

The Quadruple Helix and social science; arguments for a small EU Reformers region like Alkmaar

Working paper

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Abstract. The REFORMERS project aims to develop a sustainable ecosystem with the quadruple helix approach. This approach evolved from the triple helix theory, with universities, companies and governments of knowledge exchange for innovation, to a fourth element: the social factor. The question is whether this concept can be easily applied to smaller regions without universities for fundamental research and leading innovative industries. Although the quadruple helix adds the social factor, the literature seems to be more inspired by new information and communication technology than by sociological knowledge. This paper starts with the basic triple helix from Leydesdorff (Leydesdorff, 2020) and his scientometric operationalization inspired by Luhmann (Luhmann, 2013) followed by the extension to the quadruple helix with quite another focus. Then the four subsystems of the quadruple helix is filled in with the subsystems of the social AGIL scheme from Parsons. The philosophic line runs from Kant (Kant, 2006) (Kant, 2004) (Kant, 2021) to Parsons (Parsons & Platt, 1973) and then to Luhmann and Habermas, who differ from each other in some respects. Here the Habermas line is explored. The importance of learning and proximity is briefly mentioned. Finally, a research direction in line with network-oriented modelling for adaptive networks is indicated

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Introduction

The REFORMERS project aims to develop sustainable ecosystems through the quadruple helix approach in the Renewable Energy Region a Flagship of the region Alkmaar. This approach, which evolved from the triple helix theory of knowledge exchange for innovation, adds a fourth element: the social factor. However, the question is whether this concept can be easily applied to smaller regions such as in Alkmaar without universities and leading innovative industries. In the context of path dependency, the development of a region should be in line with activities that have arisen in the past. Information systems also determine the scenarios for paths in the future, but it is people who, through learning, must make that happen.

This paper starts with one of the founders of the triple helix followed by a brief discussion about the quadruple helix that originated from it. Then it focuses on the

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AGIL scheme and concludes with a forward-looking network. That results in the following paragraphs

1. *The triple helix of Leydesdorff* (Leydesdorff, 2020)

One of the founders of the triple helix Leydesdorff starts with philosophy and sociology but focuses mainly on communication theory with scientometric, the quantitative aspects of scholarly literature as operationalization. This has limitations certainly for regions like Alkmaar without a university with many scientific papers

2. *The Quadruple Helix* (Carayannis, Campbell, & Grigoroudis, 2021), (Yun & Liu, 2019)

The extension to the quadruple helix (including society) with the current trend is then described. Some specific characteristics makes this model less applicable for small regions without a university for fundamental research and global industries. Proximity between people in the local community becomes more important

3. *The sociological AGIL reference scheme* (Hofman & Burgmans, 2005) (Hofman, Foks, & Kokhuis, 2000).

This can be corrected by inserting the AGIL scheme taking the sociological systems theory from Parsons'. This scheme can be built up from psychology to even the human condition (like Russian matryoshka dolls) but is limited here to the social system, which can also include, for example, how success factors of companies can be created by a country or region. Special attention is for:

- *Habermas versus Luhmann discussion*,
One of Leydesdorff's key points is his choice of Luhmann over Habermas who pays attention for the lifeworld which in Habermas' view is colonized by the system. The question of whether people are controlled by systems is increasingly relevant with new (information) technology.
- *Innovation and learning*
Innovation, what the quadruple helix is about is learning. It is then important at what level one wants to learn in a region, what environment is needed and where there are limitations. Information and communication systems can be supportive in that, but it is the people in the region who have to absorb it (B. Nooteboom, 2008) (Hofman & Leeuwen, 1998) (Hofman & Huijsmans, 1995).

4. *Network oriented modelling for adoptive networks* (Hofman & Treur, 2021).

Leydesdorff used three levels of communication but takes distance from neuroscience and big data. That seems partly unjustified. By analogy and better naming relationships in terms of spheres of influence, patterns can be analyzed. For this reason, network-oriented modelling for adoptive networks

is introduced, where Leydesdorff's levels fit in the AGIL scheme (Hofman & Treur, 2021).

Conclusions and directions for future research will be completed in this paper.

1. The Triple Helix

This paragraph will focus on the main points of Leydesdorff a Dutch sociologist, cyberneticist and communication scientist at the University of Amsterdam, known for his work in the Triple Helix model of innovation (worked together Etzkowitz in the 1990s Wikipedia).

Three themes have been central to my research program: (1) the dynamics of science, technology, and innovation; (2) the scientometric operationalization and measurement of these dynamics; and (3) the Triple Helix (TH) of university-industry-government relations.

University-industry-government relations provide an institutional infrastructure carrying the potential of self-organization in the knowledge base of an economy. I elaborated these themes into the problem of relating (i) Luhmann's sociological theory about meaning processing in communications with (ii) information-theoretical operationalizations of the possible synergies in Triple-Helix relations, and (iii) anticipatory mechanisms in cultural evolutions. (Leydesdorff, 2020)

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A key issue is the scientometric operationalization and measurement of the dynamics. Leydesdorff starts with an elaboration of the of Shannon – Weaver model what is criticized for its simplicity. But Leydesdorff made useful additions.

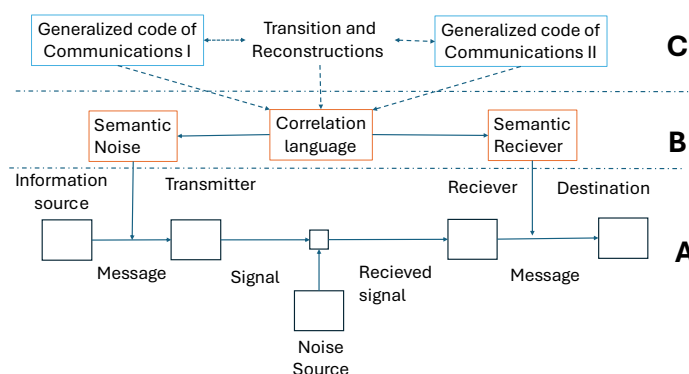


Fig. 1 Level A Shannon – Weaver, B and C added to the Shannon diagram Source: (Leydesdorff, 2020)

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In addition to the Shannon -Weaver model Leydesdorff proposes the levels B and C: meaning is conveyed at level B, and the received meaning can affect behavior from level C, so: .

- **Level A** – Information: Technical transmission of messages.
- **Level B** – Meaning: Interpretation and shared understanding among communicators.
- **Level C** – Code/Control: Symbolic rules and paradigms that regulate how meaning is formed and communication is validated.

These levels interact dynamically: meaning (B) builds on information (A), while codes (C) guide and stabilize both. This layered model explains how communication systems evolve and self-organize across time.

Leydesdorff uses the Triple Helix model (university–industry–government) to analyze how different societal subsystems communicate and co-evolve. Each helix operates with its own code (level C), creating distinct communication logics (e.g., truth in science, profit in business, power in government). Interactions between these systems generate innovation when their codes are translated across domains. Using scientometric methods, Leydesdorff maps these dynamics, showing how co-variation and mutual shaping occur through citations and knowledge flows—an application of his multi-level communication model.

According to Niklas Luhmann, science (domains), among other things, functions as an autonomous communication system that maintains itself through its own rules (level C). Scientific communication revolves around the production of truth within the system itself, for example through peer review: only experts are allowed to evaluate each other's work, which minimizes external input. Access for free publications is often limited to members of universities or institutions, further highlighting the system's closure to outsiders. This self-referential process – where only internal communication generates further communication – is what Luhmann calls autopoiesis. Thomas Kuhn approaches science from a historical perspective and introduced the concept of paradigms: shared frameworks of thought within a scientific community. According to him, science does not progress linearly, but through revolutions in which one paradigm is replaced by another. Compared to Luhmann, Kuhn (Kuhn, 2013) focuses more on substantive shifts within science, whereas Luhmann emphasizes the social structure and forms of communication. However, both recognize that science follows its own internal logic that sets it apart from other areas of society (see attachment).

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The exchange between domains of academics, companies and government in the triple helix is then due to Leydesdorff (in line with Luhmann) the translation between the (sub) systems. The way to get knowledge in the helix is looking at citations that scientists, companies and government makes among themselves in the various domains (scientometric (Leydesdorff, 2020)). The information is useful but limited. For that reason Hofman and Burgmans (Hofman & Burgmans, 2005) proposed the possibility of tracing additional the Triple Helix back to sociology with the AGIL-schema of Parsons. using insights from communication sciences but also more broadly from sociology. Various studies and insights from the different domains can in that model be used from different perspectives using clear system boundaries (Hofman, Foks, & Kokhuis, 2000). Still scientometric can be used if the researcher takes this perspective. In fact, this AGIL scheme provided already the picture of a quadruple helix.

2. The Quadruple Helix

After the Leydesdorff triple helix the quadruple helix was developed; Leydesdorff:

‘In sum, the Triple Helix can be related as a theme to theoretically and methodologically interesting questions and has become a meeting place for scholars from different disciplinary backgrounds with the aim of contributing to the improvement of innovation systems. The call for quadruple, quintuple, and next-order configurations has remained one that can be combined with other metaphors such as “responsible innovation” in “smart regions” which legitimate funding decisions but have hitherto not yet to offer substantive newness and research perspectives.’ (Leydesdorff, 2020)

This statement seems correct from his perspective (Leydesdorff & Lawton Smith, 2022) because the following helices ignore the communicative layers and the Habermas-Luhmann philosophies that he used as a basis. Civil society and later the environment is added, but the question is whether they perceive and experience history and evolution in the same way as Leydesdorff does and small regions without a university for fundamental research still get little attention.

Although the Quadruple Helix (QH) model was introduced to integrate civil society into innovation ecosystems—alongside academia, industry, and government—its practical implementation remains largely technocratic and market-oriented. As outlined in Yun and Liu’s (Yun & Liu, 2019) framework, societal engagement is frequently framed in terms of consumer involvement, crowdsourcing, and the adoption of open platforms. These approaches, while participatory in form, often serve to enhance product development cycles or market reach rather than deepen civic deliberation or normative reflection. In this sense, society is positioned more as a source of data or innovation input than as a democratic actor or enabler voor engagement.

This technocratic narrowing echo concerns raised by Galbraith in *The Affluent Society*, where he warns that corporations shape public wants to sustain their own growth, undermining autonomous public agency. Varoufakis's more recent critique of "techno-feudalism" (Varoufakis, 2024) further underscores how digital infrastructures may serve concentrated capital interests rather than inclusive democratic goals. These critiques suggest that the current Quadruple Helix configuration, as implemented in many open innovative contexts, insufficiently addresses questions of legitimacy, equity, and public empowerment.

Carayannis and Campbell (Carayannis E.G., Goletsis.Y, , & Grigoroudis.E.;, 2017) (Carayannis E.G & Campbell D.F.J, 2009) stress that the QH and its extension, the Quintuple Helix (Q5H), must be grounded in what they term "knowledge democracy"—a condition in which civil society actively co-defines the goals and values of innovation. Even MCDA is mentioned (Carayannis E.G., Goletsis.Y, , & Grigoroudis.E.;, 2017) a tool but not a philosophy how to connect paradigms. They argue that innovative systems should foster a "climate for democracy," where inclusion is not symbolic or instrumental, but structural and epistemically valid. This aligns with and should be much more connected with sociological theories that view legitimacy not merely as system performance (e.g., economic output) but as communicative inclusion (Habermas), institutional trust and negotiated meaning in pluralistic societies.

Therefore, a sociological reframing of the 'society' component within the QH could help resolve its current limitations. By incorporating concepts such as civic capacity, public reason, and social reflexivity, sociological models could enable innovation systems to move beyond tokenistic participation toward normative engagement. Such an approach would not only strengthen democratic legitimacy but also improve the societal sustainability of innovation itself. In this sense, sociology does not replace the QH model but enhances its depth and coherence, especially considering the socio-political complexities of the 4th and 5th industrial revolutions.

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3. The sociological AGIL reference scheme

This section first explains the AGIL scheme of Parsons. The sociologist (and economist) Parsons developed a reference scheme (Parsons, Bales, & Shils, 1953), applied it in practice (Parsons & Platt, 1973) (Parsons & Platt, 1973) and tried to elaborate it using systems theory (Adriaansens, 1976) see **fig. 2**. In his scheme Parsons used insights from biology and economics (Moss & Sauchenko, 2006) (Turner, 1999). However, systems theory was not yet developed well, and sociologists are not always attracted to mathematical models. So, this by itself useful reference scheme (Kerkhoff, 2007); (Jong de, 1997) was somewhat forgotten and the theory called an important 'high way out of order' (Castellani & Hafferty, 2009). Later, computer technology and modeling made great progress, e.g., (Stacey, 2001) (Kauffman, 2000). Economic science made the best use of this and became dominant over the fragmented sociological science of which it in fact forms a subdomain.

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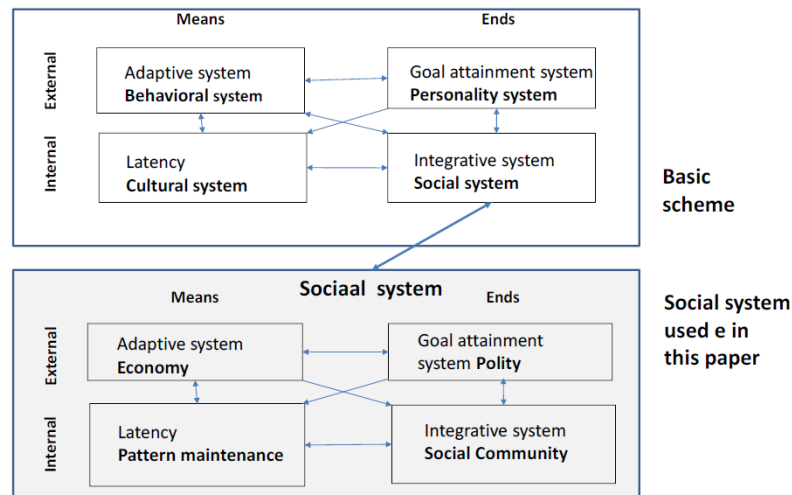


Fig. 2. Parsons reference scheme

The AGIL scheme, as it is called, is a reference scheme within which environmental influences and social changes can be interpreted. It is not a full blueprint, but it at least provides recognizable anchors. A system usually tends to reach an equilibrium, but over time it will adapt to changes in the environment to survive. It always differentiates into several processes or subsystems, each with its own function (Parsons & Platt, The American University, 1973).

Basic elements are:

- **Adaptation** that is constantly needed in interaction with the environment because resources are needed from the environment to survive.
- **Goal attainment** establishes priorities that are good for the subsystem.
- **Integration** promotes solidarity in the social system.
- **Latency** or pattern maintenance is necessary to maintain the underlying values of variables. This stems from history or evolution (Parsons & Toby, 1977) with learning and education as an important factor in the social system.

This is the top part of **fig. 2** and the basic scheme filled in with the individual part that carries the social subsystem system within it. A clear distinction is made in function of the subsystems, such for as for example means for the subsystem on the top left and ends on the top right. This can be completed at a different level for the social system:

- The economic system (A), which allows the system and *adapts* to what the environment offers to survive as a subsystem.
- The politicians for goals and *government* (G) that sometimes-subordinate individual needs for the benefit of the whole and uses power for the community.
- The community (I) is the *integration* of other subsystems based on norms and customs.

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- The *latency* (L) or pattern maintenance system for the social system, also called the fiduciary system, is necessary to maintain underlying values. This goes through the family, education, but also knowledge development is part of it (universities, research, etc.)

Depending on study, the further (sub)subsystems are filled in more specifically. For example for competitiveness of a region for a community (I) you can use factor conditions (A), demand (G), related industries (I) and firm strategy (L). This is the Porter scheme (Porter M. , 1990) (Porter M. , 1999), which is widely used in business administration and which is in turn related to more literature. Here we have a good basic scheme with elements that correspond to the quadruple helix.

A system does not only consist of objects but also of relationships between objects or subsystems. Through these relationships objects or subsystems communicate by means of media and in this way, they influence each other. One can try to reach agreement by means of language, but that is very cumbersome in the economy with barter. That is why there is the generic medium of money. If a police officer must enter discussion with every fine that is also cumbersome and so it is then the medium power that makes the offender pay. Regarding the social system, there are the following four generalized symbolic media: A: (Economy): Money. G: (Political system): Political power. I: (Societal Community): Influence. L: (Latency system): Value-commitment. As mentioned, the social system is part of a larger whole and each subsystem can be subdivided again, as for example in politics into legislative, executive and judicial power, as well as the federal law (Kerkhoff, 2007); (Hofman, Foks, & Kokhuis, 2000); (Hofman, 2018); (Hofman, 1998). They have their own media.

It is worth pointing to McLuhan with (McLuhan, 2002) (McLuhan & Powers, 1989): The instance of the electric light may prove illuminating in this connection (of media). The light bulb is a clear demonstration of the concept of "the medium is the message": a light bulb does not have content in the way that a newspaper has articles, yet it is a medium that has a social effect; that is, a light bulb enables people to create spaces during nighttime that would otherwise be enveloped by darkness. The same goes for new media like the internet, which is often used in the quadruple helix because it can accelerate information around innovation. The internet medium itself has no content but does change the world. It gives a different dynamic to the symbolic media of Parsons but they themselves do not change. New technology has consequences which can be good for one group but worse for other (Achterhuis e.a., 1997) (Achterhuis, 1992) (Ihde, 1990) and media bridge distances easily and make the world 'smaller', with new power relations (Varoufakis, 2024) but proximity between people remains important in some cases.

Habermas and Luhmann debate

eydesdorff aligns himself with Luhmann, whose starting point will be briefly outlined here. The historical trajectory runs from Immanuel Kant, through Talcott Parsons, to Jürgen Habermas and Niklas Luhmann. Habermas builds on Kant (Schmidt, 1993) and his categorical imperative: "Act only according to that maxim whereby you can at the same time will that it should become a universal law." He argues that such laws require

discursive agreement, since individuals may differ in what they consider universally desirable (Kunneman, 1985). Both Habermas and Luhmann emphasize the necessity of a theory of meaning as a foundation for sociological inquiry. Habermas developed this theory in terms of communicative action, where mutual understanding is achieved through rational discourse. Luhmann, by contrast, theorized communication as a structural phenomenon inherent to autopoietic systems.

Habermas (Heysse, Rummens, & Tinneveld, 2007) (Habermas J. , 1981) conceptualized modern society as composed of two distinct but interrelated domains: the lifeworld and systems. The lifeworld represents a sphere in which individuals coordinate action based on shared norms and communicative rationality. In contrast, systems such as the economy and the state are organized around strategic action, where coordination occurs not through argumentation and consensus but via media such as money and power. In his theory of communicative action, Habermas envisioned a power-free public discourse governed by the principles of truth, justice, and sincerity. Leydesdorff labels Habermas's approach too normative. (Leydesdorff, 2020).

Luhmann (Luhmann, 2013), by contrast, theorized society as a constellation of autopoietic (self-producing) functional systems, each with its own operative logic, communicative codes, and domain-specific rationality. Drawing on the biological work of Maturana and Varela, Luhmann asserted that a defining characteristic of a system is its capacity for self-reproduction: *"If it does not produce itself, it is not a system."* Communication between these systems requires a translation process akin to linguistic interpretation—since each system operates with internally coherent but mutually incompatible codes. This is particularly evident in innovation contexts, such as when a scientific discovery (scientific system) must be translated into economically viable terms (economic system) to become a marketable product. Here, scientific validity must be rearticulated in the language of cost-effectiveness, market demand, and investment risk.

While Habermas' ethical stance remains more closely aligned with Kantian notions of individual moral duty, Luhmann's systemic approach offers indispensable analytical tools for understanding the structural complexity of modern society. This is especially true in the context of Leydesdorff's Triple Helix model, which describes the interactions among universities, governments, and industries. These interactions often occur within entrenched paradigms that are not subject to the kind of discursive rationality envisioned by Habermas. Luhmann's framework helps illuminate the operational differences among these institutions, each of which functions according to distinct systemic logics.

Recognizing these logics is essential for fostering regional innovation ecosystems—particularly as the model expands into the Quadruple Helix (to the lifeworld). Here, the integration of diverse communicative rationalities becomes even more complex. Luhmann's insistence on the necessity of acknowledging system-specific operations thus remains a vital insight for contemporary socio-economic theory and policy design. However, in smaller communities, shared culture and mutual understanding play a central role in communication, making Habermas's theory of communicative action more applicable than Luhmann's systems theory (and the triple helix in terms of

Leydesdorff). While Luhmann focuses on functionally differentiated systems with autonomous codes, Habermas emphasizes problem-solving dialogue based on shared norms and validity claims, relevant for people to work together.

Innovation and Learning in the Quadruple Helix

To emphasize that human interaction and communicative engagement — as foregrounded in Habermas's theory of communicative action — are not only vital for learning, ethical reflection, and interpersonal relations (Miedema, 1997), but also for innovation and the dissemination of knowledge, the following provides a brief overview of processes that illustrate how interpersonal meaning-making complements the structural dynamics that are less prominent in Luhmann's framework.

1. Tacit Knowledge

Not all knowledge is explicit or easily shared. According to Nonaka and Takeuchi (1995), knowledge conversion occurs through four processes: socialization, externalization, combination, and internalization. These processes highlight the importance of tacit knowledge—deeply embedded insights that are difficult to articulate but crucial for innovation. In tech-driven regions, social proximity and unconscious behavioral patterns play a vital role in leveraging such unique, non-replicable knowledge. To harness this potential, it is essential to bring together individuals from diverse backgrounds into collaborative teams, where open, power-free discourse can flourish within project environments.

2. Triple-Loop Learning

Learning itself operates on multiple levels. Swieringa and Wierdsma (1996) describe a framework known as triple-loop learning. The first level, single-loop learning, involves making adjustments within existing rules. The second, double-loop learning, challenges and revises the underlying assumptions behind those rules. The third and deepest level, triple-loop learning, encourages reflection on core values and identity. This approach aligns with the work of Argyris et al. (1985), who emphasize the importance of recognizing discrepancies between “espoused theories” and “theories-in-use.” Such critical reflection is essential for navigating and influencing evolving societal structures, and resonates with Leydesdorff's perspectives on systemic learning.

3. Cognitive Distance and Absorptive Capacity

Innovation also depends on the cognitive distance between collaborators. Nooteboom (2008) argues that innovation emerges when actors are cognitively distant enough to introduce novel ideas, yet close enough to maintain mutual understanding. This delicate balance requires a mix of generic knowledge—such as digital skills—and region-specific expertise that remains open to new ideas while still being comprehensible by those involved.

4. Innovation Diffusion

The diffusion of innovation is a learning process in itself. As Rogers (2003) and Gross (1996) explain, implementing new ideas involves acquiring new knowledge, skills, and understanding. Within the quadruple helix model, all

societal actors—including citizens—participate in and co-own this learning process through democratic governance. A well-designed innovation process leads to optimal outcomes, while simply repeating past practices results in stagnation. It is important to recognize that not everyone adopts new developments at the same pace; innovation takes time and requires patience.

So effective innovation demands critical reflection on foundational regional principles (triple-loop learning), strategic use of tacit knowledge, and combining internal strengths with external technologies. This enhances absorptive capacity and strengthens regional competitiveness.

In smaller cities, where knowledge institutions do not primarily interact with large corporations through formal channels like papers and conferences, proximity plays a more direct role in fostering innovation. Face-to-face contact, shared local culture, and mutual understanding often support collaboration more effectively than abstract system-level communication. As a result, a sociological perspective—focused on norms, roles, and everyday interaction—can be more relevant for understanding and promoting innovation in such contexts than Luhmann’s systems philosophy. Especially where normative alignment and trust are key, Habermas’s emphasis on communicative action provides valuable insights into how innovation emerges through cooperation.

Fig 3 compares the two models where in the pattern maintenance of the AGIL scheme a further breakdown can be made, which is no part of this paper.

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quintuple helix		AGIL reference scheme Parsons		
<i>Subsystem</i>	<i>Capital</i>	<i>Subsystem</i>	<i>Medium</i>	<i>AGIL</i>
economic	economic	economic	Money	Adaptation (A)
political	political	politicians and government	Power	Goal (G)
media-based and culture-based public (also ‘civil society’)	social capital and information capital	social community (I) is the integration	Influence	Integration (I)
education	human capital	pattern maintenance	Value-commitment	Latency (L)

Fig. 3 comparison of the two models

4 Network oriented modelling for adaptive networks

Starting with neurological models (Treur, 2020) it is possible to model influence also in connection at higher order levels with Parsons in the baseline (Hofman & Treur, 2021). By indicating the structure with the influence that objects or nodes exert on each

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other, more insight can be gained into the course of the process in time. This was done as a first step in a model where two regions were compared with each other using an economic target as a basis (Hofman & Treur, 2021). For the basic level Parsons' reference scheme for the social subsystem was used. For the first-order adaptation level, Hebbian learning is used (Treur, 2020) and for the second-order adaptation level, the speed of learning is influenced by the underlying culture (loosely inspired by how plasticity and metaplasticity are analysed as first-order and second-order adaptation within neuroscience). This is done for the two basic nodes I and A, where the parameters were kept the same for the sake of clarity. The connectivity of the network model is given in **fig. 4** and in Table 3 its states are briefly explained.

Following Treur (Treur, 2020) a temporal-causal network model is characterized by here X and Y denote nodes of the network, also called *states* with activation values $X(t)$ and $Y(t)$ over time t :

- **Connectivity characteristics** **Connections** from a state X to a state Y and their weights $\omega_{X,Y}$ (for example influence X to Y).
- **Aggregation characteristics** For any state Y , some combination function $cr(..)$ (usually with some parameters) defines the aggregation that is applied to **the impacts** $\omega_{X,Y}X(t)$ on Y from its **incoming connections** from states X (Y gets influence for more relations which can have different impact on Y).
- **Timing characteristics** Each state Y has a speed factor η_Y defining how fast it changes for given impact.

For equations see (Hofman & Treur, 2021) on ResearchGate. There is a library of many functions available for Matlab. Table 1 shows the nodes at the different levels shown in the figure. Although not used here, it is also possible that nodes at a higher level interact with each other. To determine what can be used, the Hebbian learning function ¹ with certain variables can be used to make predictions for the future, if no unexpected disturbances occur. This is just a brief illustration of a model that could well illustrate the relation of forces used by Leydesdorff in figure 1, however without using scientometric (less relevant voor region Alkmaar) in this case.

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Table 1. State names of the network model including the states A, G, I, L from Parsons at the base level, and the **W**-states and **H**-states for learning at the first- and second-order adaptation level.

State nr	State name	Name	Explanation	Level
X ₁	A	Adaptation	Economic target state	Base
X ₂	G	Goals	Political instrument state	
X ₃	I	Integration	Network state	
X ₄	L	Legacy	Pattern maintenance or 'cultural state'	
X ₅	W _{IA}		First-order self-model state for Hebbian learning for connection from I to A	First-order Adaptation
X ₆	W _{GI}		First-order self-model state for Hebbian learning for connection from G to I	

¹ Neurons that fire together, wire together is the most simple explanation of the rule of Hebb, but this can be given in functions (Wikipedia and (Treur, 2020)).

X ₇	Hw _{IA}	Second-order self-model state for speed factor (learning rate) for W _{IA}	Second-order
X ₈	Hw _{GI}	Second-order self-model state for speed factor (learning rate) for W _{GI}	Adaptation

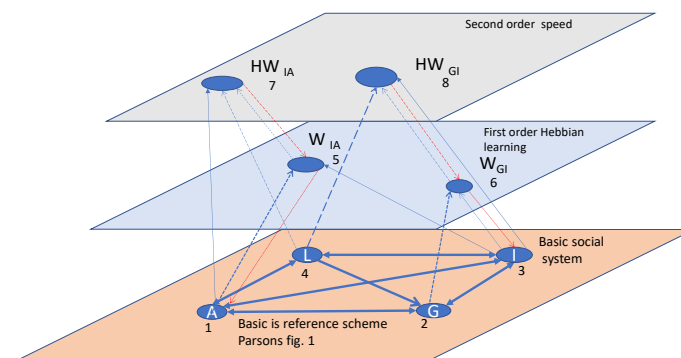


Fig. 4. The connectivity of the introduced second-order network model and with Hebbian learning at the first-order adaptation level (first-order self-model **W**-states) and second-order adaptation level (second-order self-model **Hw**-states).

With these models it is possible to analyse processes where scores only reflect the situation. However, it is important to determine the initial values of the nodes and the functions with the variables. Scientometrics could contribute to establishing those initial values but more in general also information from big data. Using higher level as an networks it should be possible to implement more the philosophy of Luhman, but specifying more clusters of domains while in the basic level Habermas seems more useful. This certainly requires further research and is beyond the scope of this paper.

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1. Conclusion and Directions for Future Research

This paper argues that the Quadruple Helix model, when theoretically anchored in sociological systems theory and enriched with learning theory, provides a viable framework for guiding innovation in small regional contexts. Rather than relying on scientometric data or ICT-driven models alone, it advocates for a more grounded approach that values proximity, tacit knowledge, and normative alignment among regional actors.

Future research should address the following:

- How can tacit regional knowledge be systematically identified and mobilized?
- What forms of triple-loop learning are most effective in different governance contexts?
- How can network-oriented models be empirically calibrated using local data?

- In what ways can digital platforms support—but not replace—social integration and knowledge diffusion?

By answering these questions, we can better understand how to nurture innovation ecosystems that are inclusive, adaptive, and grounded in local realities in smaller cities.

Attachment. Forms of communication

Table 1; Three Levels of Communication According to Leydesdorff

Level	Description	Function in Communication	Key Characteristics	Relation to Other Levels
A – Information Transmission	Based on the Shannon–Weaver model: transmission of signals via a communication channel.	Transfer of encoded messages (data) between sender and receiver.	- Encoding/decoding - Linear signal transmission - Measurable (e.g., bits, redundancy, noise)	Provides the structural base for meaning construction at level B.
B – Meaning Construction (Semantic Level)	Interpretation of information by the receiver; shared meaning among communicators.	Assigning meaning to signals; enabling mutual understanding.	- Semantic noise - Interpretation differences - Requires language and context - Meaning emerges from patterns	Built upon data from level A; shaped and regulated by codes from level C.
C – Code Regulation and Behavior	Normative structures (e.g., paradigms, roles, symbolic systems) that govern how language and meaning are applied.	Selective filtering and coordination of communication via symbolic codes.	- Communication codes - Regulative framework (e.g., scientific norms) - Enables or limits meaning exchange - Comparable to Parsons' media and Luhmann's system codes	Regulates processes at level B; feeds back into levels A and B; introduces a second-order selection mechanism.

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Table 2: Connecting Leydesdorff, Luhmann, Kuhn, and Peer Review

Concept	Linked Level (Leydesdorff)	Explanation
Luhmann: Self-referential Communication Systems	Level C – Communication codes	Social systems (e.g., science, law) operate using system-specific codes (e.g., true/false). These codes determine what is communicable within the system, reflecting Leydesdorff's level C.
Luhmann: Difficulty in Interdisciplinary Communication	Levels B and C – Semantic divergence and code incompatibility	Different disciplines develop distinct semantics and codes, making mutual understanding difficult across domains. Semantic misunderstanding (level B) stems from code differences (level C).
Peer Review as Self-regulation	Level C – Internal validation via codes	Peer review maintains internal quality and legitimacy standards. It reinforces system-specific codes and stabilizes communication trajectories within a discipline.
Kuhn: Paradigms as Structuring Mechanisms	Level C – Paradigms as regulatory codes	Paradigms determine what is considered legitimate knowledge. They guide meaning (level B) and data selection (level A), stabilizing the scientific discourse.
Kuhn: Paradigm Shifts and Scientific Revolutions	Disruption of Level C → Destabilization of B and A	When a paradigm breaks down, meaning construction becomes unstable, and new communication regimes emerge, altering how data and knowledge are interpreted and exchanged.

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