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Rotational symmetry and the transformation of innovation systems in a Triple Helix of university–industry–government relations

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ABSTRACT

Using a mathematical model, we show that a Triple Helix (TH) system contains self-interaction, and therefore self-organization of innovations can be expected in waves, whereas a Double Helix (DH) remains determined by its linear constituents. (The mathematical model is fully elaborated in the Appendices.) The ensuing innovation systems can be expected to have a fractal structure: innovation systems at different scales can be considered as spanned in a Cartesian space with the dimensions of (*S*)cience, (*B*)usiness, and (*G*)overnment. A national system, for example, contains sectorial and regional systems, and is a constituent part in technological and supra-national systems of innovation. The mathematical modeling enables us to clarify the mechanisms, and provides new possibilities for the prediction. Emerging technologies can be expected to be more diversified and their life cycles will become shorter than before. In terms of policy implications, the model suggests a shift from the production of material objects to the production of innovative technologies.

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1. Introduction

A market-oriented economy's transition to a knowledge-based economy increases the pressure of globalization because dynamics can be expected to change at the supra-national level. In this study, we argue that the conceptualization of this system in terms of a three-dimensional vector space as, for example, specified in the so-called Triple Helix of university–industry–government relations [1], provides the sufficient and necessary conditions for the specification of a mathematical model that can explain how technological trajectories can be formed between "double helices" (DH), and how a self-regenerating system can be expected to develop at the global level of a Triple Helix (TH). We illustrate how the communication field generated by the interactions among the trajectories is sensitive to the order of the relations. Thus, (linear) symmetry is broken and innovation can be expected to emerge.

A system's approach to innovation studies was first introduced by Freeman [2] with reference to the Japanese system of innovations. The approach was then generalized by Lundvall [3,4] and Nelson [5] to the theory of "national systems of innovation." Porter [6,7] abstracted from the national context by focusing on "clusters" of innovations that can be more dense and differently shaped in regional and/or national settings. Gibbons et al. [8] added that "the new production of scientific knowledge" transforms the systems dynamics from "Mode-1" into a trans-national and trans-disciplinary field that is driven by communication across institutional borders ("Mode-2").

Leydesdorff [9] specified that a system with three sub-dynamics can endogenously generate complex dynamics, but in the Triple Helix metaphor [1,10] the emphasis initially remained on integration in terms of institutional relations. Leydesdorff [11,12] then distinguished between this neo-institutional model of relations, and the neo-evolutionary model of different sub-dynamics such as Wealth generation, Novelty production, and

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Normative control in any system of innovations. These sub-dynamics can also be considered as functions and then be modeled as vectors in a vector space.

The paradox of the current situation is that "if the working of the Triple Helix (…) is relatively well explored and usually examined at a specific moment in time (a synchronic interaction), a methodology for analyzing the transition among Triple Helix regimes over time (a diachronic interaction) is a relatively under-conceptualized problem" [13], p.2]. Hitherto, the TH model has rested mostly on phenomenological case-studies. The failure to understand the mechanisms causing the dynamic evolution of the Triple Helix significantly reduces the effectiveness of this model. Case studies describe situations in different regions and are difficult to compare. In our opinion, one should avoid thinking in terms of phenomenological descriptions and instead develop analytical techniques that enable us to study how different factors interact in a systemic context. In this study, we claim that such a TH model can be specified on the basis of formal logic, and then elaborated into a mathematical formulation.

The research question of this paper is to overcome the drawbacks of the phenomenological approach by presenting a mathematical formulation of the TH model. This can help to formalize and operationalize the non-linear dynamics and reveal the features that remain hidden in phenomenological descriptions. How does the interaction among the three players—Industry (or Business), University (Science), and Government—develop an innovation infrastructure? From this perspective, the TH model is special not only because it allows us to create an effective system for the development and promotion of innovations, but also because it provides the lens through which one can make a breakthrough in understanding the fundamental mechanisms in innovation systems. The non-linear dynamics of interaction among actors can be expected to lead to a fractal structure in a TH system. Such a fractal structure provides *self-similar* patterns in innovation systems at different scales, which are replicated in innovation activities at various scale levels. Because of this fractal structure [14], innovations can be integrated into systems not only nationally, regionally, or sectorially, but also across dimensions while incorporating both separate companies and projects. At each scale a TH structure can be expected and further analyzed.

This paper is organized as follows. In Section 2, the classical TH model is described in terms of innovation systems. In Section 3, we discuss the issue of evolutionary symmetry in a TH system. The TH model can be described mathematically as a group of rotational symmetries in a three-dimensional space. In Section 4, we focus on innovation cycles and waves. The cyclical character of innovations, that is, the periodic arising of innovative activity, allows for defining waves of innovations and describing innovation as propagating in a specifically defined space. In Section 5, the combination of TH symmetry with innovation waves is shown to result in non-linearity and self-organization. In Section 6, we explain how the interactions among different technological trajectories can be expected to result in the fractal structure of the TH model. In Section 7, the results are summarized and we elaborate on options for policy-makers. Readers especially interested in the mathematics will find a more elaborate description of the model in the Appendices.

2. The Triple Helix model of innovations

The Triple Helix model assumes that the driving force of economic development in the post-industrial stage is no longer manufacturing, but the production and dissemination of socially organized knowledge. Institutions that generate knowledge increasingly play a role in the networks of relations among the key actors: University (*Science*), Industry (*Business*), and Government (*Governance*). The spheres of these activities are increasingly overlapping. In areas of intersection, the actors can partially substitute for one another.

Universities, for example, in addition to fulfilling educational and research functions, increasingly undertake a part of the business functions, creating small innovative companies and becoming thus a stakeholder in socio-economic development. Industrial corporations create their own research centers and training centers for employees. They can also use the university's infrastructure in order to conduct their own R&D activities, and thus shift part of their costs to the state as the main source of funding for universities. Governments encourage the development of small innovative enterprises through priority financing of specific universities and legislative regulation, and they stimulate industry to develop and implement new innovative technologies. Universities and industry can partially substitute for the state in the creation of an innovation infrastructure. The overlapping institutional spheres of these three actors are graphically represented in Fig. 1.

The domain of the TH model coincides with the area where the institutional spheres of the three actors—*S*, *B*, and *G*—overlap, and where there is maximum interaction among these actors. However, the respective area sizes and the nature of the agents interrelating can be expected to change constantly due to the interactions. Constant change is therefore one of the TH model's features; the other feature is the model's non-linearity.

Despite the wide acceptance of the Triple Helix model, there remain a number of issues requiring further attention. For example, one can ask: which mechanisms are responsible for the increased potential for coalition building and how can one understand the non-linearity of the model? From a

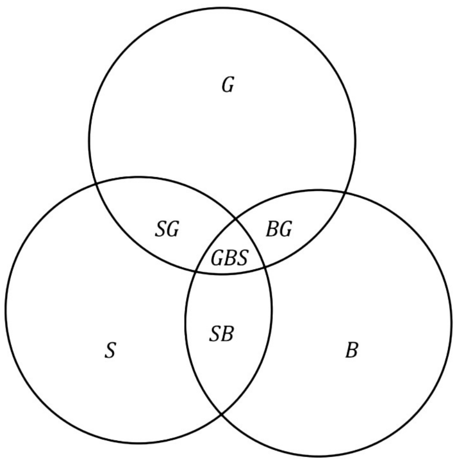

Fig. 1. A balanced Triple Helix model; *S*: science; *G*: government; and *B*: business.

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