

**Time-distance Analysis:
Evolutionary Background Theory**

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Time-distance Analysis: Evolutionary Background Theory

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Editorial

This is the second part of the second issue on time distance analysis which is devoted to the background theories for TDA and which, above all, links TDA with evolutionary theory and provides, thus, a general evolutionary framework for the study of societies, human and otherwise.

With the double issue on time distances it is hoped to have constructed a comprehensive platform for a new methodology in the fields of comparative research and of comparative dynamics.

With respect to the continuation of this journal, it is planned to produce two to three issues per year which are centered around a new methodological topic in the domain of comparative research. For the first years e-WISDOM will be devoted to

- e-WISDOM 1: Socio-economic Risk-Analysis (2004)
- e-WISDOM 2a: Time-distance Analysis (2004): Method and Applications
- e-WISDOM 2b: Time-distance Analysis (2004): Evolutionary Background Theory
- e-WISDOM 3: Robust Comparative Methods (2005)
- e-WISDOM 4: Second-order Methods (2005)
- e-WISDOM 5: Symbol-based Methods (2005)

Each issue consists of a set of articles which are devoted entirely to a new methodological issue like socio-economic risk-analysis or time distance analysis.

Contributions and suggestions for further topics outside the five domains mentioned above are highly welcome. It is the stated aim of e-WISDOM to advance the state of social science methods and methodologies as well as to present innovative designs which should enrich the current tools and instruments in comparative research.

Finally, a series of interesting articles from the old WISDOM-journal has been put on the web under www.wisdom.at.

Vienna, July 2004

Karl H. Müller
(Head of WISDOM)

Introduction: Time Distance Analysis (TDA) within an Evolutionary Framework

Karl H. Müller and Pavle Sicherl

The second part of e-WISDOM 2 is both theoretical and methodological in nature and has its main focus on the necessary criteria and on the limitations for successful TDA-applications. Additionally, these criteria and limitations are introduced with a close reference to a general evolutionary framework which, moreover, has been brought in as an appropriate TDA-background theory. It should be made clear in this introduction, however, that the linkages between TDA and evolutionary theory are different from what might be expected.

First, the terms evolution or evolutionary theory as developed within the context of e-WISDOM 2b are completely independent of semantic territories in which evolution or evolutionary are just another words for incremental, small or gradual changes. Evolutionary changes can be discontinuous, big, sudden or revolutionary and TDA is in no way committed to continuously marginal changes either.

Second, the family resemblance between TDA and an evolutionary background theory is not one of analogy-construction. In recent years, evolutionary frameworks have crossed the traditional confines which, so far, have separated various disciplinary segments in the natural world and the social universe. In this process, theories of learning and adaptation, economics, management theory, urban and regional science, innovation theory or remote areas like health have become well equipped with evolutionary types of modeling and theory constructions. Despite this successful diffusion of evolutionary frameworks, one still can observe a general analogy trap with respect to the relations between evolutionary domains and socio-economic arenas. The most elaborate version of such a "Me too-fallacy" can be found in William H. Durham (1991) where a massive parallelism has been constructed between the gene pools within biological domains like the development of organisms and populations and the meme pools and the development of individual behavior or societal differentiation. Contrary to strict analogy-makings, human societies occupy a very special niche within a broad evolutionary platform which requires special conceptual foundations, special methods, special models or special mechanisms. Nevertheless, the evolution of human societies, of languages,

of scriptures, of modes of (re)production can be studied in a highly fruitful way by analyzing

Third, the evolutionary framework introduced in this issue is clearly of a meta-theoretical type, concentrating on concepts, models, mechanisms or theoretical structures which can be qualified as evolutionary and which are strictly independent from special application domains in the natural or in the social world. Thus, an evolutionary framework has been established as TDA background theory with a main focus on (re)productive processes, on recombinations and their comparative advantages or disadvantages as well as on population dynamics and their pattern formations. Most importantly, no special or strong assumptions have been assembled as TDA-background which would be characteristic for particular empirical evolutionary arenas only.

Fourth, it must be added that most of the subsequent TDA-restrictions and TDA-conditions can be upheld even without the general evolutionary background. Thus, the ten criteria introduced in the subsequent article, namely

- (Re)productive processes
- *Longue durée*
- Stable classifications and standardization
- High variance in time
- Low substitution potential
- Goal-process-consistency
- Generative mechanisms
- Self-organization
- Socio-economic drifts and patterns formations
- An overall context of arrows of complexity

can be put forward, possibly with the exception of the first requirement, as general TDA-heuristics.

In this way, both editions of e-WISDOM 2 cover for the first time a broad range of TDA-relevant topics within a single publication. By doing so, we hope to promote TDA as a relevant comparative methodology for the analysis of the dynamics of contemporary societies.

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Time and Societal Evolution: The Theoretical Background for Time Distance Analysis

Karl H. Müller

Abstract

The aim of the present article is twofold. First, it wants to free time distance analysis from modernization assumptions both in their older or more recent versions. Second, it attempts to bring in evolutionary theory as an appropriate background framework for TDA. Moreover, the article formulates ten basic conditions or restrictions which become essential for TDA-investigations evolutionary style.

The main article of this issue is methodological in nature and will highlight potentially relevant theoretical embeddedness domains for time distance analyses (TDA). Within e-WISDOM 2a, TDA has been portrayed as a novel methodological device which requires five types of building blocks:

- socio-economic development processes across societal domains and levels
- a set of socio-economic indicators or, alternatively, dimensions of these processes
- long term observations of these processes, expressed in time series data for two or more units (cities, regions, countries, supra-national ensembles, etc.)
- a unit of reference like a specific country or an average value of country-groups (e.g., the EU 15, EU 25, OECD-members)
- an arithmetic transformation from time series data into time distance data

The subsequent article will consist of two parts, one on the issue of what time distances are not (negative TDA-heuristics) and one on a set of theoretical criteria which should be fulfilled in order to apply time distance analyses in a potentially fruitful manner (positive TDA-heuristics). As self-proclaimed goals for this article the reader should acquire, after going through the subsequent sections and arguments, an in-depth understanding on the applicability of TDA on the one hand and, on the other hand, a general impression that the widely used socio-economic indicators and time

series still miss essential parts in the unfolding and evolution of contemporary societies.

1 What Time Distance Analyses Are Not

As a starting point, two seemingly obvious TDA-background assumptions, one on the structure of societal time and one on pattern identification, are shown to be either entirely irrelevant or of limited use only.

1.1 What Time-Distances Are Not I: No Underlying Modernization Assumptions

An essential part of the negative TDA-heuristics lies in the rejection of an assumption which belongs apparently to the core TDA-background hypotheses. The hypothesis itself can be stated in the following way:

Modernization Assumption I: In order to compare two units (regions, nations, continents, etc.) in time, these two units have to follow along a similar development-path.

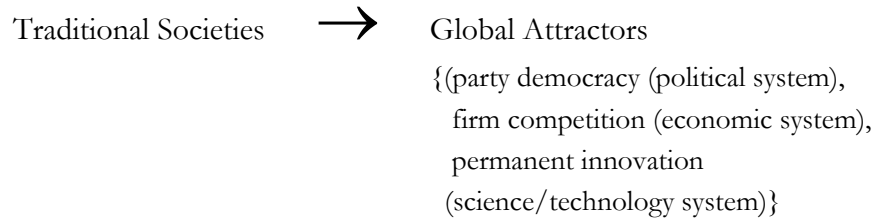
One of the shortest versions of this assumption can be already found in Karl Marx who summarized the relation between the most advanced nation of his days (Great Britain) and Germany (lagging behind) as “De te fabula narratur” – the development process of Great Britain, in essence, exhibits the future development processes for Germany or for other less-developed regions for that matter. After 1945, this assumption has become the basis for a popular school in development theory which under the heading of “theories of modernization”¹ has produced a wide variety of different approaches with a focus on a fundamental phase tradition:

Traditional Societies → Modern Societies²

¹ For a summary, see, e.g. Zapf 1971 or Wehler 1974.

² Attributes of modernity are centered around phenomena like a differentiated system of occupations, high social mobility, a high level of societal differentiation, high average incomes, media as the main instrument for societal communication, indirect control, institutionalized conflicts, high level of political participation, high productivity levels, urban settings, universal norms, high technology levels and the like. For a typology on traditional societies and modern ones, see Wehler 1974:14ff.

In one of its most widely circulated older versions by W.W. Rostow³, the societal development process has been conceptualized as a set of stages which all regions or nations have to follow, sooner or later. Modernization theory in its currently most prominent end of history-version⁴ promotes the idea of a set of evolutionary stable attractors of historical development in the subsequent format:



As developmental assumptions, the end of history-variant of modernization can be stated in the following way:

Modernization Assumption II: All units (regions, nations, supra-national regions, etc.) are drifting towards a universal basin of attraction, composed of a competitive market and political structure and, finally, of a permanently innovative science and technology system.

TDA, so it seems, is an analytical late bloomer of older or more recent off-springs of modernization theory and is committed at least to the second modernization assumption. Upon closer inspection however, it becomes easy to demonstrate that no modernization assumptions are involved in applying TDA. Consider the case of two units A and B (regions, nations, etc.) with A rapidly advancing in terms of GDP p.c. and with B on a long term path of stagnation or absolute decline. In this case TDA will show that the time distances between A and B are increasing in time, too. Thus, TDA may well serve to differentiate empirically between a variety of patterns of societal development apart from the modernization trajectory and to distinguish between well-confirmed and well-rejected approaches in the field of development theory.

³ For the classical version, see W.W. Rostow 1971, for its most extended publication see W.W. Rostow 1980.

⁴ See especially Fukuyama 1991 or, as instant-self-falsification, Fukuyama 2003.

As a more general consequence, different theoretical approaches of societal development can be characterized by different patterns of time distances. Table 1 makes it clear that TDA can be used as an evaluation instrument for different societal approaches, including modernization theories and is in no way committed to the convergence or attractor assumptions of a particular modernization framework.

Table 1 Expected Patterns of Time Distance Analyses for Different Developmental Approaches

THEORETICAL APPROACHES	EXPECTED PATTERN OF TIME DISTANCES
Modernization Theory I	Weak Convergence
Modernization Theory II	Weak Convergence
World Systems Analyses ⁵	Weak to Strong Divergence
Dependencia-Analyses ⁶	Strong Divergence
Degradation Approaches ⁷	Convergence/Divergence
Risk/Modernity ⁸	Convergence/Divergence

In sum, TDA is perfectly neutral with respect to underlying theories of development and differentiation. It can be used by theoreticians of homogeneous modernization processes, by advocates of the end of history-variety, by students of *dependencia*, degradation and persistent underdevelopment or by systematizers of global differentiation in the Wallerstein, Braudel or Beck tradition. In principle, they all can gain valuable empirical support for their noble theoretical cause by applying TDA.

1.2 What Time-Distances Are Not II: No Search for Linear Long-Term Trends

The second negative heuristic with respect to TDA has to do with trends and trend identifications. At first sight the question of the applicability of TDA for economic or societal dynamics can be solved easily since it can be apparently reduced to a single criterion, namely to the identification of long-

⁵ On world systems analysis, see for example Wallerstein 1974, 1980, 2000.

⁶ With respect to prominent approaches in *dependencia*-analyses, see, e.g., Cordova 1973, Senghaas 1977.

⁷ On global degradation approaches, see above all Kurz 1991, 2001, 2003.

⁸ On this approach, see especially Beck 1986 or 2002.

term linear upward or downward trends. Whenever time series of socio-economic processes exhibit such a general trend, then TDA can be set in motion. Upon closer inspection however, it can be shown that the identification of a general trend is neither a sufficient nor even a necessary condition for TDA applications.

- With respect to the sufficient condition it must be stressed that there exists a set of socio-economic processes which clearly exhibit a linear long-term trend. Nevertheless it would seem highly inappropriate to perform TDA. Consider the case of internet crimes within highly developed societies where one can clearly specify a long-term trend from zero around 1980 to considerably higher levels in 2004. It would be strange however, especially at second and at third sight, to perform time distance analyses and to demonstrate that country B is effectively n years behind country A or behind a group of countries C. More generally, a relatively large class of phenomena can be identified for which linear upward or downward trends can be specified although it would not be advisable to run time distance analyses based on these available time series and to interpret the results in terms of leads and lags. It will become the major challenge for the positive TDA-heuristics to provide the appropriate criteria for differentiating between, say, technological innovation waves and their inherent time distances or processes like divorce rates, suicide rates or the consumption of tranquillizers or related drugs on the other hand where TDA should not be set in motion.
- Turning to the side of necessary conditions, long-term processes with no recognizable linear trends can be used for time-distance analyses, nevertheless. In the case of consecutive innovation waves with a recurrent quasi-cyclic pattern it becomes possible to perform TDA by segmenting these innovation cycles into distinctive stages. In general, time series with no general linear trend but with consecutive phases can be used in principle for TDA as well. Consequently, long-term linear trend identification cannot be used as a necessary condition for TDA-applications either.

Both examples show vividly that long-term trend identification can serve as a preliminary approximation at best and, thus, as a first guess on potential TDA-applicabilities. However, more in-depth analyses of socio-economic processes are needed in order to give more detailed and more general guidelines with respect to the applicability of time distance analysis.

2 Ten Heuristic Requirements for TDA-Applications from an Evolutionary Point of View

Turning to the set of positive TDA-heuristics and to the TDA-application requirements, the subsequent sections will provide an appropriate background theory for TDA. The notions of time distance and time distance forecasting simply need a more general platform which is able to justify TDA-procedures and to place the overall TDA-methodology within a broader theoretical context. As a general guideline, the main theoretical embeddedness arena for TDA will be located in the broad arena of the evolutionary paradigm.⁹ Why? Because, on the one hand, the evolutionary paradigm with its transdisciplinary realm of applications across the five kingdoms of “bacteria, protocists, fungi, plants and animals” (Lynn Margulies)¹⁰ includes the development of humans and human societies as a special subset and because, on the other hand, the evolutionary paradigm offers a rich and diversified set of transdisciplinary models, mechanisms and methodologies which, after all, should constitute an underlying theoretical framework for TDA with its emphasis on time and on socio-economic development processes.

As a first overview, ten major characteristics or, alternatively, building blocks can be laid out which become essential for the evolutionary paradigm.

- First, the units of evolution constitute a heterogeneous, multi-level set¹¹ which cannot be reduced to a single reference class.¹² In particular, evolutionary processes are not to be conceptualized as the unfolding of the gene pool and its variations only.
- Second, the overall architecture of the heterogeneous set of units is distributed across two main arenas which can be described in a traditional manner with the two concepts of genotype and

⁹ On the evolutionary paradigm, see among many others, Bendall 1983, Boulding 1981, Boyd/Richerson 1985, Brooks/Wiley 1988, Dawkins 1986, 1995, 1997, Deacon 1997, Dennett 1995, Dennett 2003, Durham 1991, Edelman 1987, Freese 1997, Gilbert 18994, Goodwin 1995, Haken 1982, Jones/Martin/Pilbeam 1995, Kauffman 1993, 2000, Lloyd 1994, Lumsden/Wilson 1981, Margulis 1993, 2000, Maynard-Smith 1989, Oyama 2000, Oyama/Lewontin 2000, Pagel 2002, Sigmund 1995, Turner 2000, Wieser 1994.

¹⁰ On this distinction, see Lynn Margulis 1998.

¹¹ On the problem of units of evolution, see, *inter alia*, Ereshefsky 1993.

¹² Potential candidates are, quite naturally, selfish genes (Dawkins 1978) or single neurons (Barlow 1972). For a devastating critique of reference levels and reference units within evolutionary or cognitive frameworks, see Marr 1982.

phenotype or in a more general way as actor networks and knowledge bases.¹³

- Third, the evolutionary paradigm has its main focus on a special kind of (re)production process which is characterized by attributes like reproduction, copying, imitation or by features like maintenance and repair. It goes almost without saying that these reproduction/copying/imitation/maintenance/repair processes come about as an intensive interplay between the arena of knowledge bases and the actor network arena.
- Fourth, the interplay between knowledge bases and actor networks can be distinguished into four major stages, phases or regimes and can be described as the sequence of Darwin-, Polanyi-, Piaget- and Turing societies.¹⁴
- Fifth, recombinations both in the arena of actor networks and of knowledge bases are accomplished with the help of a small set of recombination operators which operate recursively and transform an established configuration into something genuinely new.¹⁵
- Sixth, the origin of these recombinations lies for most parts of evolutionary time in chance mechanisms and recombinations by design are accomplished only in later stages.
- Seventh, evaluation measures for and comparative advantages or disadvantages of recombinant variants become the core building blocks in the evolutionary population dynamics which determines the pattern formation both for actor networks and for knowledge bases.
- Eighth, evolutionary diffusion processes are characterized by local arrows of complexity although no global attractor towards maximum complexity, the evolutionary counter-direction to the second law of thermodynamics, can be identified in principle.
- Ninth, multi-level actor networks as well as multi-level knowledge bases, aside from being dynamically interwoven, are embedded within a non-evolutionary environment and its autonomous changes.¹⁶

¹³ For more details on the concepts of actor networks and knowledge bases, see Müller 1998a, b, 1999a, b and 2000 a,b.

¹⁴ On these phase transitions see, for example, Müller 1999a, b.

¹⁵ On the notion of recombination and recombination operators see Hofstadter 1995, 1997, Müller 2000c.

¹⁶ To be more precise: The five evolutionary kingdoms of “bacteria, protoctists, fungi, plants and animals” (Lynn Margulies) are embedded in a physical and chemical environment whose internal dynamics cannot be captured with the help of the evolutionary paradigm. Nevertheless, embedding physical and chemical processes have become the pre-requisites for the emergent properties of early life forms. Moreover,

- Tenth, self-referentiality becomes an ubiquitous feature of evolutionary processes, once again in the actor network domain as well as in the knowledge bases.¹⁷

The strong ties between time distance analysis and societal development processes on the one hand and evolutionary theorizing on the other hand can be established across ten domains. Thus, Table 2 summarizes the transformation from TDA to an evolutionary-based TDA.

Table 2 Ten Evolutionary Requirements for Time Distance Analysis

TDA DOMAINS	TRANSFORMATION	EVOLUTIONARY TDA-ARENA
Dimensions, Time Series	→	(Re)production Processes
	→	<i>Longue durée</i>
	→	Evolutionary Stable
		Classifications (ESC) and
		Standardization (ESS)
		High Variance across Time
Socio-economic Development	→	Very Low Substitution Potential
	→	Societal Advancement
	→	Generative Mechanisms
	→	Self-organization
	→	Drifts
	→	Complexity Arrow

living and non-living arenas are coupled via highly general laws like the laws of thermodynamics, etc.

¹⁷ For a similar account, see the subsequent six “essential aspects of the creative Darwinian process that bootstraps quality”.

1. There must be a reasonably complex pattern involved.
2. The pattern must be copied somehow (indeed, that which is copied may serve to define the pattern).
3. Variant patterns must sometimes be produced by chance,
4. The pattern and its variant must compete with one another for occupation of a limited work space ...
5. The competition is biased by a multifaceted environment ...
6. There is a skewed survival ... so new variants always preferentially occur around the more successful of the current patterns. (Calvin 1996, 21)

Similar views have been expressed in Daniel C. Dennett 1995, 2003.

More specifically, the next sections offer a theoretical summary of socio-economic dynamics in general and of TDA in particular from an evolutionary point of view. Subsequently, ten criteria or conditions will be set forth which in essence transfer TDA into the arena of evolutionary theorizing. These ten criteria demand for TDA to search for:

- (Re)productive processes (2.1)
- *Longue durée* (2.2)
- Evolutionary stable classifications and standardizations (2.3)
- High variance in time (2.4)
- Low substitution potential (2.5)
- Goal-process-consistency (2.6)
- Generative mechanisms (2.7)
- Self-organization (2.8)
- Socio-economic drifts and patterns formations (2.9)
- An overall context of arrows of complexity (2.10)

2.1 Evolutionary Embeddedness of Time Distances I: (Re)productive Processes

As a first evolutionary requirement, the underlying socio-economic processes for TDA should be qualified, by and large, as special kinds of production processes which are characterized by attributes such as generating, copying, imitating or, albeit to a much lesser extent, by features like maintenance or repair. Due to the high diversity in semantic fields, the term (re)production will be used throughout the paper in order to maintain the multiplicity of meanings inherent in the notion of evolutionary production processes. At this point, a few examples for evolutionary (re)production processes within societal domains might be helpful.

- Long-term innovation waves are a paradigmatic example for a (re)productive process in which recombination, imitation and copying occupy a central role. On the one hand, innovation waves are accompanied by the massive generation of new products and services, mainly, though not exclusively within the arenas of infrastructure, energy or transport. On the other hand, the generative mechanism for long-term innovation waves is based on a diffusion process in which imitation and copying play the central roles.
- The evolution of large-scale ensembles like a national employment system or an education system can be conceptualized, *inter alia*, as dynamic networks which (re)produce themselves via internal and

external transitions as well as via so-called death- and birth processes¹⁸.

- Household work in modern societies is distributed across a wide variety of domains, among them the reproductive dimension proper. Other areas include a broad range of copying and imitation processes whereby new products and services are integrated into a household organization. Furthermore, maintenance and repair work constitutes a permanent task for household work.

Thus, (re)production refers to an enormously diversified and heterogeneous class of processes where two conditions are fulfilled simultaneously.

- On the one hand, a product, very generally understood, has to be generated which increases, even marginally, the societal wealth. (Wealth Condition).
- On the other hand, the production process must turn out to be a knowledge-based one, *i.e.*, it must come about as an interplay between actors, machines, instruments or tools and of knowledge components or of a knowledge base for short. (Knowledge Base Condition)¹⁹

In order to be more specific, the concept of products should be restricted to those elements which enter into the traditional accounting systems for gross domestic products, for societal knowledge bases, for the intellectual balance of payments, for well-being, for quality of life and the like. (Wealth Condition) Thus, the production of new machinery, of investment goods as well as the proliferation of new scientific articles, of software programs, but also the generation of new laws or regulations fulfil clearly the so-called Wealth Condition. Additionally, the productions of social capital (Putnam

¹⁸ In the case of an employment system, death- and birth-processes refer to the new entrance of persons into the employment sphere (pupils leaving school, students, etc.) and to permanently retiring persons, leaving the employment sphere irreversibly. For more details see also Weidlich/Haag 1983, 1988, Haag 1989.

¹⁹ Currently, this knowledge base condition expresses itself in a large class of concepts like the information age, knowledge societies, knowledge based economies, knowledge-based information economies, learning organizations, or knowledge management. All these terms suggest intensified linkages between knowledge bases and societies and stress the increasing importance of knowledge proliferation as well as knowledge utilization in the design, production and distribution of intelligent goods and services. In particular, knowledge understood as a collection of rules, recipes, instructions or rules or as uncoded routines and practices within a production context, must be considered as a vital and hot component of (re)production within an evolutionary context. For interesting background information, see *e.g.* Dertouzos 1999, Grimmer/Kuhlmann/Meyer-Krahmer 1999, Grupp 1995, Kaiser/Wetzel-Vandai, Claussen 1999, Moravec 1999 or Negroponte 1996.

2000, Lesser 2000) or of cultural capital (Bourdieu 1982, 1985, 1991) like the founding of clubs and associations, the production of weak ties across societal networks or the invention of a new style in painting fall under the Wealth Condition, too. Thus, societal wealth is characterised very broadly by tangible and by intangible aspects as well as by objective and by subjective dimensions.

Additionally, wealth-generating processes must be of a knowledge-based nature and, thus, be the outcome of the interplay between knowledge components or knowledge bases and actors, teams, groups, organizations, machinery, information and communication technologies and the like (Knowledge Base Condition). Thus, the production chains of generating the tangible and intangible products of societal wealth have to be linked to the available knowledge bases in a non-trivial manner.

Table 3 summarizes all the dimensions which have been used for TDA throughout the entire issue of e-WISDOM 2a, 2b and divides them according to societal arenas like the economy, the science system or the social system. The obvious question which needs to be discussed is whether the dimensions in Table 3 meet the criterion of (re)productive processes.

Table 3 Dimensions for Time Distance Analysis in e-WISDOM 2a

ARENA	DIMENSION
ECONOMY	GDP p.c. Exports p.c. Imports p.c. Cars p.c. Telephone p.c. Mobile phones p.c. Internet hosts p.c. Internet users p. 1000 Internet usage at home (% of households) PC per 100 inhabitants
SCIENCE	R&D/GDP R&D in industry p.c. Scientists and Engineers in R&D per 1000 employees
SOCIAL	Life expectancy Infant survival rate

In order to answer this question, three types of indicators have to be distinguished, namely

- Indicators of (re)productive processes proper
- Structural indicators
- Performance indicators

Each of these three groups stand in a specific relation to the notion of a (re)productive process.

- Performance indicators are defined as those general concept that cover the overall state or status of a large-scale societal arena in which vital (re)production processes take place. Thus, performance indicators provide an overall assessment of the state of the economy, of households, of the science and technological system, of the political-administrative system, of media or of similarly large-scale societal domains. Looking at Table 3, four of the indicators can and should be qualified as performance indicators, namely GDP p.c., R&D/GDP as well as life expectancy or the infant survival rate.
- Structural indicators can be characterized as compounds of two or more dimensions and provide an essential structural insight into a (re)productive domain. Combing the expenditures for R&D in industry and population numbers yields a structural indicator on R&D in industry per capita. Likewise, integrating the number of the scientists and engineers with the total employment figures generates the structural indicator scientists and engineers in R&D per 1000 employees. In this sense, all indicators in Table 3, aside from the performance indicators, qualify as structural ones.
- Indicators of (re)productive processes proper should, then, refer to dimensions like the number of scientists and engineers in R&D, to the number of mobile phones, of internet hosts, of internet users, of internet usage at home, the output in manufacturing or in specific economic sectors and the like.

Table 4 re-iterates the distinction between the three indicator groups by adding new indicators which have not been included in the articles of e-WISDOM 2a.²⁰

²⁰ It must be added that it may well be that these indicators are not at all suitable for TDA. The list in Table 4 simply serves to illustrate the variety of the three indicator groups.

Table 4 Indicator Types for (Re)productive Processes

TYPES OF INDICATORS	SELECTED EXAMPLES ²¹
PERFORMANCE INDICATORS	
Social System	Overall Life Satisfaction State of Individual Health
Political System	Overall Trust in Political-Administrative Institutions
STRUCTURAL INDICATORS	Ratio of Population in Urban Areas/ Rural Areas Gender Pay Gap Market Structure
DOMAIN-SPECIFIC INDICATORS	Level of e-Commerce Number of Female Part-time Workers Number of Science and Technology Graduates

Summing up, the following requirement can be brought into the evolutionary TDA-game.

Evolutionary TDA-Postulate I: TDA has to search for (re)productive processes within societal domains, including their structural and their overall performance aspects, as its main area of investigation.

TDA-Condition I: RP

In this general form the first restriction is not particularly severe since the Wealth Condition as well as the Knowledge Condition have been introduced in a very broad manner and the addition of structural and performance aspects opens up an additional gate for socio-economic indicator groups.²²

²¹ The examples selected have not been included in the TDA and offer, thus, an additional

²² In principle, any societal process can be semantically linked to the domains of production, maintenance, damage or repair. Consequently, the first requirement does

2.2 Evolutionary Embeddedness of Time Distances II: Reproductive Processes of the Longue Durée

The second requirement for TDA analyses, like the first one, is not meant to be as a direct restriction imposed on TDA-applications. Rather, it is brought forward as a distinction between a core or reference class of TDA-utilizations and more marginal areas. As a general statement the second condition can be stated as follows.

Evolutionary TDA-Postulate II: The reference class for TDA-applications consists in (re)productive societal macro-processes of the *longue durée*, i.e., in large-scale socio-economic processes which (re)produce themselves on a time-scale of several decades or centuries.

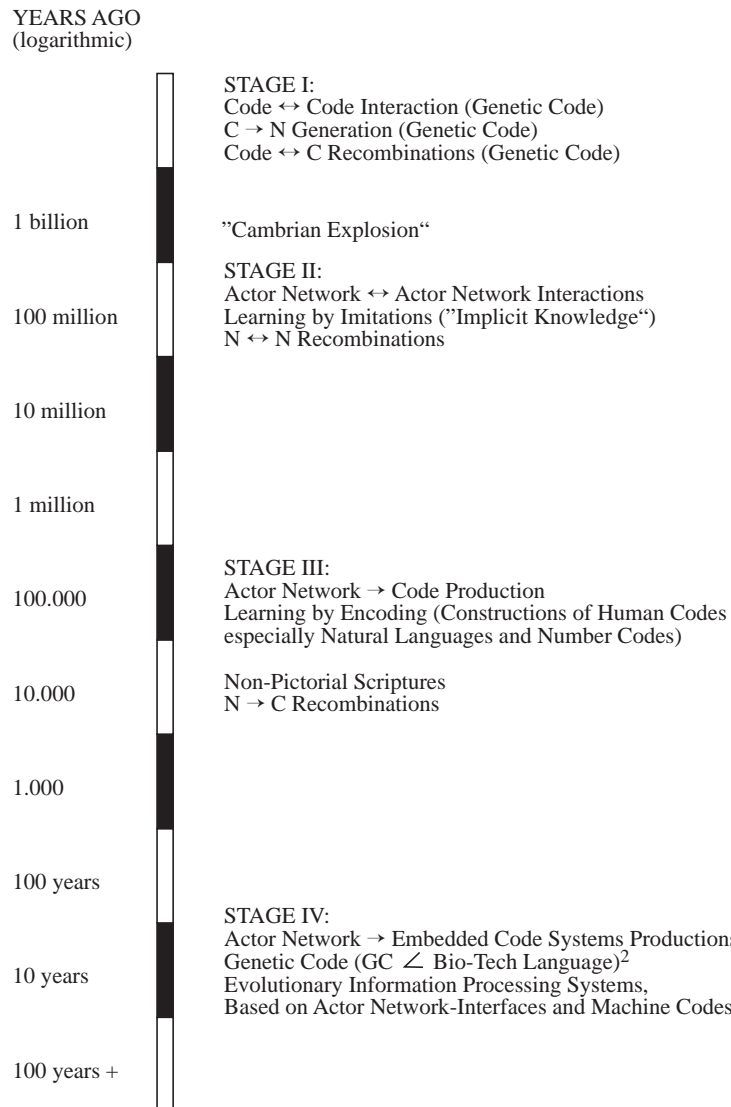
TDA-Conditions I - II: RP_{LD}

In other words, the core arena for TDA-applications lies in long-term socio-economic (re)production processes that are characteristic for global societal evolution. Diagram 1 as well as Tables 5 and 6 present two complementary space-time-frames for societal evolution. In particular, these tables and diagrams point to major phase transitions along the evolutionary time-scale.

- First, a major phase transition in evolutionary time has been suggested for the period between 1940 and 1960 which has been labelled as a transition from Piaget societies to Turing societies. (Diagram 1) Looking at the Clock of Evolution or, alternatively, of Co-Evolution, depicted in Diagram 1, this phase transition is due to a radical widening - the adding of a new machine code-based knowledge layer - and a re-configuration in the linkages between knowledge bases - the transcription of the genetic code into the language of bio-technology - and, thus, to a new interaction pattern between knowledge bases and actor networks.
- Second, despite a major phase transition in the basic architectures of Piaget and Turing societies, the underlying organizational structures at the network levels remain unchanged. They are still dominated by the expansion of market organizations as the primary generative mechanism in contemporary societies.

not act primarily as a filter or a selection instrument, but as a guiding principle for separating societal processes into core arenas and peripheral ones. Thus, the invention and diffusion of new technologies clearly stands in the core domain of (re)productive

Diagram 1 The Long-Term Co-Evolutionary Chains in Societal Formations (Actor Networks Knowledge Bases)²³



processes whereas time series on the weekly consumption of TV-entertainment fall under the heading of peripheral or very peripheral ones only.

²³ In Diagram 1, ∠ stands for a transcription relation, implying that a specific code system has been transcribed or, alternatively, translated into another code system. Transcription relations occur quite frequently like in the case of morse code ∠ language code, etc. More specifically see e.g. Avery 2003, de Duve 2002 or Galaburda/Kosslyn/Christen 2002.

Table 5 Main Co-Evolutionary Actor-Network Stages in the Great Transformations of Modern Knowledge Societies

SOCIETAL ACTOR-NETWORK FORMATIONS			
Piaget Societies			Piaget/Turing Societies
Reciprocal Formations	Redistributive Formations	⇒	
Societies under	Societies under	⇒	Societies under
Dominance of	Dominance of the	⇒	Dominance of
Personal	Political System	⇒	Markets
Exchanges		⇒	

THE GLOBAL DIFFUSION PROCESS	CAPITALIST TRANSFORMATIONS
	<i>Initial Phase I:: (Ir)reversible</i> 1450 - 1600 <i>Expansion</i>
	<i>Initial Phase II:: Consolidation</i> 1600 – 1760
	↓
Gradual integration of reciprocal as well as re-distributive societal formations; Global differentiation into three distinct regions: <i>core regions, semi-peripheries</i> and <i>peripheries</i> . Specific development patterns in each of the three global regions, reaching from differences in the world trade-relations to significantly different roles and capacities of national governments or to different compositions with respect to socio-economic status-groups or classes; Emergence of global instruments for coordinating and balancing the world-system, leading, in the very long run, to the development of global institutions and organizations; emergence of new types of "knowledge societies" (Epigenetic Regime IV) Dense intra-systemic and inter-systemic networks in production processes; integration of global and local accessibilities, etc.	Global Diffusion (1760 - 1945)
	<i>Industrial Revolution:</i> 1760 - 1820 Prosperity 1780/90 - 1820
	<i>Global Diffusion:</i> 1820 – 1945/50 Depression 1820 - 1842/50 Prosperity 1850 - 1870/73 Depression 1873 - 1893/96 Prosperity 1896 - 1913/20 Depression 1920 - 1938/48
	↓
	Epigenetic Regime IV Transnational Evolution
	Prosperity 1945 - 1966/73 Depression 1973 - 1993/97 Prosperity 1997 - ???

Table 6 Main Co-Evolutionary Code-Stages in the Great Transformations of Modern Knowledge Societies

SOCIETAL KNOWLEDGE BASE-FORMATIONS

Epigenetic Regime III				Epigenetic Regime IV
Piaget Knowledge Bases				
Distributed Knowledge Bases	Centralized Knowledge Bases	Scientific Knowledge Bases	⇒	Turing Knowledge Bases
Knowledge Bases under no Protection of Special Systems	Knowledge Bases under the Dominance of a Knowledge Generating System	Knowledge Bases under the Dominance of Modern Forms of Knowledge Generation	⇒	Knowledge Bases with a New Layer and Machine Code; Subsumption of the Genetic Code under the Biotech-Code

THE GLOBAL DEVELOPMENTAL STORY

Gradual integration of distributed as well as centralized knowledge bases; Global differentiation into three distinct regions with respect to the (re)production and to the accessibilities of local or global knowledge bases: *Centers, Semi-peripheries* and *Peripheries*. Specific development patterns in each of the three global regions in the area of program-pools, ranging from differences in regional roles- and capacities for "knowledge production" at the level of firms and markets; Differential access to the knowledge bases in cognitive core-areas; Development of limited local knowledge traditions and "subversive knowledge" against the established forms of programs within cognitive core-areas; Emergence of new types of knowledge societies; Decisive steps toward globalized program pools due to the formation of the internet, integrating the global *and* the local program production, etc.

MODERN SCIENCE PRODUCTION

Initial Phase : (Ir)rev.
1450 - 1760: *Expansion and Consolidation*



Global Distribution
(1760 - 1945)

"*Scientific Revolution*":
1760 - 1820
Emergence of New Types of Universities (Combination of Disciplinary Research and Education
Global Diffusion: 1820 - 1913/20

Gradual Recombination of R&D and Firms through Firm-Specific Research Laboratories



Epigenetic Regime IV
(1945 - ???)

Phase Transition from Piaget-Societies to Turing Societies

New Knowledge-Layer, based on a Binary Machine Code; Emergence of Bio-Technology and Translation of the Genetic Code into the Code of Biotechnology as Well as in Machine Code

It may well be that an observation set of a few years based on monthly measurement points is sufficient for TDA-applications. However, the core TDA-utilization context lies in (re)productive societal processes of the *longue durée* and on leads and lags of units of different spatial scales (regions, nations, supra-national regions, etc.).

2.3 Evolutionary Embeddedness of Time Distances III: Evolutionary Stable Classifications (ESC) and Standardizations (ESS)

The third area for an evolutionary TDA-requirement lies in the classifications and standardizations of the dimensions used for (re)productive, long-term processes. Moreover, this area belongs to the most widely neglected problems²⁴ in the field of social science methodology for in most cases, it seems to hold as a general assumption that the classification or standardization of (re)productive processes can be taken as granted, given or as self-evident²⁵. Phrased differently, TDA can be applied, so it seems, whenever one finds a set of long-term time series data of a vaguely socio-economic (re)productive process irrespective of the quality of the underlying classifications, standardizations and indicator schemes.

Quite contrary to this common procedure²⁶, a distinctly different approach will be chosen here by taking none of the common sense notions for socio-

²⁴ Surprisingly enough, one does not find, by and large, a single notice on this problem in any one of the subsequent highly recommendable books on the modeling of social systems: Fararo 1989, Troitzsch 1990, W. Weidlich, G. Haag 1983 or Weidlich 2000.

²⁵ In his Presidential Adress, Peter Checkland noted already five years ago that the systems notion has become, with detrimental effects on the systems movement in general, a much to common *façon de parler*:

The process of mapping the abstract concept 'system' onto aspects of perceived reality has been too successful for the good of the systems enterprise. The success has led to a ubiquitous error which pervades the systems movement and has held up the development of systems thinking in the last twenty years. What has happened is that the success of 'system' in mapping aspects of the world is such that it is used in everyday language in an unreflecting way as if it were a label word for an assumed ontological entity, like 'cat' or 'table'. We casually speak of the 'education system', 'the legal system', 'the health care system', 'the industrial relations system', as if all these were, unproblematically, systems. Actually, you could justify the use of the words; not, 'the education system', but some such phrase as 'those structures, processes, behaviours and values concerned with the provision of education which I choose to regard as a system'. It is much easier to say 'the education system'. But it is still an error to use the same word for an abstract epistemological device and for assumed ontological entities in perceived reality. The error is endemic. (Checkland 1987/88:2)

²⁶ If one takes, as one example among too many, George Psacharopoulos' seminal handbook on the economics of education, one finds hardly any remark, let alone a single article which would address to the problem of an *adequate* conceptualization and demarcation of the educational system. Apparently, it seem *too* obvious that young children have to be enrolled worldwide, for a specific period in time, into a public or private school system. See Psacharopoulos 1987.

economic phenomena or processes for established. More specifically, TDA has to search for those indicators and indicator schemes that exhibit, in the long run, a sufficient degree of constancy along the evolutionary time-scale. As a postulate, this requirement can be expressed as follows:

Evolutionary TDA-Postulate III: A comparative TDA-investigation into (re)productive dynamics has to meet, from its very outset, the condition of evolutionary stable classifications (ESC) and standardizations (ESS) for the indicator schemes for (re)productive processes.²⁷

TDA-Conditions I - III: $RP_{LD, ESC/ESS}$

The rationale for such a demand lies in five different areas:

- First, the long-term time horizon for TDA makes it almost imperative that the indicator classifications chosen offer a sufficiently long-term constancy. Since TDA is not only utilized in the context of past processes and development patterns but also of future scenarios, it must be demanded, even as a condition for the possibility of applying TDA, that all important changes within the period under investigation can be accounted for by the basic categorization and indicator framework.²⁸
- Second, the ESC-postulate keeps its focus on a relatively small set of classification and indicator schemes which are very closely linked with dominant differentiation patterns of the socio-economic domain under consideration. In other words, only those categorizations become acceptable ESC-candidates that exhibit both a sufficiently long-term duration and a high integration potential to account for the heterogeneity of historical forms and patterns. Take the employment system as a reference case, then one can see from Table 7 that the three selected dimensions (type of work (paid/unpaid), location (firm/household, output (goods/services) as well as their integration yields a classification scheme for employment types and for employment sectors which can be applied

²⁷ Any family resemblance to the notion of evolutionary stable strategies (see, e.g. J. Maynard Smith 1985) is neither accidental nor undesired, since, in both cases, the attempt solution addresses the same general problem, namely the identification of those strategies or concepts which, despite marginal or even major long-run changes can be assumed to remain unaltered.

²⁸ One may also cite a pendant to a famous design principle, namely Edward R. Tufte's *Show data variation, not design variation* (Tufte 1983), by stating: *Show time distance variation, not conceptual variation.*

throughout the entire history of modern societies. Consequently, these three dimensions can be qualified as evolutionary stable. Additionally, any indicator scheme for a socio-economic domain which fulfils the ESC-requirement can be qualified as core dimensions in the evolution of the socio-economic system to be analysed.

- Third, classification schemes for employment indicators like the one in Table 7 pave the way, as an intended side-effect, for bringing in morphological methods and dynamic procedures²⁹. The three evolutionary stable dimensions for employment generate an elementary phase space which is characterized by an identifiable long-term dynamics.³⁰ More specifically, one can specify a series of trajectories within this primitive phase space which have been whereas other trajectories, while equally possible in principle, have not been recorded at all.³¹
- Fourth, another reason which justifies the aforementioned postulate for evolutionary stable classifications has to do with the origins of qualitatively new development patterns. With the help of the ESC-postulate, the emergence of new phenomena, although usually, like the Popperian truth, hard to come by³², can be separated into two different configurations:

In the first case, the hitherto unrealized new forms can be accounted for, at least in principle, by the classification system already established since the new components, the new patterns or the new phase transitions have been integrated into the specified ESC-network³³.

²⁹ On the morphological method see, as a very early example, O. Neurath 1981; for later elaborations compare e.g. Dubach 1977.

³⁰ To give just one example from Table 3: The combination singular/compulsory segment within the educational system has not been, at least not to the present point in time, occupied yet and will, with an extremely low and even decreasing probability, ever come into existence.

³¹ It seems, as a starting point for a systems dynamics analysis, even a *promising* endeavor, to *use* the basic dimensions of ESC as a primitive phase space - and to identify basic trajectories, basic patterns, and the like. On such an approach with respect to the cybernetics of national societies see, e.g., Trappl, Umpleby 1991.

³² For the slogan *Truth is hard to come by* see K.R. Popper 1965:373.

³³ On the possibility to incorporate the emergence of qualitatively new phenomena within the context of *neural nets*, see, e.g. Freeman, Skapura 1991 or Ritter, Martinetz, Schulten 1991.

In the second case, the emergence³⁴ of ex ante unforeseeable new forms, be they on the level of components, of structures or of processes, will and must remain, by definition, unforeseeable ex ante and cannot be in any meaningful way anticipated beforehand, at least not in the conventional conceptual manner.³⁵ The ESC-demand imposes one important restriction, however, for any subsequent ex post analysis, since the resulting conceptual framework has, once again, to fulfil the requirement of offering a new, but evolutionary stable classification scheme which allows the combination of the ex ante unaccountable elements and the historical record in the long run ...

- Fifth, ESC-indicators need, additionally, a common frame of reference, in order to be comparable across units (cities, regions, countries, nation-groups, etc.). It goes without saying that these reference frames have to fulfil the ESC-postulate as well in order to generate comparable results across time.

Despite its apparent rationality and justifiability, the demand for evolutionary stable classification and ESC-indicator schemes has rarely been raised, neither in the fields of general methodology for the social sciences, nor in the area of evolutionary dynamics.³⁶ The consequences, though, for TDA are considerable. In Table 7 one finds a condensed summary of the implications of the ESC-requirement in the classification of three

³⁴ On the highly controversial and *context*-dependent notion of *emergence* see e.g. Müller 1986 where formal suggestions for a genuinely *non*-mythological utilization of the concept of *emergence* are put forward.

³⁵ On the conceptual difficulties which, in principle, confront any analysis on structural change and on the emergence of new phenomena as well as on possible unconventional remedies, using, as alternative, *pictorial* methods see Müller 1991.

³⁶ Take, for example, the excellent books on systems methodology by Mario Bunge, especially Bunge 1979, then one is confronted with a simple pyramid, composed of the set of physical things, the set of chemical systems, the set of bio-systems, the set of sociosystems, and the set of artificial things. (*Ibid.*, 45f.). Even worse, Bunge goes on to define social systems like the economic system, the cultural system or the political system in the following *hyper*-realistic manner -
The economic system of a society is composed of its primary workers (¹P₁), cultural workers (²P₁), and managerial workers (³P₁) (*Ibid.*, 208) ... All(!) the members of a cultural system share the same(!) environment and are linked by certain relations S_k (*Ibid.*:211) ... The political system of a society is the subsystem of the latter that controls(!) (to some extent) economic and cultural work as well as other types of soivial behavior (*Ibid.*:215) -
and arrives at very elementary and, at times, pre-modern conceptualization strategies for social systems and social structures in which the problem at hand, *viz.* the quest for evolutionary stable social classifications, due to Bunge's extremely *simple* partitionings of the social universe, does not even arise.

distinctively large scale socio-economic systems, namely the employment, the education, and the science system.³⁷

A few explanatory remarks on the main categories for the employment and the education system, as shown in Table 7, seem appropriate.

- For the employment system, the basic dimensions which have been selected for Table 7 can be applied to the separation of the labor force of core or, to a lesser extent, of semiperipheral areas from the late medieval period onwards to core, semi-peripheral and peripheral regions alike.³⁸ Segments like market-agriculture, industry, non-market services, household services³⁹ do offer both a long term perspective and a sufficient richness in variation to account for a long-term ...
- As for the education system, the ESC-dimensions for differentiating between various school-forms follow for example along the axis of degrees of compulsion, dividing schools according to the attribute compulsory (no legal exit option) and post compulsory (exit option), or along the line of employment relations, dividing schools according to the subjects taught and to the transition flows from school to the employment sphere, into singular components (a specific school type can be strongly related to one and only one of the three main economic sectors, viz. agriculture, industry, and services) and into multiple elements (a specific school type can be related to more than one of the three main economic sectors).⁴⁰ Once again, both the compulsion and the employment dimension can be applied from the very beginnings of a sufficiently general public school system, since the divisions into compulsory and post-compulsory segments and into employment related or university linked school forms was

³⁷ For more details on the *scientific* system see K.H. Müller 1992 where one finds a variety of non-linear frameworks for the analysis of dynamic processes, preferably of processes of theory dynamics and theory changes, in the scientific area.

³⁸ On the notions of *core*-regions, *semiperiphery*, *periphery*, and *external* areas see especially Wallerstein 1974 and 1980.

³⁹ It should be interesting enough to point to the fact that the sectors of agriculture and household related services occupied a prominent position throughout the nineteenth century and became, by and large, marginalized in the subsequent decades only. In Germany for instance, one finds, out of a total labor force of 14.8 million people in 1849, roughly 8.3 million people in agriculture and a surprisingly high number of 1.8 million people in household related services compared to only 0.35 million people in firm related services like banking, insurances and the like. On these numbers see Hoffmann 1965:202ff.

⁴⁰ For an operationalization of the *singular-multiple* distinction see Müller 1992b.

present from the 18th century, since the beginnings of a state organized system of education, onwards.

- With respect to the science system, the ESC-dimensions in Table 7 follow along the split into paradigm groups, into different phases of the research process or into main domains of scientific investigation.

Table 7 Evolutionary Stable Classifications for Three Large Scale Socio-economic Ensembles

EMPLOYMENT			
Dimension ₁ :	Type of Work-Location	Household	Outside
Dimension ₂ :	Type of Products	Goods	Services
Dimension ₃ :	Type of Work	Paid	Unpaid
Dimension ₄ :	Type of Qualification	Low	Medium High
Dimension ₅ :	Type of Education	Low	Medium High
Dimension ₆ :	Type of Work-Place	Low-Tech/Medium-Tech/High-Tech	
Dimension ₇ :	Type of Sector	Agriculture/Industry/Industry-Services Household-Services/State/Household	
EDUCATION			
Dimension ₁ :	Type of Schools	Compulsory	Postcompulsory)
Dimension ₂ :	School-Employment Transition	Multiple	Single
Dimension ₃ :	School-Grade	Year ₁Year _iYear _n	
Dimension ₄ :	School-Organization	Public	Private
Dimension ₅ :	School-Organization	Religious	Non-Religious
SCIENCE			
Dimension ₁ :	Type of Paradigms	Closed	Open
Dimension ₂ :	Type of Problem-Solving	Extension	Application ⁴¹
Dimension ₃ :	Domain of Inquiry	Natural World	Social World
Dimension ₄ :	Research Phase	Context of Discovery	Context of Justification
Dimension ₅ :	Research Stage	Start Phase	Work Phase Diffusion

⁴¹ For further details and operationalizations of these concepts see Müller 1992a..

Once again, the separation along the two dimensions outlined above fulfils both the criterion of a sufficiently *longue durée* and the demand for the requisite variety.

Moreover, alternative ways of partitionings both on the level of basic dimensions and on the level of the number of components within the dimensions chosen are not only possible in principle, but are, in both cases, in actual use ...⁴²

2.4 Evolutionary Embeddedness of Time Distances IV: High Variance in Time

The next point seems almost too obvious to be even mentioned. TDA requires a high variance in time so that a distinction can be made between relative forerunners and latecomers with respect to a specific evolutionary process which has the additional characteristics of being reproductive or of being classified in an evolutionary stable manner.

Thus, dimensions of technological diffusion usually fulfil this condition of high temporal variance. Likewise, following almost any type of development theory, the patterns of regional evolution are characterized by a high variance in time, too.

Since TDA is in no way committed to any of the modernization assumptions, high temporal variance cannot be confused with temporal stages or fixed temporal sequences. High variance simply means that a given level of an evolutionary socio-economic process, expressed as RP_{ESC} (LSP), like a given level of GDP p.c. has been reached by different units (regions, countries, country-groups, continents, etc.) over and over at widely divergent points in time.

Moreover, high variance in time is not to be measured along a single time scale of years only. Towards the end of the first issue on time distances, the ICT-diffusion process is measured on a time-scale of months. Following Condition 2 however, monthly time-scales and an overall time-span of a decade should be considered as the exception from the reference case of long-term (re)productive processes within decades or centuries.

⁴² On alternative ways of conceptualizing the domain of schools even in the case of a small country like Austria, see, e.g. W. Clement *et al.* 1980, dell'Mour *et al.* 1985 or Holzinger *et al.* 1991.

Evolutionary TDA-Postulate IV: For TDA ESC (re)productive processes must exhibit a high variance in time, preferably, though not exclusively, long-term temporal differences of decades or even centuries.

TDA-Conditions I - IV: $RP_{LD, ESC/ESS}(HTV)$

2.5 Evolutionary Embeddedness of Time Distances V: Very Low Substitution Potential

So far, the four initial TDA-restrictions are not particularly prohibitive. With the fifth condition however, a very strong requirement can be put forward which restricts TDA rather severely. Take as a paradigmatic example the energy intensity which at first sight seems a particularly well suited TDA-dimension. Looking at Table 8 however, it is by all means unclear in which way time distance analyses should be undertaken.

Table 8 Energy Intensity in Europe, United States and Japan

Austria	137.9
Belgium	236.0
Denmark	125.0
Finland	256.5
Germany	165.0
Greece	263.9
France	189.5
Ireland	173.1
Italy	190.8
Luxembourg	189.1
Netherlands	198.5
Portugal	242.3
Spain	227.2
Sweden	223.7
United Kingdom	229.8
Iceland	509.3
Norway	195.7
Bulgaria	1917.9
Cyprus	287.1
Czech Republic	947.6
Estonia	1316.4
Hungary	598.9
Latvia	840.7
Lithuania	926.9
Poland	717.6
Romania	1460.4
Slovak Republic	708.4
Slovenia	365.7
Turkey	494.4
US	333.6
Japan	120.8
EU 15	193.8
ACC	708.8

Looking at Table 8 it is almost self-evident to distinguish between three different main groups or clusters, namely –

- Cluster I: High GDP p.c. & Low Energy Intensity (Japan, Denmark, Austria and others)
- Cluster II: High GDP p.c. & High Energy Intensity (United States, Belgium, Finland, Unuited Kingdom and others)
- Cluster III: Low GDP p.c. & High Energy Intensity (Bulgaria, Romania, Latvia and others)⁴³

Table 6 makes it clear that for any given level of GDP p.c. as performance indicator widely diverging levels of energy intensity can exist side by side. In other words, the substitution potential for this particular indicator must be considered as high even if one restricts the comparison to countries with similar development levels only. More generally, a medium or even a high substitution potential within a specific socio-economic dimension is characterized by a high variance, given a similar level of development. In this case time distance analyses are practically impossible to perform since no suitable point of reference can be identified. In the case of a long-term time series of energy intensity, countries like Denmark, Japan or Austria are neither centuries behind the US or *vice versa*. Energy intensity, despite an important (re)productive dimension and despite its evolutionary stable characteristics, has been defined in a way which leaves ample room for a high substitution potential.

From a systematic point of view, a substitution potential can be identified in two different forms.

- Internal substitution means that the variance for units (cities, regions, nations, supra-national areas) at a similar level of development is very high. Here energy intensity serves as a paradigmatic example.
- An external substitution potential is present whenever a specific socio-economic process P can be substituted by another process P* so that a low level of P can be compensated by higher levels of P*. For an external substitution potential imports for investment goods constitute a very significant example.

Thus, the resulting TDA-condition can be formulated in the following manner:

⁴³ The criteria for the three clusters are as follows:

Cluster I: GDP p.c. > 25.000, EI < 200

Cluster II: GDP p.c. > 25.000, EI > 200

Cluster III: GDP p.c. < 25.000, EI > 200

Evolutionary TDA-Postulate V: ESC (re)productive processes, in order to be applicable for TDA, have to be characterized by a zero or a marginal substitution potential. High internal or external substitution leads to TDA results for which no meaningful TDA-interpretation can be established.

TDA-Conditions I - V: $RP_{LD,ESC}(HTV, LSP)$

2.6 Evolutionary Embeddedness of Time Distances VI: Goal-Process Consistency

As a corollary to the marginal substitution requirement another limitation must be mentioned which has been discussed within the negative TDA-heuristics already. Societal processes like drug consumption, waste, production-failures, suicides, work-accidents, severe crimes or related phenomena, while possibly exhibiting long-term upward trends, are only ill-suited TDA-candidates and have to be treated with extreme scrutiny, carefulness or, preferably, not at all. Why? Simply because there is a widespread societal or even global consensus towards reducing and decreasing the current levels of these processes in spite of their national or global increase. More specifically, one can identify an inconsistency between societal targets, preferences or goals on the one hand and the long-term patterns of specific processes on the other hand. In terms of societal goals these processes should be diminished and in terms of empirical measurements these processes exhibit a tendency to increase. Whenever an inconsistency of the form societal undesirable goals/long-term growth arises, TDA should either be not applied at or utilized with severe Caveats and provisions only.

In order to demonstrate some of the difficulties involved in long-term rising processes despite a societal consensus on level reduction, two different examples have been selected, one from the grey zone of slightly limited TDA-applicabilities and one from the red zone of extremely restricted TDA-utilizations. In both examples, the processes exhibit substantial increases over the last hundred years and pose, thus, a serious consistency problem for TDA.

- Turning to the grey zone example of divorce rates, there has been a dramatic increase in divorces in the course of the 20th century. In Germany, for example, the divorce rate was 1.9% in 1900, rose to 7.2% in 1930, to 14.6% in 1950, to 26.6% in 1980 and is currently at 50.7%. Table 9 presents selected divorce rates mostly from Europe, but includes the United States, Russia and Turkey, too.

Table 9 Divorce Rates for the Year 2000

COUNTRY	DIVORCE RATE
Belarus	68
Russia	65
Sweden	64
United Kingdom	53
USA	49
Germany	46
France	43
Switzerland	43
Austria	38
Denmark	35
Spain	17
Italy	12
Turkey	6

Table 10 Homicide per 100.000 Inhabitants⁴⁴

YEAR	AUSTRALIA	CANADA	NEW ZEALAND	ENGLAND & WALES	UNITED STATES	GERMANY	JAPAN
1972	2.2	2.2	1.0	1.0	9.0	1.3	2.0
1973	1.9	2.2	1.3	0.9	9.4	1.3	1.9
1974	2.2	2.7	1.6	1.2	9.8	1.3	1.7
1975	1.9	3.1	1.2	1.0	9.6	1.4	1.9
1976	2.1	2.9	2.0	1.1	8.8	1.4	1.9
1977	2.3	3.0	1.3	1.0	8.8	1.3	1.7
1978	2.2	2.8	1.9	1.1	9.0	1.4	1.6
1979	2.0	2.7	1.8	1.3	9.7	1.3	1.6
1980	2.2	2.5	1.7	1.3	10.2	1.4	1.4
1981	1.8	2.6	1.9	1.1	9.8	1.5	1.5
1982	2.0	2.7	2.0	1.2	9.1	1.6	1.5
1983	2.1	2.7	2.0	1.1	8.3	1.5	1.5
1984	2.1	2.6	1.8	1.2	7.9	1.5	1.5
1985	2.0	2.7	2.4	1.2	7.9	1.4	1.5
1986	2.2	2.2	2.5	1.3	8.6	1.5	1.4
1987	2.0	2.5	2.6	1.4	8.3	1.4	1.3
1988	2.3	2.2	2.5	1.2	8.4	1.3	1.2
1989	2.1	2.5	2.9	1.3	8.7	1.3	1.1
1990	2.1	2.5	3.0	1.2	9.4	1.2	1.0
1991	2.1	2.8	3.0	1.4	9.8	1.5	1.0

- Shifting to the second example within the red zone, namely to homicides per 100.000 inhabitants, Table 10 exhibits a diverse pattern with homicides generally rising between 1970 and 1991.

⁴⁴ The numbers have been quoted from a report of the Australian Institute of Criminology, <http://www.aic.gov.au/publications/rpp/07/ch6.pdf>.

For the grey zone example of divorce rates TDA can be applied by starting to select a relatively homogeneous set of countries with similar economic and socio-cultural levels. Looking at Table 9, this homogeneous group could consist of {Austria, Denmark, Germany, France, Sweden, Switzerland, UK, USA}. For this set of highly advanced countries TDA on divorce rates can be performed by using Sweden as reference case. It would create more problems than insights to choose Belarus or Russia as reference cases.

In the case of homicides however, TDA-analysis can hardly be undertaken since no suitable reference frame can be established. The only possibility would be to take Japan – the only country of low and falling homicide rates in Table 10 - and to perform TDA. Without Japan as reference case, TDA becomes either impossible or meaningless.

Another argument for very cautionary TDA-utilizations in case of goal-process inconsistencies comes from theories of societal learning and innovations. Usually, goal-process inconsistencies are accompanied by a wide array of societal learning, innovation and avoidance strategies which aim both at generating small, medium or even large substitution potentials or at reducing existing levels. From this perspective too, TDA-applications and TDA-results have to be interpreted in an extremely cautious manner.

The only suitable TDA-path in the area of goal-process inconsistencies must, thus, assume both a marginal substitution rate and a general, long-term tendency towards a reduction of current levels. In the case of adverse or societally unwanted goals in general, TDA should be applied preferably only in those instances where the (re)productive processes exhibit a long-term tendency to decline. Here it becomes possible to take the units with the lowest levels as reference cases. In social domains, infant mortality can be taken as a paradigmatic example along this line, having a zero degree of substitution and a long-term tendency to decrease globally.

Evolutionary TDA-Postulate VI: Long-term ESC (re)productive processes with a long-term rising pattern should belong to the class of societally acceptable, preferred or even desired targets. Adverse or high-risk processes with a tendency to increase can be used for TDA only with extreme caution.

TDA-Conditions I - VI: $RP_{LD, ESC/ESS}(HTV, LSP, GC)$

2.7 Evolutionary Embeddedness of Time Distances VII: Generative Mechanisms

So far, the TDA-restrictions have been focused on the special types of societal processes for which TDA can be applied. Within the next four

sections, a. As a heuristic rule of thumb, the main focus of TDA-analyses should lie on the generative mechanisms which account for (re)production processes to be analyzed. The main reason for this restriction is cognitive in nature and demands a minimal understanding of the processes under investigation.

Moreover, this move towards generative mechanisms can be supported further by the contemporary literature in philosophy of science or in the methodology of the social sciences. (Bunge 1999, Elster 1999, for an older vision, Hayek 1972) Here, a shift towards basic or generative mechanisms can be observed where these mechanisms are gradually becoming the prime targets for social science research and are, thus, gradually replacing the long time cherished notions of predictions and explanations. These generative mechanisms are not supposed to meet the strict requirements for scientific explanations but the weaker demands for explanation sketches. Moreover, these mechanisms should offer a deeper understanding of the underlying processes which produce the phenomena under consideration.

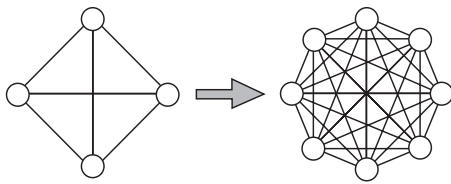
Within contemporary social sciences widely conceived, generative mechanisms have been put forward in large quantities. Below one can find three groups of examples, one for technology diffusion on a macro-scale, one for large-scale macro-societal ensembles, and one for micro-units like households.

- For long-term innovation waves a generative mechanism has been constructed which can be qualified as Schumpeter engine or, alternatively, as Schumpeter clock (Weidlich/Haag 1983) This particular generative mechanism operates with a small group of entrepreneurial explorers within the design space of new products and services, with a large number of imitators of successful innovations and with two consecutive stages of expansionary and rationalizing investments.
- From a generative mechanism point of view the (re)production of large-scale societal ensembles like a national employment system or an education system can be conceptualized, *inter alia*, as dynamic networks which (re)produces itself via the exits and entrances of new actors as well as via groups of attractivity factors and constraints which determine the relative flows within these actor-networks. (Müller/Haag 1994)
- In the case of a micro-unit like households and household production across contemporary societies various generative mechanisms have been specified, ranging from household-

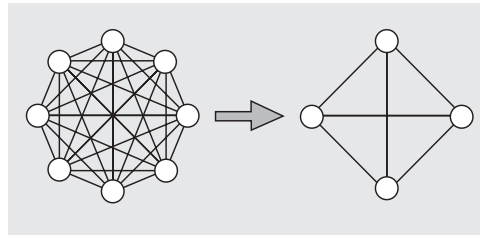
formations and household reproduction to household consumption patterns.⁴⁵

Diagram 2 Twelve Basic Mechanisms for Pattern Formations

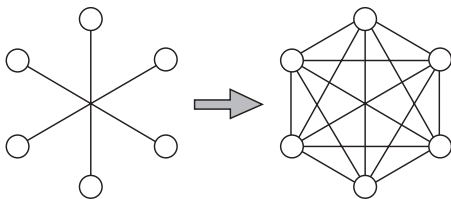
Increasing Network Densities (a)



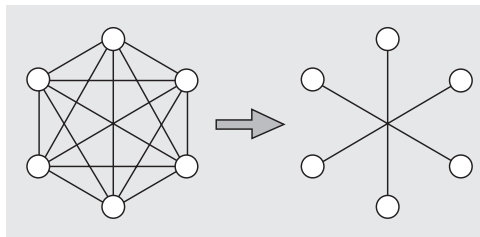
Decreasing Network Densities (b)



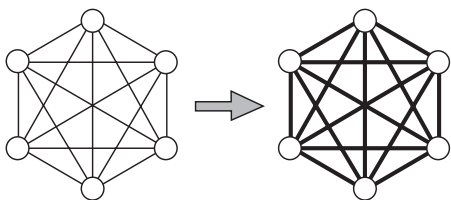
Increasing Linkage Density



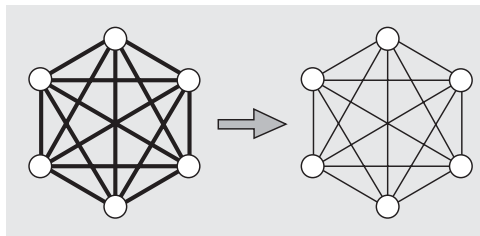
Decreasing Linkage Density



Increasing Linkage Intensity



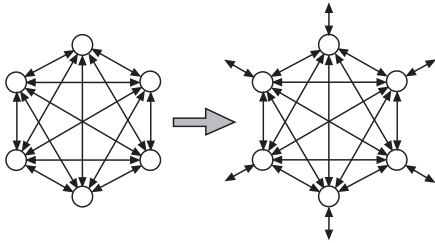
Decreasing Linkage Intensity



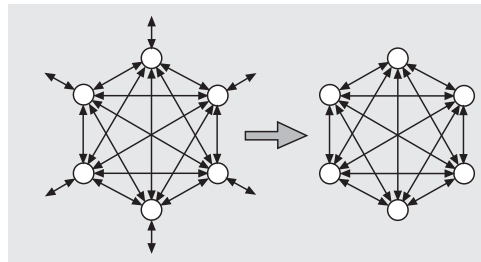
⁴⁵ On this literature, see, e.g., Beck 1986, Beck/Beck-Gernsheim 1994, Beck/Sopp 1997.

Diagram 2 Twelve Basic Mechanisms for Pattern Formations
(Continued)

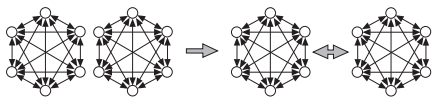
Increasing Environmental Resonance



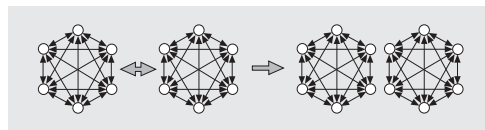
Decreasing Environmental Resonance



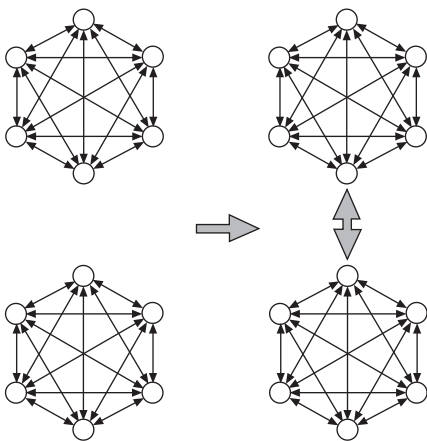
Horizontal Integration



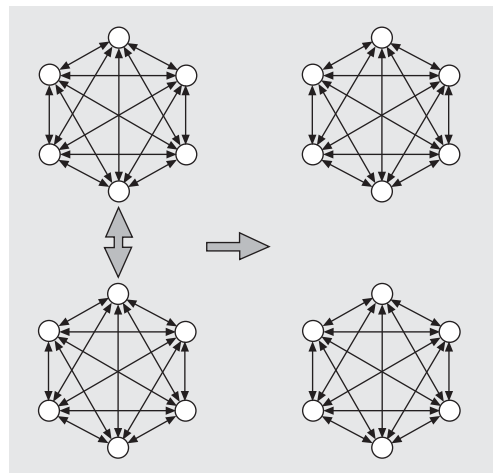
Horizontal Disintegration



Vertical Integration



Vertical Disintegration



Following this new search for generative mechanisms, one can identify a class of six elementary generative mechanisms which have become of core relevance for the emergence of the new dynamics of knowledge bases and actor networks. Accepting, moreover, a bold conjecture by Mario Bunge, each of these six generic mechanisms can be accompanied by an inverse counterpart.

Mechanisms ... consist in the making or breaking of bonds or ties ... The occurrence of mechanisms of this hybrid kind ... suggests the general concept of a dual (or mutually complementary) mechanism: one of which tends to undo what its dual does. In turn, this concept suggests a somewhat wild but possibly interesting speculation: that every mechanism has or generates at least one dual. For example, self-organization is countered by scrambling mechanisms; division of labor elicits coordination; competition calls for regulation; and the formation of any pro-X organization is countered by the assembly of anti-X people. (Bunge 1999:60)

Thus, a total of twelve generic mechanisms can be specified which by themselves or in conjunction generate or produce different patterns. Diagram 2 offers a graphical summary of these twelve patterns for generative mechanisms. In all twelve of them, the making or breaking of bonds or ties occupies a central position for new bonds or ties can be built by:

- the emergence of new components (a)
- new bonds or ties between established components (c)
- intensified ties or bonds (e)
- new or intensified bonds or ties with the environment (g)
- a horizontal coupling of networks (i)
- vertical network linkages (k).

Likewise, the dual of any of these six generative mechanisms leads to a corresponding breaking of bonds or ties namely to

- the disappearance of new components (b)
- the removal of bonds or ties between established components (d)
- weakened ties or bonds (f)
- vanishing or weakening bonds or ties with the environment (h)
- a horizontal de-coupling of networks (j)
- vertical network de-coupling (l).

In sum, TDA should be applied only in those instances where at least partial knowledge on the generative side for the processes to be analyzed is available. In this way, spurious TDA can be avoided.

Evolutionary TDA-Postulate VII: A TDA-investigation into comparative dynamics has to include the generative mechanisms for the processes under consideration.

TDA-Conditions I – VII: $GM \rightarrow RP_{LD, ESC/ESS} (HTV, LSP, GC)$

2.8 Evolutionary Embeddedness of Time Distances VIII: Self-Organizing Generative Mechanisms

An eighth essential criterion for TDA applications lies in the specific type of generative mechanism which has to be qualified as a self-organizing one. As the notion of self-organization already implies, TDA works best with processes which do not have a central control or steering unit capable of shifting crucial values at will. Why? Because in this case, time distances can be overcome in a very short interval and TDA does no longer offer any empirical guidelines.

In order to make this point more clearly, the following demarcations and restrictions, despite the apparent flavour of the self-organization-complex as a universal problem solver⁴⁶, can be outlined which offer some convenient guidelines on the domain as well as on the limits of self-organizing generative mechanisms.⁴⁷

- First, it should be reasonable, at least *prima vista*, to assume that the generated patterns are not the consequence of a central steering or

⁴⁶ Consider an introductory remark like the following:

The central question ... is whether there are general principles which govern the ... formation of structures and/or functions in both the animate and the inanimate world? When I answered this question in the affirmative for large classes of systems ..., this might have seemed absurd to many scientists ... But the past decade has brought an abundance of evidence indicating that this is, indeed the case ... These examples range from biological morphogenesis and certain aspects of brain functions to the flutter of airplane wings; from molecular physics to gigantic transformations of stars; from electronic devices to the formation of public opinion; and from muscle contraction to the buckling of solid structures. In addition, there appears to be a remarkable convergence of the basic concepts of various disciplines with regard to the formation of spatial, temporal and functional structures (Haken 1983:VIIIf.)-

Here one cannot help getting the impression that the search for the penultimate *Weltformeln* has, finally at least, come to an end.

⁴⁷ For surveys on the topic of self-organization see, among others, Casti 1989, Cramer 1989; Jantsch 1982; Küppers 1987 or Roth, Schwegler 1981.

control unit but the outcome of the interactions between the building blocks of the generative mechanism.⁴⁸

- Second, the prevalent relations of the field under investigation must lie the internal dynamics of the constitutive building blocks and not, at least not in a predominant way, in the systems-environment relations.⁴⁹
- Third, the essential processes and structures of the generative mechanism - the within-organisation - must be, in principle, observable and historically as well as actually measurable. Thus, the general requirements presented in Table 11 must be, at least in their essential segments, specifiable.⁵⁰

The notion of self-organization can be linked to the absence of an effective regulation and steering unit within a generative mechanism, societal or otherwise. In order to be more precise with respect to effective steering and control, the following concepts will be introduced. Initially, one can distinguish between a set of disturbances *D*, a regulator *R* within a specific generative mechanism and essential target values *E* which have to be maintained for the socio-economic ensemble under consideration. In the case of an employment system, *E* is composed, for example, of very low rates of unemployment, of close to zero levels of long-term unemployment, of real wage increases over time and so on. *D*, *R* and *E* stand, following W. Ross Ashby, in the following relationship.

⁴⁸ Especially the second point should make it clear that the self-organization paradigm has, also in the *social* sciences, a long established tradition since the insistence on *non-intentional* outcomes of a comparatively large number of *intentional* actions can be found both in the *sociology of figurations* by Norbert Elias (see e.g. Elias 1971 and Elias 1988) or in the idea of a *spontaneous social order* by Friedrich A. Hayek. (See, e.g. Hayek 1980/81)

⁴⁹ As a more formal corollary to the third requirement one may postulate, following Karl W. Deutsch and Bruno Fritsch, that the number of *internal* systems relations must exceed the number of the *external* ones. (See Deutsch, Fritsch 1980:40)

⁵⁰ The following demarcations offered by Francisco J. Varela use, more or less, a very similar tune:

- (1) Self-organization is a behaviour which is proper to autonomous units;
- (2) autonomous units can be appropriately characterized if we change from an input-type to a closure-type stance;
- (3) specifying the closure of a system leads to an understanding of the internal coherence (eigenbehaviors) such units have ...;
- (4) if a system has enough structural plasticity the landscape of its eigenbehaviors will be divers and complex, and the pathways of change from one to another will be constrained, but not uniquely specified: there is a natural drift ...;
- (5) such self-determined internal coherences and their natural drift, when observed under contingencies of interactions, will appear as the making of sense, novelty, and unpredictability, in brief as the 'laying down' of a world. (Varela 1984:30)

Table 11 Self-Organization Schemes for Employment, Education and Science

EMPLOYMENT							
BUILDING BLOCKS				GENERATIVE MECHANISMS			
Type	Units Reproduction	Changes Differentiation	Comp. Advantages	Environment Type	Generative Mechanism.	Steering, Control	Disturbance Int./Ext.
Sectors	Average Growth	Vertical Horizontal Differentiation	Incentives; Attractivity	Total Population	Self- Organiza- tion; Mi- grations <i>et al.</i>	Ineffective;	Economic Innova- tions <i>et al.</i>
EDUCATION							
BUILDING BLOCKS				GENERATIVE MECHANISMS			
Type	Units Reproduction	Changes Differentiation	Comp. Advantages	Environments Type	Generative Mechanism.	Steering, Control	Disturbance Int./Ext.
School forms	Average Growth	Vertical, Horizontal Differentia- tion	Incentives; Attractivity	Total Population	Self- Organization; Migrations <i>et al.</i>	Ineffective;	Economic Socio-Cult. Innovations <i>et al.</i>
SCIENCE							
BUILDING BLOCKS				GENERATIVE MECHANISMS			
Type	Units Reproduction	Changes Differentiation	Comp. Advantages	Environment Type	Generative Mechanism	Steering, Control	Disturbance Int./Ext.
Paradigm Groups	Average Growth	Vertical Horizontal Differentia- tion	Incentives; Attractivity	Total Population	Self- Organization; Migrations <i>et al.</i>	Ineffective;	Scientific and Technological Innovations <i>et al.</i>

There is first a set of disturbances D , that start in the world outside ..., and that threaten, if the regulator R does nothing, to drive the essential variables E outside their proper range of values Of all these E -values only a few are unobjectionable, so that the regulator R , to be successful, must take its value in a way so related to that of D that the outcome is, if possible, always within the acceptable set. (Ashby:1956:209)

In other words, the steering unit R must possess a regulation capacity so that R is capable of determining for each environmental input D_i a specific value E_i within the range of admissible values $\{E\}$. Thus, the main question lies in the regulation capacity of the regulator. This, in turn, leads to W. Ross Ashby's famous law of requisite variety.

The variety in the outcomes, if minimal, can be decreased further only by a corresponding increase in that of R . This is the law of Requisite Variety. To put it more picturesquely: only variety in R can force down the variety due to D ; variety can destroy variety. (Ibid.)

This fundamental law in the general theory of regulation allows to define effective control in terms of minimal variance in the outcomes irrespective of the magnitude and kind of disturbances. Turning to the global history of capitalist evolution and unfolding it becomes obvious that no effective steering and control units have been established since local regulators like a national state apparatus must be considered, by necessity, as too confined and global regulators and steering units are emerging only gradually and marginally.

More to the point, national employment systems, while subject to national regulation and steering attempts, are a far cry from being effectively controlled. Likewise, the education system turns out to be another case of ineffective control and steering by a national state apparatus since it becomes, once again, very easy to recognize that this type of regulation and steering cannot be considered as effective regulator either.

Substituting the basic dimensions for employment and education into the general requirements for the application of self-organization models, one arrives, as one among many possible forms of conceptualizations⁵¹, at the demarcations and categories which are then summarized in Table 11.⁵²

⁵¹ For each of the three systems, a large number of alternatives could be given in principle which, picking the employment system as reference case, range from a sectoral specification to a system of occupations, to types of work or to other forms centering on work locations, use of machinery and the like. Not only that, even the sectoral decomposition allows for different partitionings, ranging from a three sector frame to ten (OECD-scheme), nineteen (Input-output-matrix) or twenty six sectors (Micro-census in Austria).

⁵² For closer details, see Müller 1990:49 - 169.

Thus, self-organizing generative mechanisms require, as a heuristic rule of thumb, a thick description in terms of building blocks, their mode of reproduction, attributes of advantageous changes, relevant segments in the environment, both the internal and the external structures, and, finally, types of internal and external disturbances.

A final remark must be made. Under normal circumstances, each self-organizing arena like education, employment or the science and technology system can be analyzed with a variety of different self-organizing generative mechanisms.⁵³ It should be made clear, therefore, that the relations between self-organizing generative mechanisms and areas of applications are seen in the following perspective:

- First, the various self-organizing mechanisms are characterized by a transdisciplinary range of applications and by disciplinary core domains in which they have been developed: synergetics as the core domain of theoretical physics, especially of laser research⁵⁴, dissipative structures, with a strong emphasis on thermodynamics, as the area of chemistry⁵⁵, hypercyclic organisations as a special model family for the genesis of complex chains of molecules, including the origins of life⁵⁶, autopoiesis⁵⁷ as a mode to analyse living organizations⁵⁸ ...
- Second, over the last three decades one observes the emergence of a cross-disciplinary or, even better, a transdisciplinary set⁵⁹ of themes which can be studied with the help of various generative mechanisms from different scientific disciplines both in the natural

⁵³ See, *e.g.* the unfriendly exchange between M. Zeleny 1981: 63 - 64. and E. Jantsch 1981:65 - 88 or the demarcations and closures drawn by Niklas Luhmann, for example in Luhmann 1984.

⁵⁴ Compare the relevant publications by Hermann Haken from the early sixties or Haken 1980, 1982 or 1991.

⁵⁵ See the core work by I. Prigogine, for example in Nicolis, Prigogine 1977.

⁵⁶ So M. Eigen in Eigen, Schuster 1979. or Eigen 1987.

⁵⁷ The autopoietic tradition, can be characterized, additionally, both by the inclusion of epistemological problems and by its focusing on systems in which self-organization and self-reproduction occur simultaneously, a combination, which must be viewed though, aside from living organizations, as cosmologically highly untypical and, consequently, a lucky coincidence ... The epistemological research interest can be summarized, for the present purposes, under a single heading, namely *Bringing the observer back in ...*

⁵⁸ See for example v. Foerster 1985 or Maturana 1985.

⁵⁹ Following Erich Jantsch one is invited to distinguish between three types of collaboration across disciplines, namely *multi-disciplinarity* (common topic, various unrelated disciplinary methods and theories), *inter-disciplinarity* (common topic, common methods, separated theories), and *trans-disciplinarity* (common topic, common methods and common theoretical core). See, *e.g.*, Jantsch 1972.

and the social sciences. These transdisciplinary topics for a diversified set of generative mechanisms include -

theoretical neurophysics; the modeling of evolution, including the evolution of behavior; strategies to troublesome states of minds and associated higher brain functions; nonlinear systems, pattern recognition and human thought ..., archaeometry, and forces leading to extinction of flourishing cultures; an integrated approach to information science; (or) the heterogeneity of genetic inventories of individuals. (Cowan 1988:236)

In sum, the subsequent restriction on TDA-applications can be put forward.

Evolutionary TDA-Postulate VIII: A TDA-investigation into comparative dynamics has to be based on societal self-organization processes without effective central steering and control units.

$$\text{TDA-Conditions I – VIII: GM}^{\text{SO}} \rightarrow \text{RP}_{\text{LD, ESC/ESS}} (\text{HTV, LSP, GC})$$

2.9 Evolutionary Embeddedness of Time Distances IX: Socio-economic Drifts

As a ninth TDA-requirement, self-organizing generative mechanisms should exhibit a specific drift or direction without a specific, well-defined end-point or global attractor. This on-going direction or drift may manifest itself in various forms since it can show non-linearities or discontinuities, the direction may be sensitive for differences in initial conditions, it may proceed in cyclical swings, chaotic oscillations and the like.

In fact, most ensembles of the socio-economic world like -

economies, political organizations ... ecologies, the central nervous system, developing organisms, biological evolution rarely, if ever, 'settle down' to some repetitive or other easily described pattern. Such systems are

- intrinsically dynamic (When they settle down they are 'dead' or uninteresting.)
- far from a global optimum (There is always room for further improvement, though the system may perform quite well in a comparative sense.)
- continually adapting to new circumstances (The strategies or structures that determine the system's interactions continually change, often with accompanying improvements in performance.)(Holland 1989:463)⁶⁰

⁶⁰ On complex, adaptive systems (CAS) see also Holland 1995, 1998, 1999 or Holland, Holyoak, Nisbett, Thagard 1989.

Due to these continuous adaptations the concept of drifts can be introduced, following Humberto R. Maturana and Francisco L. Varela (1987), as a general tendency or trend among a large number of repetitive trials. For natural drifts, the drift domain must be situated within the natural world, for socio-economic drifts within the boundaries of human societies, ancient, traditional or contemporary.

In terms of TDA-requirements, the intrinsic dynamics as well as the permanent adaptations far from a global optimum can be couched into the subsequent restriction:

Evolutionary TDA-Postulate IX: A TDA-investigation into comparative dynamics has to be able to identify a self-organizing generative mechanism with an easily recognizable drift pattern $GM^{SO} \rightarrow RP_{ESC}^D$.

TDA-Conditions I – IX: $GM^{SO,D} \rightarrow RP_{LD,ESC/ESS}(HTV, LSP, GC)$

2.10 Evolutionary Embeddedness of Time Distances VIII: Arrows of Complexity

Under the heading of arrows of complexity, the final and tenth TDA-requirement focuses on the specification of a complexity measure C so that the following condition holds:

$$C_{RP,t} > C_{RP,t^*} \text{ with } t^* > t$$

In other words, the degree or level of complexity has to increase in the course of the drift pattern RP_{ESC}^D . Subsequently, the notion as well as the measures of complexity will be introduced in a very detailed manner, following largely, though not exclusively the comprehensive complexity mapping undertaken by Nicholas Rescher (1998).

2.10.1 Types of Complexity

Here, Rescher distinguishes between four groups or clusters of complexity which he has labeled as formulaic complexity, as ontological complexity, as structural complexity and, finally, as functional complexity. Each of these complexity clusters, in turn, can be separated, still according to Nicholas Rescher, into different forms or dimensions which have been summarized in Table 12.

Table 12 **Generic Groups and Clusters of Complexity Measures**

GENERIC GROUP	COMPLEXITY CLUSTER	DIMENSIONS
GROUP I	Constitutional complexity	compositional, taxonomical
	Structural complexity	organizational, hierarchical
	Functional complexity	operational, nomic
GROUP II	Formulaic complexity	procedural, computational

These four groups of complexity measures will be re-arranged into two main groups, namely, first, into a cluster of complexity measures for socio-economic processes in general, including the underlying knowledge bases, and, second, into a set of complexity measures for a small segment of the knowledge-bases only.⁶¹

Complexity Types for Socio-economic Processes across Actor Networks and Knowledge Bases

Within the next three small sections of this article a total of six different complexity measures C_i will be introduced which capture different core aspects of the complexity concept.

Constitutional Complexity

The first group of complexity measures is applicable to the entire furniture of the socio-economic world⁶², including the internal organization of actors, actor systems like social systems of production⁶³ or symbolic arrangements, machine code programs and even implicit routines.⁶⁴

⁶¹ Basically, the second group comprises the set of formulaic complexities in Rescher's terminology.

⁶² The term "furniture of the world" comes from Mario Bunge who used it as a subtitle in his book "Basic Ontology II" (Bunge 1979).

⁶³ On the notion of social systems of production, see especially Hollingsworth 2002 or Hollingsworth and Boyer 1996.

⁶⁴ Thus, ensembles like different customer-client networks in metropolitan areas, various scientific articles on a specific topic (like, e.g., on complexity), the implicit knowledge within the ICT-sector (information and communication technologies), software packages for three dimensional graphics, the triple helix-structures between science, economy and the state within a group of countries, partitures for a symphony, the organization of political parties at the national level, a group of theatre plays on tragic

(1) The first class of complexity dimensions and measures makes use of the basic intuitive notion of complexity in terms of numbers and variety. Since both the number of components and their variety refer to the basic constitution of a socio-economic ensemble, the first utilization context for complexity can be characterized as constitutional complexity. Moreover, constitutional complexity in its two dimensions of number and variety can be summarized in a single sentence: The higher the number of building blocks or the greater their variety, the higher the corresponding degrees of constitutional complexities. In a more detailed version, two basic complexity dimensions can be distinguished which, taken together, comprise the domain of constitutional complexity. Compositional complexity refers to the sheer number of building blocks within a given ensemble and taxonomical complexity is connected with different types, forms, species, populations or other taxonomical schemes which are able to differentiate between different classes of building blocks and group them into homogeneous clusters.

- Compositional complexity: This dimension stands for the number of building blocks and is measured in numbers like the number of firms in a region, the numbers of organizations in a city, the number of scientific institute in the EU, the number of scientific articles produced worldwide, the number of machine code programs within an organization, the number of program-files, the number of chapters in a book, the number of neural groups, etc.
- Taxonomical complexity: The second dimension within the group of compositional complexity addresses the degree of variation within a set of building blocks. Thus, zero taxonomical complexity is assigned for instances with a single unit of building blocks only whereas this specific dimension reaches high values in the case of a large number of distinctive units or types. Consequently a binary code with two building blocks (machine code) is less complex than an alphabet with four components (DNA-code) or 26 elements (standard number of letters in English, German, etc.). A system with firms as the only building blocks is less complex from a taxonomical point of view than an actor system, comprising firms, Non Profit-Organizations, the state, Non-Government Organizations and households, etc.

Table 13 gives a summary of both complexity dimensions, including a small list of paradigmatic examples for well-defined socio-economic contexts. Once again, it must be emphasized that constitutional complexity can and should be used within the restrictions of contextual boundaries only.

love, etc., these and many more classes of socio-economic ensembles should become evaluable in terms of their varying degrees of complexity.

Nevertheless, the first group of complexity measures can be applied across the entire socio-economic universe, including actors, actor systems and various aspects of the knowledge bases.

Structural Complexity

Aside from constitutional complexity, a second group of complexity dimensions as well as of complexity measures can be labelled, again in Rescher's terminology, as structural complexity. Like in the case of constitutional complexity, two different dimensions can be distinguished.

Table 13 **Modes of Constitutional Complexity**

MODE EXAMPLES	KEY CRITERION	PARADIGMATIC
COMPOSITIONAL	Number of Building Blocks	Number of Components of a Socio-Technical System (Bicycle, Car, Jet, etc.) Number of Actors in an Actor System Number of Building Blocks in Computer Programs
TAXONOMICAL	Variety of Building Blocks	Number of Different Types of Components within Socio-Technical Systems (Bicycle, Car, Jet, etc.) Number of Types of Actors within an Actor System Number of Types of Building Blocks in Computer Programs

- **Organizational complexity:** This complexity dimension is sensitive to varying degrees of substitution between building blocks and of their inter-relationships. Thus, low or zero organizational complexity means that a specific ensemble has a single composition of building blocks with a single interconnectivity matrix between these components only. For illustration purposes, jig-saw puzzles may vary significantly in their constitutional complexity (50, 100, 500, 1000 or more components) but have the same degree of zero organizational

complexity.⁶⁵ High organizational complexity is to be recorded in cases like the human brain where one is confronted with a set of features like degeneracy⁶⁶ and an enormous substitution potential between neural building blocks. Other examples exhibiting high degrees of organizational complexity include multi-level actor systems like “National Innovation System” with a high substitution potential within the science system, the state or the economy as well as between the science system, the economy and the state. Still another example is, once again, a social system of production (education, health, security, etc.) which shows a rich substitution potential within and between its main building blocks. In fact, most socio-economic ensembles exhibit, by and large, high degrees of organizational complexity.

- Hierarchical complexity: With respect to the second structural complexity dimension, the number of levels becomes of central importance for determining the degree of complexity. Here, one can clearly see an arrow of level-complexity where the higher-order ensembles are “always more complex than the lower-order ones” (Rescher 1998:9). Consequently, socio-economic arrangements at the global level exhibit the highest possible degree of hierarchical complexity whereas local ensembles are of comparatively smaller hierarchical complexity only. Local units like the administration of a small town may possess several hierarchy levels within their overall organization, but no hierarchical complexities beyond the local level. Consequently, a typically global player like a large transnational enterprise has developed a high degree of hierarchical complexity within and across the global, multi-national, national, regional and local levels, etc.

Once again, Table 14 presents a short summary for both complexity dimensions as well as a small number of paradigmatic examples.

Functional Complexity

The final complexity domain refers under the heading of functional complexity to the modes of operations, functions and performances and can be separated into two distinctive dimensions.

⁶⁵ The example of jig-saw puzzles can be found in Rescher (1998:9) already.

⁶⁶ Degeneracy means, following Gerald Edelman (1987), that a specific operation can be performed, in principle, by a large set of units.

Table 14 **Modes of Structural Complexity**

MODE EXAMPLES	KEY CRITERION	PARADIGMATIC
ORGANIZATIONAL	Degrees of Substitution between Building Blocks and between Inter-Relation- ships	Social Systems of Production (Education, Health, Science, Security, etc.) across Nations with Very High Degrees of Substitution in Terms of Build- ing Blocks and Inter- connectivities
HIERARCHICAL	Frequency of Subsumption Relations between Building Blocks	Multi-Level Architecture Transnational Enterprises, Religious Communities (like the Catholic Church), Social Systems of Production (Education, Health, Science, Security, etc.) within Nations, Multi-Level Architecture of the Socio-Economic Paradigm

- Operational complexity: The first dimension refers to the “variety of modes of operation or types of functioning” (Rescher 1998:9). An obvious example for this complexity dimension lies in the differences between chess and checkers where chess comprises different operations for six different types of “components (king, queen, bishop, knight, rook, pawn) whereas checkers allows, at least in the initial stages of the game, for a single mode of operation for a single type of building block only. In organizational terms, arrangements with a multiplicity of different modes of operations like highly flexible production processes are to be qualified as operationally complex while a work organization with one type of operation only falls under the class of marginal or zero operational complexity. A computer-system which is able to interact with its environment by voice, by written inputs in everyday language and by visual signals will exhibit a far higher operational complexity than the mainframe-terminals of the 1960ies and 1970ies and their severe

restrictions on programming languages and on highly specialized inputs. Generally, the higher the requisite variety of routines, practices and operations of an actor, of an actor system, of a socio-technical system, of a machine code program, etc., the higher the degree of operational complexity.

- Nomic complexity: The second complexity dimension refers to the theoretical background, necessary for the construction as well as for the description of a given ensemble. Intuitively speaking, nomic complexity increases with the amount of embodied models, mechanisms or laws within such an ensemble. Accordingly, “steam engines are more complex in this manner than pulleys” (Rescher 1998:9). Likewise, a thermostat exhibits a lower degree of nomic complexity than, say, an atomic power plant or a pipeline. Along the same line of assessments, an organization with frequent horizontal communications, with intensive private interactions outside the office hours and with large amounts of implicit knowledge exhibits a higher degree of nomic complexity than an organizational counterpart with very few and standardized interactions, very little build-up of implicit knowledge and a small amount of communication processes. In the same spirit, a mathematical and statistical tool-kit packed with special features and a large set of algorithms contains more mechanisms and exhibits, thus, a higher nomic complexity than an alternative program which is able to handle a special type of calculation only like, for example a conversion from national currencies into the Euro-currency.⁶⁷

Organizational and nomic complexity are sufficiently independent so that one can find, in principle, ensembles with a high degree of organizational complexity and a low degree of nomic complexity (e.g., an ideal type Weberian bureaucracy) and *vice versa* (e.g., organizations with high discrepancies between their explicit and implicit profiles). Once again, Table 15 summarizes the discussion so far by presenting the third complexity groups together with a short list of paradigmatic examples.

⁶⁷ In the same spirit, a graphical computer program packed with special 3D-features, animations, a rich library of symbols and ample possibilities for multi-media integration contains more “mechanisms” and exhibits, thus, a higher “nomic” complexity than an alternative program which is able to arrange two-dimensional diagrams with a limited amount of symbols only.

Table 15 **Modes of Functional Complexity**

MODE	KEY CRITERION	PARADIGMATIC EXAMPLES
OPERATIONAL	Variety of Modes of Operation	Operations of intelligent services (e.g., a conference hotel) in contrast to a single service unit (e.g., bread and breakfast) Intelligent socio-technical systems (e.g., world wide-web, expert systems) versus single purpose systems (e.g., thermostat)
NOMIC	Degree of “Elaborateness and Intricacy” of Laws, Mechanisms or Models Governing a Process ⁶⁸	Large-scale socio-technical systems versus ensembles with a single mechanism Programs utilizing a large number of different algorithms versus single algorithm-programs Exploring new ways of research versus highly standardized research sequences

Complexity Types across Knowledge Bases only: Formulaic Complexity

With respect to the second group of complexity measures, an important restriction has to be made right from the very beginning. The subsequent complexity modes refer to special ensembles within the overall knowledge bases only and are not applicable to all knowledge building blocks alike.⁶⁹ In essence, only building blocks which can be qualified as algorithms or as programs can be evaluated in terms of the second class of complexity

⁶⁸ This formulation is taken directly from Nicholas Rescher who introduces nomic complexity as “elaborateness and intricacy of the laws governing the phenomena at issue. (Rescher 1998:9)

⁶⁹ Likewise, the neural “storage” for “implicit knowledge” will depend on the length of implicit routines, on their scope and on the number of possible alternatives.

measures. Not surprisingly, the formal definitions for varying degrees of complexity for different code systems or layers within societal knowledge bases follow these basic restrictions. While Nicholas Rescher has suggested the notion of formulaic complexity, alternative characterizations like informational complexity or algorithmic complexity may be applicable as well. In any case, formulaic (algorithmic, informational) complexity adds new dimensions and measures to the previously established complexity set.

- Procedural complexity: Along the first dimension, the necessary length of programs becomes of central operational relevance. Thus, the “length of the account that must be given to provide an adequate description” (Rescher 1998:9) or a “recipe for producing” (Ibid.) The clearest instance for procedural complexity lies in the field of algorithms, where “procedural complexity” can be defined as “the minimal length of an instruction-program for generating a sequence (by use of a standardized process such as a universal Turing machine).” (Ibid., 10)
- Computational complexity: The final complexity dimension is restricted to computers and machine code programs only. Here, the complexity criterion lies in the necessary number of computations for a given task or problem.

With this mode of complexity we have $C = P \times t$ where P is a measure of the power of the information-processor at issue and t is the time required for its successful deployment in the problem-solving context at hand ... Complexity here comes down to the demands of cognitive management. (Ibid., 11)

With these two additional complexity measures for the program and for the algorithm-side of the knowledge bases, a variety of different aspects and dimensions of the immensely popular notion of complexity has been completed. Table 16 presents a final list with paradigmatic examples across the different layers of societal knowledge bases. In all these examples, special emphasis has been given to the range of complexity for programs, recipes, algorithms or rule systems.

With Table 16 the brief overview on complexity measures for socio-economic ensembles of all kinds has been completed.

Table 16 Modes of Formulaic Complexity

MODE	KEY CRITERION	PARADIGMATIC EXAMPLE
PROCEDURAL	Length of instructions	Short manuals versus long manuals Programs with a few “lines of code” (loc) versus large-scale programs with millions loc Recipes for instant meals versus recipes for a “nouvelle cuisine”-dinner
COMPUTATIONAL	Amount of time and effort	Problem solutions for mathematical, statistical logical or other formal “tasks”, ranging from instant solutions up to “unsolvable problems” in polynomial time

2.10.2 Arrows of Complexity as TDA-Core Requirement

Turning to suitable TDA-restrictions, the subsequent postulate seems to follow almost naturally from the complexity domains introduced above.

Evolutionary TDA-Postulate X: A TDA-investigation into comparative dynamics has to be conducted within an arrow of complexity context.

TDA-Conditions I - X:

$$GM^{SO,D} \rightarrow RP_{LD,ESC/ESS}(HTV, LSP, GC) \ \& \ C^{RP}_{t^*} \geq C^{RP}_t \ \text{with } t^* > t$$

An overall context for an arrow of complexity is present whenever a single or more dimensions of complexity are selected and measurements are performed in time which indicate a long-term complexity drift. The TDA-examples in e-WISDOM 2a correspond to the arrow of complexity-requirement. GDP p.c. over the last three hundred years has grown dramatically in volume and has led to an increase in constitutional, structural and functional complexity. Technology diffusion like the long ITC-wave is

accompanied by complexity increases along all four complexity domains. Finally, social performance dimensions like life expectancy or infant mortality can be viewed as proxies for an underlying complexification of the social universe.

3 A Concluding Summary

Concluding the methodological section, TDA – as developed in e-WISDOM 2a by Pavle Sicherl - should be performed under the following ten conditions:

- first, by being able to specify socio-economic (re)production processes RP which is concentrated on evolutionary features such as copying, imitation or maintenance/repair
- second by concentrating on long-term societal evolution, preferably on the time-scale of the *longue durée*
- third, by describing and categorizing a socio-economic process P with evolutionary stable classifications (ESC) (ESC-Condition)
- fourth, by focusing on a process RP which exhibits a high variance along the societal time-scale
- fifth, by concentrating on a process RP which possesses a marginal amount of substitution potential both of the internal and the external variety
- sixth, the process RP should belong to the class of societally accepted ones
- seventh, by focusing on the underlying generative mechanisms GM which produces the (re)productive process RP
- eighth, by characterizing the generative mechanism GM as one of a self-organizing nature (GM^{SO}) and, thus, as one under the absence of effective steering and control units
- ninth, by being able to produce, via the help of a GM^{SO} , a drift pattern or an overall process direction P^D
- tenth, by finding at least one complexity measure C_i which increases with the overall process direction P^D .

At first sight this set of ten TDA-requirements makes it rather difficult to arrive at successful TDA-applications. This impression is strengthened and re-enforced if one considers the set of 88 so-called structural indicators by the EU which have been selected because of their importance and relevance for measuring core aspects of contemporary knowledge-based societies. Table 17 presents a preliminary assessment on TDA-applicabilities for this indicator group in terms of the ten evolutionary TDA-conditions. The

overall result seems to add substantial support to the low TDA utilization assessment.

Table 17 EU-Structural Indicators and TDA-Applicability

Cluster I: TDA-Application	
	GENERAL ECONOMIC BACKGROUND
➤	GDP p.c.
	DOMAIN/DIMENSION
EMPLOYMENT	
➤	Life-long learning
INNOVATION AND RESEARCH	
➤	R&D expenditures
➤	Level of Internet Access
➤	Science and technology graduates
➤	ICT-expenditures

Cluster II: Potential TDA-Applications	
	DOMAIN/DIMENSION
EMPLOYMENT	
➤	Employment rate
➤	Average exit rate
INNOVATION AND RESEARCH	
➤	Spending on Human Resources
➤	Patents
SOCIAL COHESION	
➤	At risk of poverty rate before social transfers
ENVIRONMENT	
➤	Greenhouse gases emission

**Table 17 EU-Structural Indicators and TDA-Applicability
(Continued)**

Cluster III: No TDA-Applications

GENERAL ECONOMIC BACKGROUND

- Employment growth
- Unit labor cost growth
- Inflation rate
- Public balance
- General government debt

DOMAIN/DIMENSION

EMPLOYMENT

- Accidents at Work
- Unemployment rate
- Gender pay gap
- Tax rate on low wage earners

INNOVATION AND RESEARCH

- Venture capital investment

ECONOMIC REFORMS

- Comparative price levels
- Prices in network industries
- Market structure in the network industries
- Public procurement
- Sectoral and ad hoc state aids
- Market integration
- Business investment

SOCIAL COHESION

- Inequality of income distribution
- At risk of poverty rate after social transfers
- At persistent risk of poverty rate
- Dispersion of regional employment rates
- Early school leavers
- Rate of long-term unemployment
- Population in jobless households

ENVIRONMENT

- Energy intensity of the economy
 - Transport
 - Urban air quality
 - Municipal waste
 - Share of renewable energy
 - Protection of natural resources
-

At this particular bifurcation point one is faced with two choices.

- Along the first path one assumes a very narrow range of TDA-applications and a rather restricted potential for using this new methodology.
- Along the second path one becomes extremely critical with respect to the available indicator sets and measurements and upholds the high TDA-application potential once the underlying indicator groups turn into appropriately evolutionary fitting sets.

It goes without saying that the second research path, while novel and counter-intuitive at the same time, will be followed. The class of successful empirical TDA-examples has been already summarized in Table 3 and is restricted currently to the indicator class of -

{GDP p.c., Exports p.c., Imports p.c., Cars p.c., Telephone p.c., Mobile phones p.c., Internet hosts p.c., Internet users p. 1000, Internet usage at home (% of households), PC per 100 inhabitants, R&D in industry p.c., R&D/GDP, Scientists and Engineers in R&D per 1000 employees, Life expectancy and Infant survival rate}

As a huge piece of an unusually broad and almost totally unfinished agenda the TDA-indicator list has to be filled up within the next years with large groups of new indicators which reflect the evolutionary dimensions and aspects in the emergence of European knowledge-based societies.

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