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RHETORICAL AND THEORETICAL DEVICES IN THE  
ECONOMIC HISTORY OF TECHNOLOGY:  
A DISCUSSION BASED ON DECONSTRUCTIVE  
METHOD AND ON THE HISTORICAL EXAMPLE OF  
MECHANICAL ENGINEERING

INTRODUCTION

This essay is about various ways of representing technological change in the writing of ( economic ) history. The assertion is that figures of speech and theoretical devices that are frequently found in the research literature, such as " technological trajectory " and " contingency ", divide the field of inquiry into two predominant sectors or spheres. One is occupied by economists who certainly take a keen interest in the past, but are basically more interested in general laws than in history *stricto sensu*; the other is held by contextualistic historians of technology. The division implies if not exclusion then at least marginalisation of structure-oriented, Braudel-style history.

According to the latter the essential dimensions of history are *longue durée* and middle-range time. Using this pair of concepts is the same as

emphasizing that actors are restrained by more stable and general patterns than the incidental contingencies of an immediate context, while at the same time secular trends do shift at long intervals. Past social structures, as defined by artefacts, organizations, knowledge, and institutions, are more changing and historically determined than might be assumed from evidence or assumptions produced by nomothetic social science.<sup>1</sup>

Structural history, sustained by structuralistic epistemology, is, I maintain, at least as theoretically coherent and meaningful and also as empirically sound as either of the two other strategies that were mentioned. Later on it will be argued more specifically, based on examples from the history of mechanical engineering, why this is the case. First, however, I shall concentrate on how the prevailing rhetorical mechanisms tacitly anticipate the absence of structural, *longue durée* history from the relevant research agenda concerning technological change in the past.

#### TROPE AND THEORY

Scholarly terms from the social sciences and humanities should not be considered as unambiguous or accepted on face value. Terminology is not an altogether arbitrary tool; it contributes to the formation and definition of paradigms. To discover precisely how can be a subtle affair since the key terms are often figurative.

I suggest by no means that figurative language be anything but a perfectly legitimate form of academic expression. Hayden White has convincingly exemplified that any major historical narrative or philosophical pondering over history is cast in one fundamental trope or another.<sup>2</sup> Whereas H. White distinguishes between the informal, figurative language used in history, and the much more rigorous and formal style in regular science, others have pointed out that the use of rhetorical figures is part and parcel of many sorts of scholarly discourse, to no less degree in e.g.

1 F. BRAUDEL, "Histoire et Sciences sociales: la longue durée", *Annales ESC*, Vol. 13, 1958, p. 727. I. WALLERSTEIN, "The Heritage of Sociology, The Promise of Social Science", part. 2. <<http://fbc.binghamton.edu/iwprad2.htm>>.

2 H. WHITE, *Metahistory. The Historical Imagination in 19th Century Europe*, Baltimore 1973. (Further: H. WHITE, *Metahistory*).

economics than in history.<sup>3</sup> Thus the abstract notion of "market", an approximate, reductionistic representation of the general economic workings of society, was modelled over a concrete, physical space where local people meet to trade.<sup>4</sup>

Admittedly, this term is no longer fresh and suggestive. The specific metaphor "market" has stiffened and turned into a *cliché*. Others, however, are very much alive and should be taken seriously by those who wish to level a criticism against the theories they embody. As Mary Poovey phrases it: "[...] *figurative language always carries theoretical arguments; to deflate a rival's trope is thus to expose the (fallacious) argument it smuggles into public opinion*".<sup>5</sup>

Without censoring anybody for using "wrong" words, it must be fair to ask what those words basically mean when considered as elements in a discursive style. In what follows I attempt to "deconstruct" a conceptual structure, i.e. to discover how its (seeming) internal coherence is provided by tacit exclusion of inconvenient or unfit elements.<sup>6</sup>

#### TECHNOLOGICAL TRAJECTORY

Take "technological trajectory". It is not, as the literal meaning of the noun might indicate, about ballistics. In this specific context "trajectory" is a "metaphor", a common form of figurative language. When you speak metaphorically, you highlight selected characteristic(s) of one phenomenon by comparing it to another. The two phenomena will share some, but not all their attributes, and this is exactly what gets the attention of your interlocutor. The rhetorical effect of metaphor depends on the existence of some common ground between things that in other respects are quite dissimilar from each other. By the metaphor of "trajectory" semantic elements from ballistics indicate that the effect and general outcome of any

3 D. N. McCLOSKEY, *Knowledge and Persuasion in Economics*, Cambridge 1994, p. 42.

4 D. N. McCLOSKEY, "The Economics of Choice. Neoclassical Supply and Demand", in: T. G. RAWSKI *et al.*, eds., *Economics and the Historian*, Berkeley 1996, p. 125.

5 M. POOVEY, *A History of the Modern Fact. Problems of Knowledge in the Sciences of Wealth and Society*, Chicago 1998, p. 344.

6 For a working definition of the deconstructive method, see e.g.: M. DELCROIX, F. HALLYN *et al.*, *Méthodes du texte. Introduction aux études littéraires*, Paris 1987, p. 320.

technology are a consequence of the particular circumstances under which it, like a missile, was "launched". Technology is thus depicted as a series of independently evolving events. Their historical contingency is emphasized. Different trajectories make different impacts.

Arie Rip, Thomas J. Misa and John Schot have defined the meaning of the phrase as recognition of the fact that any given technology is deeply embedded in a (social) context that includes its own past.<sup>7</sup> Technology cannot arbitrarily be changed or substituted. The expression was, still following A. Rip, T. J. Misa and J. Schot, coined by the economist Giovanni Dosi in 1982. Along with other recent theories, acknowledged by G. Dosi, it was intended as a corrective to a still widespread neo-classical assumption: that technology was an exogenously generated source of growth, appearing on the market as a set of largely public, non-rivalrous goods. Investors and managers, according to such a view, could choose randomly from a large set of off-the-shelf-technologies. In production function terms it was a matter of selecting the most adequate position on the iso-quant curve, in due consideration of the slope of the iso-cost curve, i.e. the relation between factor prices.<sup>8</sup>

Against this alleged idea of technological configurations as so many degrees of freedom, only limited by logical economic constraint and some obscure limits of technical feasibility, the proposition was advanced that in practical life technology was not easily adjustable. It tended to be handed down rather than selected, its development having a strong "momentum".<sup>9</sup> This last metaphor, very much semantically related to "trajectory", lends even more credibility to the assumption of an intimate connectedness between a specific technology at a given moment in time and the initial setting of its development.

7 A. RIP, T. J. MISA, J. SCHOT, eds., *Managing Technology in Society. The Approach of Constructive Technology Assessment*, London 1995, pp. 53-4. (Further: A. RIP, T. J. MISA, J. SCHOT, *Managing Technology*).

8 G. DOSI, "Technological Paradigms and Technological Trajectories. A Suggested Interpretation of the Determinants and Directions of Technical Change", in: *Research Policy*, Vol. 11, 1982, p. 151. (Further: G. DOSI, *Technological Paradigms*).

9 G. DOSI, *Technological Paradigms*, *op. cit.*, p. 153. T. P. HUGHES, *Networks of Power. Electrification in Western Society, 1880-1930*, Baltimore 1983, p. 140.

A. Rip, T. J. Misa and J. Schot restated these views in defending the notions of "trajectory" and "momentum" against accusations of determinism. Partisans of the Social Construction of Technology-school (SCOT) had been hinting that an *ex post facto*-perspective will take a direction towards viewing technological development as a locked-in process with no room for agency.<sup>10</sup>

The response towards the opposition from SCOT was that technologies are indeed achievements of human actors, but that these active forces are often confronted with a strong element of inertia, generated in the past. On the basis of individual instances this is simply a matter of fact which does not imply determinism. It just shows that changing an existing condition may require a powerful collusion of forces. At the same time, though, it is admitted by the three authors that "trajectory" as a conceptual tool should not be judged by the criterion of its strict metaphorical signification. The missile does not, in effect, wander through empty air, but is being influenced by many factors along its path.<sup>11</sup>

Social science is certainly not a competition in literary style. On the other hand, it is hard to accept that the whole figurative meaning of "trajectory" does not matter after all. Neither is this, said in fairness, what the three authors claim; they only admit that the metaphor is not fully accomplished. So let us, "deconstructively", insist that the metaphor basically means what it says and refuse to accept any restrictions on its application as long as we remain within the semantic field that constitutes its natural environment of signification.

The "launch" of a "missile" then, and its resulting "trajectory", determined by the stipulated "target" and the calculations of the more or less skillful and well equipped "artillerymen" (the social agents or actors),

10 W. E. BIJKER, J. LAW, eds., *Shaping Technology/Building Society. Studies in Sociotechnical Change*, Cambridge 1992, pp. 8, 45, 291. Cf. even: D. MCKENZIE, *Knowing Machines. Essays on Technical Change*, Cambridge 1996, p. 55.

11 A. RIP, T. J. MISA, J. SCHOT, *Managing Technology*, *op. cit.* For the explicit and unsolicited rejection of determinism on the part of MISA *et al.*, see also: T. J. MISA, "Retrieving Sociotechnical Change from Technological Determinism", in: M. R. SMITH, L. MARX, eds., *Does Technology Drive History? The Dilemma of Technological Determinism*, Cambridge 1994, pp. 117-9.

is, logically, a local, discrete event. But an occurrence of this type must somehow be rooted in a larger set of operations: a battle or even a war. In an ordinary narrative of military events one of the last two levels would be in focus, not the individual launchings.

Of course, and still figuratively speaking, detailed knowledge of individual cases, systematized into general laws and patterns governing the outcome of artillery operations, their technique and tactics so to speak, would be a helpful contribution to understanding modern warfare and its individual manifestations.

But for the historian, whose endeavour may very well be of a generalizing kind, but "*nonetheless still tied to a particular historical context*",<sup>12</sup> "trajectory" indicates exclusion of the meso- and macrohistorical levels (metaphorically equivalent to the battle and the war). It assigns for history a secondary role: that of handmaid to economics or sociology.

From an historian's point of view, then, the concept of "trajectory" does not display any great explanatory or narrative power. In terms of style it first appears as a quite accomplished metaphor, but then turns out to be inconsistent with the non-deterministic intentions of its users. Furthermore, a "deconstructive" evaluation of its wider meaning indicates a blindness to larger historical perspectives.

#### PATH DEPENDENCY

With its emphasis on historical contingency the notion of path dependency is related, but not similar to that of trajectory. As will appear from Charles P. Kindleberger's definition there is not necessarily a narrow focus on technology or local circumstances:

[...] *path dependency* [refers to] *the impact on economic processes and institutions of events that unfold in particular ways and render the processes and institutions rigid and unalterable. When external conditions change it is frequently*

12 A. MEGILL, "Recounting the Past: 'Description', Explanation and Narrative in Historiography", *American Historical Review*, Vol. 94, 1989, p. 633.

*difficult, to the point of impossibility, to reshape some institutions that have evolved to accomodate earlier forces.*<sup>13</sup>

The term may thus be applied to differences between major geographical and societal environments, i.e. to distinguish one *Sonderweg* from another.<sup>14</sup>

However, where path dependency is specifically related to technology, it constitutes the focal point in a debate about whether market forces imply economic efficiency or may just as well have the opposite effect. The question is whether things will normally work out according to a stable pattern of optimization unless particular externalities make a significant difference. A path dependency approach suggests the opposite: that a general outcome of events is impossible to determine because the particular circumstances of the various cases will bring about results that are very much different from each other in terms of optimization.<sup>15</sup>

Advocates of an important role for path dependency tend to argue that in situations of technological innovation and diffusion alternative designs and strategies are often neglected, although they, given the proper attention and resources, might eventually, in terms of efficiency or welfare, have turned out equally good or better than the road actually taken.

Sometimes, they claim, a sclerotic tendency, stimulated by risk aversity, band wagon-effects and general institutional rigidity, overrules sensible options appearing in the shape of really existing, technologically viable alternatives. Classical examples of paths followed with allegedly sub-optimal outcome are the QWERTY-layout of the typewriter keyboard (at the expense of the DVORAK-layout),<sup>16</sup> and the VHS-system for VC-recorders

13 C. P. KINDLEBERGER, *World Economic Primacy, 1500-1990*, Oxford 1996, pp. 9-10.

14 P. K. O'BRIEN, "Path Dependency, or why Britain became an Industrialized and Urbanized Economy long before France", *Economic History Review*, Vol. 49, 1996, pp. 213-49.

15 W. B. ARTHUR, "Competing Technologies, Increasing Returns, and Lock-in by Historical Events", *Economic Journal*, Vol. 99, 1989, p. 118. (Further: W. B. ARTHUR, *Competing Technologies*).

16 P. A. DAVID, "Clio and the Economics of QWERTY", *American Economic Review*, Vol. 75, 1985, pp. 332-7.

(at the expense of Betamax).<sup>17</sup> The argument may also be counterfactual, raising the question of premature exclusion of promising, albeit still largely unexplored paths. Steam or electrical power e.g. might or might not, with a more patient and energetic R&D-effort on the part of the automotive industry, have been, at least for some purposes, a realistic alternative to the internal combustion engine.<sup>18</sup> A home refrigerator works by an electro-mechanically driven compressor, but it is within the scope of imagination that an alternative method (ammonia being alternately vaporized and condensed, thereby absorbing and releasing heat) would have worked just as well or better, had this line of innovation, hypothetically, been chosen.<sup>19</sup>

The choice of which path to follow may even be influenced by social motives and vested interests that are not unconditionally rational from a technical point of view. This is David F. Noble's explanation of why computer programming, removed from the shop floor, was chosen instead of record-playback when machine-tool controls were mechanized after World War II. Managers desired social control over the work process and consequently ruled out a "teachable machine" technology based on the manipulation of the machine by the skilled worker.<sup>20</sup>

Two most persistent critics, Stephen E. Margolis and Stan J. Liebowitz believe that the path dependence-theory implies inherent, systemic market failure, an assessment they do not share, but insistently counterargue.<sup>21</sup> Moreover, they claim that even staple examples like QWERTY are unable

17 Case cited and refuted by: S. J. LIEBOWITZ, S. J. MARGOLIS, "Network Externality: An Uncommon Tragedy", *Journal of Economic Perspectives*, Vol. 8, 1994, pp. 133-50. (Further: S. J. LIEBOWITZ, S. J. MARGOLIS, *Network Externality*).

18 W. B. ARTHUR, *Competing Technologies*, *op. cit.*, pp. 126-7. D. A. KIRSCH, *The Electric Car and the Burden of History: Automotive Systems Rivalry in America*, unpublished dissertation (Stanford, Dept. of History, 1996, this reference established through Kirsch's intervention in the WWW-debate on: <<http://www.eh.net/lists/eh.res/forum3>>).

19 R. S. COWAN, *More Work for Mother. The Ironies of Household Technology from the Open Hearth to the Microwave*, New York 1983, pp. 129-43.

20 D. F. NOBLE, *Forces of Production. A Social History of Industrial Automation*, New York 1984, p. 188.

21 S. J. LIEBOWITZ, S. J. MARGOLIS, *Network Externality*, *op. cit.* S. J. LIEBOWITZ, S. J. MARGOLIS, "Path Dependence, Lock-In and History", *Journal of Law, Economics and Organization*, Vol. 11, 1995, pp. 205-26. Similar arguments as well as counterarguments have been exchanged on the WWW, see the overview on *op. cit.*: <<http://www.eh.net/lists/eh.res/forum3>>.



to resist critical scrutiny.<sup>22</sup> There is no reliable empirical indication, they find, that technological alternatives are normally ruled out, once and for all, before getting any chance to be tested in actual competition.

The debate is certainly by itself an important one. Its reproduction in this context, however, serves only to argue that also the metaphor of the "path" posits either particular (sequences of) events or very broad generalizations based upon those events as the pivot of our understanding of technological change.

The narrow focus on the implicit meaning of the rhetorical figures that shape theoretical concepts clearly leads to a somewhat crude and simplistic picture. I maintain, nevertheless, that narratives of the past delivered from the point of view of the two figures of speech dealt with here will more often than not be basically ahistorical examples of (more or less typical) forms of behaviour on the part of entrepreneurs and other socio-economic actors. We now proceed to historical explanations of the development of technological artefacts and procedures.

### CONTEXTUALISM

Professional historians of technology predominantly adhere to the "contextualistic" school, established in the United States from 1959 and onwards, under the aegis of *Technology & Culture*, published by the Society of History of Technology. The focus of the—at the time—new history of technology was still to be on artefacts, i.e. the practical, tangible side of technology, only no longer isolated from its context. Technology was not a mere product of science. Neither was it an unproblematic, spontaneously appearing and automatically progressive exponent of modernist rationality. In contextualism any selected segment of the empirical field is to be considered as a point of departure in a broad investigation of its surrounding social and cultural institutions. No single element is one-sidedly cause or effect. An investigation gains scope and depth by

22 S. J. LIEBOWITZ, S. J. MARGOLIS, "The Fable of the Keys", *Journal of Law and Economics*, Vol. 33, 1990, pp. 1-25.

extending itself further out into the context until the original issue can reasonably be considered as accounted for.<sup>23</sup>

The contextualist focusing on the various strands that keep a technology suspended in its environment does not unambiguously encourage a belief in mainstream history of technology as an adequate corrective to economics of technology. It is certainly true that contextualist historians do not use narration of events and developments as mere "cases" from which general laws—the economist's true objects of desire—are to be inferred. As is mainly the case in history, interpretation and explanation go along with and depend on idiographic analysis. The contextualistic historian explains his or her object of investigation by inclusion of different, but adjacent objects rather than by inference based on the observation of several or many similar, but distant objects. Of these two forms of explanation the latter is typically found in economics.

On the other hand, economics and contextualist history of technology also have one important thing in common: the implicit dissociation from structurally oriented macro-history. Both tend to emphasize the discrete, contingent nature of individual developments. The economists do because they seek theories that are valid across historically separate spaces; the contextualist historians because they shun any strong determination from other factors than those to be found by following threads from one specific point to another. The inquiry goes on until a suitably large and meaningful picture can be discerned. No matter how far the mapping of the terrain goes, the definitive border, i.e. the overall structure, is never reached. The delimitation of one context from another is arbitrary and at the researchers discretion.

Put in rhetorical terms one could say that through this style of historical inquiry technology and its context are signified by the two practically

23 This is of course a very brief and unsubtle characterization of a wide-ranging research environment that also has its internal conflicts. It builds upon various passages in: J. M. STAUDENMAIER, *Technology's Storytellers. Reweaving the Human Fabric*, Cambridge 1985, see particularly Staudenmaier's finalizing remarks on p. 201. The characterization of contextualism as a general explanatory strategy is based on: H. WHITE, *Metahistory*, *op. cit.*, pp. 17-19.

coinciding metaphors: the "fabric" and the "seamless web".<sup>24</sup> The connotations of all these three words have fairly obvious implications: it is not superior or general causes that make things what they are or happen the way they do. The basic characteristic of any "fabric" is that warp and weft are continuously interwoven. Consequently, getting knowledge of the individual patterns—and the shifts between them—is a question of following the thread. The process of "weaving" goes on and on, and the possible variations of the pattern or picture are legion. The variations must be perceived individually and cannot easily be subject to generalization. Recurrent tendencies can change at any moment. The "web-image" of history emphasizes that things are only comprehensible in their connection with other things, thereby implicitly denying the importance of stable structures.

There is, to my knowledge, no evidence of strong, institutionalised lines of communication between history of technology as practiced on the one hand by specialists in this field and on the other hand by economists. However, as hinted by the metaphors employed, both groups tend to favour the contingent element. There is undoubtedly a strong difference between an idiographic (preferred figure: "a fabric") and a nomothetic (preferred figure: comparable "trajectories") way of using events and local developments. Still, rather than a conflict the relationship appears to be one of mutual legitimization.

24 It may be claimed that the "seamless web-metaphor" describing the relationship between "social", "technical" and other forces in society does not strictly belong to History of Technology, but to the Social Construction of Technology-school, which—although much admired and imitated by historians—have been shaped and dominated by sociologists. However, as generously admitted by SCOT trend-setter Trevor Pinch, it was the "melting pot" of sociology and history of technology in the 1980s, which produced a number of "overlapping models of technology" that have "seamless web" as the "pervasive metaphor": T. PINCH, "The Social Construction of Technology. A Review", in: R. FOX, ed., *Technological Change. Methods and Themes in the History of Technology*, Amsterdam 1996, pp. 22-3. (Further: T. PINCH, *Social Construction of Technology*. R. FOX, *Technological Change*). Even today there seems to be considerable affinity between mainstream history of technology and SCOT: T. PINCH, *Social Construction of Technology*, *op. cit.*, pp. 28-9. Historian T. P. Hughes, more than once a creative and successful neologist in this field, is cited by Pinch as the one who introduced the term: T. P. HUGHES, "The seamless web: technology, science, et cetera, et cetera", *Social Studies of Science*, Vol. 16, 1986, pp. 281-92.

## THE HISTORY OF TECHNOLOGY AS MACRO-HISTORY

Up to now all attempts to depict long-term developments and major or general historical shifts in technology have been ignored. They do exist, of course, and although this essay is mainly about generalized styles of representation, it is convenient to exemplify it by two remarkable individual contributions, both dealing with the particular nature of the American production system, as distinct from its sources in European manufacture. Hrothgar J. Habbakuk's *American and British Technology in the 19th Century* is about how the technology transfer from Europe to the US was followed by changes in factor mix and rate of technical progress, induced by differing relative prices.<sup>25</sup> With H. J. Habbakuk's use of microeconomic production function theory to explain macroeconomic change his work is a contribution in the tradition of classical economic history.

David A. Hounshell, in *From the American System to Mass Production*, is less preoccupied with factors of production than with the particular relationship between certain strategic product types on the one hand and the corresponding technical and organizational production processes.<sup>26</sup> With excellent awareness of the threat of fallacy by anachronism he finds important roots of mass production in the older "American System", but at the same time issues a warning against confounding the two. He then undertakes to account for the processes that linked them together.

The model value of these two historical interpretations lies in the fact that they, by their chronological scope, their level and manner of generalization and their willingness to apply theory without abandoning history, represent a necessary alternative to the more narrow contingency that is latent in historical contextualism as well as in the case-oriented, pseudo-historical variant of economics. H. J. Habbakuk and D. A. Hounshell show a superior ability to represent the macro-processes lying behind comprehensive changes in technology and society. Their work share an important characteristic of good historical writing: the exposition of conditions at

25 H. J. HABBAKUK, *American and British Technology in the Nineteenth Century. The Search for Labour-Saving Inventions*, Cambridge 1962.

26 D. A. HOUNSHELL, *From the American System to Mass Production, 1800-1932. The Development of Manufacturing Technology in the United States*, Baltimore 1984.

different stages of time in such a manner that the similarities as well as the differences between them are revealed.

On the other hand, neither of the two offers a fixed pattern, a set of heuristics or generally applicable theoretical or rhetorical figures, that broadly encompasses technological change over longer periods. An ambitious attempt to that effect has been made by others, notably by Christopher Freeman and Carlota Perez with their concept of "techno-economic paradigms".<sup>27</sup>

#### TECHNO-ECONOMIC PARADIGMS

C. Freeman and C. Perez build upon the article quoted earlier, in which G. Dosi developed the idea of technological trajectory. G. Dosi realized that not all trajectories take place in the same type of environment. With this in view he devised the concept of "technological paradigm". It was defined as a pattern of solving selected technological problems that are considered important, using selected principles and selected elements of existing science and material technology. The distinction between paradigm and trajectory reflects the difference between major transformations and the ordinary day to day development by routine procedures.<sup>28</sup>

Even if an empirical operationalization seemed less than straightforward, G. Dosi's idea implied not only a recognition of the fact that overall structures differ from each other over time, but also an awareness of the mechanisms that link them together. In the newer version by C. Freeman and C. Perez the concept, now appearing under the name of "techno-economic paradigm", was appreciably extended and elaborated. It was accompanied by a taxonomy of innovations, ranging from incremental innovations, over radical innovations to systemic changes. Most far-reaching of all changes is a shift in techno-economic paradigm which is virtually a transformation of the whole economy. The passage from one paradigm to another was now explained more explicitly in Schumpeterian terms.

27 C. FREEMAN, C. PEREZ, "Structural Crises of Adjustment, Business Cycles and Investment Behaviour", in: G. DOSI *et al.*, eds., *Technical Change and Economic Theory*, London 1988, pp. 38-66. (Further: G. DOSI *et al.*, *Technical Change*).

28 G. DOSI, *Technological Paradigms*, *op. cit.*, p. 152.

Regularly occurring clusterings of radical innovations are mediated by long Kondratieff-like waves, resulting in profound institutional as well as technological alterations of economic life.

The typical scenario was specified in five actual, consecutive historical paradigms: "early mechanisation" (1770-80, 1830-40); "steam power and railway" (1830-40, 1880-90); "electrical and heavy engineering" (1880-90, 1930-40); "Fordist mass production" (1930-40, 1980-90); "information and communication" (1980-90, ?). The schematic characterization of each phase of development contained a large number of other elements, too comprehensive to quote here.

This at the same time coherent and elaborate representation of the continuous interplay between major and minor changes in technology was finally reproduced in a textbook-style publication: third edition of C. Freeman's (now with Luc Soete as co-author) *The Economics of Industrial Innovation*.<sup>29</sup> This time the model was accompanied by numerous empirical examples. The unfolding of each of the five historical paradigms was illustrated by typical innovations, entrepreneurs and firms.

The synthesizing effort made by C. Freeman *et al.* is definitely based on a both thoughtful and thorough consideration about how to conceptualize the general, long-term tendencies and their quantitative significance without missing or even neglecting the point that those tendencies are made up by a great and varied multitude of individual innovations, occurring in different contexts. With all its merits, though, it is not a final point of reconciliation and synthesis. It is not even a common *ad hoc*-platform for theories and lines of scholarship on technology in history. My claim is, once again, that the concept does not perform well against an attempt of deconstructing its tropological core.

G. Dosi, when he first conceived of using the term "paradigm", did it by analogy with science and the philosophy and sociology of science. He found that Thomas Kuhn's classical application of the word corresponded quite well with the way the focus and loyalty of actors change in the realm

29 C. FREEMAN, L. SOETE, *The Economics of Industrial Innovation*, London 1997.

of technology.<sup>30</sup> What first is seen as the ephemeral enterprise of a marginal minority, gains increasing credibility and support. The hitherto dominant mode of conduct gradually turns obsolete and unsustainable for everybody who wants to belong to the community of scientists—or of technicians and entrepreneurs.<sup>31</sup>

The Kuhnian application of the term has, even by authors with a friendly attitude towards the approach, been criticized for not realizing that some of the revolutions that separated neighbouring paradigms from each other were actually quite shallow. Even when truly new points of departure for scientific research were established, important theories and methods, fundamental for the old paradigm, were often not disturbed, only modified or supplemented.<sup>32</sup> Since the concept, in the second, techno-economic sense we discuss here, has been established by analogy, it would appear logical if its weak points were in the same position: an understatement of the importance of structures that are active and important across different paradigms.

There is even another aspect which may point towards the weak spot of “techno-economic paradigm”. The historicity of the theory is based on successive stages of development. C. Freeman’s reasoning about the mechanisms of transition is strikingly parallel to that of orthodox Marxist historical materialism.<sup>33</sup> “Techno-economic paradigm” is the equivalent of “mode of production”. The issue at stake here is neither Marx’ way to deal with technology nor the general validity of his view on history, it is the formal similarity between the two models. In both cases there is a replacement of one regime by another through a crisis. The crisis is being built up within the existing, older regime and then solved by radical means by new actors, recently empowered by the rise of new opportunities, transcending the worn out old order.

30 G. DOSI *et al.*, *Technical Change*, *op. cit.*

31 T. S. KUHN, *The Structure of Scientific Revolutions*, Chicago 1964<sup>1</sup>, 1970<sup>2</sup>, p. 159.

32 E. MCMULLIN, “Rationality and Paradigm Change in Science”, pp. 58-9, in: P. HORWICH, ed., *World Changes. Thomas Kuhn and the Nature of Science*, Cambridge 1993, pp. 58-9.

33 K. MARX, “Zur Kritik der Politischen Ökonomie. Vorwort”, in: K. MARX, F. ENGELS, *Werke*, Bd. 13, Berlin 1975, pp. 8-9.

In the work of C. Freeman it appears as if technologies were completed during their own ascendancy, at least to such an extent that under the next paradigm and the next again, there could only be adaptations and incremental innovations. History is carved up in "ages" that, each in their turn, leave a new deposit on top of the previous ones. The technological base of society was augmented by successive steps. The creative part, the active shaping of the future, went on mainly within the leading sectors of the current paradigm. Just as the feudal lord was an alien to bourgeois, capitalist society, the inventive mechanical engineer of the industrial revolution has no business in Silicon Valley.

Development is thus perceived as a series of anti-thetical negations. Forces that were previously important and powerful are synthesized into a common background, allowing radically new and different forces to appear right at the front. Old technologies have no dynamic role. There is a succession of technologies, as opposed to a continuous development of those that already exist. Technological change is revolutionary rather than evolutionary in its nature.

Even if it proves true that the "techno-economic paradigm-approach" is another rhetorical construct that, to top it all, presupposes some fairly rigid and dogmatic "laws of motion" in history, it is undeniably a flexible and comprehensive theory and master narrative. It could still, on principle, be an adequate representation of technological change in history. In a later section, though, I attempt to show that C. Freeman's Hegelian-style theory of successive stages has one really serious flaw: while important shifts occurring across middle-range time periods are well accounted for, the *longue durée* perspective is ignored. I shall try to demonstrate how one particular "paradigm", that of mechanization and mechanical engineering, has remained active and dynamic in a historically significant way ever since the industrial revolution, i.e. an entire historical epoch, without being overturned or overshadowed, but rather supplemented, stimulated and enhanced by new technologies. First, however, attention will be concentrated on a few general ideas that suggest a positive alternative to the figures and theories criticized above.



## TECHNOLOGICAL LANDSCAPES

A proposal that technologies be imagined as slowly moving elements and figures in a landscape was advanced by Svante Lindqvist who on the same occasion levelled a criticism against the propensity to view technologies as chains of events that rapidly move towards their end.<sup>34</sup> S. Lindqvist sees the product life cycle, illustrated by the logistic diffusion curve, as the central metaphor representing this last attitude. He especially points out that the intense interest in the lower left phases of the diffusion curve tends to hide the fact that important technologies and complexes of technology have long lives. An overwhelming majority of engineers spend their professional careers applying and redesigning technology that is already mature and consolidated.

You might object that the last point is already embraced by those parts of the Schumpeterian models that describe incremental innovation. Researchers have taken great pains to show empirically, with minute accuracy, how gradual learning processes are actually performed.<sup>35</sup> Still, S. Lindqvist should have some credit for highlighting the quantitative and quasi-permanent sides of technology, especially for noticing that these are not just a back cloth giving colour and ambience to the great feats performed on the forestage. They are under constant, albeit slow development and thus deserve the attention of historians.

## CONVERGENCE

While S. Lindqvist's metaphor of "technological landscapes" excellently points out the necessity of commitment to the long time perspective and to the full body of technology, it does not seem particularly fit as an operative tool of analysis.

34 S. LINDQVIST, "Changes in the Technological Landscape: The Temporal Dimension in the Growth and Decline of Large Technological Systems", in: O. GRANSTRAND, ed., *Economics of Technology*, Amsterdam 1994, pp. 271-88.

35 W. G. VINCENTI, "Technological Knowledge Without Science: The Innovation of Flush Riveting in American Airplanes", *Technology & Culture*, Vol. 25, 1984, pp. 540-76.

A more promising model for that purpose is Nathan Rosenberg's theory of "technological convergence". The expression has sprung from an analysis of the American machine tool industry, 1840-1910.<sup>36</sup> N. Rosenberg found that new types of machine tools were first constructed in response to specific needs, but then turned out to be applicable for a wide range of purposes across the various special sectors of mechanical industry. A given technique of machining did not just diffuse within the original, more narrow group of machine tool users, say textile factories, locomotive works or arms makers,<sup>37</sup> but through many different branches of the mechanical trade.

The argument can be extended to other capital good sectors besides machine tools. In pre-industrial manufacture there was only a distant kinship between the technologies and work processes of different trades. Modern industrial manufacture, by contrast, is characterized by a very substantial and ever-increasing use of machinery. Machines (and behind them: machine construction) have thus become a defining element for most types of production processes. "Convergence", in the technological sense, is when such constructional or functional principles are shared between: "[...] industries which were apparently unrelated from the point of view of the nature and uses of the final product [...]"<sup>38</sup>

As far as diffusion and learning processes are concerned, it should be noted that the "convergent" technological knowledge regarding machinery is not, in N. Rosenberg's historical case, to any considerable extent subject to appropriation. The fundamental elements are freely and—by the very notion of convergence onto a common technological platform—even quite easily transferable to any field where somebody see them fit for exploitation. They assume the character of public, non-rivalrous, non-excludable goods, actually very much available "off-the shelf".<sup>39</sup>

36 N. ROSENBERG, "Technological Change in the Machine Tool Industry, 1840-1910", *Journal of Economic History*, Vol. 23, 1963, pp. 414-43. (Further: N. ROSENBERG, *Technological Change*).

37 N. ROSENBERG, *Technological Change*, *op. cit.*, p. 419.

38 N. ROSENBERG, *Technological Change*, *op. cit.*, p. 423.

39 G. DOSI, *Technological Paradigms*, *op. cit.*, p. 151.

Convergence may therefore be viewed as the technological correlate of some core assumptions in new "endogenous" growth theory. The fact that:

*each unit of capital investment not only increases the stock of physical capital, but also the level of the technology through knowledge spillovers for all firms in the economy,*<sup>40</sup> [allows us to] *reconcile the existence of increasing returns with that of competitive market forces.*<sup>41</sup>

In relation to theoretical statements of this kind the convergence model spells out in more detail why the provision of an ever bigger and more diversified supply of commodities does not require a correspondingly increased and diversified amount of R&D and professional training. Existing formalized knowledge and human capital is easier to replicate and can be exploited more efficiently when convergence has taken place. New configurations of technological artefacts and human competence can, within a large range of variation, be drawn from the same source, a pool of basic, generally applicable technology, widely diffused across the capital goods sector and amongst users of capital goods.

Obviously, this observation does not give an exhaustive answer to the question of the nature of the relationship between on the one hand technological development (through convergence) and on the other hand economic growth. It is already suggested by the classical case cited here, and it will be made even more plain through the following sections, that technology cannot be properly and adequately fitted into the macro-historical pattern unless it is first conceived as a relatively autonomous field. The creativity of designers, producers and users of technical artefacts is sustained by and interacting with economical resources and institutional settings, but a total integration would mean losing sight of not just the particulars, but also some general, constituent features of the technological sphere and its dynamics. While recognizing that knowledge regarding some specific issues can best be gained from an "endogenous" point of view, it

40 P. M. ROMER, "The Origins of Endogenous Growth", *Journal of Economic Perspectives*, Vol. 8, 1994, p.7.

41 G. N. VON TUNZELMANN, *Technology and Economic Progress. The Foundations of Economic Growth*, Aldershot 1995, p. 89.

remains difficult to imagine that technology should not somehow continue to be "exogenous" to the formal and quantitative conceptualization of economic growth processes in general.<sup>42</sup>

### SYSTEM AND STRUCTURE

A complex, enduring interaction between different technologies or between technology and other spheres of social life is often designated a "system". This particular meaning of the term was instituted by Thomas P. Hughes who used it to describe the coherence and historical momentum of the diverse forces that together were engaged in the creation of vast, aggregate socio-technical complexes like power networks.<sup>43</sup>

It seems natural to compare N. Rosenberg's analysis of the American machine tool industry with a "system" as defined and described by T. P. Hughes. An important difference between them is that a "system" to a considerable degree is planned, coordinated and even in possession of means to enforce important decisions made at the central level. Under normal free market circumstances this will not be the case in the machine tool or similarly organized branches of business. Within a more informal network of e.g. machine tool producers, their employees and their costumers there will of course be a considerable degree of coherence; only does it largely arise spontaneously—or by voluntary organisation—from the shared interest in the technology and from the transactions between the attached units.<sup>44</sup> Let that difference serve as a provisional means of distinguishing between "system" on the one hand and what I will call "structure" on the other.

42 N. F. R. CRAFTS, "Exogenous or Endogenous Growth? The Industrial Revolution Reconsidered", *Journal of Economic History*, Vol. 55, 1995, p. 767.

43 T. P. HUGHES, *Networks of Power. Electrification in Western Society, 1880-1930*, Baltimore 1983, p. 465.

44 The assumption of coherence within sectoral or trade environments is supported by a considerable amount of literature on organised markets, networks and national systems of innovation, e.g.: B.-Å. LUNDVALL, ed., *National Systems of Innovation. Towards a Theory of Innovation and Interactive Learning*, London 1992. R. R. NELSON, ed., *National Innovation Systems. A Comparative Analysis*, New York 1993. M. PORTER, *The Competitive Advantage of Nations*, London 1990.

It is not self-evident how wide-ranging and far-reaching a structure is. The extension of T. P. Hughes' socio-technical system is defined by the scope of the strategic decision-making carried out by the system builders. There is not, however, any such clear demarcation of the so called "structure". If one desires to generalize the theory of "convergence" and make it work on a larger material than the one used by N. Rosenberg, some sort of answer to this question ought to be found. I shall try to encircle it by briefly citing a few general examples drawn from the history of mechanical engineering, and, coincidentally, provide the previously announced alternative to the vision of technological change as a series of successive paradigms.

### MACHINE TOOLS

N. Rosenberg, in the quoted article, delimited his subject by three criteria: sectoral: machine tools, geographical: the US and chronological: 1840-1910. But it is not a foregone conclusion that the American development in the said period was so unique, compared with other segments of the history of machine tools, that the "convergence-interpretation" only makes sense within this specific context. It might be equally meaningful to see it as one instance out of several, a variation on a common theme.

The mainly British development of the first generation of general purpose machine tools has points of resemblance with the process described by N. Rosenberg. Maudslay's classical lathe from 1798-1800, the most successful of a number of designs by various inventors, was first built in a small size version. It was not conceived as a pattern to be followed by all later machinebuilders, but as a "screw-cutting lathe", i.e. a piece of special purpose machinery. As the value of its basic design became recognized, it was reproduced in enhanced technical scale and of course refined and developed further.<sup>45</sup>

45 K. R. GILBERT on machine tools in: C. SINGER *et al.*, eds., *A History of Technology*, Vol. 4, Oxford 1958, pp. 425, 432, plates 24 C and 25 A. (Further: C. SINGER, *History of Technology*). L. T. C. ROLT, *Tools for the Job*, London 1986, pp. 93-5, 109-11. (Further: L. T. C. ROLT, *Tools for the Job*). The great general importance of scaling (relating to the sizes of systems as well as artefacts) as a promotor of technological change was emphasized by: D. SAHAL, *Patterns of Technological Innovation*, London 1981, pp. 65-7, 117-22, 252-6.

The British machine tool technology was then transferred to other countries, among which the US where it constituted the solid basis of the development of the modern milling and grinding machines. These were first intended for work on small items in large batches and for a number of demanding processes in the production and maintenance of tools. As time went by they came to be built in larger and heavier versions and became standard machine tools, widely diffused in all versatile shops, not only in the US but across the world.<sup>46</sup> There was in other words a move from the generalized to the specialized machine tool and back. Growing diversity and growing universality were not separate tendencies, struggling for supremacy. They were two sides of the same coin. With many true novelties as well as minor improvements and changes, but no sudden ruptures, cleavages or fundamental changes of identity, machine tool technology flowed from one continent to another and back, being transformed and worked out according to local needs. The results of the process were eventually redirected into the common pool of basic technology.

It cannot be denied that a great deal of the 20th century mainstream development in machine tools has been of an incremental nature. But even in those periods when the basic design of machine tools remained unchanged, there were several important innovations in ancillary aspects of the technology. Notable were the substantial changes in tool materials and design. They gave a strong impetus for improvements in other parts of the technological complex of machine tools, such as their statics of construc-

46 D. F. GALLOWAY on machine tools in: C. SINGER, *History of Technology*, op. cit., Vol. 5, p. 653. R. S. WOODBURY, *History of the Milling Machine*, Cambridge 1960, pp. 48-9. R. S. WOODBURY, *History of the Grinding Machine. A Historical Study in Tools and Precision Production*, Cambridge 1959, pp. 70, 81-2, 102. B. BUXBAUM, *Die Entwicklungsgrundzüge der industriellen spanabhebenden Metallbearbeitungstechnik in 18. und 19. Jahrhundert*, Berlin 1920, pp. 20-1, 24-5, 60. T. R. SHAW, *Precision Grinding Machines*, London 1917, pp. 1-5. Regarding the importance of recognizing the intimate relationship between European and American machine tool technology, see the opinion of David Hounshell, quoted in: J. M. STAUDENMAIER, "Recent Trends in the History of Technology", *American Historical Review*, Vol. 95, 1990, p. 719.

tion and mode of control.<sup>47</sup> Even if the induced changes were in and by themselves incremental, the process as a whole kept its very much dynamic, "systemic" character. This is in accordance with another suggestive metaphor coined by T. P. Hughes: that of "salients" that on some points of a common frontline are well advanced, representing the latest improvements. On other points the salients are "reverse", indicating a bottleneck where some innovative effort is due if the wider front is to be pushed forward.<sup>48</sup>

In recent decades there have been new radical transformations of machine tool technology. The advance of numerical (digital) control and related technology has especially been fostered by the enormous potential in microelectronics, but today's highly automated and highly performing machine tools have also important historical roots in the "hard-wired" (later even semiconductor-based) electro-hydraulic servo-control technology that was well under way some time before the micro-chip had even been invented, let alone made available for industrial purposes.<sup>49</sup>

Currently evolving alterations are not only in controls, but also in other classical, major themes of machine tool technology. Cutting speed is during

- 47 R. S. WOODBURY, *History of the Milling Machine*, Cambridge 1960, pp. 48-9, 80-1. F. SCHWERD, *Spanende Werkzeugmaschinen*, Berlin 1956, pp. 171 ff, 242. G. L. CARDEN, *Machine-Tool Trade in Austria-Hungary, Denmark, Russia and Netherlands*, Washington 1910, p. 99. E. K. HENRIKSEN, ed., *Maskiner og værktøj* [Machines and their tooling], Vol. 2, Copenhagen 1944, pp. 9-15. (Further: E. K. HENRIKSEN, *Maskiner*). G. SPUR, *Vom Wandel der industriellen Welt durch Werkzeugmaschinen*, Munich 1991, pp. 455-61. *American Machinist*, "Metalworking: Yesterday and Tomorrow: the 100th Anniversary Issue of American Mechanist", New York 1978, pp. F7-F8, G5, G8. (Further: *American Machinist*).
- 48 T. P. HUGHES, "The Dynamics of Technological Change: Salients, Critical Problems and Industrial Revolutions", in: G. DOSI *et al.*, eds., *Technology and Enterprise in a Historical Perspective*, Oxford 1992, pp. 97-100.
- 49 *American Machinist*, *op. cit.*, p. G10. J. F. REINTJES, *Numerical Control. Making a New Technology*, New York 1991, pp. 47-57. The term "servo-mechanism" was introduced in 1934: S. BENNETT, *A history of control engineering, 1930-1955*, London 1993, p. 106. Examples of modern, more or less automated machine tools, some numerically controlled, others not, are found in: G. E. GENEVRO, S. S. HEINEMAN, *Machine Tools. Processes and Applications*, Englewood Cliffs 1991, pp. 231-9. Cf. even note 62.

these years, once again, being pushed substantially upward ( the so-called " high-speed machining " ).<sup>50</sup>

These are all different examples of how technological novelties continue to enter into firmly established technological structures, not as discrete events in a process of incremental aggregation, but as promoters of productivity-boosting systemic change.

### THE STEAM ENGINE

The sceptically inclined will probably object that machine tools is a really unique and therefore atypical technology. Indeed, it is the central locus of production of capital goods, laying the technological basis for practically every other special sector within the manufacture of mechanical equipment. Such a continuous, identity-preserving and yet adaptive and permanently expansive performance may not be found anywhere else, it could be argued.

Other relevant cases come from the field of motive power. The first true steam engines ( the Newcomen type ) were erected in the beginning of the 18th century<sup>51</sup>. They were designed for the operation of water pumps. With later improvements steam engines became more powerful, efficient and versatile, and safer and cheaper too. High pressure, compounding, various arrangements of cylinders, shaft and transmission mechanisms, and of course the ability and capacity to manufacture all sizes of engines made

50 R. I. KING, ed., *Handbook of High-speed Machining Technology*, New York 1985, pp. 1-16. Lectures on various aspects of the state of the art: G. SCHNEIDER Jr., ed., *High-Speed Machining. Solutions for Productivity*, Ohio 1990.

51 H. W. DICKINSON on the steam engine to 1830 in: C. SINGER, *History of Technology*, op. cit., Vol. 4, pp. 168-98. A. STOWERS on the stationary steam engine in: C. SINGER, *History of Technology*, op. cit., Vol. 5, pp. 123-40. P. H. SPRATT on the marine steam engine in: C. SINGER, *History of Technology*, op. cit., Vol. 5, pp. 141-56. G. N. VON TUNZELMANN, *Steam Power and British Industrialization to 1860*, Oxford 1978. H. W. DICKINSON, *A Short History of the Steam Engine*, London 1963. R. L. HILLS, *Power from Steam. A History of the Stationary Steam Engine*, Cambridge 1989. J. GUTHRIE, *A History of Marine Engineering*, London 1971. The question of investment and operating costs per horsepower for various sizes of machinery after 1860 is tentatively discussed, on the basis of Danish material, in: J. PEDERSEN, *Teknologisk udvikling i maskinindustrien: Burmeister & Wain, 1875-1939* [Technological Development in Mechanical Engineering: Burmeister & Wain 1875-1939], Lyngby 1999, pp. 78-81. ( Further: J. PEDERSEN, *Teknologisk udvikling* ).



mechanical power available for an increasing number of activities in several main fields: industry (large- as well as small-scale), landed transport, sea transport, generation of electricity.

This development of the classical steam engine ran over more than 200 years! There were 70 years between the Newcomen engine and Watt's important contributions. It then took another 70 years or more, until the middle of the 19th century, to create and diffuse a technology that assured the supply of steam engines at competitive prices for the majority of purposes conceivable at that time. For large-scale operation a culmination was only reached in the last couple of decades of the 19th century, with the triple-compounded engine. Even later, well into the 20th century, some not unimportant improvements of the piston steam engine were introduced, developed under the competitive pressure from turbines and diesel engines. With its long history, broad diffusion and large diversity<sup>52</sup> it is still beyond doubt that steam engine technology, like that of machine tools, was one of coherence and unity, in terms of working principles, component types, labour processes and human and physical capital employed.

Once again, the importance of that observation lies in the wide chronological extension combined with the capacity for continuous "systemic" or—as I would rather have it—structural change, with substantial effect on the economies of the technology and its consequential attractiveness to investors. The impression runs contrary to viewing technology as either completely disparate events in changing local contexts or even as broader themes that rise and exercise their transformative influence, but then vanish into the limbo of incremental innovation, followed by a quite different long wave-dependent paradigm.

52 Similar terms to sum up the development of the steam engine have previously been used in order to show the "isomorphism between technological history and natural history": J. MOKYR, "Evolution and Technological Change: A New Metaphor for Economic History?", in: R. FOX, *Technological Change, op. cit.*, p. 70. (Further: J. MOKYR, *Evolution and Technological Change*).

## THE DIESEL ENGINE

Diesel technology is yet another example of a technology that may qualify for the "structure-label".<sup>53</sup> Even if it has not historically had the same pioneering position and the same economic impact as the two previous examples, it is still a coherent technology that has enjoyed substantial qualitative improvement—of a systemic nature—over a longer period of time. Likewise, it is not just a single product. Its development included technical up- as well as down-scaling and adaptation for a considerable number of purposes.

Besides confirming the previously postulated pattern, the example of the diesel engine can elucidate another point: individually defined structures are also modular elements in superior structures. From a taxonomical point of view it is quite obvious that there is a functional and generic association between steam and diesel engines. The combustion is certainly external to the first (located in the boiler unit) and internal (located in the cylinder) to the second type of engine, but both are machines that generate mechanical power and are, in their turn, driven by thermal energy. It should also be noted that they are both mechanical contrivances made of steel and cast iron and working by the valve-regulated travel of pistons in cylindrical chambers, all encased in a rigid frame.

These observations, trivial though they are, help to understand why there is not only a technical, but also a strong historical linkage between steam and diesel technologies. Rudolf Diesel, the inventor, was during his education as an academic engineer influenced by the range of ideas concerning the famous "Carnot-cycle" that was first thought out in the first part of the 19th century in a series of reflections on the steam engine and its working. When Diesels original invention, patented 1892, was developed into a reliable prototype and later went into production, first at the original site and soon after with licensees, the active firms were already long

53 Basic accounts are: F. SASS, *Geschichte des deutschen Verbrennungsmotorenbaues, 1860-1918*, Berlin 1962, p. 383. D. E. THOMAS, *Diesel. Technology and Society in Industrial Germany*, Tuscaloosa 1987. (Further: D. E. THOMAS, *Diesel*). L. BRYANT, "The Development of the Diesel Engine", *Technology & Culture*, Vol. 18, 1976, pp. 432-46. (Further: L. BRYANT, *Development of the Diesel Engine*).

established as steam engine manufacturers, thus having a suitable—although by no means complete<sup>54</sup>—competence for entering into this new, but also in many respects similar business.

Generally the diesel engine followed the pattern sketched earlier. It was first devised for small scale industrial and artisanal users. On the basis of its sound basic working principles, however, larger sizes quickly came into being, making the diesel an efficient competitor to the steam engine for most purposes. Later there was even a technical downscaling, making the diesel engine a viable alternative to lighter internal combustion engines in small craft and vehicles.<sup>55</sup>

#### BASIC COMPONENTS IN MACHINERY

In the three previous sections I have tried, by examples, to outline the usefulness of a basic notion of structural permanence. I have used the term “structure” to cut out the empirical field along convenient lines, in relatively autonomous units, but also with the possibility of incorporating these different, but cognate structures into larger, superior structures. Steam and diesel engines, e.g., are both mechanical power generators. They are produced by means of machine tools—and so are machine tools themselves. Machine tools, on the other hand, are driven by engines. In other words: the subdivisions of mechanical engineering seem to be so closely related and so dependent upon each other that they constitute one integrated, continuously developing macro-technology. This emphasis on an integral quality in an otherwise very diversified object of study is a decisive line of separation between a structural and a contextual approach.

But the given examples, especially the first two ones, are in and by themselves so important that it remains doubtful whether they truly represent a general principle or are, in effect, quite unique and independent objects of historical interpretation. The question is whether the alleged

54 D. E. THOMAS, *Diesel*, *op. cit.*, p. 170. L. BRYANT, *Development of the Diesel Engine*, *op. cit.*, pp. 443-4.

55 The case of the major Danish manufacturer illustrates this combined process of diversification and diffusion: J. PEDERSEN, *Teknologisk udvikling*, *op. cit.*, pp. 83-115).

structure has any common medium, a cement that penetrates both superior and inferior levels.

Provisional reference can be made to the formerly stated sharing of component types between steam and diesel engines. This tendency encompasses far more items than those mentioned in the example and is valid for practically all departments of mechanical engineering. Machine parts resemble each other, they are made of the same kind of materials and by the same techniques. This fact is an important constant element in the technology. A shaft, a bearing, a piston, a threaded bolt are fundamentally the same today as they were during the industrial revolution. However, another important structuralistic quality is that the stability incorporates change. A structure keeps its identity—it does not remain the same, though.

In the case of basic mechanical components the change operates in two directions that tend to equilibrate each other: one of growth and diversification and another of simplification and standardization. New microelements are continuously added: tools, sub-items, materials, ancillary techniques—to the inventory of technical possibilities.<sup>56</sup> At the same time, though, the number of reasonable and legitimate variations and combinations from among the countless possibilities is being limited by procedures of standardization and rationalization. The point is that the profit earned from having a rich and adaptable register of possible solutions to given problems should not, in the same breath, be lost on lengthy or faulty decisionmaking or failing coordination.

Important examples of standardization to avoid the threat of negative returns to variety are Joseph Whitworth's system of threads in the middle of the 19th century,<sup>57</sup> Georg Schlesinger's standards of performance for machine tools in the beginning of the 20th century,<sup>58</sup> and the general, official standardization of mechanical items (rules of limits and tolerances, form regularity etc.) that became institutionalized in the late

56 J. MOKYR, *Evolution and Technological Change*, *op. cit.*, pp. 71, 78.

57 L. T. C. ROLT, *Tools for the Job*, *op. cit.*, p. 126.

58 G. SCHLESINGER, *Prüfbuch für Werkzeugmaschinen*, Middelburg 1927<sup>1</sup>, 1962<sup>2</sup>.

Nineteentwenties and onwards, but, in a less coordinated way, had been underway since a couple of decades earlier.<sup>59</sup>

Among several advantages technical standard specifications have facilitated the division of labour among engineering firms. Increasingly complex end products can be tailored—at viable prices—to an almost incredibly great and diversified number of needs. That would hardly be possible, were it not for the fact that individual establishments of mechanical engineering are no longer obliged to manufacture individual parts and specialized units in-house, but can purchase them at relatively low prices, thanks to the ingenious mixture of variety and simplicity—combining flexibility with economies of scale—in the mechanical arts.<sup>60</sup> A vast system of modules, flexibly adaptable as parts of or complements to other modules, has developed gradually over the industrial epoch.

#### AUTOMATION

As already indicated when speaking of machine tools, automation technology is not the result of one single technological fix, e.g. the upsurge of microelectronics. It depends historically on a blend of mechanical, electro-mechanical and electronic items. Some of the important component parts of this mixture are the result of a suitable scaling and adaptation in many other forms of well known, quite old technology. Consider the fact that—apart from the driving medium—Nasmyth's steam hammer of 1856<sup>61</sup> operated in basically the same way as a pneumatically driven piston that with

59 V. B. WAGENHOFF, "Rationalisierung vor der Rationalisierung. Der Zweite Umbruch in der Fertigungstechnik, 1895-1914", *Technikgeschichte*, Vol. 56, 1989, pp. 213-5. C. A. HENDRIKSEN, V. T. LANGE, *Forelæsninger over Massefabrikation* [Lectures on Mass Production], Copenhagen 1914, pp. 1-12. E. K. HENRIKSEN, *Maskiner*, *op. cit.*, Vol. 1, pp. 181-202.

60 It is not implied that the full enjoyment of these benefits come without any effort on the part of the firms. However, the basic technological feasibility embodied in standards and common practices is important for optimizing the division of labour between the final product manufacturer and its suppliers, whether these be individually assigned subcontractors or "off the shelf parts-suppliers": P. HINES, *Creating World Class Suppliers. Unlocking Mutual Competitive Advantage*, London 1994, pp. 5-6, 14, 53.

61 K. R. GILBERT on machine-tools in: C. SINGER, *History of Technology*, *op. cit.*, Vol. 4, pp. 430-1, plate 24 A.

great speed moves small, delicate objects on a modern production line. Even very different mechanical artefacts may share important basic qualities.

The argument also works the other way around, showing how innovations that *per se* represent something definitely new, do not necessarily revolutionize the structure they are inserted in. Transformation normally takes place in a gradual manner. A complex, mechanized line of production is once again a suitable example. The modern Programmable Logical Controller (PLC) or an even more modern software-controlled regulating unit may well enhance productivity and eliminate bottlenecks in the specific techno-structure. But they are not—in the context of manufacture at least—strategically decisive, core technologies to such an extent that they have turned established systems upside down or altered them radically over few years. Automatic regulation and control procedures, based on clicking relays, valves, etc., were already in existence before the micro-processor or even the integrated circuit. At this stage the technology was undoubtedly more clumsy and less flexible and efficient than now, but it worked and helped constitute and consolidate the general structure of automation technology before newer and by themselves smarter control technologies appeared and took their place.<sup>62</sup>

Today's state of the art technology in capital goods can be conceptualized by the term of "mechatronics". The wording itself suggests that the phenomenon in question is the result of an increasing integration between relatively independent technologies (mechanics + electronics + software). Whereas the visible, manifest functioning of this synthesis relies on traditional mechanical engineering, there is an increasing dependence: "*on computers and electronics to achieve the degree of function, flexibility and reliability demanded by users*". It is not a mere aggregation of technologies that provides

62 J. R. BRIGHT, *Automation and Management*, Boston 1958. Briefly indicates the later stages of development: D. PESSEN, W. HÜBEL, *The Design and Application of Programmable Sequence Controllers for Automation Systems*, London 1977, pp. 1-2. J. PEDERSEN, "H. Nielsen & Søn Maskinfabrik A/S, 1916-1980. Et eksempel på maskinindustriens teknologiske fornyelse i efterkrigstiden" [H. Nielsen & Son Engine Works Ltd, 1916-1980. An example of technological renewal in mechanical engineering in the post-war epoch], *Erhvervshistorisk Arbog* [Communications from the Danish National Business Archives], Vol. 46, pp. 110-55.

the efficient solutions but the "system interface".<sup>63</sup> This fusion of technologies is perhaps not the same as convergence, in the exact meaning that N. Rosenberg asserted in his path-breaking article. But there is a strong familiarity, given by the fact that not only do both types of process bring about solutions to specific problems in manufacturing, the said solutions can afterwards, in both cases, be transferred to similar use in other sectors, and eventually be integrated into a common pool of technological know-how. By then it is fair to say that a convergence has taken place.

To sum up: the pervasive influence of mechanization described in the convergence model is not just a series of recurrent, but mutually isolated phenomena. The various incidents of the pattern, distinguishable from each other by differences in time, place, sector and socio-economic context are linked together by learning processes, including technology transfers, that in the final analysis are world-encompassing. These links help constitute an organic, continuous, long term development with peculiar characteristics, worthy of historical, idiographic analysis. The process is only perceivable from a broad, *longue durée* point of view, not a strictly case-oriented or even contextualistic perspective.

#### THE RHETORICS OF STRUCTURALISM

Like other simplifying interpretations of complex socio-economic matters the one sketched here operates figuratively, i.e. by reference to other things than those which are sought explained. As is generally the case with structuralistic method, the point of reference is the human language, the way it is represented in the basic model established by Ferdinand de Saussure.<sup>64</sup>

Historians of technology Mikael Hård and Andreas Knie have recently been experimenting with an explanatory model that also has some contact with (socio-)linguistics. In a case study over diesel engineering 1920-1940 they viewed the members of the German community of diesel designers as users of language who accepted severe constraints from "grammarians",

63 D. M. AUSLANDER, C. J. KEMPF, *Mechatronics. Mechanical system interfacing*, Upper Saddle River 1996, pp. 1-2.

64 F. DE SAUSSURE, *Cours de linguistique générale*, T. DE MAURO, ed., Paris 1915<sup>1</sup>, 1974<sup>2</sup>. (Further: F. DE SAUSSURE, *Linguistique générale*).

i.e. a codifying body of experts in the VDI (the professional association of engineers in Germany).<sup>65</sup> French diesel designers, on the contrary, were—metaphorically speaking—free to express themselves in several diverging “dialects”. They were not subject to any attempts of nationwide standardization of diesel engine technology.

The de Saussurean model applied in the present essay is also based on the codification of language, but in a way quite different from the just quoted Bourdieu-inspired—“grammar-model”. Especially it should be pointed out that the de Saussure-model has no decisive or even explicit role for power-institutions. Language is conceived in terms of *langue* and *parole*,<sup>66</sup> a pair of concepts that mutually imply each other, showing the two dichotomous aspects of the same field. *Langue* is the collective behavioural system: not an authoritarian, disciplinary device, but a purely mental construct. It is the complex of rules and norms followed by individual language users, whether these reflect upon their usage or not. It may or may not be officially codified or otherwise explicit. As an intangible—but no less real for that reason—the linguistic competence of people was obviously present before the first grammarian began explaining what language is about and how it works. *Parole*, on the other hand, is the general designation of the speech-acts that are actually performed by language users. Put differently, it is the empirical, physically manifest (in speech or writing) correlate to *langue*.<sup>67</sup>

Applied on the technological development in mechanical engineering as it has been sketched above, the basic elements of the technology are equivalent to *langue*. The elements can be fitted together in manifold ways with endlessly changing results, yet these compositions, like linguistic utterances, must conform to certain rules and norms if they are to work successfully in their context. Even the rules are to some extent context-dependent, but much less than their speech-act manifestations. They do change, but not radically. The structural form is easily recognizable because it preserves its fundamental identity over longer periods of time.

65 M. HARD, A. KNIE, “The Grammar of Technology: German and French Diesel Engineering, 1920-1940”, *Technology & Culture*, Vol. 40, 1999, pp. 26-46.

66 F. DE SAUSSURE, *Linguistique générale*, op. cit., p. 38.

67 J. CULLER, *Structuralist Poetics. Structuralism, Linguistics and the Study of Literature*, London 1975, p. 9.



From a *parole*-oriented point of view any speaker/writer (in technology: any engineer) is to some extent bound by the typical discourse of the moment (in technology: the dominant style and themes in design). However, even under those constraints there will be considerable latitude for individual performance, and even for unique achievements. Just as a novelist writing in, say, the realistic tradition is not confined to repeating what others working within the same genre have already written, so the creative engineer-designer has good opportunities for expressing his creative or outright pathbreaking capabilities.

At another level of specification the language user chooses between several levels of style and several genres, from high to low style, from ordinary, relaxed everyday speech to the metric formality of poetry. Correspondingly, machine designers operate in various fields, some of the tasks being easily performed routine, others demanding and complicated, pushing forward the technological frontier. The point is that each type of actor, language users as well as engineers/designers, in their respective fields of activity, very much draw on the same resources as the other actors, past and present, in that field.

Driven by the interaction between *langue* and *parole* new forms of everyday language and new formalized genres sometimes appear. However original the result of such changes may be, there will always remain strong connecting links and many points of similarity between past and present styles.

#### IN CONCLUSION: STRUCTURAL DETERMINISM

Few would probably insist that the history of either oral discourses or styles in written language are interpreted deterministically because they are viewed from the point of view of an enduring, general linguistic structure. But in a way they actually are. Future discourses and styles develop out of present ones, and all are they bounded by those founding elements of *langue* that are only modified very slowly and very gradually.

Showing mechanical engineering technology through the image of language implies a similar structural determinism. The individual inventor or

innovator can normally give only small contributions to the cumulated stock of actually performed technological design processes. Equally little can he influence the transformative dimension of the process of change. Half jokingly one could venture the idea that even the greatest figures are dispensable. It is not likely that anybody's individual failure to appear would have left any vacuum capable of changing the general course of history. The reason for this is that the potential these important people carried into effect by their actions was not primarily, or at least not exclusively, tied up with their individual figures, appearing in particular contexts, but with the overall structures (of literature or technology) in the relevant period. Given the resources embodied in the respective spheres of culture it is not impossible that a great 19th century Russian epic could have been produced by somebody else than Tolstoy (this is the joking part, of course), nor that a self-igniting internal combustion engine would have appeared even if Rudolf Diesel had never been born. The world would definitely be a poorer place had *War and Peace* never been written. It is not the point that everything, regardless of individuals and circumstances, is bound to be the same, because structure does so determine. The point (to be sure a postmodernist, ironic one) is simply that whereas the overall development may be viewed as a seamless web of individual, context-bound events it is equally admissible to see those events as shades and variants within a slowly evolving general pattern. Structural determination is not—and is not supposed to be—a realistic twin image of the world and the way it works. It is a conceptual tool, embedded in a peculiar form of figurative speech—or if you like: theoretical discourse—founded on the illustrative potential of general linguistics.

Structural determinism, applied on history, is not teleological in its nature. No prognostic capability is claimed. It operates on a large scale and is basically retrospective. The equal weighting of the *langue*—and *parole*—aspects guarantees *eo ipso* the inclusion of agency in historical analysis. It will sooner function as a heuristic, perspective-establishing device than as a rigid theory that establishes laws of motion.

It does not even imply any strong ideological commitment, e.g. in favour or against the kind of society that has modern technology as one of its major foundations. It can be admitted that the structuralist way of inter-

preting mechanical engineering technology has a relatively optimistic ring as far as efficiency and optimization on a purely technical level is concerned. This is due to the basic notion that most individual technologies are founded on elementary modules and therefore are flexible, open to adjustment and refinement and even correction. On the other hand it is just as easily admitted that very large socio-technical complexes, as e.g. the culture of motoring in modern society, with established consumption patterns, vested interests of the automotive and oil industries, and huge sunk costs in factory plants, infrastructure etc., could not possibly be radically altered, let alone substituted by another socio-technical system, within a narrow space of time. The purely epistemological determinism that is incorporated in a structuralist approach is by no means incompatible with a realistic, sometimes optimistic, sometimes pessimistic attitude to real-life practical and political phenomena and problems.