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Positioning "Techno-Economics" as an Interdisciplinary Reference Frame for Research and Teaching at the Interface of Applied Natural Sciences and Applied Social Sciences: An Approach Based on Austrian IEM Study Programmes

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Abstract

Students who want to address the "Techno-Economics" (TE) scientific community in their final assignment (i.e. master, diploma or doctoral thesis) are confronted with the specific challenges that interdisciplinary research poses. Hence, to help them respond to these challenges, this paper aims to draft a reference frame that provides orientation in this interdisciplinary research and teaching setting at the interface of "applied natural sciences" (in terms of engineering science resp. technology) and "applied social sciences" (in terms of business economics), without limiting freedom of thought within the research process. The presented TE teaching and research reference frame is primarily based on the needs of Austrian students of industrial engineering and management (IEM). It intends to enable both IEM students and researchers, first, to identify the relevant TE scientific community and, second, to become active within this scientific community with an adequate line of research.

Key words: *Industrial Engineering and Management, Reference Frame, Techno-Economics.*

1. INTRODUCTION

High innovation dynamics, societal and environmental change force researchers and teaching institutions as well as managers in companies to create new success potential. To discover an innovative strategy in research in practice for this purpose, fields of interest situated in the interface between at least two fields of science (FOS) have to be combined.

Therefore, study programmes such as "Pharmaceutical Engineering", "Health Care Engineering", "Engineering Management", "Biomedical Engineering", "Neural Engineering", "Engineering Management" or "Industrial Engineering and Management" (IEM) have emerged. These are just a few examples of a tendency at universities towards adapting their teaching programmes and creating interdisciplinary fields of science to follow the trends in industry practice and society, and to sharpen study profiles [1]. Furthermore, it is not surprising that terms like "Techno-Economics" (TE) can be found in a wide range of recently published papers in different problem contexts, differentiated by functions in companies and/or field of science [2–22]. When looking at these international publications, it is interesting that in most cases a general reference frame within the interface area "technology" and "economics" is missing. For that reason, this paper approaches this research gap by drawing the big picture by means of recapitulating primarily German-speaking literature from an Austrian IEM point of view. It takes study programmes of the three Austrian Universities of Technology (the so-called "TU Austria") into account. Although this is a narrow focus, this work-in-progress paper can be interpreted as a first step to trigger an international discussion in order to form an international TE scientific community. That may be helpful for IEM bachelor, master as well as PhD students to position their final paper at the interface of "applied natural sciences" (in terms of engineering science resp. technology) and "applied social sciences" (in terms of business economics).

The paper is structured as follows: Section 1 gives a general overview of the problem-situation. Section 2 encompasses the starting point as well as an initial TE design frame to identify the common ground of a scientific discipline. It should, thus, subsequently lead to the development of a TE scientific community based on the IEM study programmes. The concluding section 3 presents the results and indicates the limitations of this work-in-progress position paper.

1.1 **Requirements of a TE scientific discipline**

In general, the term "science" has numerous different meanings. According to the dictionary of etymology of the German language, the term has been deduced from the Latin word "scientia", which since the 16th century has been used to refer to an *"[…] ordered correlating area of cognitions; [and a] researching activity [...]"*. "Discipline" can be defined as "branch of science" [translated from 23]. In the context of this paper it is less the terminology than the semantic content and the background that are parameters constituting a scientific discipline. According to BROCKHOFF, at least the following verifiable characteristics are necessary in order to be able to speak of a discipline in the context of business sciences [24]:

- A discipline of business sciences deals with the use of scarce resources in order to attain earnings and use them purposefully whilst taking into account the uncertainties of the economic, social and ecologic environment. This is the case in institutions as well as in businesses. A discipline (and sub-discipline) of "business sciences" is concerned with either the questions that arise "from outside" (i.e. from businesses) or with questions "from inside" (i.e. from within the discipline). In this context, for the description of economic (and technological) developments, the terms "supply push" and "demand pull" have been introduced [25].
- In order to gain answers to the questions from "inside" or "outside", a discipline uses a systematic approach which may encompass various methods concerning business methods [26], whereas a part of science deals with the theory of science, the method of analysis [27].
- A discipline disposes of techniques that preserve and make the already acquired knowledge accessible in order to be able to use it in various ways and to be able to assess it from the perspective of subsequent findings. The way of tradition of knowledge – starting from writing tablets all the way to digital databases – impressively describes the technological progress and its consequences. In a discipline, expert associations and specialist journals take over the knowledge-preserving and controlling function.
- Hence, a certain degree of institutionalisation characterises a discipline.

1.2 **"Productivity orientation": The German-speaking TE literature approach**

GUTENBERG is regarded as the most significant German-speaking founder and supporter of the modern German business economics after World War II as he published the first cohesive three-volume outline [28, 29, 30] of business economics: Vol. 1: Die Produktion [Production], Vol. 2: Der Absatz [Sales] and Vol. 3: Die Finanzen [Finance]. In his work, GUTENBERG references the methods' significance since an idea can only become part of the scientific cognition through its application. GUTENBERG mentions a four-level methodological procedure to gain rationality, precision, stability and verifiability [24]:

- Acquisition of knowledge of facts,
- causal analysis,
- final analysis as well as
- analysis according to the method of understanding social sciences.

Following GUTENBERG, these are the basic procedures within the economic research, thus stretching the methodological area of responsibility for researchers within the business scientific discipline.
It has to be mentioned that apart from the "productivity-oriented approach" by GUTENBERG, it was HEINEN [31], who developed the "decision-oriented approach", and ULRICH [32], who shaped the "system-oriented approach". In addition to these classic approaches, the "behaviour-oriented approach", the "environment-oriented approach" as well as the "approaches of the New Institutional Economics" are of great significance for the business academic life [33].

1.3 **The "scientific character" of technology and business economics**

The question concerning the scientific character equally concerns students and professors when it comes to the scientific contribution of cognition through research or to scientific professional qualification (i.e. "led by research"), tuition and further education (in terms of teaching). This is of specific interest in the present context when the question of the scientific character of TE shall be answered.
At this point, it seems worth mentioning that (basic) science in business economics as well as in technology considers the future as an investment and, hence, is always associated with particular risks [24]:

- Within the scientific discipline of business economics, these risks are assessed in different ways: (1) Science may satisfy the scientist and is, thus, a type of consumption that has to be financed. Hence, the question arises concerning the benefit of such financing activities for society. Benjamin FRANKLIN is said to have responded to this question with the following counter question: *"What is the use of a newly born baby?"* (2) New knowledge is searched for because its economic applicability is supposed to be found in the "game of supply and demand". This applicability serves to gain a certain reputation, the generating of earnings and, thus, the enhancement of tax revenue within the (association of) state(s). The physicist Michael FARADAY is alleged to have answered the question of the prime minister of that time about the benefit of his electromagnetic experiments as follows: *"One day, Sir, you will draw taxes from it."* FARADAY laid the foundation of the current electrical industry's development. Furthermore, a part of a scientist's reputation resonates with his/her country and its

- politics, and in case the scientist is at the same time entrepreneur (or cooperates with businesses), he/she creates workplaces and ensures raised tax revenue. (3) Knowledge can be part of specific demand. Hence, research commissioned by the state or a company is a type of risk minimisation for both contractual partners and is in manifold characteristics currently a source of "financial revenues by third-party funds" at universities, academies and non-university research institutions.

- Similar to the remarks above referring to business economics, there have been discussions about dropping the long-time prevailing term "technology" in the scientific discipline of "sciences of technology". There is a parallel to business economics, because a discipline requires not only an accumulation of knowledge but an ordered system of knowledge; hence, a verbalised schedule. Besides, in the sciences of technology, it is necessary for a scientist to submit to an organisation of norms and rules which direct the scientific work [34].

1.4 **TE within an organised knowledge system**

Figure 1 illustrates – albeit in an abstract way – the literature-based attempt of a synthesis of the scientific disciplines "business economics" and "technology". Furthermore, Figure 1 displays TE as an institution considering its specific elements and influential factors.

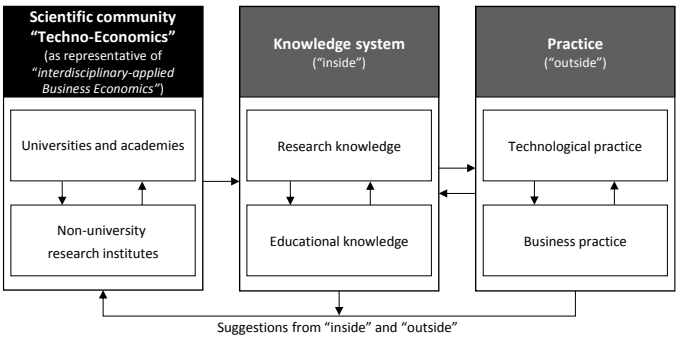

Figure 1. TE as a scientific discipline, its elements and influences [34]

Following the explanations so far, the scientific community obtains suggestions for their work at universities, academies and non-university research institutions "from outside" (i.e. the technological and business practice) and "from inside" (i.e. from the knowledge system consisting of the current research and educational knowledge) and combines existing features with the newly gained knowledge. Hence, it must be distinguished between two kinds of knowledge: The knowledge gained by the scientist due to research has to be differentiated from the knowledge imparted by teaching, the so-called educational knowledge. Educational knowledge and further educational knowledge are especially suitable for being put into practice in order to be able to be used and be developed further. Therefore, there is a resonating of (the "technological") practice to science, which is why business economics interpreted as an interdisciplinary approach becomes an application-oriented perspective of science in the case of TE.

2. TE IN RESEARCH AND TEACHING

The following remarks shall define a "perspective of TE" in research and teaching more precisely. The objective is to draft TE as an interdisciplinary application-oriented "technological approach" to the scientific subject of business economics [35, 36].

2.1 **Developing a TE teaching approach**

Since the industrial revolution, the innovation strength of a national economy has depended largely on technological developments as well as on associated rendered and marketable physical products, non-cash benefits and services. In order to guarantee the marketability of such benefits and services, natural scientists and technicians need economic knowledge for perceiving their functions in companies as well as in basic and applied research. These are prerequisites to develop, produce and market benefits in an economically sustainable way. The development of business economics in the USA, the currently largest national economy of the world (according to estimates by the International Monetary Fund 2013), for instance, emanated from mechanical engineering at the end of the 19th century and was significantly shaped by the engineer Fredrick Winslow TAYLOR, who invented the high-speed steel [37].

What is interesting in this regard is that currently, a considerable number of executives of Austrian technological companies have completed a branch of study in TE (in terms of IEM) [38].

2.2 **Teaching approach at the "TU Austria"**

As a consequence of this development and the university-strategic considerations, the research specialist field "Techno-Economics" has arisen from the interdisciplinary study and IEM teaching programme at the three Austrian technical universities – altogether "TU Austria" (Vienna University of Technology, Leoben University for Mining, Metallurgy and Materials and Graz University of Technology) over the past decades [38]. Hence, the following TE bachelor and master degree study programmes are currently offered at the "TU Austria":

- Vienna University of Technology: Master of Business and Engineering in Mechanical Engineering, Business Informatics as well as economic deepening in various technological branches of studies.
- Leoben University for Mining, Metallurgy and Materials: Industrial Management and Business Economics, Industrial Logistics as well as economic deepening in various technological branches of studies.

- Graz University of Technology: IEM – Mechanical Engineering, IEM – Civil Engineering, Electrical Engineering – Economics, Software Engineering – Economics, Production Science and Management as well as economic deepening in various technological branches of studies.

Furthermore, postgraduate university training courses in various technological areas are part of the education and advanced education portfolio of the three Austrian technical universities. Illustrated in a very pragmatic way in Figure 2, the teaching of TE positions itself within the intersection of the disciplines "Technology" and "(Business) Economics" (in terms of Micro-Economics). In this context, business economics is conceived as a social-scientific subset quantity through which the third circle – sociology – is established and the approach between disciplinary deepening and interdisciplinary concentration is explained. According to the standardised FOS classifications by the OECD, TE can be ranged between "Engineering and Technology" and "Economics and Business" [39].

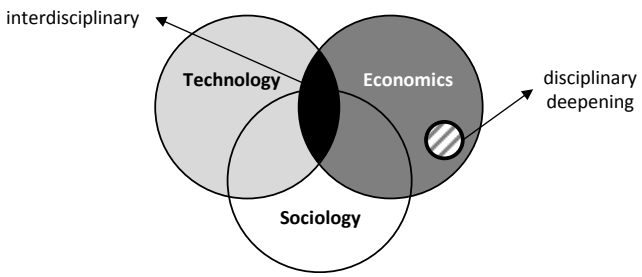

Figure 2. TE teaching approach [35]

Likewise with reference to the FOS by the OECD, this approach clarifies that, on an international level, there is the attempt to create transdisciplinary areas within the development of new disciplines and research fields in order to beneficially link the cognitions of individual scientific areas. TE deals with the science-led interdisciplinary transfer of knowledge that in a perception-driven and application-oriented way applies the disciplinary (micro-)economic theory (which is understood as part of social sciences) to applied science-oriented (in terms of technological) issues with social and practical relevance.
In the teaching of TE, technological and economic perspectives are combined and often made available for the students by practical problems in concepts based on case studies. The target in such cases is beholding and assessing engineering, resp. technology (note: concerning these terminologies see [40–46]). From an economic point of view and, based on this, imparting knowledge to the students to help shape engineering, resp. technology, economically and in a future-oriented way.

2.3 **Draft of a TE research reference frame**

The core of a TE research reference frame is primarily based on TE teaching (in terms of IEM). The TE teaching approach combines technological and economic teaching components. Derived from that, a TE research reference frame should consider an interdisciplinary-applied perspective of real occurrences within the objects of experience "(technology) businesses resp. companies". A reference to technology can either result from the type of company ("technology-oriented company"), the services rendered ("technological-industrial service") or from the "technology-oriented environment" in which companies are active and render their service. Figure 3 illustrates the described scientific approach of TE taken to mean interdisciplinary-applied business economics.

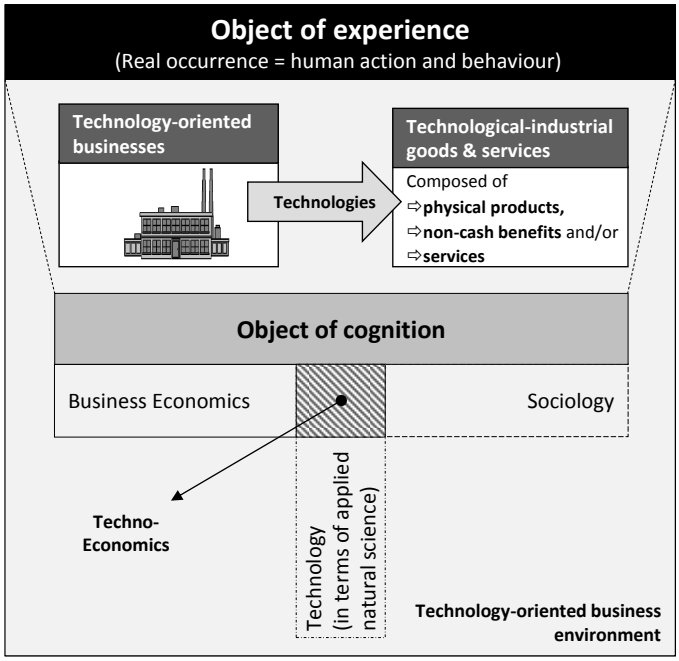

Figure 3. TE research approach [35, 47, 48]

Subsequently, the three key terms (from the author's point of view) (A) "technology-oriented business", (B) "technological-industrial service" as well as (C) "technology-oriented business environment" displayed in Figure 3 has to be clarified in order to contribute to a consistent comprehension. Special emphasis is rather placed on the relevance of particular terms than on the etymology:

(A) "By applying knowledge about target-means relations, technology-oriented businesses are able to practically solve problems with the aid of technologies. The economic activities of technology-oriented businesses focus on science-based and, thus deduced, engineering performance results, the same fields of activity and sectors." [35]

(B) If the type of service shall be in the centre of differentiation, in the literature and in scientific practice, a large number of paraphrases and descriptions can be found about what TE, "technological-industrial", "technological" or "technology-oriented" service shall mean. From the point of view of applied science, it is at first advisable to use the quoted terms synonymously

(C) and to take the following definition as a basis: "Usually, technological-industrial services integrate constituents of non-cash benefits and services. A technological-industrial service is rendered by technology-oriented (industry) businesses employing technologies and is purely engineering. The organisational, industrial demander applies technological-industrial services for creating further service for the coverage of others' needs. Moreover, technological-industrial services display inherent complexity and a resulting enhanced degree of need for explanation." [35]

(D) If, by contrast, the "technology-oriented business environment" (in terms of TE business environment that is also called industrial, technological etc. in practice) needs to be delimited as "atmosphere" of businesses, specifics of the service presentation process including the resulting "technological-industrial service results" as well as aspects of the relation are at the centre of consideration. In regard to atmosphere, the branch categorisation by EUROSTAT [50] can be adduced as delimitation from a "scientific-practical perspective" [47]. The following five categories are contained: (1) "high technology", (2) "medium-high technology", (3) "medium-low technology", (4) "low technology" and (5) "high-tech knowledge-intensive services".

2.4 **Methods and models of TE research**

With reference to the remarks so far, in Figure 4, key methods of a targeted-scientific deduction of perception within business economics are represented (and, thus, deduced from TE). The reason why methods are the key to every scientific discipline (and, hence, for TE) is that they can ensure rationality and verifiability of scientific research and make scientific findings accessible.

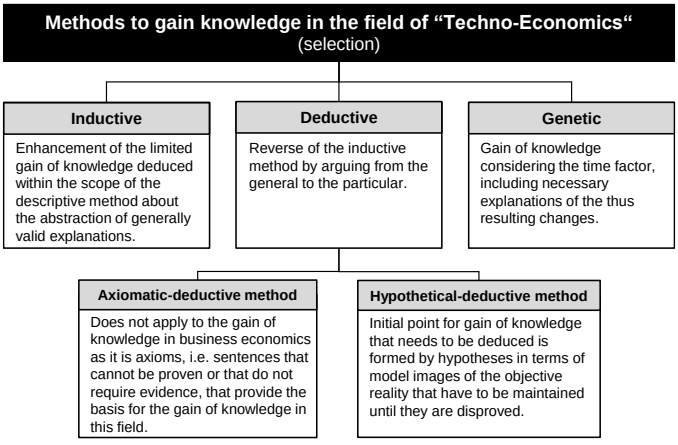

Figure 4. Methods to gain knowledge in TE [49]

To gain knowledge in business economics as well as in the sub-discipline TE, not only abstract methods but also models that reproduce complex economic reality in a simplified way are necessary. According to literature [49], these are the following five basic types:

(1) Describing models that are based on occurrences grounded on experiences without analysing and explaining them.

(2) Explanatory models that verbally and/or visually explain the reasons for operational processes including the regularities they are based on.

(3) Decision models search for ways of optimally attaining a goal. For this purpose, some variables are combined for a target function within defined restrictions.

(4) Construction models that draft a conceptual model (from defined basic terms) in which the coherences and causalities are reflected.

(5) Reductive models that reduce a certain relation observable in the objective reality to a simplified partial relation by mentally isolating the factors identified as insignificant.

3. CONCLUSION

The teaching approach to TE drafted in this article is to be understood as "work in progress" and cannot be applied to research without further ado as this would inevitably lead to terminological inconsistencies and, therefore, to an unclear understanding. Nevertheless, this paper may be helpful to (i) start a discussion among IEM students and professors to carve out lines of future development to form a TE scientific community, (ii) help professors supervising IEM bachelor, master and PhD students to frame their final theses and (iii) focus the research work done by IEM students to increase the efficiency of the research process.

This paper also has several limitations: Firstly, it is primarily based on German-speaking literature. Secondly, the teaching approach presented in section 2 is only based on IEM studies at the three Austrian Universities of Technology (TU Austria). As this is a work-in-progress paper, suggested future steps are the analysis of international comprehensive literature and the discussion of the findings in the displayed problem context. In the future, it might be a promising way to integrate an analysis of international IEM studies as well as TE research programmes to broaden the perspective presented in this conceptual paper.

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Pozicioniranje "Tehno-ekonomije" kao interdisciplinarnog referentnog okvira za istraživanje i nastavu na interfejsu primenjenih prirodnih i društvenih nauka: pristup zasnovan na austrijskim IEM studijskim programima

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Apstrakt

Studenti koji žele da se obrate naučnoj zajednici "Techno-Economics" (TE) u svom završnom radu (tj. Master, diploma ili doktorska teza) suočeni su sa specifičnim izazovima koje interdisciplinarno istraživanje postavlja. Stoga, kako bi im pomogli da odgovore na ove izazove, ovaj dokument ima za cilj da izradi referentni okvir koji pruža orijentaciju u postavci interdisciplinarnog istraživanja i nastave na interfejsu "primijenjenih prirodnih nauka" (u smislu inženjerske nauke ili tehnologije) i " primijenjenih društvenih nauka "(u smislu poslovne ekonomije), bez ograničavanja slobode mišljenja unutar istraživačkog procesa. Predstavljeni referentni okvir za nastavu i istraživanje TE prvenstveno se zasniva na potrebama austrijskih studenata industrijskog inženjerstva i menadžmenta (IEM). Namera je da omogući i studentima i istraživačima IEM-a da, prvo, identifikuju relevantnu naučnu zajednicu TE i, drugo, da postanu aktivni unutar ove naučne zajednice sa adekvatnim istraživačkim kursom.

Ključne reči: *Industrijsko inženjerstvo i menadžment, referentni okvir, tehno-ekonomija.*