



THE MANAGEMENT OF

innovation & technology

JOHN HOWELLS



The Management of Innovation and Technology

The Management of Innovation and Technology

The Shaping of Technology and
Institutions of the Market
Economy

John Howells

 **SAGE Publications**
London • Thousand Oaks • New Delhi

© John Howells 2005

First published 2005

Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the Copyright, Designs and Patents Act, 1988, this publication may be reproduced, stored or transmitted in any form, or by any means, only with the prior permission in writing of the publishers, or in the case of reprographic reproduction, in accordance with the terms of licences issued by the Copyright Licensing Agency. Enquiries concerning reproduction outside those terms should be sent to the publishers.

Every effort has been made to trace and acknowledge all copyright owners of the material reprinted herein. However, if any copyright owners have not been located and contacted at the time of publication, the publishers will be pleased to make the necessary arrangements at the first opportunity.



SAGE Publications
1 Oliver's Yard
55 City Road
London EC1Y 1SP

SAGE Publications Inc
2455 Teller Road
Thousand Oaks, California 91320

SAGE Publications India Pvt Ltd
B-42, Panchsheel Enclave
Post Box 4109
New Delhi 110 017

Library of Congress Control Number: 2004114266

A catalogue record for this book is available from the British Library

ISBN 0 7619 7023 1
ISBN 0 7619 7024 X (pbk)

Typeset by Selective Minds Infotech Pvt Ltd, Mohali, India
Printed and bound in Great Britain by TJ International Ltd, Padstow, Cornwall

Contents

List of Figures and Tables	vii
Acknowledgements	viii
Preface	ix
1 Technological Innovation	1
Variety in the Meaning Attributed to Invention, Innovation and Technology and the Organisation of this Book	1
Use of the Technology Complex	3
Technology, its Uses and the Institutions of the Market Economy	7
Implications for the Structure of this Book	10
Some Contrasting Conceptual Approaches to the Representation of Innovation	11
Conclusion	20
Notes	20
2 Invention, Science, R&D and Concepts of Use and Market	22
Invention as the Creative Contribution to Innovation	22
The Role of Existing Patterns of Use in Invention – Reference Markets for Innovation	30
The Management of Industrial R&D	41
Rise of the Organisational Innovation of the R&D Department	51
Concluding Comments	57
Notes	58
3 Patterns in Technological Development and the Creation of Technological Standards	61
Paths of Development, Increasing Returns to Scale and Dominant Designs	61
Increasing Returns and ‘Path Dependency’ – a Process for ‘Lock-in’ to Specific Designs	71
Managing Neutral Standards through the Recruitment of Competitors – VHS Versus Betamax Video Recorders	76
Conclusions on Standards and Paths of Development	83
Notes	83
4 Competition and Innovation as Substitution Threat	85
Competitive Scenarios of Innovation	85
Creative Destruction and Firm Response	86

Conflict between Competition Policy and Innovation Policy	105
Concluding Comments – and Does the Study of Innovation Necessarily Follow a ‘Chicago’ or ‘Schumpeterian’ School of Thought?	111
Notes	111
5 Intellectual Property Law and Innovation	114
The Patent Institution as an Aid to Innovation	114
Mutual Adaptation of Intellectual Property Law and Technology	137
Concluding Comments on Innovation and the Patent Institution	142
Notes	143
6 Finance – Techniques, Institutions and Innovation	145
Development and Internal Financial Evaluation	145
Development and the Market for Corporate Control	154
Development and Financial Institutions External to the Firm	163
Conclusion	178
Notes	179
7 Innovation and the Organisation of Technical Expertise and Work	182
Explaining Spectacular Achievements in Japanese Car Production	182
The Organisation of the Shop Floor – Anglo-German Matched Plant Studies of Operations Management	201
Innovation, Technology Transfer and the Craft Control of Skills	209
Management Practice and the Divorce Between Management and Technological Education	219
Conclusions	222
Notes	224
8 The State and the Management of Technology	227
Coercive Reform as a Temporary Departure from Normal Process – Engineering Association Reform in Britain	228
The State and the Reform of Engineering and Vocational Training in Germany and Britain	230
The State and the Management of Political Resistance to Technological Change	243
The Historical and Equivocal Interest of the State in Technological Change	254
Conclusion – the Continued Relevance of Techno-nationalism within an Enlarged States System	264
Notes	265
9 Concluding Comments on this Book	268
Bibliography	269
Index	280

List of Figures and Tables

1.1 A range of definitions of ‘technology’	2
1.2 The technology complex	3
1.3 EFTPOS technology as an example of the technology complex	5
1.4 Twiss’ ‘Egg’ model of innovation	12
1.5 The Schmidt-Tiedemann concomitance model of innovation	13
1.6 The square at the top of the Doric column is the skeuomorph	17
1.7 The roughly triangular area created when a viaduct is supported by arches is the spandrel	19
1.8 Diagram of the construction of the Hagia Sophia	19
Table 4.1 Solvay versus Leblanc production of sodium carbonate in Britain	90
Table 4.2 The 10 leading US transistor-based device manufacturers during successive waves of technological change	100
Table 7.1 New model car design compared in USA, Japan and Europe	185

Acknowledgements

I would particularly like to thank James Fleck, Stephen Hill, Julia Engelhardt and Kristina Cornish for comments on all or part of the manuscript. As usual, I remain responsible for any remaining errors.

A previous version of the section in Chapter 1 on the technology complex was published with James Fleck under the title 'Technology, the Technology Complex and the Paradox of Technological Determinism' in the journal *Technology Analysis and Strategic Management*, 13: 523–31. A previous version of the section on the sailing ship effect in Chapter 4 was published under the title 'The Response of Old Technology Incumbents to Technological Competition – Does the Sailing Ship Effect Exist?' in the *Journal of Management Studies*, 39, 7: 887–907.

Grateful acknowledgement is made to the following sources for permission to reproduce material in this book.

Figures 1.1, 1.2 and 1.3 reproduced with permission of Taylor & Francis Ltd, www.tandf.co.uk/journals.

Figure 1.5 from Schmidt-Tiedemann's 'A new model of the innovation process', *Research Technology Management*, 25(2) (1982): 18–22; reprinted with permission.

Preface

In this book the ‘management of technological innovation’ is about the decisions and processes that generate, develop and shape technology.

It is argued at the beginning that a very broad definition of technology is appropriate for the study of innovation and this becomes a basis for organising the book. Thus there is a rough progression of topics from ‘acts’ of invention, to management choices within the R&D department, to patterns of long-term technological development and then the nature of technological competition between firms. There follows three chapters on the role of intellectual property, finance and technical knowledge. These cover the private firm’s use and abuse of these institutions in technology development, but they also extend the idea of ‘management of innovation’ to cover the decision events that shape the form of such important institutions. The last chapter introduces some of the roles of the state in technology development.

The overall object of the book is to convey an understanding of technology as immediately shaped by the firm, but situated in ‘society’ – and situated in the particular form of society that is the market economy, understood as the working set of institutions and governance procedures that have evolved to sometimes limit and sometimes enable technology-shaping decisions by management and entrepreneurs.

1 Technological Innovation

Variety in the Meaning Attributed to Invention, Innovation and Technology and the Organisation of this Book

This chapter begins with a review of definitions of technology and innovation. This is then used to develop the device of the 'technology complex', a device that is exploited in the organisation of the rest of this book. This preference for the logical development of an argument from first principles does mean that discussion of the organisation of the book is postponed to half-way through the chapter. The second half of this chapter demonstrates the value of the technology complex as an intellectual tool by arguing for the comparative inadequacy of the more readily available concepts applicable to innovation and technological change.

Invention, Innovation and Technology

There appear to be almost as many variant meanings for the terms 'invention', 'innovation' and 'technology' as there are authors. Many use the terms 'invention' and 'innovation' interchangeably or with varying degrees of precision. At an extreme, Wiener prefers 'invention' to describe the whole process of bringing a novelty to the market (Wiener 1993). In contrast, Freeman prefers to restrict the meaning and increase the precision of 'innovation' by only applying it to the first commercial transaction involving a novel device (Freeman 1982: 7).

Some definitions are in order. In this book 'invention' will be restricted to describe the generation of the *idea* of an innovation. Innovation will describe some useful changes in technology, and technology refers to the organisation of people and artefacts for some goal. In this book then, technology is both the focus of analysis and yet is given a very broad and inclusive meaning. This usage is in contrast to many other authors and so deserves further explanation.

The term 'technology' is in a class of its own for variation in meaning and Figure 1.1 represents an effort to display some of this variety.

The 'spread' of definitions in Figure 1.1 has the striking quality that distinctly different elements appear in many of the definitions. The titles of the works from which the definitions are drawn show that the detail of the definition is linked to the discipline, or problem of study: industrial relations, organisational behaviour, operations management, and the problem of technology transfer. These are not 'wrong' definitions if one accepts the restricted focus of a subject discipline, problem or time frame and a general definition of technology should be able to incorporate such subdefinitions as special cases.

Collins Dictionary

- 1 The application of practical or mechanical sciences to industry or commerce.
- 2 The methods, theory, and practices governing such application.
- 3 The total knowledge and skills available to any human society.

Oxford English Dictionary

Science or industrial art; literally, the science of technique i.e. systematic knowledge of technique. Technique: the interaction of people/tools with machines/objects which defines a 'way of doing' a particular task.

Technology and Change – the New Heraclitus (Schön 1967)

Any tool or technique: any product or process, any physical equipment or method of doing or making by which human capability is extended.

The Trouble with Technology (Macdonald, et al. 1985)

Technology may be regarded as simply the 'way things are done'.

Technology Policy of Economic Development, IDRC, Ottawa (Vaitsos 1976)

Identifies three properties of technology:

- 1 The form in which technology is incorporated: machines/equipment/materials.
- 2 Necessary information covering patents and conditions under which technology can be used.
- 3 Cost of technology i.e. capital.

The Management of Technology Transfer, International Journal of Technology Management (Djeflat 1987)

Technology marketed as a complete entity: all technological components tied together and transferred as a whole: capital goods/materials/know how/qualified and specialised manpower.

The Business Enterprise in Modern Industrial Society (Child 1969)

The equipment used in the work flow of a business enterprise and the interrelationship of the operations to which the equipment is applied.

Competition and Control at Work (Hill 1981)

In the first place technology embraces all forms of productive technique, including hand work which may not involve the physical use of mechanical implements. Secondly, it embraces the physical organisation of production, the way in which the hardware of production has been laid out in a place of work. The term therefore implies the division of labour and work organisation which is built into or required for efficient operation by the productive technique.

The Sociology of Invention (Gilfillan 1935)

An invention is essentially a complex of most diverse elements – a design for a physical object, a process of working with it, the needed elements of science, if any, the constituent materials, a method for building it, the raw materials used in working it, such as fuel, accumulated capital such as factories and docks, with which it must be used, its crew with their skills, ideas and shortcomings, its financial backing and management, its purpose and use in conjunction with other sides of civilisation and its popular evaluation. Most of these parts in turn have their separately variable elements. A change in any one of the elements of the complex will alter, stimulate, depress or quite inhibit the whole.

Research and Technology as Economic Activities (Green and Morphet 1977)

To sum up, the technology of a particular process or industry is the assemblage of all the craft, empirical and rational knowledge by which the techniques of that process or industry are understood and operated.

Operations Management (Schroeder 1989)

That set of processes, tools, methods, procedures and equipment used to produce goods or services.

Figure 1.1 A range of definitions of 'technology' (from Fleck and Howells 2001: 524, reproduced with permission of Taylor & Francis Ltd)

Examination of the range of definitions in Figure 1.1 suggests that a suitable general and inclusive definition of technology becomes the 'knowledge of how to organise people and tools to achieve specific ends'. This is certainly general, but hardly useful, because the different elements of the subdefinitions have been lost. The technology complex¹ in Figure 1.2 has been suggested as a device that relates the general definition of technology to its subdefinitions (Fleck and Howells 2001).

The elements within the technology complex have been ordered to range from the physical and artefactual to the social and the cultural.² This captures the idea that there are multiple 'levels' within society at which people organise around artefacts to create working technologies. Any or all of these elements could be analysed in a working technology – a technology 'in use'. It is rather rare that a full range of elements are considered, but it will prove worthwhile to provide some examples of when it makes sense to extend the range of analysis over the range of the technology complex.

MATERIAL
ENERGY SOURCE
ARTEFACTS/HARDWARE
LAYOUT
PROCEDURES (PROGRAMS, SOFTWARE)
KNOWLEDGE/SKILLS/QUALIFIED PEOPLE
WORK ORGANISATION
MANAGEMENT TECHNIQUES
ORGANISATIONAL STRUCTURE
COST/CAPITAL
INDUSTRY STRUCTURE (SUPPLIERS, USERS, PROMOTERS)
LOCATION
SOCIAL RELATIONS
CULTURE

Figure 1.2 The technology complex (from Fleck and Howells 2001: 525, reproduced with permission of Taylor & Francis Ltd)

Use of the Technology Complex³

An example of how an apparently simple technology nevertheless includes a range of these elements is given by the Neolithic technology of stone-napping.

At the 'operations' level, skilled individuals use bones – tools – to shape the major raw material – flint – to produce stone tool artefacts. The stone tool artefacts then had a wider range of uses – preparing skins, weapons and wood. Their production, though involving high levels of skill, appears simple in organisational and material terms.

However, this 'simplicity' may be more the product of examining a simple context – here, routine production of the artefact. Other elements of the technology complex will be 'active' and apparent if non-routine changes in the production and use of the artefact are studied.

An excellent example of this is the account by the anthropologist Sharp of the effect of the introduction of steel axe-heads into Stone Age Aboriginal society (Sharp 1952), which reveals the complex interrelationship between artefacts, social structure and culture.

In this patriarchal society, male heads of households buttressed their social position through their control of the use of stone axes, primarily through the limitation of access to young males and women. The indiscriminate distribution of steel axe heads to young males and even women by western missionaries disrupted this balance of power within the tribe.

Steel axes wore away more slowly than stone axe heads and this physical property helped to disrupt the trading patterns that connected north and south Aboriginal tribes. The raw material for making axes existed in the south and it was progressively exchanged through a network of tribes for goods and materials from the tropical north. The annual gatherings when exchange took place had ritual, quasi-religious significance as well as economic exchange significance, but the arrival of steel axes removed the necessity to meet on the old basis and so undermined the cultural aspects of the annual ritual meetings. In these ways society and culture were disrupted by a change in the material of an important artefact.

When changes to stone axe technology were made the subject of enquiry it was clear that stone axe technology was not 'simple' in its social context. Within the society that generated and used this technology the artefact had complex significance that involved many elements of the technology complex for its description.

The technology complex warns us that what appears to be a simple technology may be simple only through the construction of the case analysis. 'Simple' here means describable through only a few of the elements from the technology complex.

Modern technologies are obviously more complex at the level of the artefact and organisation and they are sustained within a more complex society. As in the stone technology example, the study of their routine use is likely to yield relatively more simple descriptions than the study, for example, of the social process of their generation or implementation. An example of the latter is the account by Howells and Hine of the design and implementation of EFTPOS (Electronic Funds Transfer at the Point of Sale), an IT network, by the British retail banks (Howells and Hine 1993). This found that a complex set of choices of artefacts and social arrangements had to be defined by the banks. These choices ranged across the full range of complex technology elements, as shown in Figure 1.3. Decisions in these categories served to define the technology of the IT network that was eventually implemented.

Material/artefact

Variety in the designs of computer, software, communications and terminals offered imposed an expertise management problem on the banks. Isolated artefact design decisions had unexpected implications for other network component design and cost. This variety of offered designs imposed a learning process on the banks.

Topology/layout

The artefact components could be linked in different ways to represent preferences of the owning organisations. So transaction processing could take place in a jointly owned organisation, or the banks' IT departments. Terminals could be stand-alone or integrated into retailer equipment. Such decisions had implications for competition, ownership and control of the network and changed through the project.

Procedures/software

There were many ways of building security into the network. One possibility was to encrypt electronic messages, but then there were two rival proposals for encryption method that each had its own political and competitive implications.

Organisational structure and location of technical expertise – knowledge/skills

The banks had to decide on how to organise the development of the network. They first experimented with the option to contract out responsibility for network design, then a jointly owned hybrid organisation of technical consultants controlled by commercial bankers, then full scale development occurred through VISA and Switch network designs to which each bank made an individual decision to affiliate.

Cost/capital

The cost of IT networks is large and the returns depend on the speed with which paper-based systems can be closed down. There is a theoretic role here for sophisticated financial evaluation techniques, but the impetus for the technology derived from inter-bank competition rather than the immediate economics.

Industry structure

As an oligopoly, the banking industry had a range of more or less cooperative or competitive options available to it in the organisation of this large-scale project. The banks began by cooperating fully in their approach to EFTPOS, but cooperation broke down into two factions that would develop two rival designs of network.

Social/legal relations

In 1986 the UK government passed legislation that allowed Building Societies to compete with banks. This helped prompt the breakdown of the banks' cooperative approach to network design.

Culture

Past experience of government led many of the banks to expect the Bank of England to regulate the sector and to signal its approval or disapproval of bank strategies. On the EFTPOS project some banks continued to wait for Bank of England guidance, some interpreted Bank of England statements as signalling approval or disapproval; late in the project most banks agreed there was no longer the close supervision of earlier years.

Figure 1.3 EFTPOS technology as an example of the technology complex (from Fleck and Howells 2001, reproduced with permission of Taylor & Francis Ltd)

The Problem of the Attribution of Causality and the Design of a Study

These examples raise the general issue of how causation should be attributed in accounts of technology development. It is superficially attractive to express this problem in a general way as the issue of how technology and society may relate to each other. In particular the question ‘does technology shape society?’, sometimes described as the issue of technological determinism, has been intensively debated in the history and sociology of technology.⁴ The technology complex would suggest that a good response to this question is ‘what do you mean by technology?’ For technology should be understood to necessarily include people, so that to ask how technology influences society is to ask how the people organised around a particular set of artefacts influence society. Expressed this way it is easier to see that whether and how technology changes society will depend on the activity of both those most directly attached to the technology, for example through their careers or ownership rights, and those who will be affected more indirectly, by the products or pollution that result from the development of the technology. The question ‘how does technology affect society?’ is only apparently simple, because it is short and is expressed as if there could be an answer with general validity. Any answer depends on the characteristics of both a specific technology and a specific society: there is no general answer.

As part of a collection of writings on this topic of technological determinism (Smith and Marx 1994), the historians Thomas Misa and Bruce Bimber argue that subject discipline and scale of account (Misa) predispose authors to attribute causation in the innovation process quite differently (Misa 1994; Bimber 1994).

A key difference between what Misa calls ‘micro’- and ‘macro’- scale studies is the degree to which the uncertainty of the decision process is captured. ‘Micro-level’ studies of managers’ thought and behaviour, such as that of EFTPOS design and implementation, capture the messiness of real processes of change; the wrong ideas, the misconceptions, the failed bids for competitive change that formed part of the decision process. In contrast, a ‘macro-level’ study of technological change in retail banking over a long time span would find the series of technologies that were actually built – the uncertainty and the alternative paths of development are lost and long-run patterns of change would appear to have their own logic, related to the cheapening cost of computer power over time. Micro and macro studies capture different aspects of the process of innovation and in principle they should complement one another.

To caricature the possible problems of such accounts, unless micro-scale authors import values from outside their studies they may become unable to judge the value of the outcomes they describe – they tend towards ‘relativism’. In contrast, Misa argues that it is those whose research is conducted at the macro level that tend towards overdetermined interpretations of their accounts, for example by attributing excessive rationality and purpose to the actions of actors (Misa 1994: 119). His example is the business historian Alfred Chandler’s interpretation of the Carnegie Steel Company’s vertical integration through the purchase of iron ore deposits. Chandler imputes a defensive motivation to vertical integration, a desire by Carnegie to defend his company against new entrants (Misa 1994: 12). Misa’s micro-analysis of the decision to integrate vertically reveals that Carnegie and his partners were long reluctant to buy iron ore

properties and did so only when convinced by a middle-rank manager, whose arguments were largely based on the serendipitous profits that he believed would accrue to the company from the purchase of iron ore *land* – land that had become temporarily cheap as a result of earlier company actions. As Misa comments:

Vertical integration proved economically rational (lower costs for iron ore plus barriers to entry) for Carnegie Steel, but it was a two-decade-long process whose rationality appeared most forcefully to later historians and not to the actors themselves. (Misa 1994: 138)

With a broad concept for technology such as the technology complex, or Misa's essentially similar 'sociotechnical networks' (Misa 1994: 141), the effort to use and mix different types of account of technology development can be expected to generate many similar problems of interpretation.

Technology, its Uses and the Institutions of the Market Economy

The very term 'technology' implies usefulness of some kind, for someone, most obvious at the level of the artefact, an object by definition given form by humankind and whose creation necessarily implies some human purpose, some human use. Innovation in its widest sense is then some change in the way technology relates to its uses. The questions this formulation begs are of social context – useful how and to whom?

This book begins by following the convention that 'management studies' should be concerned with organisations operating within the market economy and in recent periods of time, a convention that follows the incessant demands for the subject to be immediately relevant to management practice. There is nothing wrong with such a demand in itself, but it does risk that we take the organisation and performance of the market economy for granted and forget that this is only one way of organising society and technology. One of the standard economics texts defines a market economy as one in which 'people specialise in productive activities and meet most of their material wants through exchanges voluntarily agreed upon by the contracting parties' (Lipsey 1989: 786). This clarifies the nature of the economic motivation for technology development for those directly dependent on the market economy for their financial resources – to improve, or to add to the stock of market tradable goods and services. Yet it ignores the institutional arrangements that are essential to a functioning market economy.

Institutions and state policy have always been central to the subject of political economy, and economic and business history have always found room to include the origin and development of such institutions as industrial investment banks and technical education. There is a tendency for the importance of such institutions to be rediscovered by subjects once narrowly conceived: the economics of innovation expanded its scope to include institutions and state policy in the 1990s, as symbolised by the publication of a collection of

essays on *National Innovation Systems* (Nelson 1993); Whitley has similarly sought to expand the scope of organisational sociology in a series of edited essay collections on business systems culminating in his latest book entitled *Divergent Capitalisms* (Whitley 1999). As implied by these titles, institutional endowments and state policy style vary significantly between nations and the guiding question for much of this kind of work is whether these differences matter for economy and sometimes society. The use of the word 'system' with its implication of a thorough-going master design is unfortunate, but by the end of this book it will be obvious that if one wants to understand how and why firms innovate one simply cannot ignore such institutional arrangements.

It is a matter of common observation that even modern societies organised largely as market economies contain classes of technology that are socially useful but that are developed outside, or uneasily alongside, the market economy – for example, the military technologies or the technologies developed by the publicly funded institutions of science organised so that the generation of understanding is their most immediate motivation, rather than the direct generation of economic activity. Nevertheless, once technologies have been demonstrated as viable for military or scientific purposes, in principle they are available for development for market economic purposes. According to its inventor, the idea of the useful technology of the laser was motivated by a desire to create a device that would further scientific understanding (see Chapter 2). That is indeed how the inventor sought to apply his technology, but once a working device had been publicly demonstrated, private sector firms began to develop the technology for economic uses.

In other words, even in societies largely organised as market economies, while all technologies have their uses, they do not necessarily have an economic 'market' and they are not necessarily first generated to serve economic purposes. They may nevertheless come to have a significant economic impact. To discuss technologies and their 'uses' in principle allows a discussion of any technology, whatever its social and cultural context and whatever the human purpose motivating its creation and use. To discuss technologies and their relationship to the economic institution of the 'market' implies a restriction of the range of technologies to those that generate tradable goods and services and that serve the interests of the people and organisations participating in the market. It is primarily the second class of technologies that are of interest in this book, but as in the case of the laser, non-economic institutions will be of interest when they have a productive interface with the market economy.

It is one thing to be interested in the technologies developed within the market economy and developed for economic reasons, but quite another to be uncritically committed to economic theory as an aid to understanding. Economic theory may have little to offer the study of technology. Although this book does make use of ideas from the subject of economics, it is also the case that certain ideas within economic thought have been applied to the detriment of technological development. This is very apparent in the application of US antitrust and patent law, discussed at length in Chapters 4 and 5 on competition and intellectual property. It should be said that the revision of policy in these cases has also been driven by economists, but economists with particular theoretical commitments. The point here is that our interest in technological development

in the market economy can lead quite logically into an interest in the construction and application of economic thought, as one of the many influences on the development of technology.

Socio-economic Perspectives on Technology and the Market Economy

The problem of how to include economics in the study of technology while not necessarily accepting the assumptions of economic theory has bothered the sociologists of technology. As the title of a collection of readings edited by MacKenzie and Wajcman, the ‘social-shaping of technology’ has been popularised as a term to describe some of the many ways in which technology can be influenced by society (MacKenzie and Wajcman 1999b). Like many others, MacKenzie and Wajcman understood that neoclassical economic theory, as the dominant economic theory of the relationship between technology and economics, could have little relevance when technology was changing, for then future prices, costs and competitive scenarios matter, and these cannot be known in full, as neoclassical economic theory requires (MacKenzie and Wajcman 1999a: 13). Nevertheless, MacKenzie and Wajcman recognise that economics matters to the social shaping of technology and so they take the position that the economic shaping of technology through price and cost considerations is a form of social shaping, and that such economic calculation depends on the organisation of the society in which it occurs. This is essentially the same position as the one developed here; however, none of the examples in MacKenzie and Wajcman’s text concern the mutual ‘shaping’ between technology and market economy institutions that are of interest in this book.⁵

Of greater apparent relevance is the important stream of contemporary economic thought that has attempted to reintroduce the analysis of ‘institutions’ to economics-the-subject, the so-called ‘New Institutional Economics’ (Swedberg and Granovetter 2001: 15). However, Swedberg and Granovetter are critical of this stream of thought as part of their development of what we might term a ‘counter programme’ for the study of the ‘sociology of economic life’.⁶ According to Swedberg and Granovetter, central to all versions of the New Institutional Economics is

the concept of efficiency. Institutions, it is argued, tend to emerge as efficient solutions to market failures ... another common feature is the assumption that while most of the economy can be analysed perfectly well with the help of rational choice (and with total disregard for the social structure), there do exist a few cases where you have to take norms and institutions into account. ... This way of arguing makes for a type of analysis that is only superficially social. Finally there is also the disturbing fact that when economists analyse institutions they feel no need to take into account how and why the actors, *in their own view* [author’s emphasis], do as they do. ... These two limitations – inattention to social structure and to the beliefs of individuals – make the New Institutional Economics into a kind of analysis that can best be described as a science of what economists think about what is happening in the economy. (Swedberg and Granovetter 2001: 15)

This amounts to a general warning that this school of economists have a tendency to find what they presuppose is there. In Misa's analysis of Chandler's account of the rationality of vertical integration in the US steel industry we already have an example of the kind of bias to explanation that this might produce. However, one should be careful of accepting Swedberg and Granovetter's picture of the 'New Institutional Economics' as a clear 'school of thought'. The lesson I prefer to draw is that the interpretation of evidence is more fraught than one might have supposed, and mistakes are made. The remedy would be more care in analysis and awareness of the ways that prior theoretical commitments *may* lead interpretation adrift. However, there is certainly further justification here for other ways of studying economic life than solely through the lens of contemporary economic thought.

Implications for the Structure of this Book

This book adopts such another way. The technology complex and the issue of scale and attribution of causation will be used to organise the contents of this book. First, the book seeks to introduce the *variety* of reciprocal influences between social, organisational and artefactual forms that constitutes the design and creation of technology. Second, it seeks to move between micro- and macro-level accounts to capture the different forms of technological reality. Third, it introduces the shaping and reshaping of relevant institutional forms as part of the management of innovation.

The chapters are organised to flow from fundamental issues of technology development and growth to the relationship between institutions and the ability of the private sector to develop technologies. The institutional forms of intellectual property, finance and education that are the subject of the later chapters tend to be more stable through time compared with specific instances of innovation and so lean towards being taken for granted. They are nevertheless subject to their own processes of change, in which the private sector participates, but in collaboration with other actors such as the state. They are included here both because they influence the conditions for technology development in the firm and because they extend the coverage of elements of the technology complex.

In sum, this book seeks to emulate the success of the social shaping texts in offering a rich surrogate experience in the sheer variety of how social forms and human purpose influence technological design, but within the narrower range of the operation of the market economy. In response to the discussion above of the limitations of any one school of thought, there will be a preference for detailed contextual analysis of change processes. This makes it more likely that disjunctions between empirical material and theoretical commitments can be teased out of the sources. This also implies the choice of a relatively small number of texts and cases for their richness, detail and significance, rather than an attempt to comprehensively cover the management literature. This approach represents my definition of the management of innovation and technological change. It does not pretend to offer direct help for immediate practical problems,

but if this text succeeds in its effort to make an original synthesis of material that explicates an extended understanding of the process of technological change, then because good understanding is the basis for good practice, it will have value.

A brief review of some contrasting, alternative approaches to innovation follows. This should reinforce the value of the broad concept of technological change outlined here; on this matter the problem is not one of a lack of research volume or of examples, but of fragmented and inadequate, often competing and overlapping, frameworks of understanding.

Some Contrasting Conceptual Approaches to the Representation of Innovation

The Structure of Management Education

The most obvious route to provide a broad understanding of innovation in management might be thought to be the MBA; so, for example, organisational behaviour might be thought to deal with the organisational design aspects of technology, strategic management to deal with strategies for technology development, and so on.

As forcefully argued by Rickards in his review of the typical MBA curriculum, there is no shared concern with innovation and change (Rickards 2000). The academic specialisations that comprise the MBA did not develop around the object of 'explaining' technology or technological decisions, but around their own professional agendas and method preferences. There is no single definition, or discussion of technology, shared between the subjects – at best there are partial and incompatible definitions of the sort collected in Figure 1.1. Taken as a whole, one is in danger of obtaining a fragmented and contradictory understanding of technological change and the role of management.

The distinct institutional history of management education compared with the engineering subjects (in the USA and Britain) is also likely to play a part in promoting a partial understanding of technological change and management. Artefacts and their design are the preserve and principal focus of the engineering disciplines.⁷ Business and management education is provided in distinct institutions and so there is a strong tendency to define business and management subjects free from concern with particular classes of artefact; in other words, without roots in a technological context. The potential value that may come from building appropriate business and management material into a particular technological context is lost.

Diagrammatic Models of Innovation

An example of the effort to condense and simplify understanding of innovation is the effort to build a general model of the innovation process in diagrammatic

form. A model is a simplified representation of a more complex reality and its object is to make that reality more readily understood in its essential features so that it can be used – to educate, or to instruct policy.

Forrest has reviewed many of the diagrammatic ‘box and line’ models of the innovation process and her review makes apparent the bewildering variety within even this modelling format (Forrest 1991). Some of this variety derives from the degree of complexity of models. Rather like the technology complex, the more complex models were the result of authors adding more elements of the innovation process to improve what we might call the representational coverage of the models – at the cost, of course, of the simplicity which is the object of this kind of modelling process (compare, for example, the models in Figures 1.4 and 1.5). Forrest observed that not even these complex models were complete, in that it remained possible to think of further elements that one should include in a model (Forrest 1991). Her ‘minimum list’ of such elements included:

A definite pre-analysis and pre-evaluation stage, definitive feedback loops, both internally within the firm and externally with the environment; the industry and life stage of the organisation within the industry; a recognition of the environmental variables – not only the marketing and technological, but the socio-cultural and political environmental variables and the internal environment (culture) of the firm; and the important dimensions of time and cost/resource commitment. (Forrest 1991: 450)

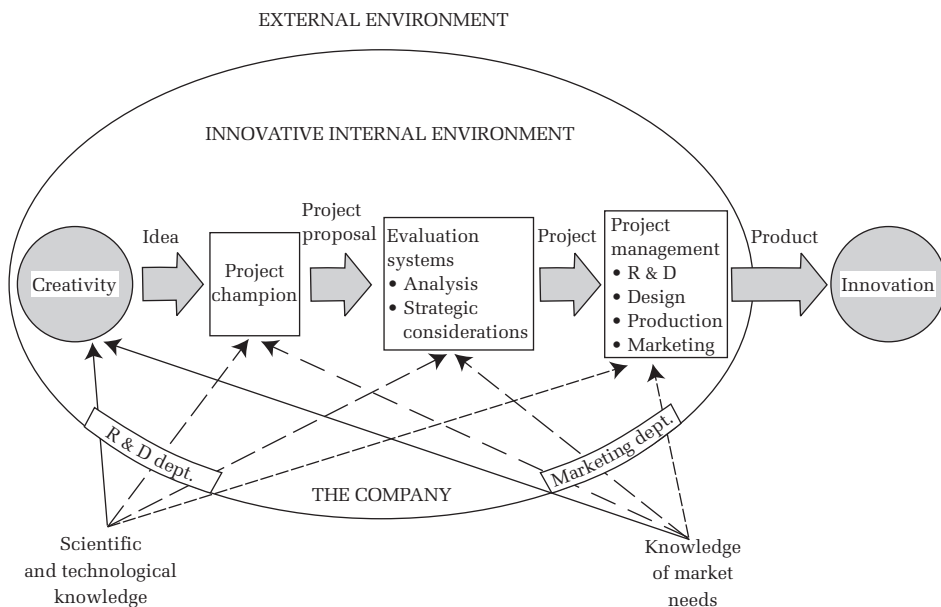


Figure 1.4 Twiss's 'Egg' model of innovation (Twiss 1992: 25)

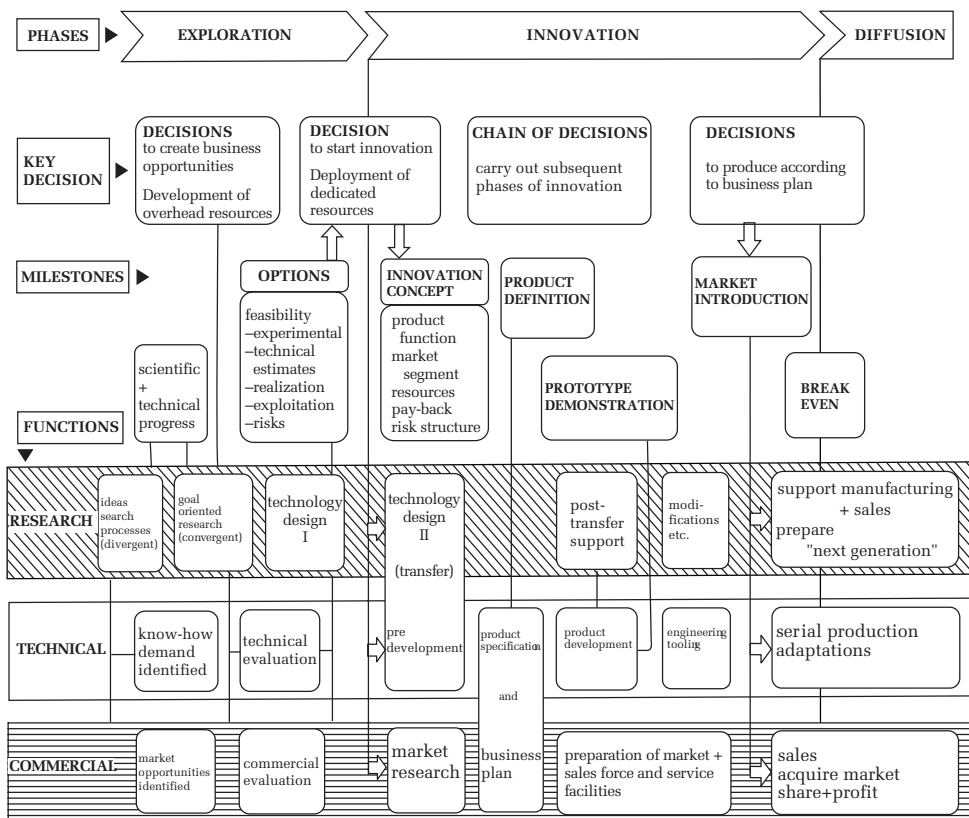


Figure 1.5 The Schmidt-Tiedemann concomitance model of innovation (Schmidt-Tiedemann 1982, reproduced with permission from *Research Technology Management*)

This begins to resemble the list of the technology complex, with the added complication that the modelling form is burdened with the object of representing a definite set of stages or functions *and their causal relation* to each other, usually by means of arrows. The more complex models modify any strong causal connections, for example by having arrows point in both directions to represent reciprocal or iterative influence of functions, or by many of the functions or stages being interlinked by arrows to show that innovation does not necessarily proceed in neat, ordered stages.

It may not be surprising that Forrest concludes by questioning whether this pursuit of a truly general innovation model is possible given the complexity and variety of the innovation process. Yet she does not dismiss outright the utility of this kind of modelling process – instead she urges management to create their own technology or industry-contingent innovation models. So the pursuit of a diagrammatic representation in a particular innovation context may be a useful aid to clarifying thought, but Forrest warns that one should be wary of any particular ‘model’ being taken too seriously and applied too rigidly as a guide to action out of the context in which it was created.

Technology or 'Manufacturing and Services'

The very *creation* of primary, secondary and tertiary categories of economic activity was made to demonstrate the trend with which we are all now familiar: the steady movement of employment from agricultural to manufacturing and now service activities⁸ that has occurred in developed countries over many decades and centuries. Yet even an author like Bell who made these categories fundamental to his forecasts of a 'post-industrial society' comments that the category of services is a 'residual': that is, it is defined by *not* being agricultural or manufacturing activity (Bell 1973: 15). And here is the problem, for if the focus of analysis is technology, the artefact and associated social change, the category of manufacturing captures economic activity where the artefact is the end result of economic activity, but 'services' contains such diversity it is well nigh useless as a descriptive category; it contains personal services like hairdressing, but also software production, financial services, scientific research, health and government services.

The reality is that despite the general fall in manufacturing employment, manufacturing output continues to rise strongly in almost all industrial countries, with the exception of Britain: so between 1973 and 2000, manufacturing output increased by 114% in the USA and 14% in Britain (Rowthorn 2001). The widespread reporting of economic activity through the categories of manufacturing and services tends to promote the illusion that the decline in manufacturing employment means that the production and use of artefacts is of decreasing importance. Hence the counter-argument makes a periodic reappearance, evident in the titles of works such as 'The Myth of the Post-Industrial Economy' (Cohen and Zysman 1994) and *In Praise of Hard Industries* (Fingleton 1999). If 'industrial' means the ability to produce artefacts, then no rich, developed country is 'post-industrial' – they are more 'industrial' than ever.

It is worthwhile to explore how the artificial division between the statistical categories of manufacturing and services largely breaks down if we insist on thinking of economic activity in terms of technologies, artefacts, and their uses. This is perhaps most obvious with the imposed classification of software production as a 'service'. This is despite the fact that the output of software production is a 'made thing', an artefact, albeit with distinct properties, and also despite the fact that the organisation of software production has much in common with the organisation of production of other forms of artefact. This seemingly arbitrary act of classification allows the great recent growth in software production to add to the measured growth of service activity.

Some services are specialisations in the *provision of use* of highly complex artefacts, and their growth – and existence – are clearly dependent on improvements in the artefact; the airline industry is a good example of such a service. Other categories of service are 'tightly-linked' (in Cohen and Zysman's term (Cohen and Zysman 1994: 33)) to particular manufacturing industries; these include repair, maintenance and design and engineering consultancy services. In other words, 'tightly-linked' services are the characteristic activities organised around a specific kind of artefact that together give a technology its separate identity.

Such tightly linked activities have the property that they may be organised in-house, in which case they are classified by the statisticians as manufacturing, but if they are organised separately to the production of artefacts – in today's jargon, if they are outsourced – they are classified as services. One can imagine that if there were a net increase in outsourcing in the economy, it would increase the measured statistical trend towards more service activity – yet for such services, the 'organisational shell' from which, or within which, they are provided is less important than that they exist at all and that they continue to relate to a specific form of artefact.

Indeed, in order to make sense of recent organisational trends in complex product industries, some writers have dropped the terms 'manufacturing' and 'services' in favour of the 'business of systems integration' (for example, Prencipe et al. 2003). It is well known that companies such as the US car manufacturers and General Electric have moved 'downstream' into high value-added services such as the provision of finance to supplement their product incomes, but in the 1990s General Electric continued to expand the services offered by its financial services division, GE Capital, so that it could offer 'integrated solutions' to its customers' needs, including products, finance and maintenance (Davies 2003: 338). By 2002 GE Capital generated 49% of the firm's total revenue (Davies 2003: 338).

Ericsson offers a more radical case, where much of its product manufacturing has been outsourced to a favoured manufacturing contractor, Flextronics, while service offerings and business consulting activities have been combined into a new division, Ericsson Global Services, created in 2000 with the object of the provision of high-value integrated systems and services to all mobile phone operators (Davies 2003: 352). As some of Davies' cases show, while such firms as these are moving from manufacturing into integrated systems provision, other firms have moved from being 'pure' service providers into integrated systems provision: this is the case with WS Atkins, the former project management and technical consultancy provider (Davies 2003: 352).

What this reveals is that the appropriate bundle of activities for containment within the firm is very much in flux and very much a focus of management attention. Our focus of enquiry is management activity in a technological context and it will prove hardly possible not to refer to the specific 'services' that are tightly linked to artefacts. The custom of categorising economic activity by the end product of the firm so that firms are *either* manufacturing *or* service firms obscures more than it reveals.

Reading from the Artefact Alone – Common Sense and Some Limitations

It is an interesting exercise to consider what can be learnt from artefacts alone. An instructive and contrasting pair of thought experiments consists of trying to isolate significant innovation that on the one hand has no artefact component and on the other hand concerns the artefact alone.

So, for example, if the effort is made to think of a 'pure marketing' innovation, it is possible to imagine changes in marketing technique, but one soon

realises that as marketing is a service to the major activity of the firm, where that activity involves changing artefacts, marketing activity is likely to be adapted to the nature of such changes. So the search for pure marketing innovation should seek examples where there is a minimum of artefact change in evidence. It is difficult to beat Foster's nice, laconic account of what innovation amounts to in cola drinks:

We all remember the familiar 6.5 Coke bottle and its Pepsi equivalent. And we can also remember when the 6.5 ounce bottle was joined on grocery shelves and vending machines by the 12 ounce can. This advance – and some people considered it one – was so successful that it was followed with the 16 ounce glass bottle, and then the 26 ounce bottle, the 28 ounce bottle and finally the 32 ounce bottle. From there the competition got dirty. First one company went to the 48 ounce, then the other. Then both followed quickly with the 64 ounce bottle. Where would all this exciting competition lead? To the metric system when the 64 ounce bottle was replaced by the 2 litre bottle...now made of plastic, and then by the 3 litre bottle....What non-advance can we expect now? Five litre bottles with wheels? (Foster 1986: 254–5)

Such a business is driven by advertising and marketing as the means of manipulating consumer perceptions of symbolic and minor changes to the presentation of the product. These activities are interesting in their own right, but the scope for material change that might advantage the consumer is obviously largely absent. Indeed, the example sharpens another question: what can 'advantage' mean in the absence of some element of artefact change?

The complement of the 'imagine innovation without the artefact' exercise is to consider the meaning of a change in the artefact alone. But this is an absurdity because by definition change in an artefact is a result of human intention and activity. However, these activities are often complex with an elaborate division of labour and expertise; so this question can be changed to become a search for those individuals that experience changes in artefacts with a minimum of access to the human processes upon which these rely.

Common sense suggests that in our society it is in our role as consumers that we come closest to experiencing artefactual change without the allied knowledge of production and distribution. More than this, it is because of our individual social and cognitive limitations that we have necessarily restricted knowledge of the diversity and complexity of design and production of these same artefacts. There is a fundamental asymmetry between our degree of access to consumer and to producer technology.

And yet, as consumers, we have the 'knowledge of use' of many artefacts. We are familiar with the problems of acquiring this knowledge of use – these artefacts must be set up, used and maintained and they all fail in various ways. When they fail we tend to make judgements about the human design process that produced the artefact and a common struggle that occurs is over the attribution of 'fault' either to artefact design or to our manner of its use. In other words, we are all to some degree experienced in the *interpretation* of artefacts as indicators of the design and production process, *despite* our intrinsically limited ability to grasp the detail of all these production processes.

All this is basic and perhaps obvious, but it is worth restating here because it helps avoid the mystification of technology. The ‘imaginative basis’ for understanding the design process in its various contexts is widespread, yet usually limited by having access only to artefact forms. Of course experts in methods of production and design should make the better interpreters of artefacts – what is ‘reverse engineering’ but a highly and actively developed ability to read from artefact design the nature of the production and design process that created that artefact? And outside engineering we find the discipline of archaeology to be the study of human history through the ‘science’ of reading defunct artefacts (and other material remains).

Limits on the Interpretation of the Artefact – Skeuomorphs and Spandrels

From such disciplines’ intensive relationship with artefact form and meaning we can derive useful and general ‘limiting’ concepts on what is probably our default assumption about any artefact form – that *every element of design* that we observe in an artefact is there by the designer’s intention and for utilitarian reasons.

A skeuomorph is an element of design that has lost its original function but has nevertheless been retained in its artefact. The classic example in architecture is the square at the top of the much imitated Doric column (Adam 1989) and reproduced in Figure 1.6. Early Greek architecture was constructed from wood and this square had a stress-distributing function for wooden columns. The retention of the ‘square’ when marble and stone materials were used instead of wood was for reasons of style. Another example is the retention in

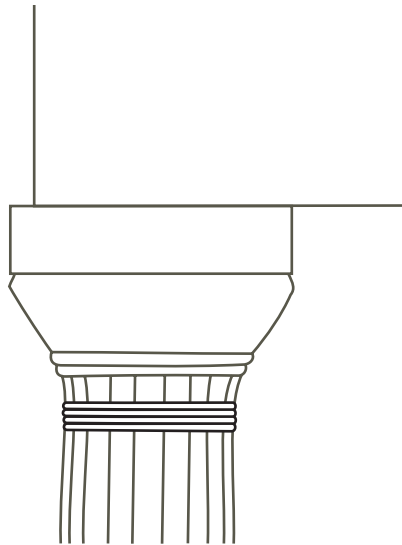


Figure 1.6 The square at the top of the Doric column is the skeuomorph

modern dust-pressed clay plates of the disc shape once necessarily obtained from wheel-spun pottery production. Many other shapes, such as squares, are in principle possible with the dust-pressing manufacturing process (Adam 1989). Adam suggests that the freezing of form in the plate may be partly aesthetic and partly prevalent usage; the spread of dishwashers designed around the standard form in crockery begins to limit the latitude in crockery design.

A quite distinct class of limitations on our ability to work out the design process from its resultant artefact is that what may appear to the artefact observer as an element of design may be the *byproduct of other design choices*. The difficulty of distinguishing between byproduct and intentional design elements, within the artefact alone and without production knowledge, is demonstrated in a controversy over the significance of the 'spandrel' as a byproduct of design in architecture.

A much discussed paper in evolutionary biology by Gould and Lewontin used the architectural 'spandrel' to argue that elements of biological form might also be byproducts of other design elements, rather than adaptations under natural selection, as conventionally assumed (Gould and Lewontin 1979). Their paper has been notoriously misused to undermine the public perception of evolution, but that controversy does not concern us here.⁹ Gould and Lewontin's use of the spandrel in architectural form as a straightforward example does concern us and they comment that 'such architectural constraints abound, and we find them easy to understand because we do not impose our biological biases upon them' (Gould and Lewontin 1979: 581). On the contrary, they are not so easy to understand and for the same reason that the attribution of function may be complicated in biology: casual observation of the artefact or the biological form alone, without sufficient understanding of the process of construction or growth, is not sufficient to determine the function of all elements of form.

Gould and Lewontin's example of 'spandrels' is the Basilica of San Marco in Venice, which has a main dome supported by four arches. First it must be pointed out that the correct name for the roughly triangular segment of a sphere that tapers to points at the feet of its supporting arches is a pendentive, not a spandrel (Dennett 1996: 3). The difference between a spandrel and a pendentive is evident when Figures 1.7 and 1.8 are compared.

Now the historian of architectural technology, Robert Mark, has used arguments drawn from his understanding of then-contemporary construction knowledge to judge that the pendentives of San Marco do, after all, have a function.

In the earlier building (537 AD) of Justinian's Hagia Sophia in Constantinople (Figure 1.8), Mark found that pendentives had the function of stabilising the dome, which would otherwise be in danger of exploding outwards under *tensile* stress derived from its own weight¹⁰ (Mark 1996; Mark and Billington 1989: 308). The pendentives performed this function when their outside surface was loaded with material to provide a stabilising weight – these weights are visible on the outside of the dome in Figure 1.8. Mark then argues that because construction knowledge in the prescientific era was developed by observation of the behaviour of existing buildings, the builders of the Basilica of San Marco in the late eleventh century would have been extremely unlikely to use any

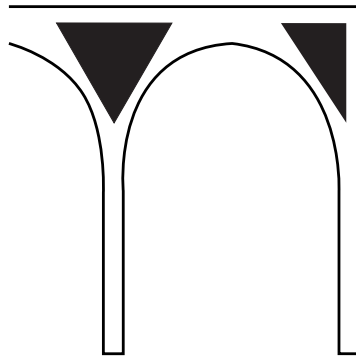


Figure 1.7 The roughly triangular area created when a viaduct is supported by arches is the spandrel

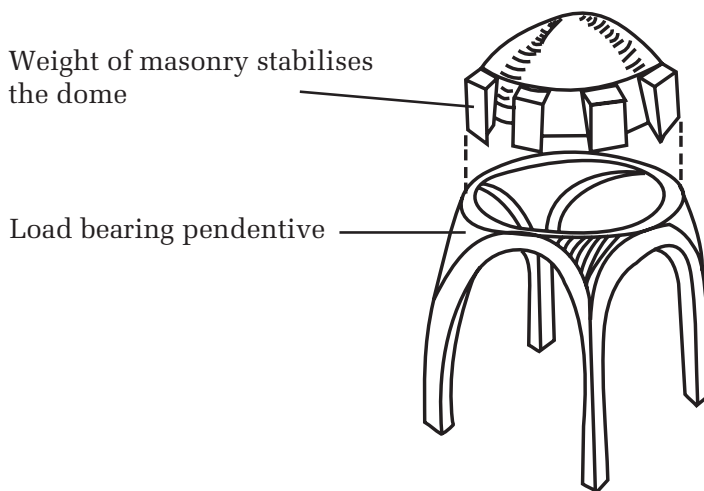


Figure 1.8 Diagram of the construction of the Hagia Sophia. The pendentives are the curving, three-dimensional and tapering triangular areas between the arches and the rim of the dome. The tensile stress within the dome is stabilised by blocks of masonry that rest on the pendentives

other construction method than pendentives to stabilise its large, 30 m diameter dome (Mark 1996). In other words, in the Basilica of San Marco, pendentives were not a 'necessary architectural byproduct' (Gould and Lewontin 1979: 581) that resulted from the design *choice* of arches to support a dome, but they were a *necessary structural feature* of the proven system of support for large domed buildings: arches with loaded pendentives were the necessarily combined elements that together achieved the purpose of stabilising a dome. This leaves the Gould and Lewontin discussion of 'spandrels' not only wrong in its use of

terms, but wrong in its conclusions on the significance of 'byproduct design' in both architecture and evolutionary biology.¹¹

The significance of this is that even in architecture, whose product is that most visible of artefact forms, the building, mere inspection of the artefact is not a reliable means of working out the constraints on the design and construction process. In this example, the interpretation of architectural form was assumed to be simple; in reality, the problem of interpretation of architectural form proved as complex as some of the examples that could have been provided from evolutionary biology.

In conclusion, this pursuit of the feasibility of interpretations of the artefact tends to reinforce the conclusion that if innovation is most interesting when there is an element of artefactual change, the understanding of such change is necessarily accompanied by an understanding of change in other elements of the technology complex. The attainment of that understanding is often obscure and difficult to access, but in this book, in the search for understanding of patterns in technological change, we will be repeatedly drawn into investigations of the detail of the relevant technology, understood in its broad sense through the technology complex.

Conclusion

In this review of alternative conceptions of innovation, the problem revealed is not necessarily that innovation is inaccessible and neglected, but that many readily available conceptions and straightforward daily observation, give at best only a limited view of the innovation process. This is perhaps not surprising, but it reinforces the conclusion drawn in the first part of this chapter: that if general understanding is the object, then a broad conception of technological change is the appropriate one. It follows, then, that the rest of this book should be dedicated to an analysis of change in the elements of the broad definition of technology.

Notes

¹ Fleck developed the idea as a result of many years of teaching the management of technology at the University of Edinburgh. In 2001 he and I published a paper describing the technology complex and giving examples of its utility. Much of this section and the following section on the uses of the technology complex are from that paper (Fleck and Howells 2001).

² The list could be expanded through the addition of more subdefinitions of technology, for Fleck and Howells did not attempt a 'complete' review of disciplines with active and distinct uses of the term 'technology'. Such additions and the pursuit of an ideal 'complete review' would not change the essential pattern revealed here: that a given technology includes elements that range from the artefactual through various social forms.

³ This section is almost entirely derived from Fleck and Howells (2001: 525–6).

⁴ For example see Smith and Marx 1994; MacKenzie and Wajcman 1985.

⁵ A branch of the sociology of technology based on the writing of Callon and Latour termed 'Actor Network Theory' (ANT) seems to be increasingly popular with prospective PhD students – as if it offered a coherent theory of technology. One of their virtues is that they are in favour of more 'thick description' of technological development, but they actively develop a jargon