Neo-Triple Helix Model of Innovation Ecosystems: Integrating Triple, Quadruple and Quintuple Helix Models

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Abstract

This article proposes the neo-Triple Helix model of innovation ecosystems by integrating the Triple, Quadruple and Quintuple Helix models, inspired by Lewontin's gene, organism and environment Triple Helix metaphor. The model considers innovation ecosystems evolved through interactions between 1) innovation dynamics (or innovation genes), 2) social structures and 3) the natural environment. The systems include two-layer triple helix interactions (or triads): university, industry and government at the gene level, and innovation genes, social structures and the natural environment at the system level. Innovation dynamics are conceptualised by integrating the neo-institutional and neo-evolutionary perspectives of the Triple Helix model. The dialectical relationships between innovation genes, social structures and the natural environment are primarily explained using aspects of the Quadruple and Quintuple Helix models. The neo-Triple Helix model clarifies debates on different helix innovation models, advances helical approaches through synergy building and can guide empirical research and policy design on innovation ecosystems.

Keywords

Introduction

While the Triple, Quadruple and Quintuple Helix models share similar analytical grounds, such as applying metaphoric approaches in identifying key components in innovation processes, scholars have debates on which model is the most useful for analysing innovation ecosystems (Cai and Lattu, 2021). After the panel ‘Triple Helix vs. Quadruple and Quintuple Helix Dialogue’ at the Triple Helix Conference 2020 (Zheng and Cai, 2020), the panellists – Loet Leydesdorff, Elias Carayannis, David Campbell and Yuzhuo Cai, together with their co-authors – published three articles in 2021 about their understandings of the relationships between these models. All their works draw attention to potential synergy building among the Triple, Quadruple and Quintuple Helix models.

Leydesdorff and Lawton Smith (2022) drew particular attention to Simmel’s triad concept: while a triad significantly differs from a dyad, ‘the further expansion to four or more persons by no means correspondingly modifies the group any further’ (Simmel, 1950: 138). Leydesdorff and Lawton Smith (2022) argue that Quadruple, Quintuple or N-tuple helices ‘can – for analytical reasons – always be decomposed and recombined into interacting Triple Helices’ (2022: 2). Their objective was ‘to explain the potential generation of synergy in TH [Triple Helix], QH [Quadruple Helix] and higher-order policy models’ (Leydesdorff and Lawton Smith, 2022: 2).

Carayannis et al. (2021) argued that the Quadruple and Quintuple Helix models are not simply expansions of the Triple Helix model but rather that ‘the Quadruple Helix integrates and contextualises the Triple Helix, while the Quintuple Helix integrates and contextualises the Quadruple Helix (and the Triple Helix)’ (2021: 3). Such a position contrasts with the common perception that Quadruple and Quintuple Helix models add ‘the public’ and ‘the natural environment’ as parallel helices to the Triple Helix, which was also implied in Carayannis and Campbell’s (2009) early work.

Cai and Lattu (2021) compared the strengths and weaknesses of the Triple Helix and Quadruple Helix models in terms of their explanatory power regarding dynamics in innovation ecosystems. They concluded that although the Triple Helix model is nearly 30 years old, its theoretical core (including Simmel’s social geometry of triadic interactions) still has the potential to analyse interactions among actors in innovation ecosystems. To realise such potential, some important concepts, such as ‘civil society’ and ‘sustainable development’, must be explicitly addressed in the Triple Helix thesis. The comparison aims to pave the way for building synergy among helix models and better theorising about innovation ecosystems.
Besides the three articles mentioned above, Zhou and Etzkowitz (2021), re-affirmed their positions regarding the differences between Triple Helix and Quadruple/Quintuple Helix: while the Triple Helix model views helices as actors or institutional spheres, the helices in Quadruple and Quintuple Helix models are treated as ‘political, economic, educational, natural, and public’ sub-systems (2021: 5). Given the importance of the public and natural dimensions, they proposed Triple Helix twins (Etzkowitz and Zhou, 2006; Zhou and Etzkowitz, 2021), adding the university–public–government Triple Helix to supplement the university–industry–government Triple Helix, which represent the sustainability and innovation dimensions, respectively.

In a recent editorial proposing a research agenda for Triple Helix research, Cai and Amaral (2021) discussed the limitations of the Triple Helix model in terms of its analytical scope and explanatory power. Understanding its limitations provides insight into its relations with the Quadruple and Quintuple Helix models, particularly in terms of the differences between the models and the potential for synergy building.

This paper constitutes a continuous effort to integrate the Triple, Quadruple and Quintuple Helix models and propose a novel model for elucidating the nature of innovation ecosystems – the neo-Triple Helix model of innovation ecosystems. It is structured as follows. First, I present the three primary concepts that inspired me to work on the model: Triads in the Triple Helix (Leydesdorff and Lawton Smith, 2022), Helix Trilogy (Carayannis et al., 2021) and Lewontin’s (2001) Triple Helix. Here, the propositions about each concept are drawn. Then, I elaborate on the neo-Triple Helix model of innovation ecosystems by synthesising these propositions and other relevant insights of various helix models. Next, I discuss the relations between the Triple Helix and the Quadruple/Quintuple Helix from the Neo-Triple Helix model’s perspective to clarify debates on different helix innovation models and advance helical approaches. Finally, I highlight the theoretical contributions and practical implications of the neo-Triple Helix model.

2 Triple Sources of Inspiration: A Literature Review

2.1 Triads in the Triple Helix
Both Etzkowitz and Leydesdorff, as originators of the Triple Helix model, tried to defend its legitimacy following the development of the Quadruple and Quintuple Helix models (Etzkowitz, 2015; Leydesdorff, 2012; Leydesdorff and Etzkowitz, 2003). They emphasised Georg Simmel’s sociological concept of triads, in which the Triple Helix model is rooted, as an Occam’s razor
principle. The core of Occam's razor is necessity: ‘if it is not absolutely necessary to introduce certain complexities or hypothetical constructs into a given explanation, then don't do it’ (Braithwaite, 2017: 2). Simmel's core idea regarding the triad was described by Leydesdorff and Lawton Smith (2022: 9) as follows:

The sociologist Simmel ... argued that the transition from a group of two to three is a qualitative one: another awareness of space becomes available. In a triplet, the realization of one or the other relation may make a difference to the further development of the triad. According to Simmel, a dyad remains a private relation whereas the triad introduces "sociality": each third person can watch the other two and thereby have the advantage of the tertius gaudens (the third who benefits); that is, the third person may see options in the relations between the other two which can be used to their advantage. If the third person actively participates in breaking the tie between the other two, one can consider this as an instance of divide et impera (divide and rule).

When developing the Triple Helix model, Etzkowitz and Leydesdorff extended Simmel's micro-level analysis of dyads and triads to the meso level of organisational interactions (Cai and Etzkowitz, 2020). However, Etzkowitz and Leydesdorff have different views on what constitutes the core of triple helix interactions, namely neo-institutional and neo-evolutionary perspectives, respectively (Leydesdorff, 2012). The neo-institutional perspective emphasises the relations between the three institutional spheres: university, industry and government (UIG). To better account for the mechanisms of interactions between the triple helix spheres, Etzkowitz (2008) proposed the concepts of knowledge, consensus and innovation spaces. He maintained that while ‘[a] regional Triple helix emerges from knowledge, consensus, and innovation spaces’ (2008: 77), developing each space requires the participation of actors across institutional spheres. From the neo-evolutionary perspective, the three helices are ‘selection mechanisms’ that asymmetrically influence on one another and such ‘mutual selections may shape a trajectory as in a coevolution’ (Leydesdorff, 2012: 28). The three selection mechanisms are related to the functions of wealth creation, knowledge production and normative control, which are the primary functions of UIG, respectively (Leydesdorff, 2012; Leydesdorff and Lawton Smith, 2022).

Etzkowitz’s concept of triple spaces and Leydesdorff’s concept of triple functions are not so different, since both are used to understand the roles of UIG in innovation processes, particularly how they overlap. According to
Etzkowitz (2008), triple helix spaces are created through interactions between UIG via the mechanism of ‘taking the role of the other’. Leydesdorff (2012) argues that triple helix synergy can be measured in terms of the overlapping of UIG’s functions, namely knowledge production, wealth creation and normative control. Specifically, the triple helix indicator measures ‘mutual redundancy’ (Shannon, 1948), ‘that is, the extent to which the same information is coded from two (or more) different perspectives’ (Leydesdorff and Park, 2014: 4).

Etzkowitz’s and Leydesdorff’s approaches supplement each other. On the one hand, Leydesdorff’s Triple Helix indicator (about triple helix functions) better explains and operationalises the mechanism of ‘taking on the role of the other’. For instance, when a university takes on the roles of industry and government, it is performing the roles of wealth creation and normative control while maintaining its primary function of knowledge generation. On the other hand, Leydesdorff’s mathematical calculation of ‘mutual redundancy’, which remains at the level of abstraction, can be concretised when linked to the interactions between triple helix spheres and spaces. For instance, a higher level of ‘mutual redundancy’ represents more frequent ‘taking the role of the other’, which is likely to result in greater overlap in triple helix spaces. In other words, in overlapped Triple Helix spaces, there exist organisations from the spheres of UIG, which take on the role of the other. The integration of neo-institutional and neo-evolutionary perspectives on the Triple Helix is illustrated in Figure 1.

The triple helix spheres, spaces and functions, shown in Figure 1, can be hypothetically related to the three orders of innovation dynamics described by Leydesdorff (2021): UIG interactions correspond to the first-order ‘institutional dynamics among the agents’ (Leydesdorff, 2021: 96); spatial interactions are related to the ‘second-order dynamic of interacting communications’ (Leydesdorff, 2021: 96); and functional interactions reflect the ‘next-order dynamics … based on interactions among selection mechanisms’ (Leydesdorff, 2021: 102). While Leydesdorff (2021) posits that higher-order dynamics are built upon lower-order ones, Figure 1, which is based on integrating both neo-institutional and neo-evolutionary Triple Helix models, implies the dialectical relations between the three dynamics.

The discussions above lead to the following tentative propositions:

– Proposition 1: A triad is the basic unit for analysing the dynamics of innovation processes.

– Proposition 2: UIG interactions can be measured by calculating the mutual redundancy between the functions of knowledge production, normative control and wealth creation.
Proposition 3: In an ideal-type Triple Helix model, UIG interactions, in which organisations take on the roles of the others, appear in the overlap of the triple helix spaces (Figure 1).

2.2 Helix Trilogy
In a recent article, Carayannis et al. (2021) explained how Quadruple and Quintuple Helix models draw on aspects of the Triple Helix model and extend it to address the democratic and ecological aspects of innovation ecosystems. They conceive of the three Helix models, or Helix Trilogy, as follows: the Triple...
Helix represents a core model of innovation for the knowledge economy; the Quadruple Helix describes the importance of knowledge democracy as an enabler of innovation in knowledge society; the Quintuple Helix deals with social ecology or society–nature interactions in innovation ecosystems. According to this formulation, civil society and the environment are not helices parallel to UIG but broader contexts in which the Triple Helix is situated (Figure 2).

Carayannis et al. (2021) attempted to expand the Triple Helix model to Quadruple and Quintuple Helix models in response to society’s transformation from a knowledge economy to a knowledge society or knowledge democracy. Therefore, it is necessary to briefly explain the relationship between knowledge society (or knowledge democracy) and the knowledge economy. Biesta (2007) argued that the knowledge society could be interpreted as knowledge democracy while recognising the co-existence of the knowledge economy due to ‘the importance of techno-science for economic development’ (2007:
in 't Veld (2010) described the transition from the knowledge economy to knowledge democracy as follow: ‘As the industrial economy has been combined with mass democracy through universal suffrage and later by the rise of mass media, one might suggest that the logical successor of knowledge economy is a new type of governance, to be called “knowledge democracy”’ (2010: 6).

Carayannis et al. (2021) further relate the Helix Trilogy to Quadruple and Quintuple Helix innovation systems that emerged as a response to the transition from Industry 4.0 to Industry 5.0. Carayannis et al. (2021) consider Industry 5.0 and Society 5.0 interchangeable terms. They distinguish Industry/Society 5.0 from Industry 4.0 as follows: ‘While Industry 4.0 focuses on production, Society 5.0 aims to put human beings at the centre of innovation, taking advantage of the impact of technology and the results of Industry 4.0 with the deepening of technological integration in improving quality of life, social responsibility and sustainability’ (Carayannis et al., 2021: 13). Another significant contribution of Carayannis and Campbell to conceptualising innovation ecosystems is their elaboration of the Mode 3 knowledge production system (Carayannis and Campbell, 2012). Mode 3 extends Mode 1 (discipline-based) and Mode 2 (practical and interdisciplinary) knowledge production systems (Gibbons, 1998). Model 3 knowledge production is defined as follows:

The nexus or hub of the emerging twenty-first century Innovation Ecosystem, where people, culture, and technology ... meet and interact to catalyse creativity, trigger invention, and accelerate innovation across scientific and technological disciplines, public, and private sectors ... and in a top-down, policy-driven as well as bottom-up, entrepreneurship empowered fashion.

Carayannis and Campbell, 2012: 4

Both Society 5.0 and Mode 3 knowledge production systems address the importance of knowledge democracy and the natural environment in innovation ecosystems. Mode 3 knowledge production and the Quadruple and Quintuple helices help ‘convert the “creative destruction” (at least partially) into a “creative learning” and a “creative co-evolution”’ (Carayannis and Campbell, 2010: 58). Carayannis and Campbell (2021) summarised the core theme of the Quadruple and Quintuple Helix innovation systems in two aspects. First, the further advancement of knowledge and innovation is seriously constrained without democracy or knowledge democracy. Second, environmental protection also acts as a driver for further knowledge and innovation, which should result in a win–win situation for environmental sustainability and sustainable innovation.
Carayannis and Campbell (2021) also emphasised that innovations developed in the context of intertwined knowledge democracy and ecology are likely to be socially responsible or aligned with the United Nations' Sustainable Development Goals. They define ‘sustainable development as a co-evolution of the different systems of society, based on knowledge and a mutual cross-learning that is socially and environmentally sensitive and that is receptive for concepts of a quality of democracy’ (Carayannis and Campbell, 2010: 59).

While Carayannis and Campbell initially developed both Quadruple and Quintuple Helix models as approaches to innovation (eco)systems, Etzkowitz and Leydesdorff distinguished the Triple Helix from innovation systems. Etzkowitz and Zhou (2017) note that the Triple Helix goes beyond innovation systems. The innovation system has its theoretical root in general systems theory. The Triple Helix model is grounded in Simmel's triadic interactions. Leydesdorff explains that triadic interactions are used to ‘measure the extent to which innovation has become systemic instead of assuming the existence of national (or regional) systems of innovations on ... prior grounds’ (Leydesdorff, 2012: 25). Nevertheless, the Triple Helix model, emerging in the transition from the political to the knowledge economy (Leydesdorff, 2021), is enabled by social conditions (Cai, 2014, 2015).

The discussions above lead to the following tentative propositions:

– Proposition 4: The Triple Helix and Quadruple/Quintuple Helix address innovation dynamics and innovation (eco)systems, respectively, and although these influence each other, they belong to different layers of analysis.

– Proposition 5: Knowledge democracy and ecological sensitivity enable innovation associated with sustainable development.

– Proposition 6: The dynamics and systemness of innovation ecosystems can be reflected (measured) by triadic interactions elaborated in the Triple Helix model.

2.3 Lewontin's Triple Helix

American evolutionary biologist Richard Lewontin's (2001) book *The Triple Helix: Gene, Organism, and Environment*, partially, inspired me to integrate the helix models. Lewontin's Triple Helix does not refer to triple-stranded DNA that makes up genes but rather to the relations between genes, organisms and the environment. Lewontin criticises both genetic determinism (that organisms are developed through sequential genetic programming) and environmental determinism (that organisms adapt to their environment). He argues for dialectical relationships between the genes, organisms and the environment, all of which are causes and effects simultaneously (Lewontin, 2001). Although
Lewontin elaborated on the triple helix interactions between genes, organisms and the environment in his book, but did not provide diagrams to help readers (especially laypersons) quickly understand his model. At the risk of oversimplifying it, I have illustrated Lewontin’s Triple Helix in Figures 3 and 4. Figure 3 describes spatial relations between genes, organisms and the environment, whereas Figure 4 indicates the cause-and-effect (co-evolution) relations between genes, organisms and the environment.

I introduce Lewontin’s Triple Helix not to apply the biological metaphor for modelling social processes but because it triggers my thinking. Lewontin’s Triple Helix is somehow similar to Helix Trilogy; the relations between the Triple Helix model, civil society and the natural environment are similar to...
those between genes, organisms and the environment. However, I consider Lewontin's Triple Helix a source of inspiration in developing a new helical approach because it offers new perspectives (implied in Figure 3 and 4) to reconsider the Helix Trilogy. On the one hand, Figure 3 reminds me that instead of visualising the Triple Helix, social structure (civil society) and natural environment as each representing a circle as illustrated by Carayannis and Campbell (2021) (See Figure 2), there could be multiple interconnected Triple Helix models (as innovation genes) within one social structure and multiple interconnected social structures within the natural environment. The multiple Triple Helix models and social structures better reflect the complex reality. On the other hand, my inspiration taken from Figure 4 is that besides looking at the spatial relations between Triple, Quadruple and Quintuple Helix models (i.e. the latter contextualising the former), it is also important to understand their 'dialectical relationship of cause-and-effect' (Hegel, 1969), which have not been well elaborated in the existing literature on helical approaches. The discussions here lead to the following tentative proposition:
Proposition 7: The relations between Triple Helix, Quadruple Helix and Quintuple Helix can be better understood when taking the perspectives of spatial relations and dialectical relationship of cause-and-effect.

3 Neo-Triple Helix Innovation Ecosystems

Based on the above propositions, I propose the neo-Triple Helix model of innovation ecosystems. Before elucidating the model, I discuss the concept of an innovation ecosystem.

3.1 Innovation Ecosystems

While the literature frequently discusses the concept of an innovation ecosystem, ‘few academic articles [use] “innovation ecosystem” in a manner that would distinguish an innovation ecosystem from an innovation system’ (Oh et al., 2016: 2). Based on their review of the literature on innovation ecosystems, Cai et al. (2019: 6) concluded that ‘what is new in the innovation ecosystem is its ecological aspect, characterised by the interdependency among different collaborative actors and the co-evolution/co-creation that binds them together over time, along with the sustainable development dimension’. Moreover, the innovation ecosystem fosters sustainable innovation, which is defined as ‘innovation that improves sustainability performance, where such performance includes ecological, economic, and social criteria’ (Boons et al., 2013: 2). In light of this, Cai et al. (2020: 2) define innovation ecosystems as co-innovation networks, in which actors from organisations concerned with the functions of knowledge production, wealth creation and norm control interact with each other in forming co-evolution and interdependent relations (both direct or indirect) in cross-geographical contexts, and, through which new ideas and approaches from various internal and external sources are integrated into a platform to generate shared values for the sustainable transformation of the society.

Compared to the most commonly cited definitions of innovation ecosystem (Gomes et al., 2018; Scafarto et al., 2019), Cai et al.’s (2020) definition highlights three new aspects of interactions in co-innovation networks, namely cross-sectoral interactions, transnational spanning and indirect relations, drawing on the innovation, geography and biology studies literature. They address an urgent need to enhance conceptual or theoretical understandings of innovation ecosystems. As noted by Oh et al. (2016), the concept of an innovation...
ecosystem has been defined in an abstract manner and is loosely used; it is often understood as a metaphor rather than a theory or framework. Thus, Ritala and Almanopoulou (2017) and Gu et al. (2021) called for future research to improve the conceptual, theoretical and empirical rigour of the notion of an innovation ecosystem.

The Quadruple and Quintuple Helix approaches provide a relatively comprehensive conceptualisation of innovation systems (Carayannis and Campbell, 2021). The Quadruple and Quintuple Helix models of innovation ecosystems were first elucidated by Carayannis et al. (2018: 159), who developed ‘a theoretical framework for the study and design of regional and sectoral co-opetitive innovation ecosystems embedded within a Quadruple/Quintuple Helix context’. Carayannis et al. (2018) understood innovation ecosystems as ‘agglomerations of organisational and institutional entities or stakeholders with socio-technical, socio-economic, and socio-political conflicting as well as converging (co-opetitive) goals, priorities, expectations, and behaviours that they pursue via entrepreneurial development, exploration, exploitation, and deployment (DEED) actions, reactions, and interactions’ (2018: 149). From the Quadruple and Quintuple Helix perspectives, the core organisational entities or stakeholders in innovation ecosystems are UIG (emphasised by the Triple Helix model), and the socio-technical, socio-economic and socio-political conflicts among stakeholders (through their goal pursuing and interactions) can be better understood by taking into account knowledge democracy and ecology (emphasised by the Quadruple and Quintuple Helix models). Carayannis et al. (2018: 149) also characterised innovation ecosystems as ‘fractal, multi-level, multi-modal, multi-nodal, and multi-lateral configurations of dynamic tangible and intangible assets’.

To gain a deeper theoretical understanding of innovation ecosystems, one should pay attention to the ‘social ecosystems’ model developed by Kenneth Boulding, co-founder of general systems theory. Current conceptualisations of innovation ecosystems, to a large extent, are built on Boulding’s statements about the fundamental ideas of ecosystems, such as that ‘the first principle of an ecosystem is that everything depends on everything else’ (Boulding, 1970: 24). Arnold (2015) provided a thorough review of the ‘social ecosystems’ model based on an analysis of several of Boulding’s relevant publications. Arnold noted that ‘Boulding’s thought provides fertile ground for rethinking the connection between social and natural systems and for rethinking ... how technologies unfold and affect the natural environment’ (2015: 16). Boulding’s comparison of social systems and ecological systems helps rationalise the analogy between Lewontin’s Triple Helix and the neo-Triple Helix model of innovation ecosystems.
3.2 *Key Components of the Neo-Triple Helix Model of Innovation Ecosystems*

My conceptualisation of neo-Triple Helix model of innovation ecosystems uses the metaphor of Lewontin’s Triple Helix relations between gene, organism and environment, which differs from the triple-stranded DNA metaphor used by Etzkowitz and Leydesdorff when developing their Triple Helix. Although a biological metaphor cannot be used to explain social systems due to differences between cultural and biological evolution (Giddens, 1979), a metaphor can help researchers ‘to reduce the complexity for the discursive understanding’ (Etzkowitz and Leydesdorff, 2000: 114). This implies that the use of metaphors (e.g. for developing the Triple Helix model and the neo-Triple Helix model) is mainly for simplifying the description of complex phenomena, rather than illuminating social systems using the models of biological systems that were criticised by Giddens (1979). As Lewontin (2001: 3) put it, ‘It is not possible to do the work of science without using a language that is filled with metaphors’. My purpose in referring to Lewontin’s Triple Helix is to simplify the complicated relations between the Triple, Quadruple and Quintuple Helix models. Specifically, I developed an analogy between Lewontin’s Triple Helix and the neo-Triple Helix model of innovation ecosystems (Table 1).

**Table 1: The Analogy between Lewontin’s Triple Helix and the Neo-Triple Helix Model of Innovation Ecosystems**

<table>
<thead>
<tr>
<th>Lewontin’s Triple Helix</th>
<th>Neo-Triple Helix model of innovation ecosystems</th>
<th>Relations to helical models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gene</td>
<td>Innovation dynamics (innovation genes): UIG triple helix interactions fostering innovation and entrepreneurship</td>
<td>That innovation dynamics derive from the UIG triads is a core theoretical assumption of the Triple Helix model</td>
</tr>
<tr>
<td>Organism</td>
<td>Social structures emphasising knowledge democracy/civil society</td>
<td>Knowledge democracy is the most novel aspect of the Quadruple Helix model</td>
</tr>
<tr>
<td>Environment</td>
<td>The natural environment</td>
<td>The importance of the natural environment in innovation and sustainable development are addressed by the Quintuple Helix model</td>
</tr>
</tbody>
</table>

Source: The author
The analogy can be justified by the Quadruple and Quintuple Helix models, as the former helps elaborate the relations between the social structures (emphasising civil society or the public as a growingly important dimension in the knowledge society) and innovation dynamics (innovation genes) and the latter deals with the relations between innovation genes, social structures and the natural environment (Carayannis et al., 2021).

Edquist (2001) suggests that when theorising about innovation systems, it is crucial to identify the key components and the relations between them in the systems. The key elements in the neo-Triple Helix model of innovation ecosystems are innovation dynamics (genes), social structures and the natural environment. Next, I elaborate on each of the components and their relations by integrating the Triple, Quadruple and Quintuple Helix models. My elaborations are mainly based on the seven propositions mentioned above.

3.2.1 Innovation Gene/Innovation Dynamics
Here, I use genes as a metaphor for innovation dynamics, which refers to the interactions between three spaces: knowledge, consensus and innovation spaces, in which knowledge production, normative control and wealth creation take place. Innovation genes (innovation dynamics) are made up of triple helix DNA – an ideal-type Triple Helix model (Etzkowitz and Leydesdorff, 1995, 2000). These are illustrated in Figure 5. In each space, multiple players are engaged in performing related functions. The Triple Helix model regards UIG as primary players (Etzkowitz and Leydesdorff, 1995, 2000). The dynamics for innovation primarily come from their interactions through the mechanism of ‘taking the role of the other’ (Etzkowitz, 2008), which both leads to and is facilitated by an overlap of the three spaces. However, the model does not exclude other actors, such as intermediaries, legal firms and non-governmental agencies, but treats them as secondary players (Cai and Etzkowitz, 2020).

3.2.2 Social Structure
Borrowing the term organism from biology, Herbert Spencer developed the concept of ‘social organism’ as a reference point to elucidate the meaning of ‘society’ (Offer, 2019). According to Boulding, social and biological organisms are similar in their functions and roles in social ecosystems and ecologic systems, since both are ‘behaviour units’ or ‘behaviour systems’ and ‘engage in processes of exchange’ (Arnold, 2015: 7). As Masyuk et al. (2019) put it, ‘The ecosystem approach considers innovation systems of all levels (national, regional, cluster, etc.) as living social organisms, subject to continuous variability under the influence of new motivations of participants and new circumstances.’
Social organisms can be understood as social structures concerning not only ‘a dynamic set of organisations and institutions’ but also ‘a mobile set of their multidimensional internal connections’ (Masyuk et al., 2019: 2).

The Triple, Quadruple and Quintuple Helix models all address social structures in innovation systems. Etzkowitz and Leydesdorff (2000) suggest that the Triple Helix model displaces the patterns of the social structure. Etzkowitz (2008: 16) emphasises that the Triple Helix is developed in the context of civil society (represented by voluntary organisations), being ‘the social structure of the Triple Helix’. This implies that the Triple Helix model both influences and depends on the social structure. However, Etzkowitz and Leydesdorff have not

**Figure 5** Innovation Genes/Innovation Dynamics

*Source: Based on synthesising Etzkowitz and Leydesdorff (2000), Etzkowitz (2008), and Cai and Etzkowitz (2020)*
committed to specifying the social structure, probably because they focused on the mechanisms of innovation dynamics within the structure.

According to the Quadruple Helix model, an innovation ecosystem is associated with the social structure promoting knowledge democracy (Carayannis and Campbell, 2021). In other words, innovation ecosystems exist in political systems that ‘must be democratic in substance, and not only in form’ (Carayannis and Campbell, 2021: 2050). Knowledge democracy is enabled by ‘media-based and culture-based public and civil society’ (Carayannis and Campbell, 2012: 13) and constitutes the fourth helix or, more accurately, the contextual condition of the Triple Helix. Certainly, ‘the public’ does not represent the entire social structure; however, it is the essential aspect of the structure in innovation ecosystems. Carayannis and Campbell (2009: 206) argue that ‘plausibility for the explanatory potential of such a fourth helix is that culture and values, on the one hand, and the way how “public reality” is being constructed and communicated by the media, on the other hand, influence every national and every multilevel innovation system’.

Carayannis et al. (2018) also noted that innovation ecosystems can be local, national and transnational. As such, the social structures associated with innovation ecosystems can exist at different levels, such as one district within a city, a city, a province, a state or a transnational context (e.g. the EU). Innovation genes exist within social structures. In the social structure of a district, one innovation gene (place-based triple helix interactions between knowledge, innovation and consensus spaces) is likely to be observed (e.g. Cai and Liu, 2015). There can be more innovation genes in the social structure of a larger context, such as a city or country (Figure 6).

3.2.3 The Natural Environment

While the Quadruple Helix model implies that sustainable development for an economic system must be socially and environmentally sensitive (Carayannis and Campbell, 2009), the Quintuple Helix model makes the point explicit by addressing the relations between the natural environment, society and economy (Carayannis and Campbell, 2010). The Quintuple Helix approach to innovation ecosystems accentuates the perspective of social ecology in understanding the process of knowledge production and innovation. As Carayannis et al. (2021: 8) put it,

environmental problems, for example, climate problems such as global warming, represent themes and topics in relation to the survival of human civilisation or humanity as a whole. But at the same time, the
Quintuple Helix regards environmental or ecological challenges also as possible drivers for further and new knowledge and innovation, by this future knowledge and future innovation, which may have the potential to also finally advance society, economy and democracy.

Innovation genes, social structures and the natural environment constitute the neo-Triple Helix model of innovation ecosystems (Figure 7). Within the natural environment, there is a wide array of interrelated social structures on
various levels and in different geographical locations. Innovation genes are not only linked to each other within the same social structure, but also connected with innovation genes in other social structures. Their connections are mainly through collaborations between universities, firms and governments. Such connections are the microfoundations of transnational innovation ecosystems (Cai et al., 2019).

3.3 Relations between Innovation Genes, Social Structures and the Natural Environment

The core components of the neo-Triple Helix model of innovation ecosystems, namely innovation genes, social structures and the natural environment, can be understood further in the context of the dialectical relations between them (Figure 8). The relations or interactions, which are value co-creation in nature (Sanna & Katri), take place in a co-evolutionary process (Carayannis and Campbell, 2010). The interactions create dynamics for sustainable development. These relations are explained below.
3.3.1 Relations between Innovation Genes and Social Structures

The interrelations between innovation genes and social structures are clearly reflected in the classic literature on helix models. First, as discussed earlier, the Triple Helix model of UIG interactions is not equal to the innovation system but is the DNA of innovation genes. Innovation genes can influence and displace social structures (Etzkowitz and Leydesdorff, 2000). Leydesdorff and Lawton Smith (2022) claim that, unlike ‘biological DNA, the [Triple Helix] genes are not “given” in processes of cultural evolutions, but theoretically constructed’ (2022: 4). Second, the social structure enables innovation genes and Triple Helix DNA. The Triple Helix thesis asserts that an ideal-type Triple Helix model occurs in certain social conditions (Cai and Etzkowitz, 2020). Both Etzkowitz and Leydesdorff acknowledge that civil society is the societal foundation of the Triple Helix model (Etzkowitz, 2015; Leydesdorff, 2012). By synthesising the relevant Triple Helix literature, Cai et al. (2015) identified a list
of enabling conditions (both tangible and intangible) that facilitate the triple helix interactions of UIG. The contribution of Quadruple and Quintuple Helix models to the Triple Helix model is to elaborate on the social–environmental contexts of the Triple Helix (Carayannis et al., 2021).

3.3.2 Relations between Social Structures and the Natural Environment
When proposing the Quintuple Helix model, Carayannis and Campbell (2010) were inspired by Schumpeter’s understanding of the relations between economic change in capitalism and the environment, including both social and natural dimensions, as part of his elaboration of the concept of ‘creative destruction’ (Schumpeter, 1942). As Schumpeter (1976: 82) put it, the ‘evolutionary character of the capitalist process is not merely due to the fact that economic life goes on in a social and natural environment which changes and by its change alters the data of economic action; this fact is important and these changes (wars, revolutions and so on) often condition industrial change, but they are not its prime movers’. Thus, the conceptualisation of the Quintuple Helix model suggests that while environmental challenges affect value systems and communication discourse, social actions (among other factors) also lead to environmental changes (Carayannis et al., 2021).

3.3.3 Relations between Innovation Genes and the Natural Environment
Innovation genes and the natural environment influence each other through social structures, as in Lewontin’s Triple Helix, in which genes and the environment influence each other through organisms. However, in social systems, human behaviour and innovations as outcomes of triple helix interactions of UIG can directly affect the environment. Similarly, environmental challenges may trigger changes in social norms and public policies, on the one hand, and strengthen the ethos for sustainable development of individuals engaged in innovation genes, on the other (Carayannis and Campbell, 2021).

3.4 From a Concept to a Potential Theory
The neo-Triple Helix model is still at the conceptual level. Like other helical models, it applies a metaphor; however, this metaphor differs from the metaphors of others. The Triple Helix model employs a triple-stranded DNA metaphor (Etzkowitz and Leydesdorff, 2000). The Quadruple and Quintuple Helix models employ ecological metaphors (Carayannis and Campbell, 2021). The neo-Triple Helix model’s metaphor is Lewontin’s Triple Helix, which integrates both biological and ecological perspectives. As mentioned earlier, by using metaphorical language, these helical approaches seem ‘to appeal to the understanding of the world that we have gained through ordinary experience’
(Lewontin, 2001: 3). In addition, the neo-Triple Helix model is conceptualised by integrating the Triple, Quadruple and Quintuple Helix innovation models.

While the neo-Triple Helix model of innovation ecosystems was conceptualised with detailed explanations and visual illustrations above, it can be simply described as triads within triads in terms of spatial relations (Figure 7) or two-layer triple helices in terms of the level of dynamics (innovation gene-level as shown in Figures 5 and innovation ecosystem-level as shown in Figure 8). The dynamics of the two levels are concerned with innovation and sustainable development, respectively. The two sets of triads or triple helices are different in nature: the UIG triple helix interactions mainly concern agents and their relations; the interactions of innovation genes, social structures and the natural environment entail agency-structure relations. Together, they constitute the ‘duality of structure’, where individual and social structures influence each other (Giddens, 1984), but in the social-ecological contexts.

By synthesising the insights of Triple, Quadruple and Quintuple helical approaches, the neo-Triple Helix model has the potential to provide nuanced theoretical accounts of new characteristics of innovation ecosystems, such as ‘sustainable innovation’, ‘cross-sectoral interactions’, ‘transnational spanning’ and ‘indirect relations’, as discussed in the section on innovation ecosystems. To realise this potential, especially for enhancing the model’s efficacy in empirical studies and policy analyses, more solid theoretical foundations are required. Nevertheless, the current conceptualisation can pave the way for further theorising, since it meets the three criteria for developing an optimal theoretical approach to innovation ecosystems, which Cai and Lattu (2021) suggested by referring to some classic literature.

First, Lundvall noted that ‘what qualifies as a good theory of innovation is not carved in stone but has to evolve as a result of changes in society and our attempts to understand these challenges’ (Fagerberg et al., 2013: 7). The development of helical approaches, from the Triple Helix to the Quadruple Helix and the Quintuple Helix, reflects scholarly efforts to capture new changes and emerging challenges in a knowledge society (Cai and Lattu, 2021). By integrating insights provided by these helical approaches, the neo-Triple Helix model provides a conceptual framework for advancing our understanding of contemporary society for sustainable innovation.

Second, when developing a theoretical/conceptual framework, one must avoid overcomplicating its analytical foci. This concerns Occam’s razor principle, which advocates including complex constructs only if essential (Braithwaite, 2017). The Triple Helix model considers triadic interactions as Occam’s razor principle; the complex interplays between innovation actors are simplified according to Simmel’s social geometry of triadic interactions.
The neo-Triple Helix model also focuses on triadic interactions but in two layers: the innovation gene layer and the innovation ecosystem layer.

Third, the theory of innovation ecosystems deals with the conditions and mechanisms that foster sustainable innovation, including environmental, social and economic dimensions (Elkington, 1998). The neo-Triple Helix model explains dialectical relations between the key components in innovation ecosystems – i.e. innovation genes, social structures and the natural environment – which address sustainable innovation in economic, social and environmental dimensions as well as their interrelations.

Re-Examining the Relations between the Triple Helix and the Quadruple/Quintuple Helix from the Neo-Triple Helix Model’s Perspective

From the perspective of neo-Triple Helix model, there are fewer discrepancies but more potential for synergy building between the Triple Helix and the Quadruple/Quintuple Helix.

Harmonising Discrepancies between Triple Helix and Quadruple/Quintuple Helix

Etzkowitz and Leydesdorff’s main criticism of the Quadruple/Quintuple Helix models was that they violate Occam’s razor. As noted by Zhou and Etzkowitz (2021: 3), for example, ‘the triadic model is in line with the reasonableness parsimony criteria of Occam’s Razor’. Leydesdorff and Lawton Smith (2022) suggest that helices that include more than three dimensions should be decomposed into multiple triplets, each of which generates synergy. However, from the neo-Triple Helix model perspective, the Quadruple and Quintuple approaches to innovation ecosystems can also align with Occam’s razor: they do not amend the triadic interactions between UIG as the sources of dynamics for innovation (or innovation genes) but bring in a system perspective on the triadic interactions between innovation genes, social structures and the natural environment. In sum, the Triple Helix model deals with triads at the gene level, and from the Quadruple/Quintuple Helix perspective, innovation genes can be part of system-level triads. Nevertheless, it should be noted that there is debate about Occam’s razor in innovation studies. For instance, Lundvall (2010:331) warned that ‘the methodological dictum within neoclassical economics that a theory should be both general and abstract sometimes takes Occam’s razor too far leading to negligence of the concrete and historical’. When Carayannis and
Campbell developed the Quadruple and Quintuple Helix innovation models, they probably did think Occam's razor applied to their models.

Carayannis and Campbell (2021) argued that the Triple Helix thesis does not explicitly address democracy and ecology, which are crucial aspects of innovation ecosystems. When analysing Etzkowitz and Leydesdorff’s classic publications on the Triple Helix, Carayannis and Campbell (2021) found that terms such as ‘civil society’, ‘democracy’ and ‘ecology’ only appeared sporadically. They inferred that while Etzkowitz and Leydesdorff recognised the importance of civil society and the natural environment for the Triple Helix, they did not integrate them into the Triple Helix thesis. From the neo-Triple Helix model perspective, however, the Triple Helix model, which conceptualises innovation dynamics at the gene level, is supposed to remain an independent analytical unit from the concepts of social structure and the natural environment.

Resolving the aforementioned disputes helps address a dilemma in building synergies between Triple and Quadruple/Quintuple Helix models: while integrating the two supplementary models could potentially provide a useful analytical tool for understanding the mechanisms of innovation processes in contemporary society, it is a challenge to integrate them due to their different theoretical orientations (Cai and Lattu, 2021). The neo-Triple Helix model largely keeps the merits of both the Quadruple/Quintuple Helix and Triple Helix – being ‘flexible enough to incorporate emerging factors on the one hand’ and ‘adhering to the Occam’s razor principle on the other’ (Cai and Lattu, 2021: 18) – simultaneously.

4.2 Advancing Helical Approaches
The neo-Triple Helix model’s unique perspective facilitates 1) the rethinking and enhancement of the theoretical grounds of the Triple Helix and Quadruple/Quintuple Helix models and 2) the clarification of the relations between them.

When rethinking the Triple, Quadruple/Quintuple Helix models from the neo-Triple Helix model perspective, one must know how the latter model is different from the former. Like the Triple Helix model, which emphasises the triad as a basic unit of analysis following Occam’s razor, the neo-Triple Helix model also satisfies this principle, since it simplifies innovation ecosystems as two kinds of triple helices or triads. As mentioned earlier, Leydesdorff and Lawton Smith (2022) suggested decomposing the Quadruple, Quintuple or N-tuple helices into interacting triple helices. Zhou and Etzkowitz (2021) proposed decomposing the Quadruple Helix model into Triple Helix twins: combining the UIG Triple Helix and the university–public–government Triple Helix. However, the neo-Triple Helix model does not suggest breaking down
Quadruple/Quintuple Helix, which adds the public (P) and the environment (E) to the Triple Helix, into multiple triads (e.g. UIG, UIP, UIE, UGP, UGN, and UCE etc.). Instead, it insists that the triple helix interactions of UIG remain the core triads for understanding and measuring innovation dynamics at the gene level. At the same time, it emphasises that innovation genes (dynamics), which are made of Triple Helix DNA, are dialectically related to civil society (the public) and the natural environment, constituting the triad at the system level.

Both the neo-Triple Helix model and the Quadruple/Quintuple Helix approach consider positioning the Triple Helix model in the context of civil society and the natural environment. However, unlike the visualisation of the Triple Helix, society and natural environment developed by Carayannis and Campbell (2021), wherein each of the components is represented by a circle (Figure 2), the neo-Triple Helix model distinguishes multiple interconnected innovation genes (composed of Triple Helix DNA) within one social structure (Figure 6) and multiple interconnected social structures within the natural environment (Figure 7). Configuring multiple Triple Helix models and social structures in the neo-Triple Helix model can explain the growing intensity and complexity of interrelations between actors across geographical boundaries and highlight the transnational nature of innovation ecosystems.

Some examples of how the neo-Triple Helix model can clarify debates on different helix innovation models and advances helical approaches are provided below.

First, it answers a hotly debated question in innovation studies: How is the Triple Helix model different from an innovation system? In the second edition of The Triple Helix, Etzkowitz and Zhou (2017) directly respond to the question by arguing that the Triple Helix thesis goes beyond innovation systems theory, but their explanations of the differences between the Triple Helix and innovation systems remain relatively abstract (Cai, 2020). Recently, Zhou and Etzkowitz (2021: 3) further elaborated on their position that the Triple Helix, as a universal model, serves as a spiral tool to develop an innovation system and ‘can be used to address issues in micro, meso and macro levels’. In line with their thinking, the neo-Triple Helix model further distinguishes the Triple Helix model and innovation (eco)systems by conceptualising the former as a Triple Helix DNA (which constitutes innovation genes) and the latter as innovation ecosystems consisting of innovation genes, social structures (civil society and knowledge democracy) and the natural environment.

Second, when conceptualising innovation genes, I have critically reflected on and integrated Etzkowitz’s neo-institutional and Leydesdorff’s neo-evolutionary perspectives of the Triple Helix. The integration of the two perspectives better explains how the triple helix spheres and functions make up
triple helix spaces. It also makes it possible to operationalise or measure ‘taking the role of the other’, which can hardly be grasped in empirical research due to lacking appropriate analytical tools. The measurements include not only Leydesdorff’s method of measuring triple helix synergies, but also other approaches, such as the one measuring how efficiently the triple synergies are achieved (Jovanović et al., forthcoming).

Third, the neo-Triple Helix model further explains Carayannis and Campbell’s (2021: 2056) proposition that ‘the Quadruple Helix integrates and contextualises the Triple Helix, while the Quintuple Helix integrates and contextualises the Quadruple Helix (and the Triple Helix)’. Specifically, the neo-Triple Helix model simplifies the complex Quadruple/Quintuple Helix innovation ecosystems as triads within triads or two-layer triple helices. The relations between innovation genes and social structures account for how the Quadruple Helix integrates and contextualises the Triple Helix. The relations between social structures and the natural environment account for how the Quintuple Helix integrates and contextualises the Quadruple Helix. The relations between the natural environment and innovation genes account for how the Quintuple Helix integrates and contextualises the Triple Helix. Nevertheless, the relations between innovation genes, social structures and the natural environment, described in the neo-Triple Helix model, are on a conceptual level. The Triple Helix models’ concrete theoretical explanations about the mechanisms underlying Triple Helix interactions at the gene level can be used as a basis for further theorising about how Triple Helix genes influence or are influenced by civil society and the natural environment. Etzkowitz (2008) pointed out that the innovation dynamics of the Triple Helix model are derived from both internal transformations in UIG and the three actors ‘taking the role of the other’. Thus, when trying to understand the influence of citizens’ participation on Triple Helix interactions, one can focus on how citizens’ engagement helps transform organisations in each sector, on the one hand, and facilitate the mechanism of ‘taking the role of the other’, on the other.

5 Conclusion

As a response to recent calls for building synergies between the Triple, Quadruple and Quintuple Helix models (Cai and Lattu, 2021; Carayannis et al., 2021; Leydesdorff and Lawton Smith, 2022), I proposed the neo-Triple Helix model of innovation ecosystems, which consists of two layers of triple helix interactions (or triads within triads): the UIG Triple Helix at the gene level and the triple helix interactions between innovation genes/dynamics, social
structure and the natural environment at the system level. The neo-Triple Helix model, as a conceptual tool, can help researchers fully utilise and creatively combine insights provided by the triple, Quadruple and Quintuple Helix models. Moreover, it provides a template for integrating other approaches in innovation studies and other relevant social science theories to develop a more powerful theoretical framework to guide empirical research and policy design (analysis) on innovation ecosystems.

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