Economics of Technology
O. Granstrand (Editor)

CHAPTER 19

Summary and Reflections upon Further Developments[1]

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Chapter contents:

Abstract

This concluding chapter summarizes the preceding chapters and indicates the general nature of the main focus, key conceptualizations, methodology, main findings and suggestions for further research. The chapter also presents some reflections upon further developments of the field of economics of technology regarding interdisciplinary research and teaching. The need for pluralism in choice of research problems and methods as well as the need for disciplinary perspectives complementary to economics is pointed out. The caveat of biological analogies is emphasized, while general evolutionary modelling and systems theory are advocated. The chapter ends with a philosophical reflection on technocentrism and optimism in a holistic perspective.

[1] Helpful comments on this chapter have been received from Erik Dahmén and Christopher Freeman.

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19.1 Summary of Previous Chapters

What can be learnt from the foregoing chapters, viewed as a collection? A first general observation is that technology, with all its facets and pervasiveness, is hardly coherent enough to be coherently dealt with in a comprehensive way. This fact is reflected in the present book's intellectual variety, which has also been fertilized by a diversity in disciplinary perspectives. The variety pertains to focus, concepts, methods, empirical data, theory, findings and suggestions for further research. Table 19.1 attempts to give a summarizing overview of the chapters. A few observations will be made below in connection with each of the headings in Table 19.1.

19.1.1 Main Focus

Regarding general focus, all chapters by design deal with science and technology, although to varying degrees. The dominant disciplinary perspective is economics, but there is also the perspective of history of technology (notably Hughes, Lindqvist, and Wengenroth) and to some extent the perspective of engineering. The level and the "time window" of observations vary a great deal, which illustrates the wide scope of technology as a phenomenon or rather as a category of phenomena. Incidentally the opening chapter by Carlsson, with its focus on FMS-induced productivity in Swedish industry in recent years, and the chapter at the end by Yakovets, with its focus on technology-induced cyclicity in human civilization on earth in recent millennia, together illustrate the wide span of foci in the book as a whole. However, there is still room to focus more in depth on technology, distinguishing between different technologies, their specific features, their continual improvements and failures as well as related major innovations and catastrophes, their interdependencies and so on. To make this point clear here, the macro-micro distinction between levels of foci so commonly used in economic analysis can be applied to analysis of technology as well, either in its own right or in combination with economic analysis as indicated in Table 19.2.[2] Many studies of economics of technology in general are in fact *macro-technology studies*. They are macro-technology studies rather than micro-technology studies in the sense that, although the heterogeneity of technology may be recognized, it is largely left unspecified and individual technologies are not distinguished and systematically compared on phenomenological grounds.[3] The chapters that more or less present empirical micro-oriented technology studies are those by Carlsson, Grupp, Phillips, Scherer and Wengenroth.

Several authors (Carlsson, Dosi, Eliasson, Dahmén) focus on both micro and macro levels of analysis and especially on the interaction between micro and macro levels of analysis. This is important in light of the watershed in economic analysis created by the traditional distinction between micro- and macro-economics. However, if the interaction between technological and economic changes at both micro and macro levels is focused upon, it appears important as well to focus on some future analysis of the diagonal

[2] Of course, more levels than macro and micro could be distinguished. For example, a trichotomy with a meso level inserted between the macro and micro levels can be more useful in many cases.

[3] However, technologies may be classified into broad categories such as product/process, military/civilian etc.

TABLE 19.1
Overview of the Chapters in the Book

Chapter Title Author(s)	Main focus	Key/novel concepts	Approach/Empirical data	Main findings/ arguments	Suggestions for further research
[1] Granstrand, O.: "Economics of Technology - An Introduction and Overview of a Developing Field"	The emergence of economics of technology as an academic field of inquiry	Economics of technology	Historical and science citation data and a questionnaire survey among researchers	Despite being an old phenomenon, long recognized as important, the interaction between technological and economic changes has not until recently given rise to an academic field of inquiry. C. Babbage deserves recognition as one pioneer in the field. Economics of technology could in the 1990s be considered an established field, dominated at the core by economists but with some new entrants from other fields	A survey of literature surveys and a history of economic ideas about technology as well as a history of ideas in science and technology about economics
[2] Carlsson, B., et al.: "Factory Automation and Economic Performance: A Micro-to-Macro Analysis"	Impact of factory automation, especially FMS, on productivity and growth in Swedish engineering industry	Classification of units/firms into: Product-determined, process-determined and technologically progressive	Three-pronged with 23 interviews in 2 Swedish firms, questionnaire data from about 150 Swedish plant units and simulations. Factor analysis	There is a complex relationship between automation and economic performance with many dimensions and situational contingencies	
[3] David, P.: "Positive Feedbacks and Research Productivity in Science: Reopening Another Black Box"	Causes of observed patterns of skewness in productivity of research scientists and possible implications for the economics of science and for science policy	Cumulative advantage process Path dependency Positive feedback	Literature survey and exploratory qualitative reasoning in a stochastic, dynamic modelling spirit around empirical findings mainly drawn from sociology of science and scientometrics, mainly based on publication and citation statistics	The common observation that, regardless of area of science, the productivity of individual scientists varies a great deal with increasing polarization of them into high and low achievers over their lifetime, could be viewed as a bifurcating stochastic process with positive feedbacks	Empirical work about various sub-processes of competition in research, their feedback mechanisms and their sources of heterogeneity. Synthesis into models, permitting stochastic simulation experiments

TABLE 19.1 (cont)

Overview of the Chapters in the Book

Chapter Title Author(s)	Main focus	Key/novel concepts	Approach/Empirical data	Main findings/ arguments	Suggestions for further research
[4] Dosi, G.: "Macrodynamics and Microfoundations: an Evolutionary Perspective"	Micro-macro level relations in economics and compatibility of stylized facts at macro level with evolutionary and non-evolutionary modelling (equilibrium modelling) at micro level	Micro-, macro-behavior, evolution, learning, selection, institutions, path-dependency, micro-interactions, self-organization	Theoretical and eclectic. Evolutionary modelling. Test with set of stylized facts	Evolutionary modelling is more compatible with received stylized facts than are received equilibrium theories, and is more promising as a research agenda	Learning processes and the nature of corporate competencies. Better understanding of markets as selection mechanisms. Modelling industrial and macro dynamics as the outcome of far-from-equilibrium self-organization. The role of institutions in microbehavior and collective organization
[5] Eliasson, G.: "Technology, Economic Competence and the Theory of the Firm - discussing the economic forces behind long-term economic growth"	Theoretical aspects of firm behavior, innovation-based competition and long-term economic growth in a national economy	Competence team Experimentally organized economy	Argumentative, based largely on simulations on a micro/macro model adapted to the Swedish economy	Highly unpredictable innovations, sustained by competition and experimental search by firms in an inexhaustible opportunity set, will drive selection mechanisms that dominate long-term economic progress and threaten every firm's long-run survival, in face of widely varying but limited learning abilities among firms	-

TABLE 19.1 (cont)

Overview of the Chapters in the Book

Chapter Title Author(s)	Main focus	Key/novel concepts	Approach/Empirical data	Main findings/ arguments	Suggestions for further research
[6] Fransman, M.: "Knowledge Segmentation—Integration in Theory and in Japanese Companies"	Knowledge segmentation and integration in Western economic Theory and in Japanese Companies"	Knowledge segmentation Knowledge integration RwD (= research associated with development)	Analysis of some leading economists' (Smith, Marshall, Hayek, Polanyi, Simon) thinking on the subject and an empirical interview study of (a) the evolution and use of just-in-time and Kanban systems in Toyota, (b) the organization of R&D in some Japanese companies, especially in electronics, and their use of e.g. an internal market for R&D	Japanese organizational practices are currently suited to deal with the problem of knowledge segmentation and integration. However, these practices have evolved incrementally as pragmatic responses to short-run problems rather than by initial design	Historical analysis of the evolutionary paths that in some cases have led to efficient organizational practices in Japanese companies. Empirical studies of actual decision-making processes in firms
[7] Granstrand, O.: "Technological, Technical and Economic Dynamics - Towards a Systems Analysis Framework"	The analysis of dynamics in a comprehensive techno-economic micro-level system with an explicit representation and cardinal measure of technological and technical changes. The impact of such changes on market structure and growth illustrates one application of the framework	Technological vs technical change Technological distances/cardinal measure of knowledge Knowledge/technology algebra Buyer and seller diffusion Techno-economic feedbacks	Theoretical with systems engineering modelling and illustrative simulations	An explicit representation and measuring of technological and technical changes enables economic analysis to extend from neo-classical to evolutionary paradigms. Technological distances and features of the compound buyer and seller diffusion processes are important determinants behind the degree of market structural change	Further empirical work applying and developing the framework, including exploratory work on cardinal measurements of knowledge, plus studies of technical characteristics and their development. Theoretical work on evolutionary properties and optimality conditions in dynamic modelling, stochastic or not

TABLE 19.1 (cont)
Overview of the Chapters in the Book

Chapter Title Author(s)	Main focus	Key/novel concepts	Approach/Empirical data	Main findings/ arguments	Suggestions for further research
[8] Grupp, H.: "The Dynamics of Science-Based Innovation Reconsidered: Cognitive Models and Statistical Findings"	Science, technology and innovation relations and their changes over time	Strongly and weakly science-based technology Feedback models of technological change	Cognitive modelling. Statistical analysis based on patenting and literature citation data, macroeconomic data for the triad countries, and case studies (polymers, lasers, fuel cells)	The science involvement in technology is dynamically changing and technology-specific, while not so country-specific. Technologies with high growth (in terms of patents) in the 1980s were more science-based. For the individual cases strong non-linear (non-sequential) effects were observed	Improvement of measures for technological change. Better integration of evolutionary theory with new quantitative approaches
[9] Håkansson, H.: "Economics of Technological Relationships"	Technological/business relationships, their nature, economic rationale and impact on e.g. governance structures	Homogeneous/ heterogeneous resources Buyer-seller relationships	Qualitative network modelling of relationships, especially regarding resources and their homogeneity/ heterogeneity and the causes and effects of heterogeneity. Examples from industrial supplier organizations	Business relationships prevail and accumulate from short-term exchanges, are in general continuous, complex, informal, symmetric, adaptive, with coexisting cooperation and conflict, giving rise to concentration and connectivity and functions as a governance structure. Quantity and quality of relationships are important explanatory variables behind costs and revenues, as are heterogeneity of exchanged resources and actor capabilities behind choice of governance structure. Heterogeneity depends on variations in business idea and technology, which could be lowered by standardization and internationalization	-

TABLE 19.1 (cont)
Overview of the Chapters in the Book

Chapter Title Author(s)	Main focus	Key/novel concepts	Approach/Empirical data	Main findings/ arguments	Suggestions for further research
[10] Lindqvist, S.: "Changes in the Technological Landscape. The Temporal Dimension in the Growth and Decline of Large Technological Systems"	Historic evolution of technological systems and the history of inquiry into such systems. The fallacies of the S-curve image	Technological system Technological volume The inverted U-curve	Historical discourse, with empirical and literature illustrations	Too much myopic emphasis has been placed on change, growth and innovation rather than on persistence and permanence of technologies, i.e. on the new rather than the old, on the growth rather than the decline stages in the life of technological systems	Study technological coexistence and decline of technological systems
[11] Phillips, A., et al.: "The Formation of the U.S. Market for Business Jets: A Study in Schumpeterian Rivalry"	The impact of technological innovation upon market structure and the formation of a new market with possible early mover disadvantages, overbidding etc.		Case study of the US market for business jet aircraft during the 1960s and the development of jet aircraft during 1950s and 60s	Decline of early movers failing to upgrade their technology under a Schumpeterian regime with "sailing effect", overbidding, highly endogenous market-structural change, strong government role, high risks, management failures and "animal spirits" among engineers and entrepreneurs	Developing useful generalizations about the advantages and/or disadvantages of being the leader or follower in making innovations

Table 19.2 Principal Levels of Foci in Economics of Technology with Examples

		Technology: Micro	Technology: Macro
Economics	Micro	Engineering economics, e.g. value analysis and cost estimation Multi-technology analysis	R&D resource allocation and rivalry at firm level Technology systems cases[1]
	Macro	Case studies of macro-economic impact of single inventions, e.g. in steel-making Development block cases[1]	Macro-economic growth accounting and use of general technology indicators

Note:

1 The concepts of technology systems (from T. Hughes) and development blocks (from E. Dahmén) should more properly be regarded as meso-level concepts (which then presupposes a trichotomy of levels of foci).

relations, that is, between changes at micro-technology and macro-economic levels and between changes at micro-economic and macro-technology levels.[4] An example of the first diagonal techno-economic relation would be the impact of changes in high-temperature superconductive materials on macro-economic growth and/or employment and an example of the second would be the impact of new economic methods or perspectives in investment appraisals upon aggregate R&D resources and outcomes.[5]

As for focused variable relations and phenomena, the various chapters have related R&D and technological innovations to economic variables such as productivity, growth, organization, market structure, trade, competitiveness, investments etc. A couple of chapters (Grupp, Rosenberg) have also related science and technology to each other.

Finally, some traditional economic variables have not been particularly covered, for example, unemployment and regulation. On the other hand several chapters have dealt with phenomena hitherto not so commonly emphasized, e.g. research productivity (David), economic competence (Eliasson), business and technological relationships (Håkansson), decline of technological systems (Lindqvist), market formation (Phillips), and military technology (Hughes).

In studies in general focusing on some binary relation between a technology variable or factor and an economic variable or factor, there is a certain tendency to look mainly at the causation from technological changes to economic changes rather than the other way around. Certainly, technology is no longer looked upon as autonomous or totally exogenous to the economic system.[6] Still, more studies seem to be needed with a focus

[4] The possibility to focus on these diagonal relations shows that one dichotomy is not a special case of the other in the conceptual structure. (Compare the importance of diagonal elements in supporting a building structure.)

[5] The seminal work of Arrow [2] would be an example.

[6] Seminal works on the endogenization of science and technology include previous works by A. Phillips and N. Rosenberg.

on the degree to which technology is endogenous and the nature of the causal links from economic changes to technological changes. However, what is especially needed as well, as pointed out in several chapters (e.g. by Hughes), is more research with a systems approach, not focusing primarily on one specific binary relation but on several interrelated causal relations that together form a system with possible feedback structures at various levels.

19.1.2 Key/Novel Concepts

Regarding concepts and classifications, much can of course be said about the importance of consistent language formation and new conceptualizations for the furthering of a developing field. Suffice it to say here, without entering debate too much, that the confrontation of new concepts and classifications across disciplines with operationalizations and historical case studies is fruitful and needed.

The various chapters use or propose several novel or fairly recent concepts and terms, e.g. evolutionary-oriented concepts like selection, cumulation, path-dependency, learning (e.g. David, Dosi), experimentally organized economy (Eliasson), knowledge segmentation and integration (Fransman), technological distances and algebras (Granstrand), technological volume (Lindqvist), aggressive/submissive R&D strategies (Scherer), technological upheaval (Yakovets), development block (Dahmén), reverse salient (Hughes). Economists may have a higher propensity to create new terminology and theoretical concepts than historians of technology, as pointed out by some of the authors.[7] Often, however, empirical observations offer some ground for common conceptualizations, which emphasize the continual need for careful empirical and historical work in close connection with conceptual work. It is interesting to note that the novel concepts in the chapters mostly are empirically founded and related to alleged features of technology phenomena, while the economic analytical concepts used are much the same as in other fields of economic analysis. A natural reflection is whether economics of technology need some new specific analytical concepts. Particularly important would be concepts that relate directly to factors in the interaction between technological and economic changes.[8]

19.1.3 Approach/Empirical Data

Regarding research approaches the chapters are mainly empirical in nature. They employ a variety of methods, tools and data sets, collected in diverse ways (available statistics, questionnaire surveys, simulations, interviews). Several authors (Carlsson, Grupp, Scherer) use a distinct multi-method empirical approach, consisting of modelling and theory, statistical analysis of broad data sets and finally case studies. Without encouraging a "Methodenstreit" with all its polemic advocacy for or against historical versus theoretical approaches, qualitative versus quantitative approaches, exploratory versus hypothesis-testing approaches, etc., one may note the frequent use of case studies in the chapters. The

[7] Also, there is sometimes a tendency to use too vague or too wide concepts with little distinguishing power. A certain conceptual impreciseness may be necessary to accept as always, however.

[8] Schumpeter's concept of entrepreneur and Dahmén's concept of development block are examples of such concepts, as is the concept of innovation.

use of case studies has often been criticized, general historical studies perhaps less so, although a historical study can essentially be viewed as a single-case study. A multi-case study gives rise in principle to a data matrix with many variables, qualitative and quantitative, and few objects of study, i.e. cases. Typically this data matrix is (in a simple metaphor) like a long, open-ended rug with many emerging patterns, colours, holes and fringes.[9] Viewed in this way it is easier to comprehend the merits and limitations of case studies in research, and e.g. to judge how the trade-offs could be made when case studies are combined with broad data sets having sufficiently many objects in relation to the number of variables to permit statistical analysis. There is no inherent obstacle to using case studies for hypothesis testing and theory building. At the same time one could argue that traditional historical studies, viewed as single-case studies, can learn something from the systematic multiple case study approach. In a sense such an approach, combined with quantitative and qualitative analysis, may be viewed as offering an important bridge from history to theory, especially in a young and developing field. (Compare the "cliometric" approach in the so-called "new economic history", combining theory, quantitative analysis, statistical testing, counter-factual analysis and traditional historical methods.) History of technology in the context of economics of technology also offers new sets of data and measurements, e.g. of technical attributes and replicable technical performances.

This is not the place to favor specific methods, however. Rather a methodological pluralism could be advocated, just as is done by Scherer in Chapter 13. The multi-method approach is in line with this. The combination of methods does not always have to occur at the level of individual projects and researchers, but sometimes that is preferable.

Compared to the methods and approaches used for example by Babbage and Schumpeter and other scholars of their times, research methodology in economics of technology has come a long way. There is no reason to believe that this evolution will cease. Apart from general developments and innovations in methods and tools, e.g. in terms of new statistical techniques, methods for data analysis and most importantly the use of computers and network communication, the collection and accumulation of data will continue. New data sources will be exploited with new data collection techniques. The data sources will be purely empirical but will probably also increasingly derive from simulations on more and more elaborate simulation models, models that also will be partly empirically calibrated, maybe even from real economic experiments. The actual or possible use of such simulations is indicated in the chapters by Carlsson, David, Eliasson and Granstrand. Computer modelling, new data collection techniques and simulations are already an important part of making R&D in S&T more productive, and are likely to become an increasingly important part of economic research as well. In the case of economics of technology, modelling and simulation of large, technical and economic systems could very well be increasingly integrated and used.[10] Such developments will of course not come without efforts and problems, some of which are well known for simulations (problems with reliability, validity, falsifiability etc.).

[9] This view might be regarded as somewhat positivistic, sacrificing the hermeneutic merits of case studies, but in principle it is possible to translate an alleged hermeneutic research approach into a fragmented data matrix, taking emergent properties into account. It is rather a matter of mode of presentation. However, a hermeneutic approach may still be valuable as a research strategy for generating deeper insights and discoveries, although not as easily codified for dissemination to wider audiences.

[10] Such modelling and simulation are frequently employed when designing and operating large technical systems, e.g. in the energy, transportation and communication areas.

Availability of pure empirical data and its amenability to analysis will increase through the use of computers and telecommunications. There are large amounts of data, collected or collectable, e.g. about patents, publications, personnel, products and pecuniary flows, pertaining to R&D products, production and trade. Some of these data sources have only recently begun to be exploited, e.g. patent and publication data as done by Grupp in Chapter 8, detailed product line statistics as done by Scherer in Chapter 13 or detailed educational statistics as done by Jacobsson and Oskarsson [15]. Some data sources are clearly underexploited in economics, e.g. the massive amount of technical data about products and processes. Data sources also improve, and increasingly become internationally harmonized, e.g. data about R&D and technology trade, collected according to OECD standards.

At the same time various data sources commonly used in economics may increasingly lose some of their validity. One example is traditional industry statistics at various hierarchical sector levels, losing validity due to increasing lack of concordance between industry, product, technology and company activity classifications, in turn partly due to the nature of technological developments, partly due to company developments (e.g. diversification). Another example is traditional trade statistics, increasingly losing validity due to increasing internationalization of companies. Beyond some point the continued exploitation of such data sources along traditional lines will be subjected to diminishing returns, and other factor inputs in terms of new data sources and other techniques for producing analyses must be employed. In this context it seems fruitful to blend econometric modelling and "cliometrics" with more of the developing approaches, found under labels such as scientometrics, technometrics, bibliometrics and even sociometrics and psychometrics, the latter two pertaining to relations, competencies, abilities, perceptions and so on.

19.1.4 Main Findings/Arguments

The achievements in the chapters viewed as a collection are exploratory in various directions rather then coherent or convergent.[11] Altogether they present more new questions than closed answers. This is natural at an early stage of a developing field, when it is more important to discover what is not known than to emphasize what is known. Refutations are also important at such an early stage, yet primarily refutations not of past research, but of past assumptions and myths created in the absence of research. Several of the chapters contain refutations or challenges of that kind.

A few observations regarding overall findings may be made. There are really no conflicting findings among the chapters, although there are shifting degrees of emphasis on certain matters (e.g. the role of science in economic growth). Conflicts may otherwise be a sign of problems at a research frontier, and may also be fruitful points of departure for further research, but again, the chapters are fairly dispersed on broad issues.

[11] A certain degree of convergence of economists and technology historians may perhaps be taking place at present.

A recurrent theme is the complexity of the phenomenon of technology. This is emphasized by several authors, especially the historians, with Thomas Hughes as a good proponent. The various authors in this book and in other works of theirs have added to our comprehension and appreciation of the complexity surrounding S&T and R&D, as have many other authors in the field. Examples are Rosenberg on science, technology and economy interactions and their absence of simple, one-way causation; Grupp on the technology-specific level of and increase in scientific involvement in various technologies (enabling A. Toynbee's metaphor of science and industry as a dancing pair to be extended into a disco-dancing culture when applied to science and technology); Carlsson on the complex of intervening variables between a specific technology, FMS, and economic pay-off in terms of productivity and growth; David on the highly skewed distribution of productivity in research and the complexities behind it, a fact that seriously challenges the value of using R&D input indicators as proxies for R&D outputs; Dosi on the dynamic complexities in micro-macro level interactions arising from technology; Eliasson on the complex uncertainty generated not only by matter but also by random agent behavior, and even the need for randomized agent behavior in experimental search and selection; the complexities displayed in the detailed case stories of Phillips, Scherer and Wengenroth, not least emanating from deviant human behavior and complex company behavior in relation to innovation, etc.[12]

To deal sensibly with complexity, theories and models are necessary. The different chapters have used or touched upon a wide and related variety of theoretical approaches, encompassing e.g. neo-classical theory, evolutionary theory, network theory, and new international trade theory.[13] It would indeed lead too far here to try to expose, compare, and synthesize received theories and suggest new theoretical developments. However, suffice it to point out at least one fairly common denominator in the employed theoretical approaches and modes of argument, namely the advocacy of dynamic, evolutionary modelling, stochastic or deterministic, with or without explicit feedback structures, but preferably not without a systems perspective. It is also a fair bet that taking science and technology explicitly into account when theorizing will reshape parts of received economic theory, a development that has already been under way for some time (e.g. in evolutionary economics as described by David and Dosi, and in trade theory as described by Scherer and Soete).

19.1.5 Suggestions for Further Research

The various chapters contain a number of implicit and explicit suggestions for further research. It would indeed be inappropriate here to select among them and construct any kind of research program. The general gap, or perhaps rather the general canyon area, between economics and technology is difficult terrain and will remain so, although increasingly explored and made communicable. Trails, bridges etc. must be worked from many sides. Certain research paths will sooner or later become popular, increasing returns

[12] It is naturally easy to refer to complexities in general and difficult to proceed to characterize types of complexities. Evidently, there is a mixture of subjective and objective, internal and external complexities involved in the various phenomena investigated.

[13] Network theory is rather called network approach by many of its proponents (still).

to adopting them will accrue, and dominant paradigms are likely to become established under intellectual competition. The risks that further research will become "locked in" along less fruitful paths and canyons are there, especially in a young and developing field, which calls for pluralism and variety, rather then selection.[14]

To stimulate the generation of variety in further research, a number of suggestions made in the various chapters could then be pointed out and recapitulated as in Table 19.1. One may also note that several chapters (e.g. Dahmén, Dosi, Lindqvist) have more comprehensive research agendas. There are also various issues that the papers have not addressed but merit further research.[15]

Several observations and suggestions for further research are also made elsewhere in this chapter, e.g. the need for micro-oriented technology studies and linking macro-micro levels of analysis for both technology and economics; the need to focus more on the endogenization of S&T; the need for continued conceptual analysis; the need for a systems approach; the need for dynamic and evolutionary analysis and modelling; the need to build and exploit new data sources and measurement techniques; the need to look not only at successful innovations but also at failures, including catastrophes,[16] and their interplay; and the need for an interdisciplinary approach. The latter need will be particularly addressed in the next section.

19.2 Reflections upon Further Interdisciplinary Research

Thomas Hughes emphasizes in Chapter 18 the necessity to go beyond the economics of technology and approach the technology phenomenon in an interdisciplinary fashion and counteract reductionist tendencies. Nathan Rosenberg in Chapter 12 stresses the benefits of, as well as obstacles to, performing interdisciplinary work in physical science and technology. Similar benefits could accrue in social science as well. Given the pervasiveness and complexity of technology plus the insufficient attention given to it in social sciences, these points should be well taken to make a case for more interdisciplinary work focusing on technology. This general idea may be undisputed but the roles of various disciplines and their mutual relations in such an undertaking are always subjected to dispute. Demarcation problems are inherent and so are reductionist forces and tendencies to disciplinary expansionism. The search for generality and regularities in social sciences, with ideals often inspired by natural sciences, creates a tendency to focus on universally pervasive features or phenomena, such as uncertainty, relations, interactions, roles, organizations, purposeful behavior and hopefully technology. This tendency should in principle create a basis for interdisciplinary work.

[14] Phenomena and principles in evolutionary economics and evolutionary epistemology in general may be applied to various degrees to academic research fields and Economics of Technology as well, and similarly to S&T fields, including industrial R&D with its emphasis on parallel approaches in early stages, leading to convergence in designs, eventually becoming dominant on the market.

[15] Examples mentioned are environmental issues, regulatory issues, unemployment issues and finance issues.

[16] A "survival bias" in research is common, and inherently unavoidable also in evolutionary approaches. The underrepresentation of failures has other causes as well, perhaps especially the minor and medium-sized ones. Major catastrophes like Titanic, Hindenburg, thalidomide, Soweto, Tjernobyl, air crashes etc. are perhaps getting their due share of analysis. Still there might be a need for incorporating such a focus in behavioral and economic theorizing.

However, a counteracting force is the tendency to let reductionism go too far. This happens when a science has developed a tradition of focusing on a pervasive phenomenon and uses its pervasiveness to try to reduce to special cases what other sciences do with the same phenomenon. A territorial-like competition among sciences emerges, which could be fruitful but within limits. (See e.g. [11].) This intellectual competition may also go too far and develop into unproductive forms, such as offensive, invasion-like behavior or defensive behavior, erecting barriers to intellectual entry, overly avoiding another discipline, or overly drawing on another discipline.

Against this background it seems natural to ask: How are the relations between economics and other disciplines affected by taking technology seriously into account? This question may be asked for the relation between economics on one hand, and disciplines like mathematics, political science, management science, history, sociology etc. on the other. Elaborating that question comprehensively would lead too far here, but the relations between economics and biology and between economics, psychology and sociology will be touched upon, especially since considerations of technology have stimulated evolutionary approaches in economics, although with a tendency to infer biological analogies, which may perhaps mislead interdisciplinary work.

Economics, Biology and Technology

It is well known how economics has drawn on mechanics and biology for analogies, and on mathematics for analysis and theory. Much debate has indicated the pros and cons in so doing, which cannot be reviewed here. Newton and Darwin have had profound impact not only on their disciplines but on the Western "Weltanschauung" on a broad scale, affecting many disciplines, not only economics. Biological analogies have been particularly "sticky" in social sciences, at least since Darwin, and have spurred heated disputes among social scientists.[17] Early advocates among economists include Veblen and Marshall, although on different grounds.[18]

In contemporary economics the transition from mechanical models to evolutionary approaches is long overdue, as Freeman [8] argues. Evolutionary economics is developing with Nelson and Winter [19] as one pioneering work accompanied by several others, e.g. the landmark work of Dosi et al. [6].[19] These developments are often spurred by criticism of the dominance of received orthodox theory, mostly referred to as neo-classical. The relation between neo-classical economics and evolutionary economics has similarities to (the young) Thomas Kuhn's depiction of paradigm shifts or substitution of theories in science, and also similarities to behavior in connection with substitution of technologies

[17] Most evolutionary schemes in theories of societal development have some underpinnings from plant and animal biology. Exceptions and critics of this fashion include Jürgen Habermas and Anthony Giddens.

[18] Marshall's advocacy has a bit of historic irony. While making important contributions to economics under the influence of Newtonian thinking in mechanics, and Leibnizean thinking in mathematics, his marginalistic and formal utilistic approach triggered criticism by Veblen and the latter's advocacy of evolutionary and behavioral thinking (Veblen [24]). At the same time Marshall also advocated biological thinking and dynamic modelling and planned to continue his work with contributions along such lines but never came to realize his plans. One may also note that Veblen's advocacy of evolutionary economics is primarily a quest for dynamic considerations, as opposed to static ones, rather than a quest for using biological analogies. He saw the developments of biology from a taxonomic to a dynamic science from Linné to Darwin as a pattern for economics to follow.

[19] For a historic survey of evolutionary economics, see [4].

(including the "sailing effect": see Chapter 7). Some argue that this is only on the surface and that the differences are reconcilable in principle; others argue that they are not, i.e. one has to make a strategic choice between neo-classical and evolutionary approaches in further research. There is a variety of criticism of neo-classical theory (e.g. of optimality and equilibrium concepts) and a variety of evolutionary approaches; see [6] and [21] for examples. Several approaches are inspired by biological analogies. At the same time, technology considerations in economics foster much evolutionary thinking in general.

It is then natural to make a closer scrutiny of what biology can offer economics in general and more specifically if technology is taken into account. A number of works have addressed this issue without reference to technology. There are outright advocates of biological analogies in economics like Marshall [17][20], Hodgson [13] and Hirschleifer [10]. The latter presents a comprehensive comparison of economic and biological systems, which has been further used and modified by Mark et al. [16], and which is comparable with Matthews [18]. A classic critique of biological analogies in economics is Penrose [20].[21] Saviotti and Metcalfe [21] include several papers on the subject and Freeman [8] gives a recent survey. Freeman advocates a seasoned view that economic and biological systems must be compared in order to identify similarities and differences, and that economics can learn something from biology but ultimately has to develop evolutionary theories of its own.[22] Such a view seems particularly relevant for economics of technology, a view that has also been forwarded by De Bresson [5]. Such views do not, of course, exclude similarities between biological and technological systems (see also [23]).

It is then also natural to compare technological systems with biological systems, and draw implications from the type and degree of similarities and dissimilarities between economic and biological systems. This task must be left for further research. However, the hypothesis is forwarded here that technology considerations weaken the applicability of biological analogies in economics and present some idiosyncratic features to evolutionary economics and its modelling. As a starting point for probing this issue, Table 19.3 displays some differences between biological and technological systems, differences which also serve to point out the caveats of biological analogies in economics of technology.[23] Such caveats are particularly important when analogies, being non-perfect, become mathematized and economics runs the risk of being carried too far away from its empirical grounds by the forces of mathematics. Mathematics and biology in themselves will certainly continue

[20] See also Hodgson [12] on Marshall's advocacy of biology. An often-cited passage of Marshall is: "It [economics] is a branch of biology broadly interpreted." His preceding sentence (in the margin) is also interesting in this context, however: "But economics has no near kinship with any physical science." (Marshall [17] p. 772, see also p. xiv, Vol. I.) One should not go too far in interpreting this ad verbatim but one may at least observe that an implication of Marshall's two propositions is that the perspectives, methods and developments of all physical sciences are remote from both economics and biology. Contradictory or not, one value of Marshall's propositions rests with their clear provocation of further studies of the issue.

[21] Penrose focuses her criticism on differences between firms as organizations and biological systems. Such criticism is still valid, perhaps even more so, for R&D organizations.

[22] Conversely, biology has to, and does, develop evolutionary theories of its own. This does not preclude applications of economics in biology, e.g. those under the label 'bioeconomics' related to environmental protection. Interdisciplinary work clearly must go beyond the use of analogies.

[23] A reflection near at hand, not least after the discovery of discontinuous genes by Roberts and Sharp, is that genetic technology will in fact change biological systems in the future in ways that will create new similarities with technological systems.

to develop together in many interesting ways, e.g. in the area of dynamic modelling. But some of these ways may be misleading for economics, as important differences may be suppressed in the abstraction process.[24] One possible guard against such risks, which are aggravated by low empirical falsifiability, is to have a more general and flexible theoretical framework such as a more general systems theory and to critically evaluate biological analogies. This is by no means to argue against evolutionary theorizing, quite on the contrary.

Economics, Psychology and Technology

Next comes the question of how technology considerations affect the relation between economics and the behavioral sciences psychology and sociology. As is well known, the economic doctrines of utility theory and profit maximization do not leave much room for realistic behavioral assumptions and perhaps do not even contribute to basic happiness and "joy". These doctrines have been challenged by many authors, e.g. T. Veblen, H. Simon, A. Tversky, T. Scitovsky. See further Albanese [1].

In relation to technology and innovation the existence of important behavioral traits, viewed as exogenous to the economic system, has been dealt with to some extent by Schumpeter, also by Keynes, and later on by Freeman. Behavioral traits commonly attributed to S&T professionals, inventors, entrepreneurs, and the like, are deviant and include curiosity, vanity, conflicting propensity, urge for success itself, propensity to form subcultures, etc. ([9, Ch. 9-11]).[25] Typical behavior related to S&T professionals constitutes what could be labelled as 'technological man'[26]. Moreover such behavioral traits are by and large robust and invariant under changes in economic regimes, which renders a significant element of exogeneity to the determinants of S&T change and progress.[27] This does not necessarily exclude that a stretching of economic theory to include such behavioral traits would be possible.[28] However, it would mean involving psychology to a considerable extent, thus calling for psychologists to interact with economists, with some psychological theories, approaches, concepts etc. presumably having a larger scientific pay-

[24] Concepts that originally have been empirically grounded may often be redefined theoretically to increase generality. At the same time the specific empirical features of the concepts become disguised.

[25] To some extent this deviancy is by definition, since creativity, inventiveness and entrepreneurship involve novel and uncommon accomplishments by definition. Creators, inventors and entrepreneurs are therefore not representative agents by definition, neither are they typical economic agents, mainly driven by economic motives and expectations. For example, *technological dreams* are important for many inventors who may be obsessed by them without economic considerations, as witnessed by many case stories and biographies. Mere curiosity is also important (cf. Veblen's notion of "idle curiosity").

[26] This term has been suggested by Erik Bohlin. It does not typically encompass entrepreneurs: that would constitute still another behavioral archetype, complementary to 'economic man' (and 'organization man' and 'political man').

[27] Hughes [14] gives a good example of the important economic role of technological enthusiasm. This was spurred by many factors, remotely linked to economy.

[28] Perhaps in the form of Becker-type approaches and/or principal agent extensions. However, non-reductionist "hybrid" approaches to include technology and psychology considerations in economics would be preferable. For example, it would be possible to use Herbert Simon's notions of satisfying behavior subject to economic goals and constraints, but applying them to goals and constraints expressed explicitly in both technical and economic terms. That is compatible with actual behavior in R&D organizations. It requires knowledge about engineering and economics at the same time, just as in practice, plus a great deal of knowledge about the psychology of entrepreneurs and R&D professionals, including inventors.

Table 19.3 Examples of Differences between Biological Systems and Technological Systems[1]

Biological systems[2]	Technological systems[2]
Heterosexual reproduction in general	"Promiscuous" reproduction and practically unlimited recombinations of both knowledge and artefacts
Finite life of specimen	Almost infinite life a possibility for artefacts and the rule for knowledge[4]
Spontaneous mutation[5]	Invention by design, not only by default or serendipities
Regular life cycle stages of development of specimen (birth, growth, stagnation, death) and species (formation, propagation, exclusion, extinction)[3]	Irregular and erratic appearance of stages of development

Notes:

1 The exposition of differences is not meant to rule out the possibility of similarities, but to indicate some limitations to the use of biological analogies in economics, deriving from technology. Needless to say, a techno-economic system, which includes human actors and therefore intersects with a biological system, should display some similarities, e.g. certain types of purposeful behavior and competition for scarce resources.

2 It is not obvious what the relevant comparisons are. But this, too, contributes to the scepticism about the value of the analogy.

3 Life cycle conceptualizations tend to creep into economics with a certain ease, e.g. regarding the evolution of firms, products, technologies and industries, perhaps essentially based on the need to divide a temporary process into stages. By its very nature a temporary process has some feature of rise and fall, or emergence and disappearance, since it is temporary. Many times, however, the analogy with a life cycle breaks down when carried further.

4 If knowledge is taken to correspond to genes and different product areas (rather than individual, physical products) correspond to different species the analogy is strengthened but still deficient.

5 The 1993 Nobel Prize winners in medicine and physiology, R. Roberts and P. Sharp, discovered in 1977 what appears to be a powerful biological evolutionary mechanism for higher organisms besides mutation, based on combinations of different segments of genes (so-called splicing). This evolutionary mechanism in turn seems to strengthen to some extent the analogy between biological and technological evolution. That would particularly be the case when splicing is used artificially in bio-genetic engineering. Thus, the strength and usefulness of an analogy may change over time as a consequence, and often as a cause as well, of new discoveries. Similarly, modern physics, which is vastly different from classical mechanics, offers new sets of analogies, although again limited, with its discoveries cast in various stochastic and dynamic frameworks, which are also basically evolutionary.

off than economic theories which are stretched for the main purpose of saving them by endogenizing S&T progress fully. The "technological man" and the Schumpeterian entrepreneur are hardly best understood as curious offspring of "economic man".[29]

Economics, Sociology and Technology

Also the relations between economics and sociology and organization theory in general would naturally be affected by taking technology-related institutions and organizations more explicitly and comprehensively into account. There is apparently a certain confluence of economics, sociology and political science, including the renewed interest in institutional economics.[30] Of course, to a considerable extent the S&T-system has been looked into from combined economic and sociological perspectives. However, there is much more that could be done as the relative role of this system grows in society, and as its relative role also grows in social science research, qualitative leaps in social science theory are likely. There is still much to be learnt about institutions like military R&D and large R&D organizations (see e.g. Chapter 18 by Hughes), universities (see e.g. the Chapters by David and Rosenberg), technology finance institutions (see e.g. Chapter 17 by Dahmén), government institutions for S&T policy (see e.g. Chapter 14 by Soete), the technology and innovation oriented firm (see e.g. the Chapters by Dosi, Eliasson, Fransman, Granstrand, Håkansson, Phillips and Scherer) and the legal institutional framework connected to intellectual property rights.[31] The central importance of the firm as a legal institution and a social organization in a market-type economy is widely recognized, although not being the only important R&D organization as pointed out by T. Hughes. Yet, technology has not penetrated theories of the firm as it has penetrated the firms themselves.[32] There is quite a lot of knowledge about how R&D organizations work and how the general work organization in the firm is responding to technological changes, but not very much recognized, less incorporated, in economic theory.[33]

19.3 Reflections upon Teaching Economics of Technology

Teaching activities at higher educational levels are usually considered to have economies of scope with research activities, not only because they share common knowledge but also because they involve similar learning processes. Thus it seems appropriate also to reflect

[29] Incidentally, common biological analogies are not particularly useful in distinguishing human personality types as a way to enrich economics.

[30] The need to bridge e.g. the gap between economic theory and organization theory has been frequently pointed out, regardless of technology considerations. The latter could in fact spur such an integration if viewed as a common denominator.

[31] Of course, this relates to law rather than sociology. However, it may be similarly argued that relations between economics and social sciences in general, including judicial sciences, will be affected by focusing more on technology. There is also an increasing need for technology and judicial sciences to interact, not only in relation to IPR but e.g. in relation to product liability and insurance contracting and also in relation to technology-based economic crime, which can be expected to increase without a matching policing technology or ideology.

[32] Again there is a tendency to reductionism. One example is how transaction cost theory, at least originally, more or less subsumed technology considerations under transaction costs.

[33] Nevertheless, there is also a research need to be addressed to sociology in the first place to focus on such phenomena as the internal and external social dynamics of heterogenous S&T elites and R&D organizations, intra-firm as well as inter-firm.

here upon some implications for teaching in economics of technology, although just a few general teaching issues can be touched upon. What then are the implications for teaching due to the rapid growth of research efforts in Economics of Technology in recent decades, starting from a state of widespread ignorance, as described in Chapter 1?

The simple immediate answer would be to teach more economics and other social sciences to engineering students, and more S&T to students in economics and other social sciences. This is an old idea, succinctly expressed by Charles Babbage in his book "The Decline of Science" from 1830 [3]. Babbage, in his efforts to reform British science, also engaged in the related endeavor to reform university education, which he saw as necessary to link to science in general. One of his proposals was (Babbage 1830 [3, pp. 5-6]):

> "If it should be thought preferable, the sciences might be grouped, and the following subjects be taken together:

Modern History.	Political Economy.
Laws of England.	Application of Science to Arts and Manufacture.
Civil Law.	
Chemistry.	Zoology, including Physiology and Comparative Anatomy.
Mineralogy.	Botany, including Vegetable Physiology and Anatomy."
Geology.	

His proposal to combine economics and technology courses was perhaps over a century ahead of his time, just like his proposed computer. The Western educational system has meanwhile rather enforced an institutional separation of economics and technology, and an intellectual separation at the various educational levels where economics and technology (i.e. engineering subjects) enter the curriculum.[34] Usually these subjects enter separated at a fairly late stage, if at all, in schooling, while in fact older science and humanity subjects enter early, e.g. mathematics and physics, language and history. It could, of course, be argued that such important subjects for daily, adult life as economics and technology should enter at basic educational levels. The main argument here is, however, that specialization in one of these areas at higher educational levels should be accompanied by at least some complementary knowledge in the other area.

Slowly this has in fact started to happen, at least in higher engineering education. However, it is still to a low degree and there are several pending issues. Should the blending of economics and technology subjects always be at individual level? How far should it go for various categories? Should the blend be at degree level, course portfolio level or individual subject level? Should it be sequential or simultaneous blending? Should it be left to continued education and/or on-the-job learning through job rotation? etc.

These questions cannot be dealt with here. However, to the extent that Economics of Technology develops as a field of research and practice, there will be an increasing supply

[34] This particular separation could be seen partly as a reflection of a wider and deeper separation of social sciences and humanities on one hand and S&T on the other, which in retrospect is both cause and consequence of a fragmentation of Western culture into (at least) two large subcultures (see Snow [22]).

of teachers with a corresponding knowledge and perspective. On the demand side one can note an expansion of the working roles for engineers, demanding more non-technical competence as well. This demand is expressed not only through industry's need and concomitant engineering career paths, but also through various expressions of social concern as well as through preferences of the contemporary student generation. At the same time social science subjects are still met with distrust in parts of the S&T community as to the scientific standing and relevance of such subjects.

Some engineering schools, particularly in Europe, have started to meet this kind of demand by going as far as creating hybrid engineers, blending (in roughly equal proportions in the M.Sc. degree curriculum) technical and non-technical subjects, the latter including economics, management, behavioral science and law. A derived need then arises for adapting and developing economics accordingly. The future will show whether this teaching idea is viable in the long run.

Similarly one could conceive of expanded working roles of economists in general, as well as economists specializing in technology aspects. To the extent that this would affect education not only in economics but in social science as a whole, there would be a growing need for popularizing the teaching of S&T and making relevant S&T knowledge more accessible to wider audiences. Contemporary history of S&T could come to play an important role in this connection, as could S&T journalism.

Finally, raising the perspective above teaching Economics of Technology, one could hope for decreased institutional separation in higher education and more possibilities of interdisciplinary teaching, as well as interdisciplinary research. There are many forces at work in such directions, including economic forces (e.g. internationalized university competition) as well as technological forces. Without resorting overly to optimism about technology, one could point at the educational possibilities offered by information and communication technologies, e.g. in creating networks of teachers, remote interactive teaching, virtual universities, tele-presence, tele-schools, and the like. Despite initial problems and disappointments, these possibilities are likely to become of great importance in the future, due to the increasing need for efficient learning. Pedagogical innovations, technology-based or not, are also likely to appear that could facilitate e.g. interdisciplinary teaching. As the knowledge-and-information society gradually develops, an important pressure for long-run changes in learning modes and institutions in general will come from educational technology, exploited not only by traditional institutions of learning (i.e. incumbent organizations) but also by other actors, like private institutes, industrial firms and educational service organizations, challenging the distinctive advantages that e.g. universities might have. All these conceivable developments in the educational sector are part of Schumpeterian "creative destruction" phenomena that Economics of Technology not only teach us about but also will be affected by.

19.4 Technocentrism and Optimism – A Final Reflection

By definition and design this book is technocentric in an economic perspective. That obviously does not hold for economics as a whole, quite to the contrary; nor does it hold for any general branch of social science. However, the unique cumulative nature of technical knowledge and its reproductive power through artefacts may very well lead to

a technocentric world in a true sense.[35] Will this be a better world or worse? That is a question that concerns everyone. It is also a basic economic question, even by fiat. It is also a question for science in general, including economic science. Not because it is necessarily wrong to claim that the scope of the question makes it unanswerable by scientific means, but simply because values and valuations, explicitly expressed or implicit in behavior, are legitimate objects of scientific study, restricted or holistic, although it is hardly possible for such study to be conclusive. This is in addition to the by now legitimate claim that scientists ought to get actively involved in ethical questions. The tendency among scientists to refrain from universal, existential questions and leave them to philosophers, artists, politicians, priests, novelists etc. is understandable. However, scientific minds and methods could contribute to throwing light on such questions in various ways. Questions like the one above are impossible to give definite answers to on purely scientific grounds. Nevertheless, they are after all being answered in practice, consciously or not, and these answers and their resulting behavior can be scrutinized. For example, in simple and brief terms, technical knowledge has traditionally been viewed, either as inherently good because knowledge is good, or as value-free because values accrue only in the use of knowledge, or as possibly bad in some circumstances although more knowledge may adjust it to the contrary. The resultant behavior is generally in favor of generating more technical knowledge.

But knowledge in general, and technical (and scientific) knowledge in particular, has some inherent economic properties that must be considered. S&T knowledge is expensive to generate and increasingly so, as is well recognized. Its resource opportunity cost may be high in society and there may be overinvestments, despite perceived appropriability problems. However, once it is generated, the variable cost for using the knowledge in various applications is low (even possibly negative due to learning by using), especially in relation to the quasi-fixed cost of generating the knowledge in the first place. This gives a particular strength to the economic incentive, in addition to other incentives, to use knowledge once it has been acquired and to advance the frontiers of its application. Moreover, its uses, in particular when embedded in artefacts, may have good or bad effects, often highly unpredictable, often interwined, often highly skewed, often with mixed positive and negative externalities. These effects are difficult or costly to sufficiently separate and handle in an economic system. The difficulties are aggravated since knowledge is also difficult to transact by its very nature. The knowledge generation process is, moreover, essentially irreversible. A "bad lemon" piece of knowledge cannot be recalled from the market, and enforcing a ban of its use is costly. Luddites can smash machinery but not technology. Books may be burnt but not their content.

[35] In fact it may be argued that this has already taken place, even with a narrow conception of technology. Phenomena such as civilization, industrialization, urbanization, informatization etc. would have been void without technology. The pervasiveness of technology is indisputable therefore, and the question remains to what extent this pervasiveness is at the center rather than some other pervasive phenomenon. What make technology unique, however, are its close links with artefacts and its cumulative power. The cumulative nature of technology has been emphasized by several authors (David, Dosi, Freeman, Nelson, Pavitt, Price, Rosenberg and others). However, the codifiability of technology in conjunction with massive investments in S&T and artefacts makes it *uniquely cumulative*, and hence eventually dominant. The "cybertech" virtual reality is only one, as yet exotic and hardly representative, expression of the general development towards a technocentric world and a technocentric "Weltanschauung".

There is a strong presumption in Western thought that science and technology are, if not inherently good, at least good on an average, leading to progressive evolution on an average. This idea is of old age, deriving from Jerusalem and Athens to use the metaphoric language of von Wright [25], being nurtured during the Renaissance and the Age of Enlightenment and by movements such as utilitarianism and scientism, and finally being fortified through the industrialization of the 19th and 20th centuries. Expressions of this idea are many-faceted and include advocacy of science for the ultimate benefit of mankind, "technological fixes", and R&D for growth and competitiveness. Comparatively few scholars have questioned the idea in its entirety. Marx and Veblen criticized parts of it, largely pertaining to the effects on humans and society of production processes. Ellul [7] is a contemporary critic and von Wright [25] a contemporary sceptic.

Considering what future S&T in various fields such as energy, space, information, materials and biogenetic technology with all its possible applications (civilian, military, criminal etc.) can empower, and the inherent economic properties of S&T knowledge mentioned above, it seems at least necessary to challenge the naive evolutionary optimism based on S&T with more thorough economic analysis. This is not primarily because there are some radical S&T changes "around the corner" with possible disastrous effects among the good ones, although nuclear S&T once presented such changes and probably genetic S&T will. Primarily this is because changes may be gradual and induce a multitude of adaptations, therefore making it more difficult to react in time.[36]

And what if economic analysis tells us to stop along some paths or redirect certain R&D efforts? Apart from the enormous problems of making such an analysis convincingly conclusive, there are perhaps insurmountable problems. Perhaps S&T is sufficiently exogenous for economic analysis to become merely a restricted academic exercise and for economic policy, based on analysis or not, to become futile. Has S&T by its sheer size and complexity become sufficiently autonomous to make any action futile? A laissez-faire attitude towards S&T could of course result from defeatist pessimism, just as it could result from naive and/or irresponsible optimism; but hopefully economic science will not let it result from ignorance.

After all, Pandora's box does accompany Prometheus' offering of the by now brilliant flame of science and technology. But economics is part of her hope.

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[36] A typical case would be the continual collective adaptations of communities to increments in environmental pollution. Compare with the observation that if a frog is put into a pan of hot water it will jump out, but if put into cold water that is gradually heated the frog will stay in, even to its death.

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PERSONAL INFORMATION

TABLE 19.1 (cont)
Overview of the Chapters in the Book

Chapter Title Author(s)	Main focus	Key/novel concepts	Approach/Empirical data	Main findings/ arguments	Suggestions for further research
[12] Rosenberg, N.: "Science - Technology - Economy Interactions"	Relations between science and economy, between science and technology, among S&T disciplines and between university and industry, with related policy issues		Historic discourse, with empirical illustrations	Less of a "direct drive" from science to economic performance and less of a one-way traffic from science to technology than commonly assumed. The links from economy to science, from technology to science, and the interdisciplinary links are of increasing importance, creating e.g. organizational problems in the economy	Policy research on: (a) Intra- and interorganizational relations and incentives that are conducive to high-quality interdisciplinary research (b) Determinants of private R&D spending and its profitability
[13] Scherer, F.M.: "Competing for Comparative Advantage Through Technological Innovation"	US incumbent company reactions to foreign technological challenges/innovations especially from Japan, in terms of R&D spending. Macro consequences in terms of international trade and division of labor, duplication of R&D and rate of technological progress. Technological innovation in the "new" international trade theories	Aggressive/submissive R&D reactions/ strategies	Three-pronged micro-economic approach: (a) Theory of dynamics of inter-firm R&D rivalry (b) Statistical analysis focused on e.g. import, export and R&D data for 308 US companies in 272 four-digit US manufacturing industries for 1971-1987 (c) Systematic case studies of 12 diverse product areas in which US companies were challenged by foreign technological advances/innovations, especially from Japan	Incumbent reactions were diverse with random factors influencing outcome. Company R&D reactions were on average slightly submissive in the short run. Submissive R&D reactions were associated with e.g. market protection and links to academic science. Specialization of the US industry increased. Wasteful R&D duplication may occur. Aggressive R&D reactions were associated e.g. with large domestic sales, market concentration, company diversification, and technical background of executive officer	Extension to a cross-national study. More quantitative case studies, e.g. of changing product characteristics, industrial international organization of parallel R&D

TABLE 19.1 (cont)
Overview of the Chapters in the Book

Chapter Title Author(s)	Main focus	Key/novel concepts	Approach/Empirical data	Main findings/ arguments	Suggestions for further research
[14] Soete, L.: "International Competitiveness, Trade and Technology Policies"	Post-war internationalization and developments in economic thought about international trade and technology and the evolving challenge to free trade advocacy from "strategic" trade advocacy in practice and theory	Strategic trade policies	Argumentative, based on secondary data (OECD etc.) and literature	Technology considerations are key to strategic trade advocacy and international competitiveness with national technology policy consequently a key policy concern, however with risks for international distortion effects, leading to a need for international policy-making	-
[15] Wengenroth, U.: "The Steel Industries of Western Europe Compared, 1870-1914"	The history of business and technology in steel-making 1870-1970 and the main features, causes and consequences of technological choices	Bifurcation Path-dependency	Historical. The cases of UK and German steel industries, being the two most important ones during the first phase 1870-1914	From a state with a dominant steel process technology (puddling) lasting until the 1870s, technological options expanded with Bessemer, open-hearth and Thomas processes and country-specific industrial strategies bifurcated until the establishment of a new dominant process (basic oxygen process) after the 1960s. Neither the UK nor the German trajectory was evidently superior	-

TABLE 19.1 (cont)
Overview of the Chapters in the Book

Chapter Title Author(s)	Main focus	Key/novel concepts	Approach/Empirical data	Main findings/ arguments	Suggestions for further research
[16] Yakovets, Y.: "Scientific and Technical Cycles: Analysis and Forecasting of Technological Cycles and Upheavals"	Long-term cyclicity of technical and economic changes and their interaction. Survey of economic thought on this, and a proposed theory with an application to Russia	Technoevolution Technosystems Technogenetics Technological crises and upheavals	Macro-historic and macro-futuristic, speculative	There are and will be several cycle pattern types, varying in duration from years to centuries and millennia. Technosystems at different levels go through 5 phases in a life cycle. A transition to a 5th technological structure takes place at the end of 20th century, which in Russia is preceded by a deep technological crisis	-
[17] Dahmén, E.: "Towards Research on the Technology of Economic Development: Summary Remarks 1"	Economists' past neglect and current interest in technology. Research agenda for industrial transformation approach	Industrial transformation Development block Structural tension Market creation and market following Competitive power and development power	Economic historian's approach with a conceptual framework suited to focus on entrepreneurial activity and industrial dynamics	Historically unique growth slow-down and frustrations with policy experiences behind current rise of interest among economists in economics of technology, an interest earlier blocked by their interest in economic policy "engineering" and in mathematics. Focus on meso-level concepts like development block in an industrial transformation approach is needed for linking micro and macro levels of analysis	The financing of development blocks. Problems of disinvestment and liquidation with special focus on the importance of ownership structure and bank relations

TABLE 19.1 (cont)
Overview of the Chapters in the Book

Chapter Title Author(s)	Main focus	Key/novel concepts	Approach/Empirical data	Main findings/ arguments	Suggestions for further research
[18] Hughes, T.: "Beyond the Economics of Technology: Summary Remarks 2"	Limitations of received economic analysis of technology. Military technological change as a major case	Technological systems Reverse salient Seamless web	Historical Conceptual and case analysis	Current economic analysis of technology is too reductionistic to comprehend the seamless-web complexity character of technological changes and the importance of non-economic factors behind them. A systems approach to the study of technological changes, transcending disciplinary borders, enhances their scholarly comprehension	-