final Aim: study economic development as the interactions among several aspects of structural change (**process & outcome**)

Main **source** of *structural change*: *innovation*

Main **sources** of *innovation*: **producers and consumers** (in a system)

Innovation is an outcome of an evolutionary process involving the **interaction** among several actors: **complex system**

⇒ Understand economies as **Evolutionary Complex Systems**

⇒ **Agent Based Models**

Plan for the next four of days

Part I: discuss some evidence and properties of *innovation* (as an evolutionary process)

Part II: discuss some **evidence** and **properties** of *complex systems*

Part III: introduce the use of **ABM** to study complex economic systems – taster of ACE

Part IV: •modelling micro aspects of innovation

- The basic evolutionary process: replicator dynamics
- Search: NK Model
- Path dependency: technological choice

⇒ Part V: model **growth and structural change** as an evolutionary complex dynamic

Innovation & evolution

Part I
Technological change: some properties and empirical evidence

Plan for Part I

- Introduction: innovation as an evolutionary process
- Basic concepts
- Basic properties – empirical evidence
- Diffusion

Main references: Innovation and evolution

- Dosi, G. & Nelson, R. R. (2010), Ch 3 Technical Change and Industrial Dynamics as Evolutionary Processes, in Bronwyn H. Hall & Nathan Rosenberg, ed., *Handbook of the Economics of Innovation*, North-Holland, pp. 64-94
- Fagerberg, Jan. (2013). Innovation – a New Guide. https://ideas.repec.org/p/tik/inowpp/20131119.html.
- Hall, Bronwyn H. (2006) Innovation and Diffusion. In *The Oxford Handbook of Innovation*, edited by Jan Fagerberg, David C Mowery, and Richard R Nelson, 459-84. Oxford: Oxford University Press.
- Malerba, Franco, and Luigi Orsenigo (1997).Technological Regimes and Sectoral Patterns of Innovative Activities. *Industrial and Corporate Change* 6 (1): 83-118. doi:10.1093/icc/6.1.83.
- Metcalfe, S. (2014). Capitalism and evolution. *Journal of Evolutionary Economics*, 24(1), 11-34

A tale of a (capitalistic) economic system

What is the core determinant of change (evolution) of an economic system? (Metcalfe, 2014)

1. Innovation is the key transformative event (continuous search): new products, businesses and organisations, resources, input output, regulations, etc [model]

2. Innovation is relevant only if it diffuses: adapting the innovation to production processes and consumer needs [models]

A tale of a (capitalistic) economic system

3. Diffusion requires changes (uncertainty)
    - firms to produce the new good: new productive capacities
    - consumers to abandon an existing good and “learn to consume” a new one (Witt, 2001)

4. New products require incremental adaptations (more uncertainty)

5. Increased adoption, adaptation, imitation: define a new trajectory and regime [model]
    - Knowledge, institutions, sunk costs (path dependency)

6. Are influenced by and have an influence on other innovations...

A tale of a (capitalistic) economic system

$\Rightarrow$ Technological change is cumulative: builds on previous technology/knowledge/wealth

$\Rightarrow$ Unbalances and structural changes in the process of growth: no condition of equilibrium

$\Rightarrow$ We need an understanding of the economic system mainly from the behaviour of single actors (e.g. how firms innovate)
and of populations to which they pertain (e.g. industrial dynamics)

Our aim in these lectures is not to find ways to predict, but to represent observed dynamic

Basic features of innovation

An intrinsic human activity: understand nature to use its properties to improve humans' well-being

⇒ Change in knowledge

- Learning: individual and collective
  - Context specific (e.g. microsoft vs linux vs apple)

Combine different types of knowledge, skills and resources

Takes time

- accumulation of knowledge – organisation and evolution: the organisation of innovation changes through time

Question

So, if you use your knowledge and time to develop an idea for a new gadget (or app), which is a better than a previous gadget (app), or which does not exist in the market, is this idea (or its prototype) an innovation?

Invention

An idea, sketch, or model for a new means (device, product or process) for achieving some function not obvious beforehand (Kline and Rosenberg, 1986)

Agents: mainly the outcome of an individual (inventor)

Locus: anywhere (Universities, research labs, garages)

Result: most inventions never enter the market

Innovation

Attempt to put the invention into practice and in the market (a technology)

Agents: Mainly the outcome of a systemic effort (entrepreneur is one)

Locus: mainly firms (now Universities)

Result: lag between invention and innovation

- Need/want/demand?
- Technological/knowledge feasibility
- Complementary knowledge

Risk applies to both inventions and innovations: enter the market is no guarantee of success

Incremental Vs radical

Incremental innovation: continuous improvements

Radical innovation: more often related to invention – e.g. car

- Radical to whom? Introducing in a new context: innovation Vs Imitation – e.g. low income country
- Adaptations to a new context may involve incremental innovations – e.g. mobile banking

Technological paradigm: a change in systemic components – e.g. ICT

CAVEAT: often improvements are necessary on a radical change – e.g. the car: $\Rightarrow$ sequence of incremental innovations can have more impact than a radical innovation

Which type of firm innovates?

Schumpeter Mark I

Small entrepreneurs that try to change the society: struggle between innovators and (social) inertia

Schumpeter Mark II

Large firms (teamwork, different sources of knowledge) with capital to invest in R&D

Properties

Innovation and evolution	
Dynamics	**Change**
Knowledge	Accumulation and heterogeneity
Clustering	Accumulation and discrete changes
Trajectories	Path dependence
Uncertainty	Risk / high variance
Heterogeneity	Evolutionary dynamics
Non linearity	Feedbacks / unpredictability
Sectoral differences	Persistent heterogeneity
Systemic	Interactions & contagion
Diffusion	Contagion, innovation, & structural change

Summary

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Knowledge and learning

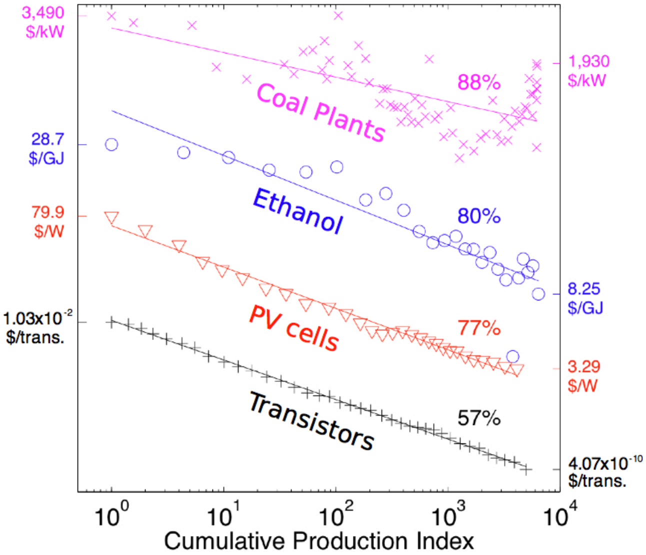
Innovations and knowledge can be appropriated under specific circumstances

- IPR (codified)
- Knowledge embodied in people and goods (even those who work on and with AI)
- (⇒ differences in sectoral systems of innovation)

Knowledge is cumulative

- Not like accumulating capital: only partially traded in markets (some embodied in individuals)

Learning by doing



Source: McNerney et al. (2011)

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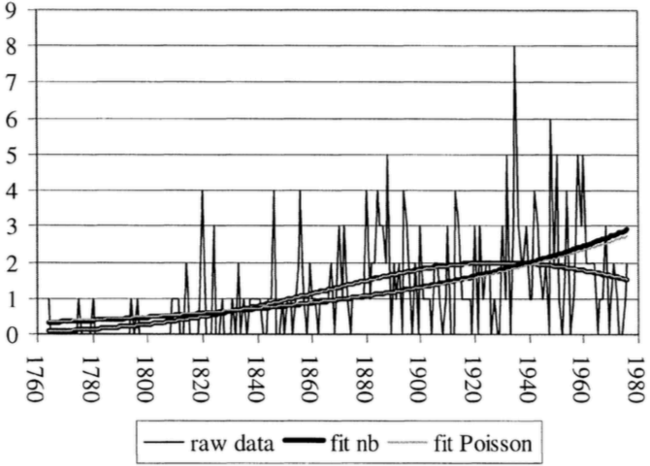
Innovations cluster in time: basic innovations and relevant patents



Source: Silverberg and Verspagen (2003)

Clustering is highly statistically significant; overdispersion (negative binomial models preferred over simple Poisson); no periodicity of clusters.

Cumulativeness

Related to other aspects of cumulation in the economy: physical capital (Young/Kaldor cumulative causation & Verdoon law)

Related to persistent inequalities and multiple equilibria

Source of the next two properties

- path dependence
- generation of heterogeneity and skewed distribution

Sectoral differences: in some technologies/sectors knowledge cumulates more than in others (Malerba and Orsenigo, 1997)

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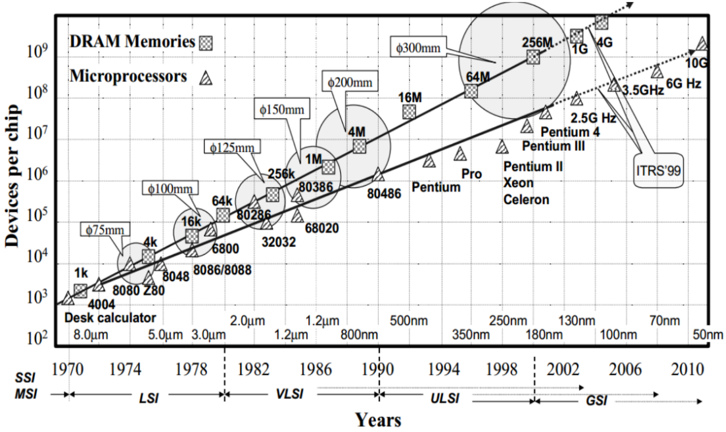
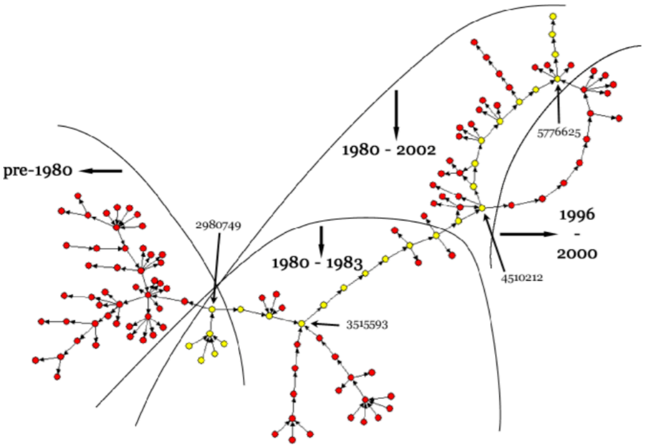
Technologies follow a given trajectory determined by technological conditions (paradigms) and a number of factors



Source: Dosi and Nelson (2013)

Given technological heuristics (path dependent), and social practices

Evolution of main path (fuel cells 1860–2002): ‘main flow of ideas’



Source: Verspagen (2007)

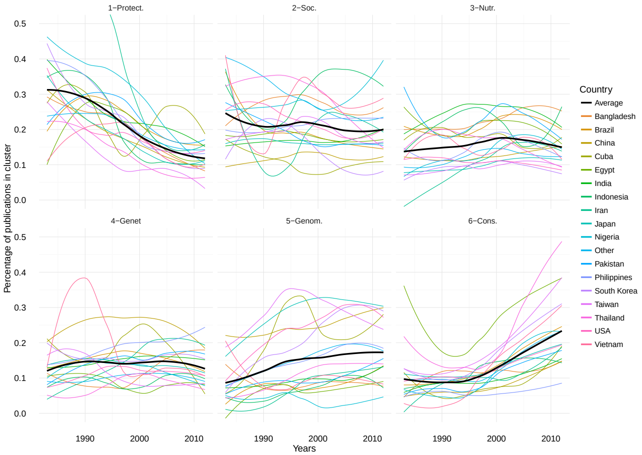
Initial exploration (pre-1980); Merging of three different technologies (3515593); Final linear phase with bifurcation in two technologies (1983-2000)

Knowledge/research also follow trajectories

Trajectories differ across space

Influenced by a number of factors: technology (Dosi, 1984), techno-economic factors (Freeman, 1991), actors (Freeman, 1995), socio-economic (Dosi and Nelson, 2013; Smith et al., 2005) and political (Johnstone and Stirling, 2015) factors

Rice research publications across topics



Source: Ciarli and Ràfols (2018)

Notes: each series represents the locally smoothed regression (LOESS) of the percentage of papers published in a topic. The topics are derived from clustering using co-word analysis. *1-Protect*: plant protection (weeds and pests); *2-Soc*: practices and socio economic; *3-Nutr*: plant nutrition and yields; *4-Genet*: rice varieties, and genetics; *5-Genom*: genomics; *6-Cons*: consumption.

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Uncertainty

Risk: when we know the probability distribution of future events

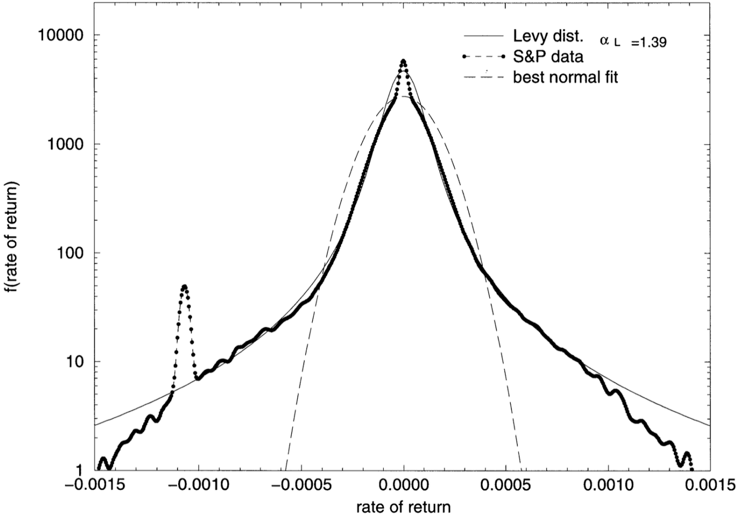
- Incremental innovation

Knightian Uncertainty: when the risk cannot be measured

- Radical innovation: future directions and trajectories of technologies? E.g. environmental impact of innovations, AI
- Returns from investment in innovations? e.g. pharma before biotech

⇒ How to take decisions? Animal spirits: procedural, bounded, rationality (incremental): routinised behaviour
⇒ no Bayesian agent with a clear set of possible outcomes (radical): innovation as a guess, requires intuition, animal spirits

Extreme losses and gains (with non-negligible probability)



Source: Levy (1998)

S&P 500 1 minute rate of return distribution (90-95)

Technology drives uncertainty

Source: Little green blog

“dishwasher versus hand washing”: 374,000 results (0.54 seconds) hits on google (four years ago 60,000)

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Skewed distribution of innovation by size

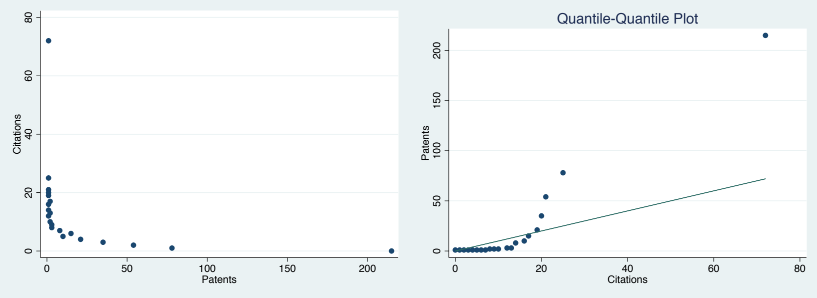
Not all innovations are equally relevant

- Citations, value, returns to investment

Returns to innovation are also fat tailed (high kurtosis): variance is not finite

$\Rightarrow$ So is the risk of returns

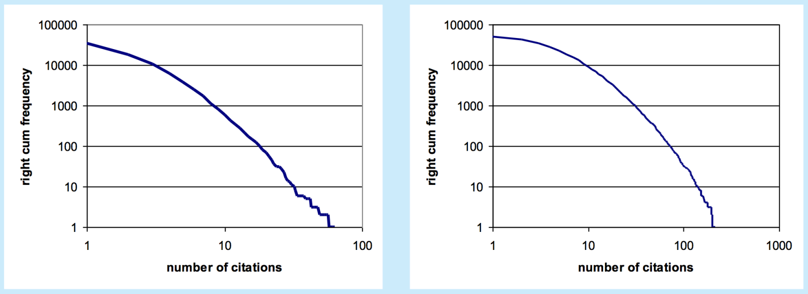
Computed Tomography scanner patents



(a) Linear scale (b) Q-Q Plot

Source: Trajtenberg (1990)

Innovation size distributions (Pareto Plots) based on patent citations



Source: Gerry Silverberg

EPO 1989 patent citations (left) and USPTO 1989 patent citations (right)

More evidence

Size of innovation is drawn from a very skewed distribution (Silverberg and Verspagen, 2007)

Distribution of firm size in an industry is heavily skewed (Simon and Bonini, 1958)

Firms' heterogeneity persists through time (technology, productivity, profits, growth) (Dosi et al., 2010)

Large differences across sectors and small differences across countries within sectors in firm's demography (Breschi et al., 2000)

Heterogeneity, innovation and evolution

Innovation occurs differently in different (competing) sectors/firms/agents: organisations make different choices and take different actions (Nelson and Winter, 1982)

Different organisations and agents hold different knowledge

Organisations seek to improve their fitness: catching-up (reducing heterogeneity) or differentiating (increasing heterogeneity)

"Economic variation is the outcome of innovation and selection is the means by which the economy adapts to variety"' (Metcalfe, 2014, p. 29)

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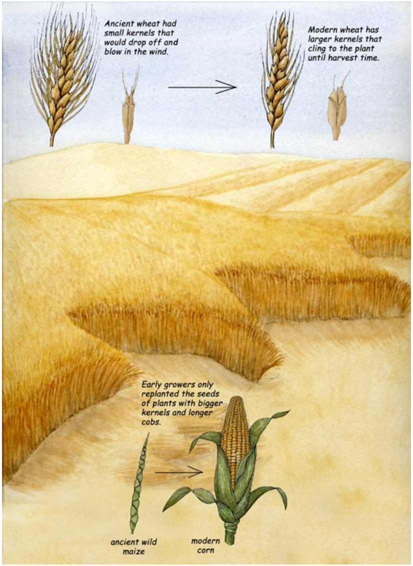
How does innovation occur?

Does it follow a stylised process? Can we identify regular patterns?

How can we best represent of an innovation process?

Example: new seeds

Then



Source: https://www.exploringnature.org/db/view/1523

Example: new seeds

Now

- **Basic research**: molecular biology, synthetic biology, chemistry (and many other related disciplines)
- **Applied research**: breeding, transgenic experiments, testing in labs
- **Invention**: find seeds with given properties (successful in labs)
- **Development**: on the field trials, experimental plots (further selection)
- **Commercialisation**: distribution to selected farmers, showcasing, marketing, packaging, instructions, etc
- **Diffusion**: adoption by farmers

Example: new software

Then

Source: Pegasus Vertex

Example: new software

Now

- **Basic research**: mathematics, queuing theory, AI
- **Applied research**: cryptography, sorting algorithms, data storage systems, language
- **Invention**: program, design, basic features
- **Development**: programming, detailed specifications, alpha testing, graphical interfaces
- **Commercialisation**: beta testing, marketing, sale
- **Diffusion**: adoption by consumers

Source: Bronwyn Hall

Innovation models

1st Generation Technology push 1950s to mid-60s	Simple linear sequential process. Emphasis on R&D push. The market 'receives' the results of the R&D
2nd Generation Market pull Mid-1960-1970s	Market (or need) pull; again a simple, linear sequential process. Emphasis is on marketing. The market is the source of ideas and provides direction to R&D. R&D has a reactive role
3rd Generation Coupling models Mid 1970-1980s	Sequential model, but with feedback loops from later to earlier stages. Involves push or pull-push combinations. R&D and marketing more in balance. Emphasis is on integration at the R&D-marketing interface
4th Generation Integrated model Early 1980-1990	Parallel development with integrated development teams. Strong upstream supplier linkages and partnerships. Close coupling with leading edge customers. Emphasis on integration between R&D and manufacturing (e.g. design for manufacturability). Horizontal collaboration including joint ventures and strategic partnerships
5th Generation Innovation System	

Source: Hobday (2005)

The critique to linear models

Science push linear model

- Science often follows technology: bottlenecks
- Relevance of incremental innovation

Demand pull linear model

- Technological and scientific possibilities? E.g. medical demand
- Inventions not always translated in innovations (maybe in the long run)

The critique to linear models

Sequential structure is not observed. Innovation is a trial and error (uncertain) process – learning, through feedbacks.

Innovation activities are overlapping and there is often communication and mutual learning

The critique to linear models

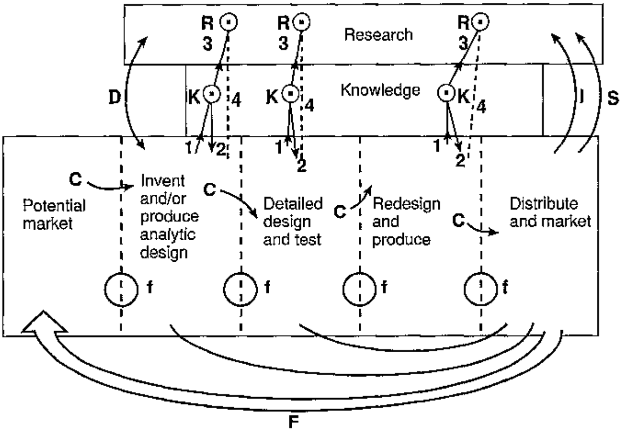
Innovation occurs by chance: LASER (Light Amplification by Stimulated Emission of Radiation)

- invented by Townes at Bell Labs around 1960
- lawyers at Bell labs did not patent, thinking it not relevant for the telephone industry
- now used in navigation, precision measurement, chemical research, surgery, compact discs, printing, cutting, and even a cheap consumable

Knowledge is not only generated in labs

- Learning by doing (manufacturing)
- Learning by using (consumers)

Chain-linked model (Kline and Rosenberg, 1986)



C: central chain of innovation; f: feedback loops; F: particularly important feedback.

K-R: Links through knowledge to research and return. If problem solved at node K, link 3 to R not activated. Return from research (link 4) is problematic

D: Direct link to and from research from problems in invention and design: radical inn..

I: Support of scientific research by instruments, machines, tools, and procedures of technology

S: Support of research in sciences underlying product area to gain information directly and by monitoring outside work. The information obtained may apply anywhere along the chain.

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Do innovation activities differ across industries?

How do (firms') innovative activities differ, across industries?

Which are the main differences (and similarities)? Are there any regularities?

Why do we observe these differences?

WIPO patent applications worldwide: output

Field of technology	2008	2009	Publication year 2010	2011	2012	Average growth rate (%): 2008-12
Electrical engineering						
Electrical machinery, apparatus, energy	105,246	111,479	115,865	122,817	145,440	8.4
Audio-visual technology	91,122	85,244	80,252	75,755	78,552	-3.6
Telecommunications	68,772	60,458	56,311	49,975	50,374	-7.5
Digital communication	65,250	69,536	74,512	79,714	89,687	8.3
Basic communication processes	17,733	17,162	16,558	15,616	16,098	-2.4
Computer technology	134,273	132,793	129,710	134,396	152,692	3.3
IT methods for management	21,871	25,183	23,430	23,751	28,127	6.5
Semiconductors	81,072	78,617	77,557	80,036	86,747	1.7
Instruments						
Optics	74,361	69,316	64,134	61,551	64,716	-3.4
Measurement	71,864	76,156	76,827	77,156	93,891	6.9
Analysis of biological materials	11,398	11,768	11,426	11,802	12,066	1.4
Control	28,660	29,019	28,717	27,857	32,279	3.0
Medical technology	77,174	77,573	77,381	79,123	87,014	3.0
Chemistry						
Organic fine chemistry	53,826	52,771	52,349	51,461	53,478	-0.2
Biotechnology	35,626	37,541	38,311	41,007	41,933	4.2
Pharmaceuticals	73,803	71,905	69,114	69,820	72,842	-0.3
Macromolecular chemistry, polymers	28,234	28,701	28,591	28,750	33,557	4.4
Food chemistry	23,633	27,172	27,877	30,894	34,552	10.0
Basic materials chemistry	41,045	42,169	43,787	45,386	53,042	6.6
Materials, metallurgy	33,955	34,732	36,953	38,623	47,285	8.6
Surface technology, coating	30,748	32,716	33,123	33,890	39,233	6.3
Micro-structural and nano-technology	2,535	2,907	3,163	3,261	3,753	10.3
Chemical engineering	35,208	35,769	36,681	38,261	43,990	5.7
Environmental technology	22,630	24,290	25,556	26,425	31,596	8.7
Mechanical engineering						
Handling	42,875	42,765	42,368	44,482	50,683	4.3
Machine tools	38,423	40,442	43,159	46,375	56,080	9.9
Engines, pumps, turbines	43,676	48,039	48,256	48,559	55,559	6.2
Textile and paper machines	33,710	32,259	30,657	30,421	34,448	0.5
Other special machines	46,124	47,437	49,015	51,212	60,449	7.0
Thermal processes and apparatus	25,755	27,215	29,324	29,890	33,854	7.1
Mechanical elements	47,590	47,197	46,307	46,953	53,913	3.2
Transport	67,780	70,362	66,938	65,618	77,525	3.4
Other fields						
Furniture, games	44,911	43,594	42,521	42,243	47,515	1.4
Other consumer goods	32,015	32,076	32,112	33,414	38,229	4.5
Civil engineering	52,687	54,640	55,947	57,752	66,311	5.9

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Source: WIPO (2014)

Why these differences in patents?

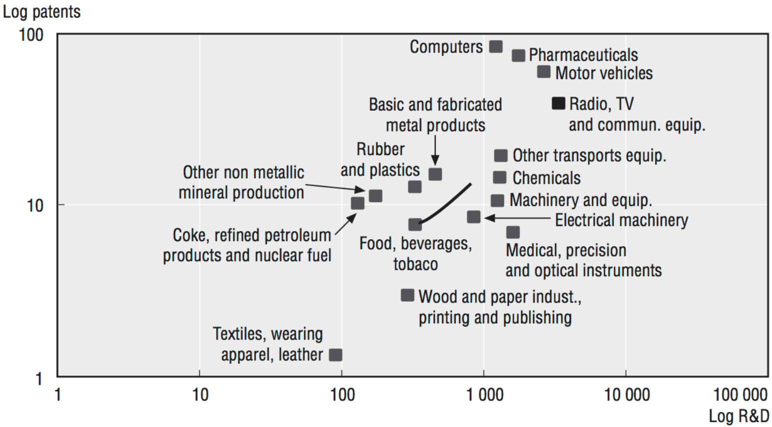
Is it due to a difference in the product? E.g. a drug is more complex than a shirt? Not enough

Certainly sectors differ by production of technology,

but they also differ, e.g. by appropriation of innovative outputs, use of past knowledge, IO, etc

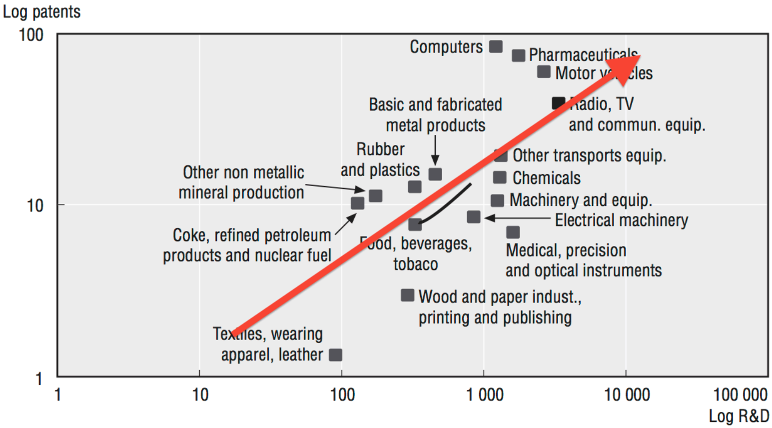
- (Appropriation: codified vs tacit knowledge)

R&D and patenting: source & output



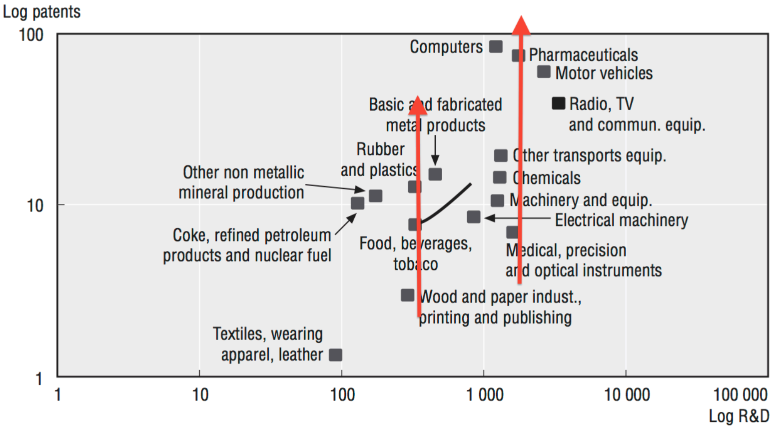
Source: WIPO (2014)

R&D and patenting: input → output



Source: WIPO (2014)

R&D and patenting: not all hight tech patent



Source: WIPO (2014)

Some explanations

Why some industries patent relatively more than other, for a similar R&D?

Probability of success of Research, and Development

Technological complexity may be related to sunk costs: some sectors require more investments

Differences in appropriation: not all innovations requires patenting → trade secrets

- Different types of innovation output

Rankings of IP protection methods (small French firms)

	Product	Process
Trademark	41.6	28.9
Lead Time	37.9	29.6
Patent	29.9	19.5
Complexity	29.5	22.3
Secrecy	25.4	21.0
Drawings and Graphics	25.3	19.0
Copyright	10.5	9.0
Observations	296	311
Total obs.	447	

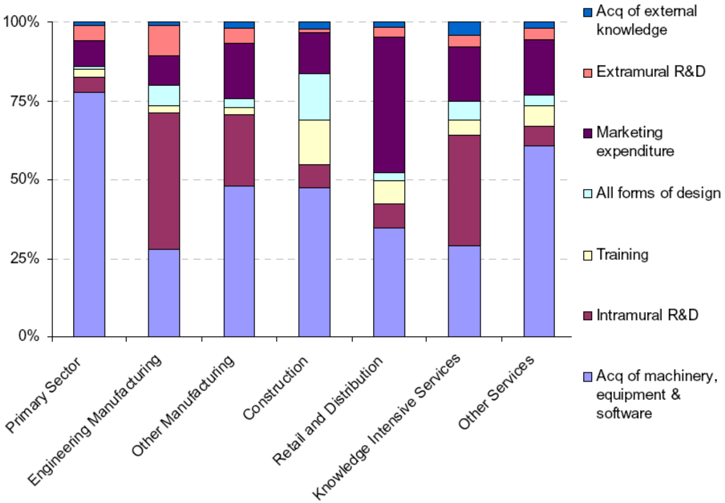
Source: Pajak (2016)

Frequency of use of patent and secrecy, by industry

	Patent	Secrecy	Patent-to-secrecy ratio	Small innovation	Large innovation
Textile	.17	.14	.55	.36	.24
Woodwork	.23	.09	.70	.17	.39
Paper	.30	.34	.47	.24	.44
Chemicals	.37	.40	.49	.27	.47
Plastic	.39	.30	.55	.39	.36
Metalwork	.37	.31	.54	.38	.41
Intermediate goods	.49	.37	.56	.52	.60
Automobile	.30	.17	.63	.39	.41
Furniture	.17	.14	.55	.42	.19
Telecoms	.13	.09	.60	.57	.14

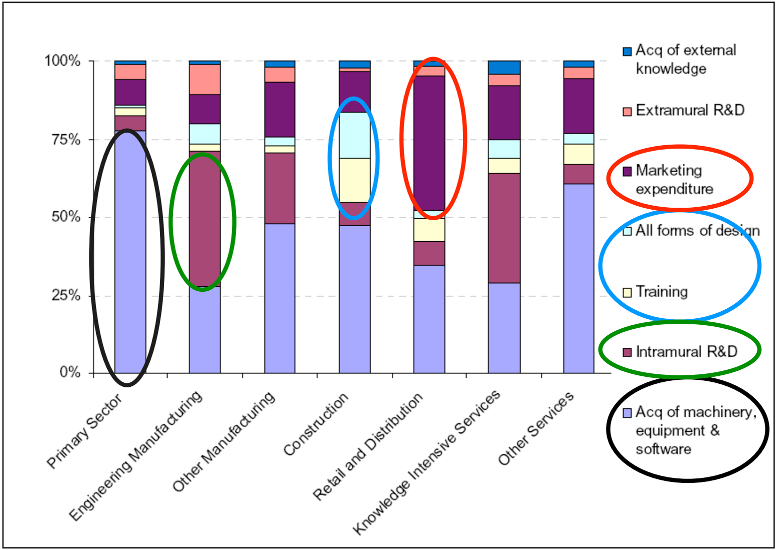
Source: Pajak (2016)

Different sources of innovation



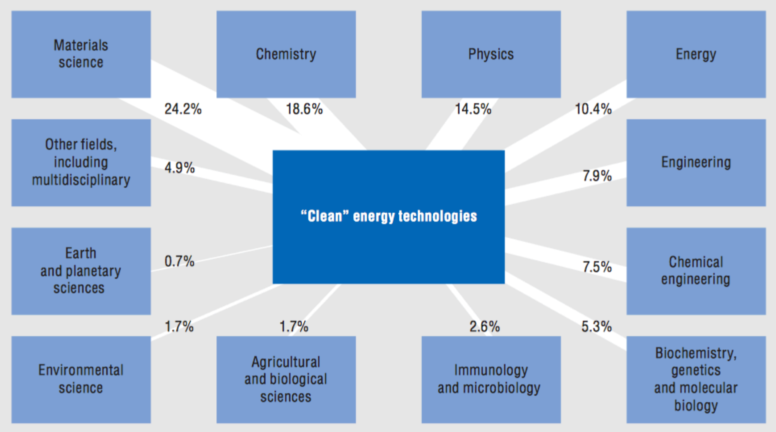
Source: DIUS (2008)

Share of expenditure & sources of innovation



Source: DIUS (2008)

Sources of basic science



Source: OECD (2011)

Sources of basic science by sector

D. Olivastro, 1995, CHI Inc.		No of Citations per Patent			% Sectoral share of all citations to scientific
Manufacturing sector	No. Patents	Patents	Sci Journals	Other	journal papers
Chemicals (less drugs)	10,592	9.8	2.5 (18.5%)	1.2	29.1
Drugs	2,568	7.8	7.3 (43%)	1.8	20.6
Instruments	14,950	11.8	1.0	0.7	16.3
Electronic equipment	16,108	8.8	0.7	0.6	12.2
Electrical equipment	6,631	10.0	0.6	0.6	4.4
Office and computing	5,501	10.0	0.7	1.0	4.3
Non-electrical machinery	15,001	12.2	0.2 (1.5%)	0.5	3.3
Rubber and misc plastics	4,344	12.4	0.4	0.6	1.9
Metal products	6,645	11.6	0.2	0.4	1.5
Primary metals	918	10.5	0.8	0.7	1.0
Food	596	15.1	1.3	1.6	0.9
Oil and Gas	998	15.0	0.6	0.9	0.7
Motor vehicles & transport	3,223	11.3	0.1	0.3	0.4
Textile	567	12.4	0.3	0.8	0.2
Aircraft	905	11.6	0.1 (<1%)	0.3	0.1
Total	**99,898**	**10.9**	**0.9 (7.2%)**	**0.7**	**100**

Source: House of Lords: Science and Technology Committee (2010)

A few sectors ‘use’ most of the basic research

D. Olivastro, 1995, CHI Inc.		No of Citations per Patent			% Sectoral share of all citations to scientific
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Total	**99,898**	**10.9**	**0.9 (7.2%)**	**0.7**	**100**

Source: House of Lords: Science and Technology Committee (2010)

Similarly innovative sectors use different sources

D. Olivastro, 1995, CHI Inc.		No of Citations per Patent			% Sectoral share of all citations to scientific
Manufacturing sector	No. Patents	Patents	Sci Journals	Other	journal papers
Chemicals (less drugs)	10,592	9.8	2.5 (18.5%)	1.2	29.1
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Aircraft	905	11.6	0.1 (<1%)	0.3	0.1
Total	**99,898**	**10.9**	**0.9 (7.2%)**	**0.7**	**100**

Source: House of Lords: Science and Technology Committee (2010)

Differences across countries (BERD as % of VA)

	B	DK	GER	SPA	FR	I	A	FIN	SVE	UK	**EU-7**	**US**	**JAP**
Tot. Manufacturing	6.4	5.7	7.5	2.1	7.	2.2	4.6	8.3	11.3	5.4	**5.7**	**7.8**	**8.4**
Food, Bev. & Tob.	1.6	1.4	0.6	0.5	1.0	0.4	na	2.8	1.0	1.2	**0.8**	**na**	**1.9**
Tex., apparel & leather	2.0	0.8	2.1	0.6	0.9	0.1	na	2.2	1.2	0.4	**0.7**	**0.6**	**2.1**
Paper & Print.	0.9	na	0.3	0.4	0.3	0.1	0.5	1.3	na	na	**0.4**	**na**	**na**
Pharmaceutical	25	40	na	10.1	27.6	na	15.1	na	46.5	48	**na**	**23.3**	**19.0**
Non-electrical Mach.	6.6	6.6	5.8	2.9	4.6	1.4	4.4	9.0	11.1	4.8	**4.6**	**4.7**	**5.7**
Comp. & Office Mach.	12.3	18	17	7.5	13.3	7	3.7	na	39.5	3.5	**14.1**	**22**	**na**
Electrical Mach.	7.6	8	3.4	3.3	7.7	na	5.7	na	18.2	7.8	**4.5**	**12**	**17.6**
Electronic Mach.	32.7	13.5	39.6	19.1	34.1	na	28.5	28.1	38.6	12.1	**32.7**	**na**	**23.6**
Instruments	11.3	15.3	11.9	3.7	16.9	2.2	6.8	22.5	18.5	7.3	**11.5**	**32.6**	**23.8**
Motor Vehicles	4.0	na	18.3	2.6	13.1	10.4	10.1	3.6	28.9	9.2	**14.3**	**16**	**13.2**
Aerospace	6.5	na	na	25	40.1	na	na	na	na	24.3	**na**	**30.9**	**0.6**

Source: Dosi et al. (2005)

Differences across countries (BERD as % of VA)

	B	DK	GER	SPA	FR	I	A	FIN	SVE	UK	EU-7	US	JAP
Tot. Manufacturing	6.4	5.7	7.5	2.1	7.	2.2	4.6	8.3	11.3	5.4	**5.7**	**7.8**	**8.4**
Food, Bev. & Tob.	1.6	1.4	0.6	0.5	1.0	0.4	na	2.8	1.0	1.2	**0.8**	**na**	**1.9**
Tex., apparel & leather	2.0	0.8	2.1	0.6	0.9	0.1	na	2.2	1.2	0.4	**0.7**	**0.6**	**2.1**
Paper & Print.	0.9	na	0.3	0.4	0.3	0.1	0.5	1.3	na	na	**0.4**	**na**	**na**
Pharmaceutical	25	40	na	10.1	27.6	na	15.1	na	46.5	48	**na**	**23.3**	**19.0**
Non-electrical Mach.	6.6	6.6	5.8	2.9	4.6	1.4	4.4	9.0	11.1	4.8	**4.6**	**4.7**	**5.7**
Comp. & Office Mach.	12.3	18	17	7.5	13.3	7	3.7	na	39.5	3.5	**14.1**	**22**	**na**
Electrical Mach.	7.6	8	3.4	3.3	7.7	na	5.7	na	18.2	7.8	**4.5**	**12**	**17.6**
Electronic Mach.	32.7	13.5	39.6	19.1	34.1	na	28.5	28.1	38.6	12.1	**32.7**	**na**	**23.6**
Instruments	11.3	15.3	11.9	3.7	16.9	2.2	6.8	22.5	18.5	7.3	**11.5**	**32.6**	**23.8**
Motor Vehicles	4.0	na	18.3	2.6	13.1	10.4	10.1	3.6	28.9	9.2	**14.3**	**16**	**13.2**
Aerospace	6.5	na	na	25	40.1	na	na	na	na	24.3	**na**	**30.9**	**0.6**

Source: Dosi et al. (2005)

Technological regimes

Knowledge base, **O**pportunity, **C**umulativeness, and **A**ppropriability: different technological regimes (Malerba and Orsenigo, 1997).

	High	**Low**
O	High successful rate High incentives High entry/exit Unstable firm hierarchy	Low entry Low growth of incumbents Stable environment
A	Innovation protection Low spillovers High concentration Clusters of innovation	Large positive externalities Many innovators/imitators
C	Persistent innovative activities Stable firm hierarchy Selection favours incumbents	High entry

Technological regime and MarkI vs MarkII

Schumpeter Mark I: creative destruction. OCA?

	High	**Low**
O	High successful rate High incentives High entry/exit Unstable firm hierarchy	Low entry Low growth of incumbents Stable environment
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Technological regime and MarkI vs MarkII

Schumpeter Mark II: creative destruction. OCA?

	High	**Low**
O	High successful rate High incentives High entry/exit Unstable firm hierarchy	Low entry Low growth of incumbents Stable environment
A	Innovation protection Low spillovers High concentration Clusters of innovation	Large positive externalities Many innovators/imitators
C	Persistent innovative activities Stable firm hierarchy Selection favours incumbents	High entry

Pavitt Taxonomy

Pavitt (1984) studied 2000 innovations in Britain from 1945 to 1979 and the firms producing those innovations to explain how and why technical change differs across sectors:

(with respect to knowledge, technology, uses of inputs, demand, and interactions)

Four different classes of firms/sectors

Pavitt Taxonomy

	Sector class			
	Production Intensive			
	Supplier dominated	Scale intensive	Specialised suppliers	Science based
Source of technology	Suppliers of equipment and materials	Production engineering department, R&D	Design and development users	R&D labs, public science
Type of users	Price sensitive	Price sensitive	Performance sensitive	Price and performance sensitive
Means of appropriability	Non-technical (trademark, design, advertising)	Process secrecy and know-how, technical lags, patents, learning economies	Design, know-how, knowledge of users, patents	R&D know-how, patents, process secrecy and know-how, learning economies
Relative size of innovating firms	Small	Large	Small	Large
Type of innovation	Process	Process	Product	Process and Product
Technological trajectories	Cost reduction	Cost reduction	Product design (performance)	Cost-reduction and product design (performance)
Sectors	Traditional sectors such as manufacturing, agriculture, housebuilding, financial and commercial services	Bulk materials, automotive, energy	Machinery, instruments, software	Electronics, chemicals, pharmaceuticals

Source: elaborated from Pavitt (1984)

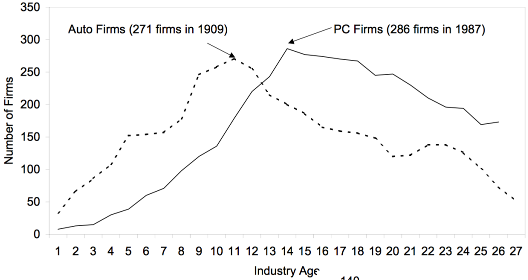
Sectoral change: industrial dynamics

Technological regimes and sectoral systems change over time (with differences across sectors)

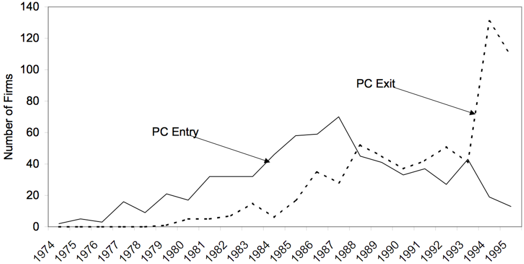
Industry life cycle

Mark I	→	Mark II
Rapid change in knowledge		Knowledge paradigm
Tech. uncertainty		Dominant design
Low barriers to entry		Economies of scale
New firms main innovators		First mover advantage
		Learning

Industry life cycle: PC



Source: Mazzucato (2002)



Source: Mazzucato (2002)

Sectoral change: technological paradigms

Technological regimes and sectoral systems change over time (with differences across sectors)

Change in technological paradigms

Mark II	→	Mark I
Sudden change in knowledge		New opportunities
Stable/mature technology		Rapid change in new knowledge
Economies of scale		Start ups
Large R&D investments		Inventions and radical innovations
Saturated demand		New niches

E.g. Pharmaceutical industry

Summary

	Innovation and evolution
Dynamics	Change
Knowledge	Accumulation and heterogeneity
Clustering	Accumulation and discrete changes
Trajectories	Path dependence
Uncertainty	Risk / high variance
Heterogeneity	Evolutionary dynamics
Non linearity	Feedbacks / unpredictability
Sectoral differences	Persistent heterogeneity
Systemic	**Interactions & contagion**
Diffusion	Contagion, innovation, & structural change

Innovation does not occur as an isolated process

knowledge (science), skilled workers

firms' imitation

consumers

finance

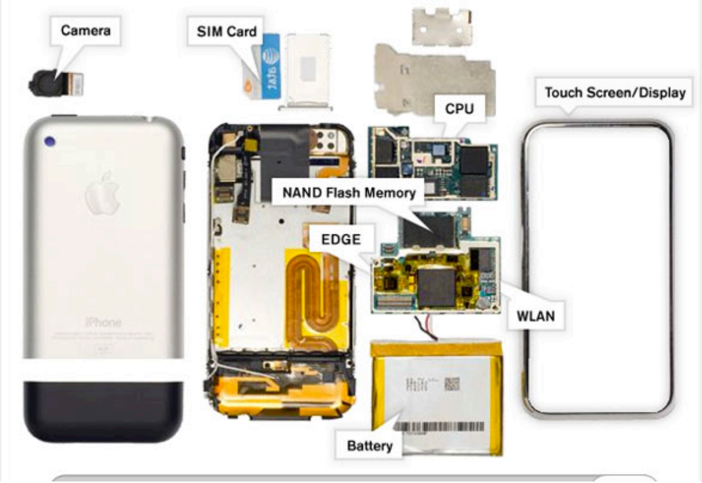
business services

Infrastructures

etc...

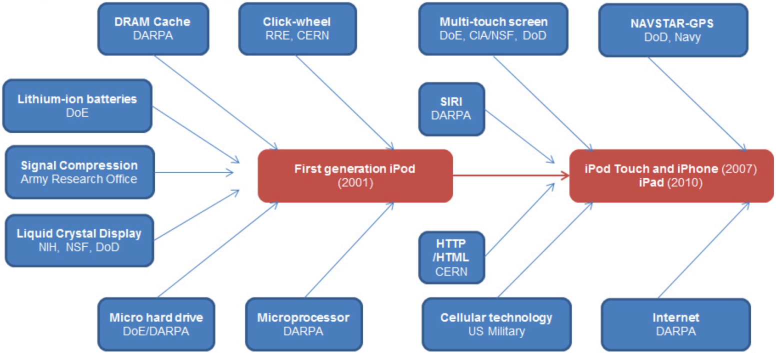
Where do major innovations come from?

Consider the iphone



Source: MIT Technology Review

Origin of iphone technologies



Source: Mazzucato (2013)

CERN: European Organisation for Nuclear Research; CIA: Central Intelligence Agency; DARPA: Defence Advanced Research Project Agency; DoD: Department of Defence; DoE: Department of Energy; NIH: National Institute of Health; NIST: National Institute of Standards and Technologies; NSF: National Science Foundation; RRE Royal Radar Establishment

Interactions in an Innovation System

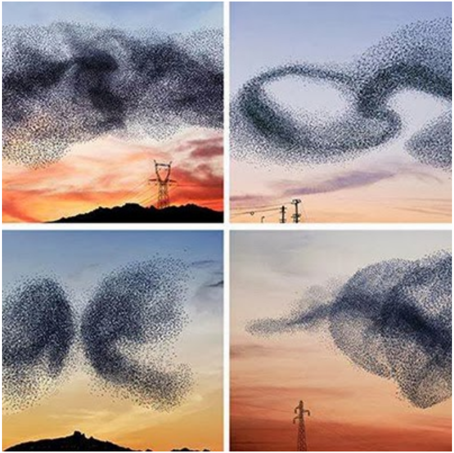
The innovations that we observe (new products, services, processes, industries) are the result of the action of several **interacting** actors, through time and space

Many such interactions are governed by non-market **institutions**

$\Rightarrow$ Institutions, organisations, learning, and networks play a central role in innovation

Innovation is not only *more*, it is also *different*

Emerging process: by studying the system we also study who drives and stirs the direction of technology and innovation



Source: `http://io9.com/tag/emergent-properties`

Summary

	Innovation and evolution
Dynamics	Change
Knowledge	Accumulation and heterogeneity
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Trajectories	Path dependence
Uncertainty	Risk / high variance
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Non linearity	Feedbacks / unpredictability
Sectoral differences	Persistent heterogeneity
Systemic	Interactions & contagion
Diffusion	**Contagion, innovation, & structural change**

Diffusion

Innovation is relevant only if it diffuses: adapting the innovation to production processes and consumer needs

Where is this macaque running to?

Source: ARKIVE

Washing sweet potatoes from the mud

Source: Blog

Why? To imitate an improvement

"In 1953, a *young female* Macaque monkey in the south of Japan washed a muddy sweet potato in a stream before eating it. This obvious *improvement* in food preparation was *imitated* quickly by other monkeys and in *less than 10 years it became the norm* in her immediate group; *by 1983, the method had diffused completely*" (Hall, 2006, p. 459)

⇒ Contagion effect: learn about a better way of doing things

⇒ Time to diffuse

Definition

"Diffusion is commonly used to describe the process by which individuals and firms in society/economy *adopts* a *new technology*, or *replace an older technology with newer*" (Hall, 2006, p. 459)

Does not apply only to consumers

Adoption is a sunk cost [learning, irreversibility, uncertainty]

Diffusion may be innovating [e.g. laggard firms]

Diffusion may imply adapting [e.g. consumers]

Diffusion implies setting a standard (dominant design) [e.g. the iphone]

Diffusion generates path dependency lock-in [e.g. QWERTY]

Diffusion is about learning and improving

Most innovations do not diffuse, some take long time [push vs pull]

Fax was invented in 1843 by Alexander Bain (transmission over telegraph lines): No adopters for over a century

Xerox in the 1960s sold improved fax machines: Still a very few adopters

- Required operator assistance
- 8 minutes to transmit

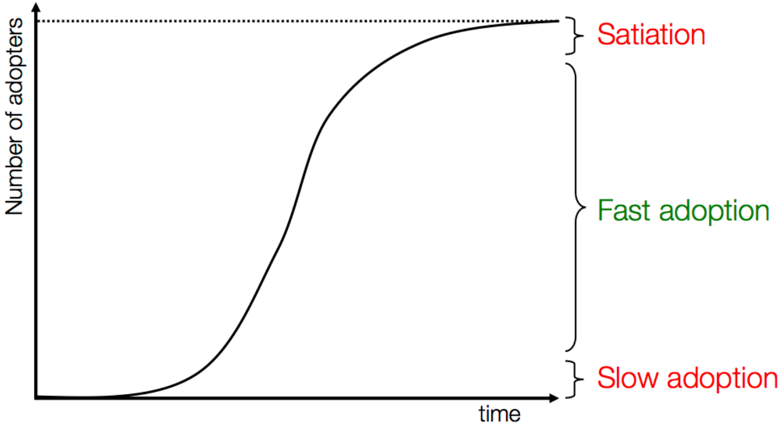
Finally, the product improved, became easier to use, and infrastructures were in place: still very high price ($2,000)

The fax boom started in the USA around 1983: faster and cheaper than mail

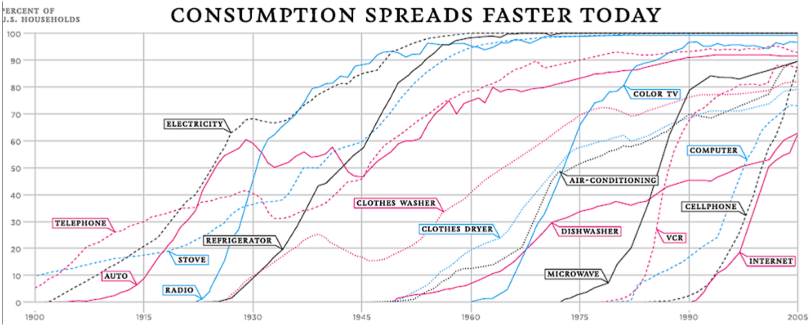
However, the adoption rate remained quite slow until 1987, after which, it dramatically increased (Rogers, 2010)

Logistic curve

The rate of adoption of technologies tend to follow an s-shaped curve (logistic): the aggregate outcome of individual choices to adopt an innovation



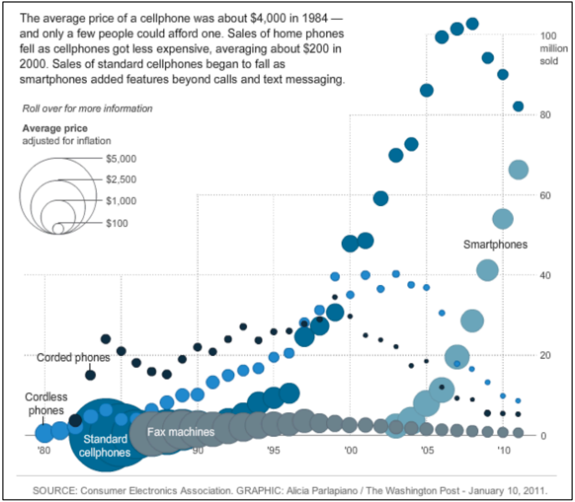
But we observe many interesting regularities



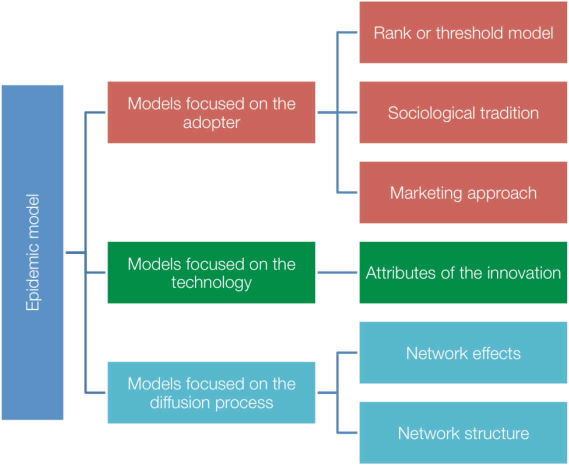
Source: VisializingEconomics

Several ways to explain this dynamics (Geroski, 2000)

Price is crucial



Several ways of explaining/modelling the logistic curve



Epidemic model: central information

$y(t)$ firms have adopted in t

$N - y(t)$ still have to adopt

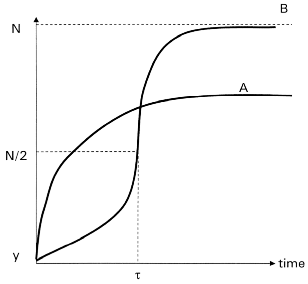
Information is spread at a rate that reaches $\alpha\%$ of population

$\alpha = 1$ immediate adoption

$\alpha < 1$ partial adoption

$$\Rightarrow \Delta y(t) = \alpha \left(N - y(t)\right) \Delta t$$

$$y(t) = N\left(1 - exp^{-\alpha t}\right)$$



Source: Geroski (2000)

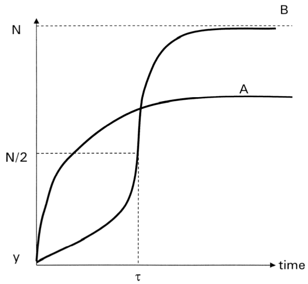
Epidemic model: word of mouth

Each user contacts a non adopter with a probability β

Each non adopter has a probability $\beta y(t)$ to be informed
$\Rightarrow \Delta y(t) = \beta y(t)\,(N - y(t))\,\Delta t$

$$y(t) = \frac{N}{1 + \frac{(N - y(0))}{y(0)} exp^{-\beta N t}}$$

assuming $y(0) > 0$



Source: Geroski (2000)

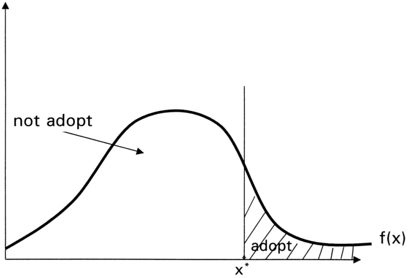
Mixed model: probability of being informed $\alpha + \beta y(t)$

Adopter benefit: rank/threshold/probit model

Rate of adoption depends on the differences in the adopter's preferences (benefit differently)

Adopters will adopt only if the benefit is larger than some threshold x^*

Each adopter benefit = x_i. Adopt if $x_i > x*$



Source: Geroski (2000)

Adopter benefit: rank/threshold/probit model

Now assume that through time benefits increase: price reduction, network effects, economies of scale, etc

Assume that the benefits/preferences are normally distributed as in the above figure

Assume that the benefits increase linearly

Rank/threshold/probit model: example

Diffusion of the reaping machine (David, 1971)

A population of farmers, endowed with a plot of different size

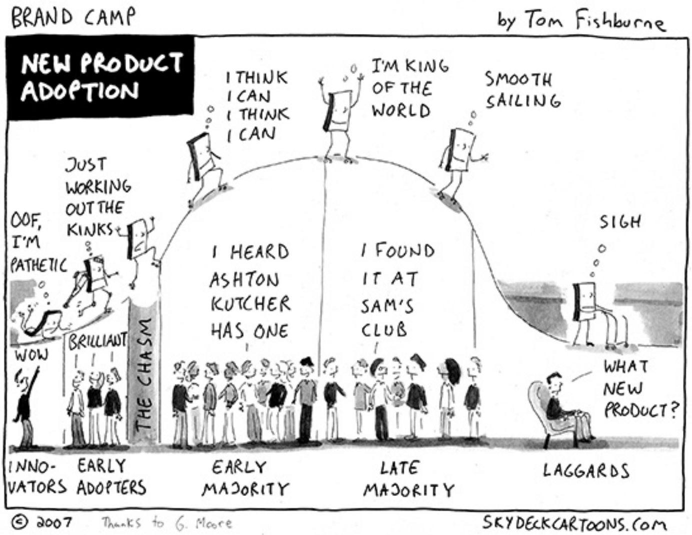
Reapers allow to substitute for labour cost, but has a high fixed cost: high economies of scale

In each period t, for a given price p of the reaper, a given wage w, a farmer adopts if the size of the land is large enough

As w increase and p falls more farmers adopt

The main trigger of diffusion is the rising w in the US

Adopter behaviour



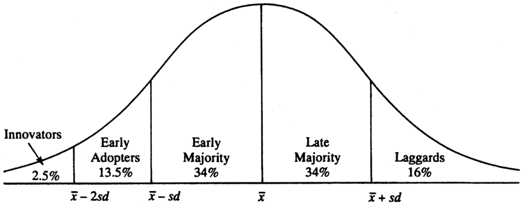
Source: skydeckcartoons

Adopter behaviour

Adopters are heterogeneous not only for their preferences/benefits, but also for their risk aversion, trust in technology, etc. (Rogers, 2010)

Given the average time of adoption we can distinguish 5 types of adopters [no interactions]

Figure 7-3. Adopter Categorization on the Basis of Innovativeness



The innovativeness dimension, as measured by the time at which an individual adopts an innovation or innovations, is continuous. The innovativeness variable is partitioned into five adopter categories by laying off standard deviations (sd) from the average time of adoption ($\bar{x}$).

Source: Rogers (2010)

Adopter behaviour

Innovators: venturesome and innovative people (risk lovers) with access to venture capital

Early adopters: Opinion leaders (wealthy) who's behaviour represents a model for the rest of the society

Early majority: They massively adopt the technology inducing the take off of the diffusion

Late majority: Sceptical adopters that will use the technology only when the majority does

Laggards: Adopters that are very sceptical to new ideas, strongly linked to the traditions, of older age

Generalised Bass model

Mix different sources of information (of the new technology) and behaviours (of the Roger type)

Behaviours

- Innovators adopt independently (no epidemics)
- Imitators adopt after interaction with peers

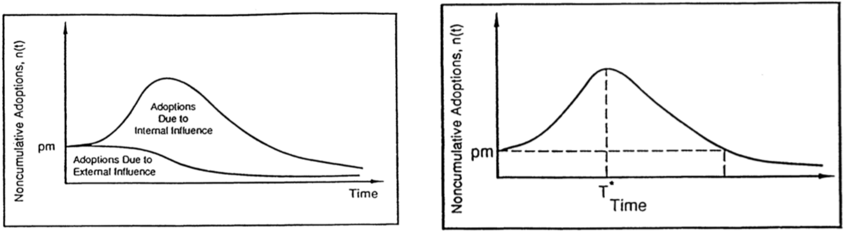
Information

- Marketing influences the behaviour of innovators
- Peers influence imitators

Diffusion depends on

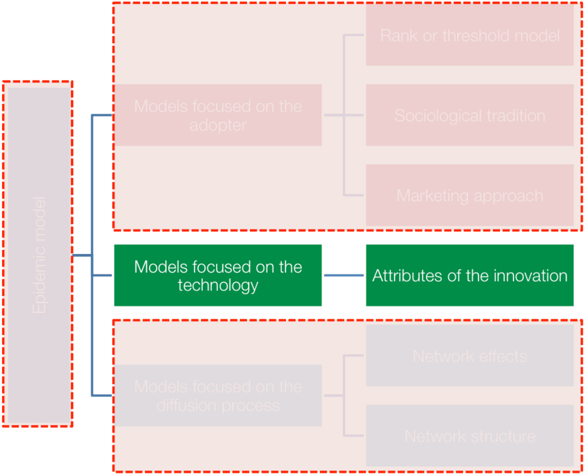
- the number of innovators and imitators
- the degree of innovation/marketing and imitation

Generalised Bass model



Source: Mahajan et al. (1995)

Focus on technology features



Focus on technology features

So far we have considered only one technology available on the market

Only heterogeneity considered: adopter condition

We relax also the following assumptions:

- the technology is the only available option
- the user has no influence on innovation
- the good is radically new (no substitute)
- adopters consider different characteristics

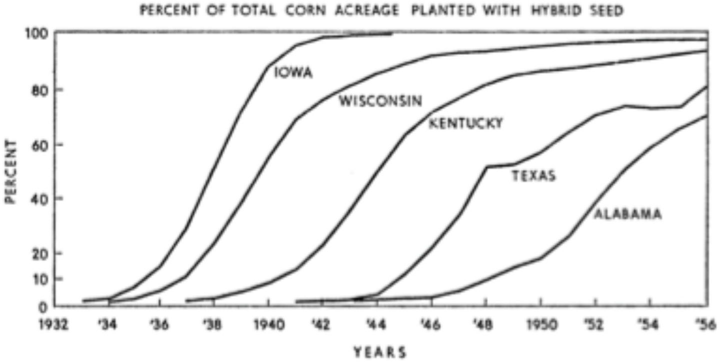
Focus on technology features: example

Consider the adoption of a new seed variety

- Improved? What is improved?
- Modular? What else should change?
- Learning costs?
- When will the advantages show?
- Other farmers observable results?

Adoption of hybrid corn in the US

Profits, scale and adaptation to local conditions



Source: Griliches (1957)

Focus on technology features

Consider the adoption of a new OS

- Improved? What is improved?
- Modular? What else should change?
- Learning costs?
- Collaborations?

The characteristics of the technology (Rogers, 2010)

Relative advantage: The extent to which a technology is considered better that the current & other available options. Marginal utility

Compatibility: To extent to which a technology is consistent with the adopters' current way of doing things

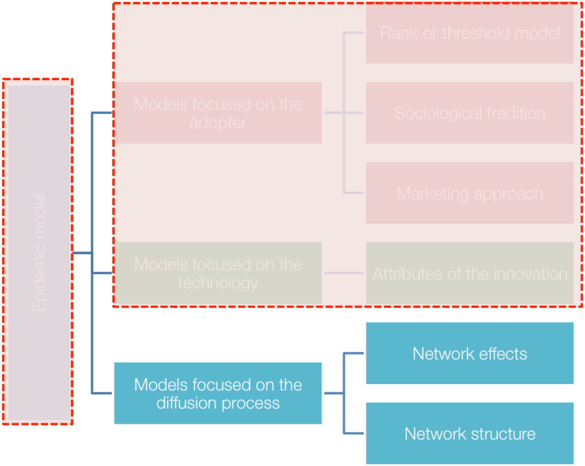
- sociocultural values and beliefs
- routines
- client needs for innovations

Complexity: To extent to which a technology is perceived difficult to understand and use

Trialability: To extent to which a technology can be tested by potential adopters [network effects] (E.g. trial plots)

Observability: To extent to which a technology can be easily evaluated by others (E.g. software vs. hardware)

Focus on the diffusion process



Externalities and increasing returns

The adoption of a technology influences later adopters **beyond the contamination effect**

- Economies of scale of first movers
- Learning, accumulation of knowledge and experiences (cumulativeness...)
- Technological interrelatedness (e.g. train tracks)
- Network externalities (e.g. phone)
- Imitation (e.g. fads)
- Infrastructures (e.g. post sale services)
- Network size (e.g. bank branches)

⇒ Adopters value a technology for its value and for the value added by wider use

Information cascades

Two variants of a new technology: A and B

If, by chance, early adopters prefer A: more information on A

$\Rightarrow$ later adopters are more inclined to follow the same decisions: bandwagon effect

$\Rightarrow$ more adopters will choose A: lock-in

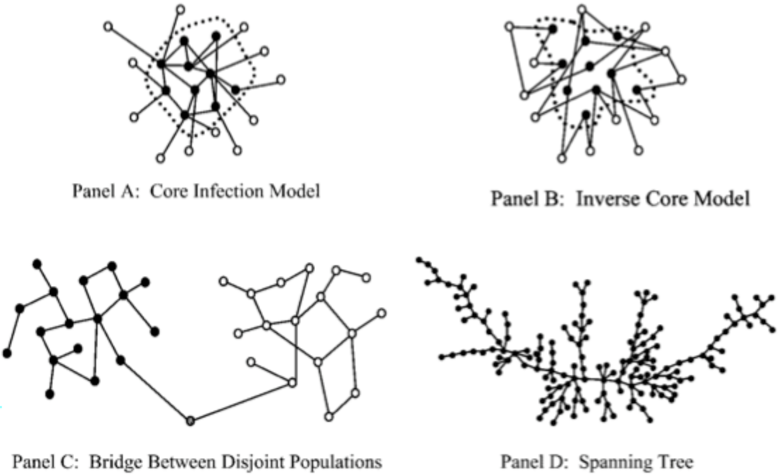
$\Rightarrow$ Only successful technologies show an S-shaped diffusion curve

Networks and adoption

Social diffusion through networks (Lee et al., 2006; Pegoretti et al., 2012)

Network structure: do technologies diffuse within networks?

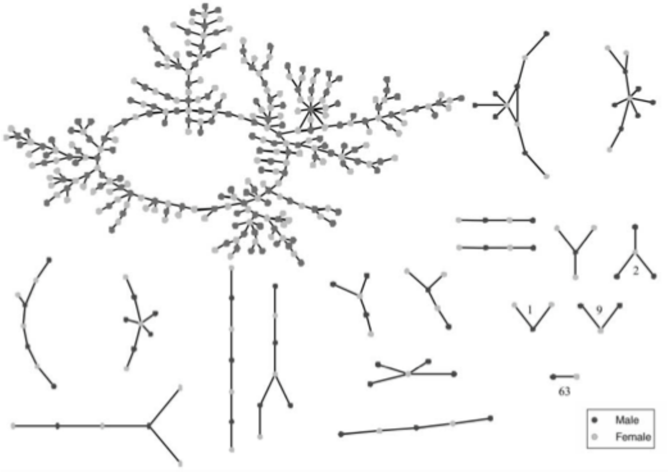
Networks structure and diffusion



Source: Bearman et al. (2004)

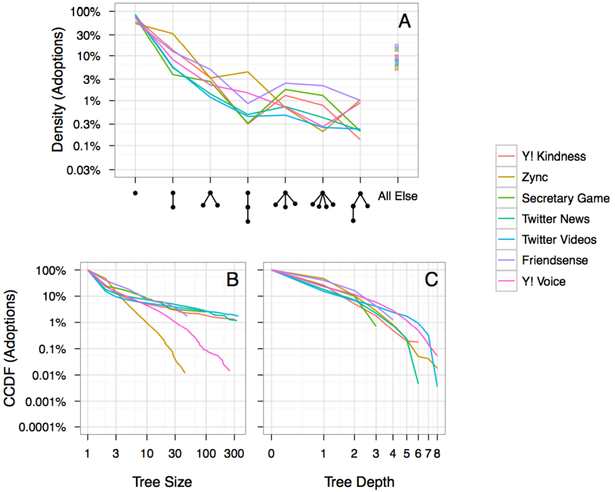
Romantic and sexual network

"Jefferson High School", 573 students, relatively isolated



Source: Bearman et al. (2004)

On-line diffusion: minority of adoption within cascades



Source: Goel et al. (2012)

Co-evolution of coalition formation and diffusion (Pasimeni and Ciarli, 2018)

Some goods need to be purchased collectively – high fixed costs (e.g. smart grids)

We develop an agent based model to study the interplay between coalition formation and the diffusion of shared goods

Goods can be adopted only if a coalition is formed, which has enough resources to purchase the good, and whose demand can be satisfied by the good

The model

Utility maximising consumers

- Some are initiators

Regular network – close neighbourhood

Two options: purchase a service from a central provider or invest in an expensive capital good

In each time period iterative process of coalition formation

- Initiators and consumers invited earlier can ask neighbours to form a coalition
- Pareto optimality: no agent can be better off by changing

Coalition formation is a dynamic process of continuous interactions among agents because many features evolve over time and agents adapt behaviour accordingly

Results

Both coalitions and diffusion are subject to network effects

- agents' behaviour is affected by others' decision and by societal trends
- social network evolves because of the changing links between consumers

Although coalitions are essential to the adoption of shared goods, they also reduce future adoption, by isolating consumers

Network clustering and the speed at which information flows determine higher adoption

Consumers prefer to form larger coalitions: expensive goods with higher capacity

- Lower contribution and price of service
- Even increasing free riding (non linear)

Results crucially depend on the speed at which networks form and information circulates

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