3. Basic Concepts in Technology and Innovation

3.1. Institutionalisation of R&D

- ‘The Research Revolution’

  “Its growth is perhaps the most important social and economic change in the twentieth-century industry.” (Freeman 1982)

Institutionation of industrial R&D

- 'Great individualists'
  → contract research labs
  → corporate inhouse R&D
  cf. Transition embodied in Thomas Edison
    - owned 1,093 patents (World record)
    - setting up the world first contract research labs (Newark → Menlo Park)
    - his engineers and scientists helped to build up earlier corporate inhouse R&D labs in Germany, Britain, and the U.S.

The Increase in R&D Investment

- Firm level expenditure
  - constant dollar R&D expenditure for US industry
    1953-1990: 5.5 fold increase
    1980-1990: 1.5
  - R&D expenditure to sales doubled for 16 years
    1.9% in 1976 → 3.8% in 1992
      (Kobrin 1997: 149-150)
  - Some big high-tech firms spend over 10% of their gross revenue on R&D

The Increase in R&D Investment

- National level expenditure
  - GERD 2-3% of GDP in advanced countries

Table 1. *Estimated gross expenditure on research and development as a fraction of GNP, (GERD/GNP ratio) 1934–1983*

	1934	1967	1983	1983 civil R&D only
USA	0·6	3·1	2·7	2·0
EC*	0·2	1·2	2·1	1·8
Japan	0·1	1·0	2·7	2·7
USSR	0·3	3·2	3·6	1·0

*Estimated weighted average of 12 EC countries.
Source: Author's estimates based on Bernal (1939) adapted to 'Frascati' definitions (1963), OECD statistics, and adjustments to Soviet statistics based on Freeman and Young, (1965).

Freeman (1995)

Table 1.2 Trends in gross domestic expenditures on R&D (GERD)

	GERD million current PPP $	Average annual growth rate		Percentage change from preceding year(s)				GERD as a percentage of GDP		
	1993	1981–85	1985–89	1990	1991	1992	1993	1981	1991	1993
USA	169,964	7.3	2.0	3.2	—[9]	1.4	−0.5	2.4	2.8[9]	2.7
Canada	8,320	6.7	2.4	6.0	1.9	0.8	1.3	1.2	1.5	1.5
Mexico	1,964	—	—	—	—	—	—	—	·	0.3
Japan[1]	60,535	8.9	6.5	8.4	3.2	−1.0	−3.0	2.1	2.9	2.7
Australia[2]	3,713	8.2	4.6	5.0	—	—	—	1.0	1.4	—
New Zealand[3]	410	—	—	0.3	−0.8	—	—	—	0.9	—
Austria	2,416	4.0	4.6	8.0	8.8	3.2	3.7	1.2	1.5	1.6
Belgium[3]	2,853	—[9]	—[9]	—	1.6	—	—	—	1.7	—
Denmark	1,786	6.9	7.0	6.4	5.8	3.6	3.6	1.1	1.7	1.8
Finland	1,755	10.5	8.1	4.2	—[9]	1.4	0.3	1.2[9]	2.1[9]	2.2
France	25,984	5.0	4.0	6.1	0.5	0.9	−0.8	2.0[9]	2.4	2.4
Germany[4]	37,268	4.3	[9]	1.5	[9]	[9]	1.1	2.4	2.6[9]	2.5
Greece	560	—[9]	—[9]	—	1.1	—	15.3	0.2[9]	0.5	0.6
Iceland[3]	65	5.4	12.2	−1.8	18.8	10.8	—	0.6	1.2	1.3
Ireland[5]	504	5.6	5.3	13.4	18.6	10.7	—	0.7	1.0	1.1
Italy	13,220	8.3	5.8	6.7	3.2	−0.3	−1.3	0.9	1.3	1.3
Luxembourg	—	—	—	—	—	—	—	—	—	—
Netherlands[3]	4,965	—[9]	3.6	−0.6	−3.3	−1.3	—	1.9	1.9	1.9
Norway	1,632	—[9]	2.4	—	1.1	—	4.2	1.3	1.8	1.9
Portugal[5,6]	709	5.6	9.8	16.1	—	9.8	—	0.4	0.6	0.7
Spain	4,567	8.7	13.2	16.9	5.1	—[9]	−5.3	0.4	0.9	0.9
Sweden	4,578	8.2	3.0	—	−1.4	—	2.4	2.3[9]	2.9	3.1
Switzerland[5,7]	4,243	—[9]	—[9]	—	—	−1.4	—	2.3	2.9[9]	2.7
Turkey	1,436	—	—	—	64.3	−1.7	—	—	0.5	0.5
United Kingdom	21,581	1.8	3.2	1.9	−4.8	0.3	2.5	2.4[9]	2.2	2.2
North America[8]	180,248	7.3	2.0	3.3	—[9]	1.3	−0.6	2.3	2.6[9]	2.4
EU-15[4]	123,056	4.6	4.4	3.7	—[9]	0.3	−0.3	1.7	2.0[9]	2.0
Total OECD[4,6]	385,495	6.6	3.6	4.3	1.6	0.7	−0.8	2.0	2.3	2.2

The Increase in R&D Investment

- The rise of a professional 'R&D establishment'

  : RSE growth rate over 2%

  cf. population growth rate 0.1% in developed countries

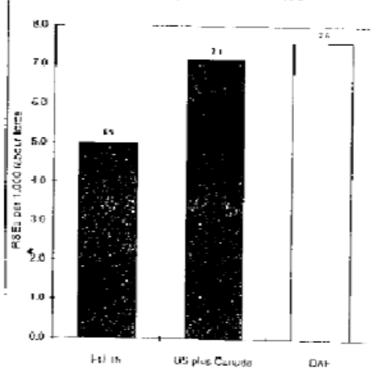
Table 1.2c Average annual growth rates in total resources devoted to R & D during the 1970s

	United States	*Japan*	*Germany*	*United Kingdom*	*France*
GERD, 1970–9	1.5	6.9	4.1	1.9[c]	3.1
RSE, 1970–9	2.2[a]	9.5	4.3[b]	2.1[d]	2.2[b]
Total R & D employment, 1970–9	..	2.2	2.5[b]	..	1.3[b]

[a] 1971–9. [b] 1969–77. [c] 1969–78. [d] 1971–8.

Source: OECD

Figure 1c.15: Research scientists and engineers per thousand labour force, main blocs, 1995 estimates



Note: in FTE

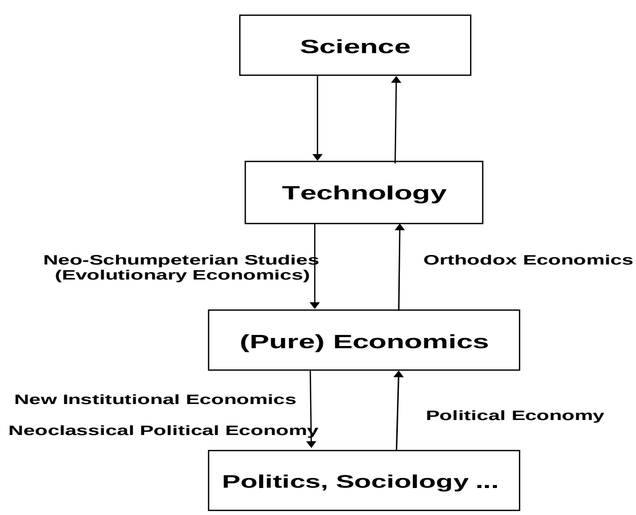
Source: DGXII-AS4, IES, Data: Eurostat/OECD/UNESCO/national sources

Second European Report on S&T Indicators, 1997

Why?

(1) The increasing scientific character of technology : the rise of science-related technology "[Many technologies] could not have been developed at all without a foundation in theoretical principles. This corpus of knowledge ... could never have emerged from casual observation, from craft skills or from trial and error in existing production systems ... (Freeman & Soete 1997: 198-199)

- Science, Technology, Economy and Society



eg1. the steel industry

- puddling → Bessemer process
  → BOF

"Only men of remarkable strength and endurance could stand up to the heat for hours, turn and stir the thick porridge of liquescent metal, and draw off the blobs of pasty wrought iron. The puddlers were the aristocracy of the proletariat, proud, clannish, set apart by sweat and blood. Few of them lived past forty." (Landes 1969: 218)

eg 2. electricity

- Franklin's kite
- Faraday's 'principle of electronic motor' in the 1820s, discovery of electromagnetic induction in 1831

→ electro-chemistry

"... electricity and chemistry ..[are] the two areas where scientific research began to be directly and intimately related to industrial development." (Freeman & Soete 1997: 75) eg 3. chemicals

- the first specialised R&D lab emerged in 1870s: the German dyestuff industry

cf. IG Farben

IG Farben

- World's largest chemical combine, and the fourth largest company only behind GM, US Steel, and Standard Oil in 1925
- R&D over 7% of turnover during 1925-39
  cf. other large companies 3-5%

- maintain 1,000 strong researchers
- employing outstanding academic consultants, including a number of Nobel Prize winners like Professor Staudinger of Freiburg and Ziegler who made major theoretical contribution to the plastic industry ...

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Table 5.5 Patents and innovations in synthetic materials (percentage world total)

Patents and innovations	*Total*	*Percentage world total*		
		IG Farben[a]	*Du Pont*	*ICI*
All plastics patents taken out by firms 1791–1945	6,777	20	6	2
All plastics patents taken out by firms 1931–45	4,341	20	8	2
'Major technical advances' in patent literature 1791–1945	117	26	10	6
Innovations in synthetic materials 1870–1945	56	32	9	2
'Major innovations' 1870–1945	20	45	10	5
Innovations 1925–45	36	44	11	3
First 'imitations' 1870–1945		14	4	8

[a] Including predecessors and successors.

Sources: Author's estimates from Delorme (1962), Hufbauer's analysis of innovations (1966) and Redfarn survey (see p. 60).

IG Farben

- War criminal
  - broken up into BASF, Bayer and Hoechst
- Konrad Adenanuer

  " …the patents formerly belonging to IG Farben have given the American chemical industry a lead of at least 10 years. The damage thus caused to the German economy is huge and cannot be assessed in figures."

Table 5.3 Patents for plastic materials taken out by leading firms

30 leading firms' patents taken out in UK, USA, France, Germany

	1791–1930	No.
1	IG Farben	346
2	Eastman Kodak	169
3	Du Pont	78
4	Celluloid	66
5	Bakelite Corp	59
6	Bayer[a]	55
	Meister, Lucius and Brüning[a]	55
8	CIBA	42
9	Bakelite GmbH	40
10	BASF[a]	38
	GE	38
12	British Thomson-Houston	35
13	Consortium für Elek[b]	33
14	British Celanese	28
15	Chem. Fab. Albert	26
16	Barrett	25
	Ellis-Foster	25
	ICI	25
19	Cie. Fr. Thomson-Houston	24
	Naugatuck	24
21	Kroll	23
	Canadian Electric	23
	Pathe	23
24	AG für AF	21
	Kunsthorn Pollak	21
26	Chem. Fab. Griesheim	16
27	Carbide and Carbon	15
	FF Instruments	15
29	E. Schering	14
30	Hercules Powder	13
	Soc. Chem. des Usines du Rhône	13

	1931–45	No.
1	IG Farben	889
2	Du Pont	321
3	Röhm and Haas[c]	145
4	Hercules Powder	132
5	GE	120
	Eastman Kodak	120
7	Dow	115
	Kodak-Pathe and Kodak	115
9	ICI	90
10	Carbide and Carbon	88
11	Phrix Arbeitsgemeinschaft	73
12	Celanese	67
13	A. Wacker Ges	65
14	American Cyanamid	60
15	CIBA	56
16	Ellis-Foster	51
17	Bakelite	48
18	Deutsche Hydrierwerke	46
19	Pittsburg Plate Gl.	44
20	British Celanese	42
21	Standard Oil	41
22	Bakelite Ges.	40
	Cie. Fr. Thomson-Houston	40
24	Monsanto	37
25	Deutsche Kelluloid	35
26	B. F. Goodrich	32
27	Thuringische Zellwolle	30
28	Rhône-Poulenc	26
29	Harvel Research	
	Consortium für Elek[b]	24

	1946–55	No.
1	Du Pont	637
2	Monsanto	283
3	American Cyanamid	266
4	Shell/N.V. de Bataaf	263
5	ICI	253
6	Röhm and Haas[c]	210
7	Dow	187
8	B. F. Goodrich	160
9	US Rubber	156
10	Eastman Kodak	140
11	Standard Oil/Esso	131
12	BASF[a]	115
13	F. Bayer[a]	111
14	CIBA	101
15	St. Gobain	77
16	Distillers	74
17	Gen. Aniline and Film	73
	Celanese	73
19	Wingfoot	72
20	Cie. Fr. Thomson-Houston	69
	Carbide and Carbon	69
22	Hercules Powder	65
23	Hoechst[a]	57
24	Phillips Petroleum	55
25	Kodak-Pathe	47
26	American Viscose	45
27	Chemstrand	44
28	Rhône-Poulenc	43
	GE	43
30	Chem. Werke Hüls[a]	42
	Koppers	42

30 leading firms' patents taken out in UK only

	1954–8	No.
1	ICI	299
2	Du Pont	288
3	Standard Oil/Esso	243
4	F. Bayer	199
5	US Rubber	170
6	Midland Silicones	168
7	Monsanto	143
8	GE	128
9	Celanese	113
10	Courtaulds	109
11	Shell/NV de Bataaf.	108
12	Union Carbide	107
13	BASF[a]	106
14	Dow Chemical	100
15	Röhm and Haas	87
16	American Cyanamid	76
	Dow Corning	76
18	B. F. Goodrich	75
19	Hoechst[a]	68
20	Hercules Powder	64
	Distillers	64
22	Dunlop Rubber	60
23	Phillips Petroleum	57
24	CIBA	56
25	Wingfoot	38
26	Minnesota Mining	28
27	Chemstrand	23
	Rhône-Poulenc	23
	Wacker-Chemie	23
30	Gen. Aniline and Film	20

	1959–62	No.
1	ICI	485
2	Du Pont	428
3	F. Bayer[a]	346
4	Union Carbide	327
5	Standard Oil/Esso	266
6	Hoechst[a]	207
7	Montecatini	205
8	CIBA	168
9	Dow Chemical	162
10	Phillips Petroleum	153
11	BASF[a]	145
12	Röhm and Haas	132
13	Shell/NV de Bataaf.	118
14	American Cyanamid	112
15	US Rubber	110
16	Midland Silicones	109
17	Monsanto	100
18	GE	92
19	B. F. Goodrich	89
20	Dunlop Rubber	79
21	Minnesota Mining	77
22	Courtaulds	73
23	Celanese	60
24	Hercules Powder	63
25	Distillers	53
26	Chemstrand	51
27	Rhône-Poulenc	47
28	Chem. Werke Hüls[a]	42
29	Wacker-Chemie	41
30	Dow Corning	34

[a] Part of IG Farben.
[b] Undertaking research in association with A. Wacker.
[c] The German and American parts of Röhm and Haas are listed together here.

eg4. electronics

- becoming more R&D intensive with increasing contents of science

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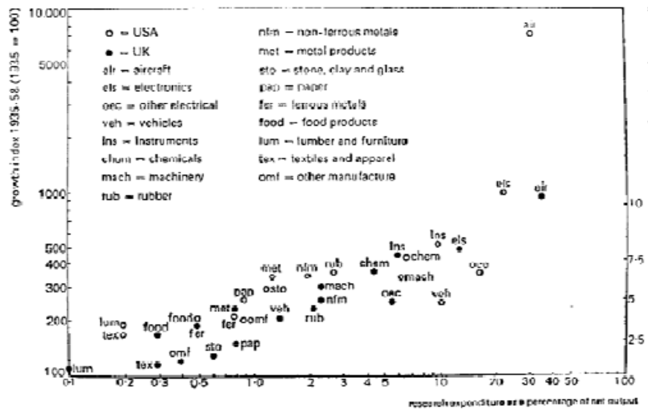

Fig. 7.1 Research expenditure as a percentage of net output in 1958, and growth of industries, 1935–58

Why?

(2) The growing complexity of technology

- increasing risks in experimenting with production lines
- partial replacement of ‘batch’ and ‘one-off’ systems of production by ‘flow’ and ‘mass’ production lines

→ separation of production and experiment: proto-type production

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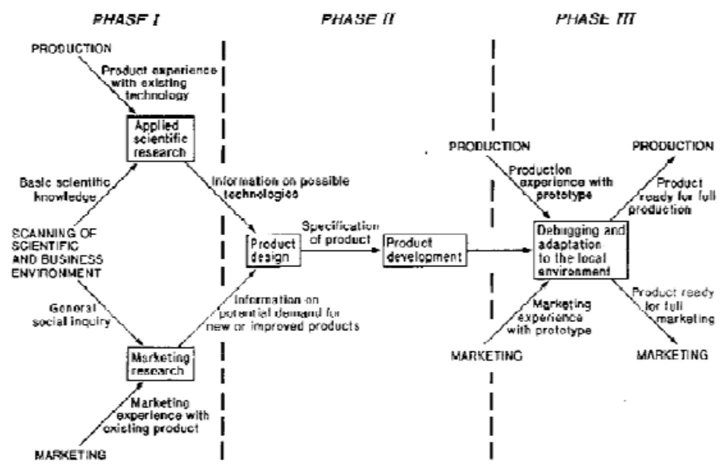


Figure 7.7 Elements of the research and development process (*Source*: Buckley and Casson (1976), Figure 2.7)

Dicken

Why?

(3) The growth of firm size & market and subsequent division of labour

- emergence of specialised research labs inside and outside firms

Qualitative importance of the institutionalisation of R&D

- Endogenisation of technological progress

cf. production function analysis

cf. the early Schumpeter (model 1) vs. the late Schumpeter (model 2)

"the 'bureaucratic' management of innovation was replacing individualistic flair and that the large corporation was becoming the main vehicle for technical innovation in the economy" (Schumpeter 1928, quoted in Freeman 1982)

- The 'routinisation' of innovation

- 'internalisation' of many scientific and inventive activities by the firm

$\rightarrow$ reflecting 'the real change' which had taken place in the American economy between the two world wars and the rapid growth of industrial R&D in large corporations during that period.

3.2. Uncertainties, Technological Trajectory, and Clustering

Inherent uncertainties in technological innovation

- Not knowing

(1) not knowing future technologies

- information gap: don't know what is the best technology for the purpose

  eg. technology to travel to the Sun?

- competence gap: don't know how to develop it

  eg. reliable electricity car

Inherent uncertainties in technological innovation

(2) Not knowing market potential of technologies

eg1. market potential of synthetic rubber

"IG Farben stopped the production of polyethylene and offered to sell their synthetic rubber patents to the natural rubber cartel because they thought the market for the synthetic rubber will be small during the peace time and the synthetic products would not be able to compete with natural products. (Freeman & Soete 1997: 202)

eg2. computers

"The general view prior to 1950 was that there was no commercial demand for computers. Thomas Watson … felt that the one SSEC machine which was on display at IBM's New York offices 'could solve all the scientific problems in the world involving scientific calculations" (Freeman & Soete 1997: 172) eg3. Intel's early ignorance of the market for microprocessor

- 20,000 mainframe computers in 1971

  → 10% market share: a week's production

eg4. Internet

Inherent uncertainties in technological innovation

- Appropriability
  - the importance of intellectual property right

eg. The development of the S/W industry & Intel's dominant leadership in microprocessors

“American copyright law, traditionally used only to protect works of art like novels, plays, and movies, had been extended in 1980 to cover computer software” (Jackson 1997: 268)

- ‘microcode’ in microprcessors
- operating system

Not everything is uncertain

- If everything is uncertain, there would be no ground for rational decision-making.
  - Decision-making under limited information and bounded rationality
- Difference in innovation capability across firms and countries
  - R&D institution has in fact emerged to reduce uncertainties while exploiting the possibilities of ‘New Combinations’

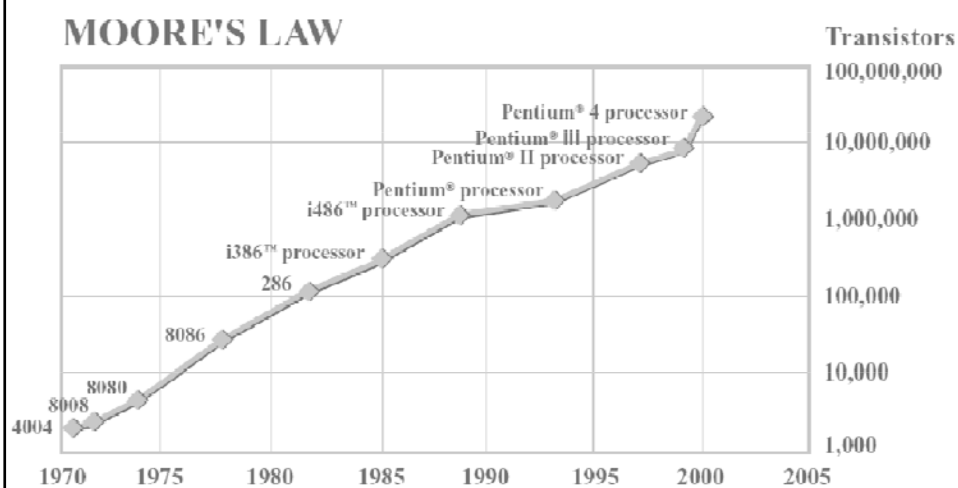
Nelson’s (1990) ‘generic knowledge’ and ‘particular technique’

- Generic Knowledge: disciplines or shared knowledge of the field
  - ‘technological paradigm’ and ‘technological trajectory’ (Dosi 1982)
  - ‘natural trajectory’ (Nelson & Winter 1977),
  - ‘technological guideposts’ (Sahal 1985)

- ‘Rule of thumb’ among scientists and engineers

  eg. Moore’s law, learning curve in the aircraft industry

  They embody regularities of technological change, thereby provide "strong prescriptions on the *directions* of technical change to pursue and those to neglect" (Dosi, 1982, p. 152). So technological progress becomes a continuous process once technological trajectory is set up.



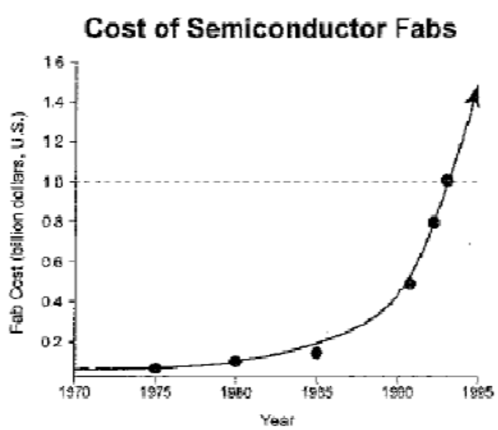


Figure 1. Construction and equipment costs of state-of-the-art semiconductor fab, 1970-95. Sources: Saraswat (1994); Castrucci (1995)

"... technological paradigms define the technological opportunities for further innovations and some basic procedures on how to exploit them. The they also channel the efforts in certain directions rather than others." (Dosi 1988: 225)

→ providing search activities with some constraints

Particular techniques: mixed bag

- 'particular ways of doing things' (Dosi 1988: 224)

(1) explicit knowledge: non-appropriable part once accessed

(2) tacit knowledge: appropriable part

"Some practiced technique is widely applicable and easily learned by someone skilled in the art, if access were open. But ... much of prevailing industrial technique is of little use outside the firms employing it, involving fine tuning to their particular products and processes". (Nelson 1990)

$\rightarrow$ 'socialisation of technological knowledge' $\rightarrow$ 'cultural evolutionary process'

Implications of technological trajectory

- Localised search but with some direction
  - mitigating uncertainties
- Interconnectedness of technological progress
  - enabling 'swarming'