

Technological Innovation as an Evolutionary Process

Edited by JOHN ZIMAN

on behalf of The Epistemology Group



CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK <http://www.cup.cam.ac.uk>
40 West 20th Street, New York, NY 10011-4211, USA <http://www.cup.org>
10 Stamford Road, Oakleigh, Melbourne 3166, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain

© Cambridge University Press 2000

This book is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without
the written permission of Cambridge University Press.

First published 2000

Printed in the United Kingdom at the University Press, Cambridge

Typeface Swift 9.5/14pt System 3B2 [CE]

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

Library of Congress Cataloguing in Publication data

Technological innovation as an evolutionary process / edited by John Ziman
on behalf of the Epistemology Group

p. cm.

Includes bibliographical references and index

ISBN 0 521 62361 8

1. Technological innovations – Social aspects. 2. Evolution (Biology)

I. Ziman, J. M. (John Michael), 1925– .

T173.8.T363 2000

600–dc21 99-15474 CIP

ISBN 0 521 62361 8 hardback

Contents

<i>List of contributors</i>	xiii
<i>Preface</i>	xv
I EVOLUTIONARY THINKING	1
1 Evolutionary models for technological change	3
JOHN ZIMAN	
1.1 The biological analogies	3
1.2 The technological ‘disanalogies’	5
1.3 Is ‘evolution’ compatible with ‘design’?	6
1.4 Artefacts as cultural constructs	7
1.5 Institutions, roles and behaviour	8
1.6 Selectionism versus instructionism	10
1.7 Understanding innovation	11
2 Biological evolution: processes and phenomena	13
EVA JABLONKA AND JOHN ZIMAN	
2.1 Darwin’s theory today	13
2.2 Heritable variation	15
2.3 Multiplication and heredity	18
2.4 The objects of selection	18
2.5 Adaptation	21
2.6 Speciation and macroevolution	23
2.7 Progress and its ambivalences	25
3 Lamarckian inheritance systems in biology: a source of metaphors and models in technological evolution	27
EVA JABLONKA	
3.1 The genic model	27
3.2 Dysfunctions of the genic model in cultural evolution	29
3.3 Epigenetic inheritance systems (EISs)	31

3.4	Induction and selection of epigenetic variations	37
3.5	The 'unit' problem	39
4	Selectionism and complexity	41
	JOHN ZIMAN	
4.1	Adaptation by selection	41
4.2	Other selective systems in biology	44
4.3	Selectionist methodology	46
4.4	Emergent properties of computer models	47
4.5	Complexity theory	49
5	Evolutionary phenomena in technological change	52
	JOEL MOKYR	
5.1	Introduction	52
5.2	Techniques and evolution	53
5.3	Selection units and replicators	58
5.4	Vehicles and interactors	60
5.5	Selection and teleology	61
5.6	Innovation and adaptation	63
5.7	Summary: information and selection	64
6	Selection criteria and selection processes in cultural evolution theories	66
	RICHARD NELSON	
6.1	Different perspectives on technological evolution	66
6.2	Technological change as one aspect of cultural evolution	66
6.3	Differing views on selection criteria and mechanisms	69
6.4	Technology as both practice and understanding	72
II	INNOVATION AS A CULTURAL PRACTICE	75
7	Technological evolution and involution; a preliminary comparison of Europe and Japan	77
	ALAN MACFARLANE AND SARAH HARRISON	
7.1	The industrious revolution	77
7.2	The West-European trajectory	77
7.3	The decline in the use of domesticated animals in Japan	79
7.4	The declining use of the wheel in Japan	80
7.5	The outcome: intensive rice agriculture in Japan	81
7.6	The puzzle of the different trajectory of Europe and Japan	84
7.7	Possible reasons for the absence of domesticated animals in Japan	85
7.8	Theories to explain the declining use of the wheel	87
8	Stasis in complex artefacts	90
	GERRY MARTIN	
8.1	A skilled craft in a sophisticated civilization	90
8.2	The Japanese sword	91
8.3	Iron + 0.7% carbon = steel	92

8.4	Quench hardening	96
8.5	Keeping to what has been found, from long experience, to work	98
9	Gothic tales of spandrels, hooks and monsters: complexity, multiplicity and association in the explanation of technological change	101
	DAVID TURNBULL	
9.1	Explaining technological change	101
9.2	Two contrasting stories	102
9.3	The social construction of science and technology	106
9.4	Thinking with cathedrals	107
9.5	The power of the template	112
9.6	The power of talk	113
9.7	Theory and practice	115
9.8	Analysing artefacts in use	116
10	Path dependence and varieties of learning in the evolution of technological practice	118
	PAUL A. DAVID	
10.1	Introduction: varieties of learning in the economics of technology	118
10.2	A concrete historical application	121
10.3	Inquiry by means of computer simulation: the 'Bayesian adaptive rhythm' (BAR) model	122
10.4	The historical frame and the computational bounds upon inferential learning	124
10.5	Simulation results	127
10.6	Some extrapolations	129
10.7	Instructionist versus selectionist mechanisms in evolution	131
III	INVENTION AS A PROCESS	135
11	Invention and evolution: the case of Edison's sketches of the telephone	137
	W. BERNARD CARLSON	
11.1	The evolutionary role of the inventor	137
11.2	Demystifying the process of invention	138
11.3	A historical interlude: Edison, acoustic telegraphy, and the Reis telephone	139
11.4	Edison's transformative sketches of the Reis telephone	143
11.5	Another historical interlude: Bell, Western Union and Edison's contract	148
11.6	Sketches as fossils: taking a palaeontological approach	149
11.7	Making maps to find patterns in the fossil record	150
11.8	A narrative overview of Edison's work on the telephone	151
11.9	So what do these maps tell us about invention and evolution?	155
11.10	Edison as breeder	157
12	The evolution of adaptive form	159
	DAVID PERKINS	
12.1	The evolution of adaptive form	159

12.2	The challenge of adaptive form	160
12.3	Strategies of search	164
12.4	How biological evolution is Klondike smart	167
12.5	How human invention is Klondike smarter	169
12.6	Is invention Lamarckian or Darwinian?	171
13	Real-world variation-selection in the evolution of technological form: historical examples	174
	WALTER G. VINCENTI	
13.1	The constraints of the real world	174
13.2	Variation-selection in direct use	175
13.3	Variation-selection in design	177
13.4	Variation-selection in a design community	182
13.5	Observations	187
14	Learning to be inventive: design, evaluation and selection in primary school technology	190
	JOAN SOLOMON	
14.1	Education	190
14.2	The nature of technology	191
14.3	Technology and history	192
14.4	Starting the design process	193
14.5	Problems with drawing for selection	194
14.6	Spatial ability and mental modelling	195
14.7	Evaluation	199
14.8	Creativity and conclusions	200
15	Technological evolution as self-fulfilling prophecy	203
	GEOFFREY MILLER	
15.1	From genetic algorithms to Darwinian engineering	203
15.2	How computer science turned Darwinian	204
15.3	How genetic algorithms work	206
15.4	Some strengths and weaknesses of genetic algorithms	209
15.5	Fitness evaluation in Darwinian engineering	211
15.6	The future of technological evolution	214
IV	INSTITUTIONALIZED INNOVATION	217
16	Recursive practice and the evolution of technological knowledge	219
	EDWARD CONSTANT	
16.1	Introduction	219
16.2	Recursion in engineering science and practice	221
16.3	What evolves?	224
16.4	A quasi-Bayesian solution	224
16.5	Recursion and rationality	228
16.6	Recursive practice and the evolution of technological knowledge	230

17	The concept of 'design space'	234
	RIKARD STANKIEWICZ	
17.1	A conceptual framework for technological evolution	234
17.2	Cognitive dimensions of technology	234
17.3	Design spaces	235
17.4	Dynamics of design spaces	237
17.5	The evolutionary regimes of technology	237
17.6	Structuring design spaces	240
17.7	Design languages	241
17.8	Hierarchies of design languages	242
17.9	The expansion of design spaces	243
17.10	The convergence of design spaces	245
17.11	Technological change as conceptual evolution	246
17.12	Organizational and institutional implications	246
18	Artefact↔activity: the coevolution of artefacts, knowledge and organization in technological innovation	248
	JAMES FLECK	
18.1	Introduction	248
18.2	Technology development	248
18.3	The units for technological evolution	249
18.4	The role of artefacts	251
18.5	The role of knowledge	254
18.6	The role of organization	256
18.7	The artefact-activity couple	257
18.8	Stable replication	259
18.9	Technological lineages	260
18.10	Variation and innovation	263
18.11	Lamarckianism, Darwinism and neo-Darwinism in technological evolution	265
19	The organization of innovative enterprises	267
	GERARD FAIRTLOUGH	
19.1	Styles of organization and patterns of evolution	267
19.2	A typology of innovation	267
19.3	Types of organization	271
19.4	Choosing the right management style	272
19.5	Features of innovative organizations	273
19.6	Organization and technological evolution	277
V	TECHNOLOGICAL CHANGE IN A WIDER PERSPECTIVE	279
20	The evolution of war and technology	281
	EDWARD CONSTANT	
20.1	The partnership of Mars and Vulcan	281
20.2	Macroevolution	283
20.3	Coevolution and complementarities	288
20.4	'Fitness' and the problem of selection	291
20.5	Directed mutation, vicarious selection and institutional memory	296

21	Learning about technology in society: developing liberating literacy	299
	JANET DAVIES BURNS	
21.1	Understanding technological change	299
21.2	The role of social groups in technological development	299
21.3	Liberating literacy	302
21.4	Liberating literacy in a risk society	304
21.5	Education for technology	307
21.6	Conclusion	310
22	An end-word	312
	BY ALL CONTRIBUTORS	
	<i>Notes</i>	317
	<i>Bibliography</i>	324
	<i>Index</i>	347

Evolutionary models for technological change

JOHN ZIMAN

1.1 The biological analogies

Go to a technology museum and look at the bicycles. Then go to a museum of archaeology and look at the prehistoric stone axes. Finally, go to a natural history museum and look at the fossil horses. In each case, you will see a sequence, ordered in time, of changing but somewhat similar objects. The fossils, we know, are sampled from the history of a family of biological organisms. They are similar because they are related by reproductive descent. But here – and quite generally throughout this book – when we say that they have *evolved* we mean more than that they have ‘developed gradually’.¹ We are indicating that this development has occurred through genetic variation and natural selection, sometimes, in outwardly static circumstances, apparently spontaneously, sometimes as an adaptive response to a changing external environment. Can technological innovation be explained in similar terms? Do *all* cultural entities ‘evolve’ in this sense – that is, change over time by essentially the same mechanism?

These museum displays, and the similarities between them, are, of course, highly contrived.² But the basic analogy between biological and cultural evolution has often been remarked.³ From the middle of the nineteenth century onwards, it was noted more or less independently by such eminent scholars as William Whewell, Karl Marx, Thomas Henry Huxley, Ernst Mach, William James and Georg Simmel. The basic idea has been extended by later authors such as Jean Piaget, Konrad Lorenz, Donald Campbell, Karl Popper and Jacques Monod. Sometimes it is presented as just one aspect of a general principle of ‘Evolutionary Epistemology’, which interprets the whole story of human social, intellectual and material development as the continuation of organic evolution

by other means.⁴ But it is a simple idea that makes obvious sense in its own right – for example, in accounting for the immense variety of artefacts that are invented and put on the market, and for the superior utility of the few that eventually survive.⁵

What is more, it is an idea that can easily be developed in considerable detail. Try it out in conversation around the coffee table. Most people nowadays know enough about how Darwin explained ‘the origin of species’ to apply the same reasoning to ‘the origin of inventions’. They regularly refer to technological concepts in quasi-biological terms – ‘fitness’, ‘survival’, ‘niche’, ‘hybrid’, ‘genealogy’, etc. – as if the analogy needed no further explanation. This usage is so convenient that we shall employ it throughout wherever it is not misleading. Indeed, the theme of this book is perfectly exemplified by the usefulness of the technical language of evolutionary biology for summing up succinctly a variety of cultural phenomena.

First of all: it is very easy to point to *structural* analogies between certain biological processes and the processes involved in technological innovation. One can immediately think of mechanisms whereby material artefacts – indeed, also, less tangible cultural entities, such as scientific theories, social customs, laws, commercial firms, etc. – undergo *variation by mutation or recombination* of characteristic *traits*. Many different variants are put on the market (or published, or practised, or adjudicated, or invested in, etc. as the case may be). There they are subjected to severe *selection*, by customers and other users (or competing groups, courts of appeal, banks, and so on). The entities that *survive* are *replicated*, *diffuse* through the population and become the predominant type.

Further thought reminds us that *mutualistic* relationships are very common, as between pens and inks, or between bombers and radar systems. Indeed, technical innovations in an industry such as car manufacture are so interrelated that one might describe it as a whole *ecological system of coevolving* artefacts. As the selective environment changes, so do such systems evolve and *adapt* to it. On the other hand, isolated subpopulations – *demes* – may separate and evolve independently in different directions for long periods before recombining. And so on.

What is more, the history of technology provides numerous episodes that are remarkably similar to well-known biological phenomena. Some of these *phenomenological analogies* will be discussed in later chapters of this book. Overall they make an impressive list. In my own limited reading I have come across suggested technological analogues of what an evolutionary theorist would term *diversification*, *speciation*, *convergence*, *stasis*, *evolutionary drift*, *satisficing fitness*, *developmental lock*, *vestiges*, *niche competition*, *punctuated equilibrium*, *emergence*, *extinctions*, *coevolutionary stable strategies*, *arms races*, *ecological interdependence*, *increasing complexity*,

self-organization, unpredictability, path dependence, irreversibility and ‘*progress*’. Admittedly, some of these suggested similarities are very questionable, so that it would take us too far afield to cite, decode and try to justify them in detail. Indeed, the whole biological analogy is often dismissed as naive. But the mere fact that such a list can be compiled at all shows just how many quite specialized ‘evolutionary’ characteristics are apparently common to both technological and biological systems.

1.2 The technological ‘disanalogies’

The directness and diversity of these analogies strongly suggest the possibility of transforming the notion of ‘technological evolution’ from an evocative *metaphor* into a well-formed *model*. But before trying to set up such a model, we must look at the flip side of the comparison. Unfortunately, as many students of the subject have pointed out, there are many ‘disanalogies’ to take into account. Technological systems are not like biological systems in a number of important ways.

The most obvious difference is that novel artefacts are not generated randomly: they are almost always the products of conscious *design*. In the language of neo-Darwinism,⁶ they are not ‘Weismannian’: the variations that are presented for selection are not produced by a mechanism that is entirely blind to their ultimate fate. Inventors learn by experience and experiment, and visualize their creations before they make them. Their inventions thus acquire characteristics which are deliberately handed on to the next generation. Technological innovation thus has ‘Lamarckian’ features, which are normally considered to be forbidden in biology.

Another major difference is that there is no strict technological equivalent of a biomolecular *gene*. To sustain the overall analogy, it is convenient at times to talk about technological systems in terms of ‘memes’⁷ – elementary concepts that endure over long periods, replicate themselves and shape the actual artefacts. But this terminology is abstract and metaphorical. ‘Memes’ are not operationally equivalent to the indivisible entities hypothesized by Mendel and made flesh by Crick and Watson. The characteristic features of an artefact cannot be analysed uniquely into precisely defined design elements that endure unchanged for long periods. Thus, all bicycles have wheels, but these are so varied in design and construction that it is not very useful to regard them as manifestations of a ‘wheel meme’ that persists from type to type.

‘Meme’ language is instructive, of course, in emphasizing the heritability of technological traits, as distinct from the physical survival of the artefacts that exhibit these traits. Biological theorists make much of the relationship between

the *phenotypes* that are actually subjected to selection, and the *genotypes* that encode them. This is much simpler and more precise than the relationship between artefacts and their ‘memotypes’. The design of a novel artefact is often analysed and revised many times before any engineering work begins. Technological memes can be transmitted, stored, revived, varied and selected independently of the actual artefacts to which they might apply. It would be possible, for example, to construct a workable modern ‘penny-farthing’ bicycle solely on the basis of an old photograph or patent specification.

But here again, there are serious ‘disanalogies’. The genome of a biological organism is a ‘recipe’ for its development from conception, rather than a ‘blueprint’ of its adult form. In technological evolution, ‘memes’ from distant lineages often recombine, and ‘multiple parentage’ is the norm. No biological organism is like, say, a computer chip, which combines basic ideas, techniques and materials from a variety of distinct fields of chemistry, physics, mathematics and engineering. Does the differentiation of organisms into separate *species*, which Charles Darwin made central to evolutionary theory, truly apply to inventions? The ‘cladogram’ of a technological artefact usually looks more like a neural net than a family tree!⁸

1.3 Is ‘evolution’ compatible with ‘design’?

At first sight, then, the evolutionary metaphor for technological innovation is very appealing. In many respects, both the underlying mechanisms and the broad patterns of technological change are quite reminiscent of those found in biological evolution. But the idea of turning these structural and phenomenological analogies into a realistic model soon meets obstacles. Indeed, these obstacles have seemed so daunting that only the most daring scholars of the subject – notably the late Donald Campbell – have tried to surmount them. The viability of the project embodied in this book is thus seriously in question!

To proceed further, it is essential to understand what we are up against. The first major obstacle has deeper roots than the Lamarckian heresy. ‘Design’ is central to modern technology.⁹ How can that be reconciled with ‘evolution’, which both Darwin and Lamarck explained as a process through which complex adaptive systems emerge *in the absence* of design? We may well agree that technological change is driven by variation and selection – but these are clearly not ‘blind’ or ‘natural’. This work is being done largely by conscious human effort, without apparently needing guidance from any ‘hidden hand’, whether of Nature, the market, or God.

An evolutionary model incorporating intentional factors, such as memory

and mental imagery, thus seems self-contradictory. Should we abandon the project altogether, in favour of some other theoretical paradigm, such as ‘self-organization’, or ‘social constructivism’? To avoid this, advocates of ‘universal Darwinism’¹⁰ rightly point out that human cognition is the product of natural selection, and operates on selectionist principles.¹¹ They thus maintain the ‘blindness’ of the whole process by locating all the action in lower-level neural events whose causes might as well be considered random for all that we can find out about them. Alternatively, the effects of design are assimilated notionally into the selection stage of the cycle, where already-achieved wisdom is used, as in computer problem-solving, to reduce the search space.¹² But these are reductionist strategies that complicate the model far beyond any hope of practical application. Throughout this book, therefore, we shall accept these intentional factors in the way that we ordinarily understand them – for example, as reported to us in everyday psychological terms by ‘creative’ persons engaged in inventive activities.¹³

But does the ‘random variation’ that is such a fundamental element of an evolutionary mechanism really have to be as ‘blind’ as, say, the mutation or recombination of molecules of DNA in sexual reproduction? Remember Darwin’s insight that it is *populations* that evolve, not individual organisms. All that may be required is that there should be a stochastic element in what is actually produced, chosen and put to the test of use.

In practice, design processes are always imperfect and indeterminate. As we all know, the ‘best-laid plans’ of inventors, engineers, research managers, market analysts, company directors, etc. ‘gang aft agley’. What is more, there is usually so much uncertainty and disagreement on so many significant points that a wide range of artefacts is made available for selection. Again, the criteria by which technological innovations are selected are not universally agreed, so that artefacts with similar purposes may be designed to very different specifications and chosen for very different reasons. In other words, this apparently deep-rooted obstacle has little substance. There is usually enough diversity and *relatively* blind variation in a population of technological entities to sustain an evolutionary process.

1.4 Artefacts as cultural constructs

‘Design’ denotes more than rational construction. It indicates *purpose*. A technological artefact is defined in terms of its practical use. Unless novel specimens are made completely mindlessly – and that would not be true even of the stereotypical stone axe – their variant features are bound to be correlated with their intended role in the lives of their makers. After all, this is what

distinguishes an 'artefact' from a 'useful object', such as a pebble picked up for throwing.

A technology is not really separable from the *culture* in which it is embedded. Material artefacts encode, embody, convey or transmit whole systems of immaterial ideas and behavioural patterns. It is only for brevity that we talk about them as if they were specimens in a museum, identified only by a name and acquisition date, as if unaware of the invisible cultural aura that gives each object its meaning.

Indeed, the concept of 'technology' – 'the application of practical sciences to industry or commerce'¹⁴ – is not restricted to material objects. It also includes a whole variety of systematic technical procedures, such as farming routines or medical therapies, where the material instruments are not the centre of attention. The spectrum of *social constructs* stretches without a break from concrete objects such as stone axes, bicycles and aspirin pills, to the most abstract entities such as commercial contracts, legal precedents and economic theories.

In other words, a comprehensive model of technological innovation would have to cover almost every aspect of *cultural* change. In this book, we focus, for simplicity, on the evolution of tangible cultural objects such as swords, cathedrals, turbojets and pharmaceutical products. But the social context in which and for which they are produced is not merely a passive environment to which they must adapt. Many intangible features of the surrounding culture – for example, military techniques and commercial practices – change over time, hand in hand with the changes in the artefacts to which they are connected.

Thus, if technological entities (in the narrow sense) are deemed to 'evolve', then this interpretation must surely extend to the social entities with which they interact. In default of an alternative theory of a socio-cultural change, we have to include them in our evolutionary model along with their technological counterparts. This book is necessarily much concerned with the complications arising from this widening of the basic metaphor.

1.5 Institutions, roles and behaviour

The above argument can be turned on its head. One could well say that we are interested primarily in the evolution of *cultural* entities in general,¹⁵ and choose to study material artefacts because they have the useful property of being concrete, relatively stable physical objects. They are amongst the few socially meaningful entities that can be preserved unchanged for centuries and are not dissipated by close scrutiny. Their evolutionary trajectories ought to be much

easier to investigate and understand than those of less tangible cultural entities, such as languages, rituals, organizations or ideologies. Thus, the study of technological innovation, seemingly so marginal to the humanistic endeavour, could eventually lead right into its centre.

In other words, our starting point might have been evolutionary interpretations of cultural change as such, rather than the analogies between technological and biological evolution. Indeed, there is an extensive, if rather incoherent literature on this subject,¹⁶ which will be referred to in detail at various points in this book. But much of this literature is not really relevant to our theme, since it mainly derives its conceptual framework from *sociobiology*. That is to say, it is concerned primarily with the evolutionary interaction between the biological traits of human beings – in particular, hereditary traits such as sexual preferences, linguistic capabilities, affective responses, etc. – and their social behaviour.¹⁷ This *coevolutionary* process was obviously fundamental to the emergence of modern humans as social beings.

But the biological engine of sociobiology seems to have run out of steam many tens of thousands of years ago.¹⁸ On the other hand, cultural evolution has continued at an ever-increasing pace. Indeed, quite enough technological innovation has taken place since then to provide ample material for our study. We may confidently assume, therefore, that all the ‘inventions’ that we are concerned with in this book originated amongst people who were physically, intellectually and emotionally ‘just like us’.

What is more, we can discard the ‘methodological individualism’ intrinsic to sociobiology and evolutionary psychology. That is, instead of trying to reduce social action to patterns of individual *behaviour*, we can analyse it in terms of the *institutions* that shape it and give it meaning. Here, of course, we are adopting a much disputed sociological stance. But it does allow us to talk intelligibly about the evolution of organizations, social roles, cultural practices, languages, symbols, concepts, etc. without being committed to any particular opinion about whether such entities are ‘really real’.¹⁹

Indeed, as we noted incidentally above, ‘Darwinian’ processes of variation and selection can be observed at work amongst commercial firms, social customs, laws, scientific theories, etc. For example, *evolutionary economics*²⁰ focusses on industrial firms, treating them as social institutions driven by market forces to adapt to changing technological regimes. One of the obvious features of technological innovation in an advanced industrial society is that it involves the coevolution of marketable artefacts, scientific concepts, research practices and commercial organizations. The transistor, for example, was a novel engineering device conceived theoretically by solid-state physicists working in the research

and development laboratory of a telephone company. Each of these elements not only contributed to the process of innovation, but was itself changed by its participation.

But here again, by starting with entities at the material end of the spectrum of cultural entities, we do not run head-on into the fog of indefinability surrounding more general theories of 'cultural Darwinism'. Even the most systematic of these theories²¹ have encountered very serious conceptual difficulties in trying to identify the units of variation and selection in, say, the abstract world of scientific theories. The application of evolutionary theory to narrowly 'technological' change promises to avoid some of these difficulties, or at least to meet them in a different order, with different weights, and sometimes in simpler forms.

1.6 Selectionism versus instructionism

We can now see that a realistic evolutionary model of technological change must be more complicated than its biological counterpart. It has to incorporate 'design' as well as 'selection', and must extend into the domains of social institutions and abstract ideas. Biologists often complain about the misconceptions of non-biologists about the nature of organic evolution, and about their ignorance of the diversity of its mechanisms.²² But the processes at work in technological innovation are extremely heterogeneous, and change radically from era to era. As a result, the analogies and disanalogies between biology and technology look different according to what we choose to place at each end of the comparison.

There is a temptation to leap over these messy complications by proposing ever more abstract versions of Darwinism. But a watered-down model designed to meet all such objections would be weaker even than the basic metaphor. The standard neo-Darwinian account of biological evolution has a logical coherence and proven explanatory power which is hard to match. The challenge is to retain and exploit these virtues in the cultural domain.

In particular, what are we to make of the striking phenomenological similarities of biological and technological change? Perhaps these phenomena are not really sensitive to the structural details of the system. Perhaps they are common to all systems that evolve by mechanisms that include stages of partially random variation, selection and replication.²³

This line of argument is confirmed by the results of computer simulations on very simple models. The burgeoning literature on artificial life, genetic algorithms, cellular automata, etc.²⁴ contains instances of almost all the phenomena common to technological and biological evolution. For example, some forms of

artificial life clearly exhibit ‘punctuated equilibrium’: they evolve almost imperceptibly for long periods, with sudden episodes of radical change.

Thus, instead of lumping technology and biology together into the same species, we should perhaps treat them as distinct members of a larger genus of *complex systems*.²⁵ Rather than insisting that our ideas about evolutionary processes should conform to strictly ‘Darwinian’, or ‘neo-Darwinian’ principles, we should be exploring the properties of a more general *selectionist* paradigm.²⁶ We could then give up such Procrustean exercises as trying to make industrial firms look just like organisms, and design concepts just like genes, and concentrate on the actual structural relations between the entities that make up each type of system. In other words, our evolutionary model of technological innovation need not be quasi-biological, just as our evolutionary model of the biological world need not be quasi-cultural, even though they have many general features in common

1.7 Understanding innovation

That, in outline, is the realm of thought that opens up behind the evolutionary metaphor for technological innovation. What do we hope to gain by exploring it further?

In the first place, improved understanding of cultural change is not irrelevant to evolutionary biology. Evolutionists tend to take biology as the standard model, as if all evolutionary processes had to conform to its peculiarities. The exploration of an alternative system throws into relief those features that are specific to biology, such as nearly permanent genes and sexual reproduction, and suggests limits to their evolutionary functions. Would a ‘Lamarckian’ factor necessarily alter the nature of a ‘Darwinian’ mechanism? Might it not just improve the efficiency of the search for a higher peak in fitness space? Could it perhaps facilitate self-organization and damp out some of the random fluctuations as the system – life itself – approaches the edge of chaos?

Less hypothetically, technological change is one of the most striking features of our present-day civilization. And yet, in spite of much research effort, it still escapes elucidation. It would overwhelm this book to go through all the different theories, models and metaphors that have been proposed to explain how it occurs. A ‘selectionist’ approach to this puzzling problem area promises to show more clearly the relative roles of apparently contrary factors, such as ‘creativity’ and ‘design’. Should one think of material artefacts or conceptual ‘memes’ as the entities that evolve? Historians, ethnographers and prehistorians of technology might then consider whether there has been a progressive move away from selection towards design in the invention or improvement of artefacts. We shall

probably never know how much systematic thinking went into the production and selection of stone axes; it is still unclear how much random trial and error will really be needed in the creation of the next generation of 'designer pharmaceuticals'.

Indeed, technological innovation is of such enormous social importance that it is worth pursuing such questions further into the interstices of scientific, industrial and commercial life. What is the actual relationship between 'selection' and 'design' in the research and development divisions of industrial firms? Does this relationship differ from firm to firm, or from industry to industry – and if so, why? Is the overall process speeded up by more feedback (and feed forward) between the various stages, or does each system evolve at its own characteristic rate? What are the real selection criteria in various types of market? An evolutionary perspective should yield new insights into such practical matters.

This exploration of a plausible proposition thus starts with many more questions than it can ever expect to answer. There is evidently plenty of conceptual and empirical space into which it can expand and evolve. That, surely, is a blessed state for any worth-while intellectual enquiry!