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A hypothetical improvement of the quadruple helix model of innovation

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Orientation: Innovation is forged by sub-revolutions as described by the quadruple helix (QH) model.

Research purpose: Innovation model formation is complex, and the useful QH model can develop and improve to be exemplary.

Motivation for the study: The rationale of the study is to validate and improve the QH model with additional concepts, fresh perspectives of experts and the investigation of the primary sub-revolutions forging innovation.

Research design, approach and method: A conceptual and critical review approach implied narrative data of the model from secondary sources; a convenience sample of five innovation experts for critical reviews was thematically analysed.

Main findings: Ultimately, the improved QH model must accommodate the legal, moral and ethical world to merge with the physical, biological and digital worlds; appropriate terminology for QH innovation leadership is needed, and triple technology theory (TTT) should be incorporated with the triple management theory (TMT) dimension of the model; the review conformed the sub-revolutions of innovation with respect to (1) innovation leadership, upscaling agility and innovation essentials, (2) the triple helix (TH) ecosystems sub-revolution and epochal society and (3) the new technological paradigm, technology intensity and TMT.

Practical/managerial implications: The already useful QH model is confirmed and may develop to become exemplary with respect to the hypothetical improvements suggested.

Contribution/value-add: A fresh and improved QH model is suggested in the context of complex innovation model formation and the paucity of literature.

Keywords: innovation concepts; quadruple helix (QH) model; triple helix (TH); entrepreneurial university; epochal society; agility; triple technology theory (TTT); triple management theory (TMT); tenacious thought leadership.

Introduction

The excitement of the Fourth Industrial Revolution (4IR) may cause more scepticism than the upsurging advent of innovation itself. The 4IR is not necessarily compulsory, or by definition good, as the exponential movement for faster and better cannot be imperious to be always beneficial. Steenkamp (2019b) noted that:

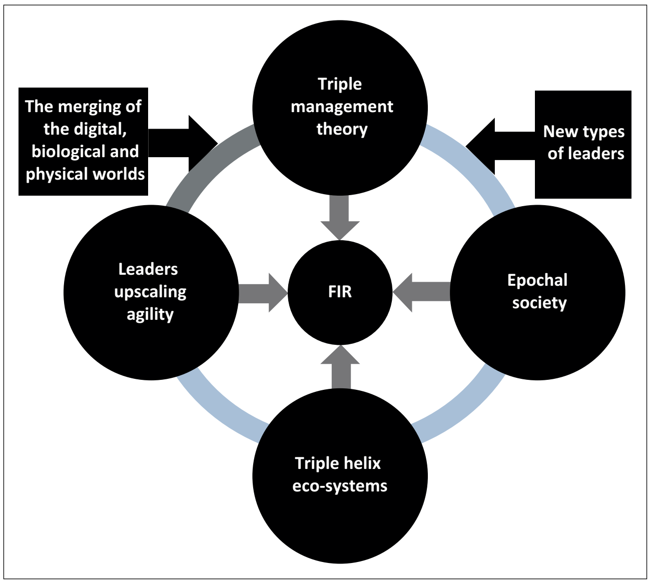
> [*A*] mere going with the flow can be a human weakness, and it may be necessary to approach the 4IR with care. This aggressive thrust may not be for a remarkable utopia with radiance but driven by ravenousness. The changes in industry may be normal or anomalous, but with artifice. (p. 518)

Hence, the focus of this study is the forces of innovation and not the 4IR *per se*.

A wide-reaching change in operation with respect to a scientific-technical revolution was introduced by Braverman (1974). While previous revolutions focused much on electric power technologies, the modern era shows a holistic mode of production and technology into which science and not mere engineering has been integrated as part of ordinary functioning. The modern innovation culture, which is underpinned by digital technology, has almost re-invented innovation in the sense that the current digital force is being merged with the biological and physical worlds for more revolutions to come. This phenomenon brings a new model of innovation with many underlying social dimensions, such as the academic revolution (Etzkowitz & Viale 2010) and social change (Andretsch 2014; Reischauer 2018), not only to be found in electronics and automatic machinery but rather in the transformation of science itself.

Todd (2006) provided a good perspective on innovation models, while Kotsemir and Abroskin (2013) provided insight into innovative concepts. The quadruple helix (QH) model for innovation is utilised to better understand the more recent models of innovation. Model formation is a complex process and not perfectly cast in stone, and it is proposed that the useful QH model (with potential gaps), which is based on multiple perspectives on innovation, may become exemplary after further review and improvement. As the multiple dimensions or forces bringing about innovation are complex, it is challenging to encapsulate and at the same time simplify them in a model. This is especially true for the modern economy producing new types of leaders for exponential organisations with triple abilities, triple principles and triple outcomes (3BL).

The QH model for innovation is one of a few indicating these current forces or movements forging innovation. In a paper at the International Conference on Industrial Engineering and Operations Management, it was specifically noted that 'the magnitude of the modern economy sees social sub-revolutions (e.g. social ergonomics) underlying the smart factories organising itself by means of unique cyber-physical systems' (Steenkamp 2019a:515). The conventional technological intensity dimension of innovation is described as triple management theory (TMT) and other 'triple' concepts, discussed next.



Source: Steenkamp, R.J., 2019a, 'The quadruple helix model of innovation for Industry 4.0', *Acta Commercii* 19(1), a820. https://doi.org/10.4102/ac.v19i1.820

FIGURE 1: The quadruple helix model of innovation.

The quadruple helix model of innovation

The QH concept in the context of innovation was originally suggested by Carayannis and Campbell (2009) with respect to the 'Quadruple Helix model towards a 21st-century fractal innovation ecosystem' emphasising the co-existence and co-evolution of different knowledge paradigms. The initial QH model for innovation (Steenkamp 2019a) was validated with a fresh perspective from the World Economic Forum (WEF) (Steenkamp 2020). The most crucial limitation identified was the leadership dimension with respect to 'new types of leaders' (in search of a suitable descriptive term).

The QH model was initially developed within the 4IR context, with entrepreneurial universities seeking triple helix (TH) partners with government and industry within broad innovation ecosystems. The trend also sees a new kind of knowledge management (KM) with an intelligent and sophisticated society with the fast-changing values of universities with a business mind-set becoming a natural phenomenon of our time, widening the scope of university research, valorisation and interaction with larger ecosystems. These organisations seek to find operational synergy for the triple bottom line (3BL), with leaders who upscale agility, who think differently, and who take followers on a transformation journey. This new type of leaders is unique as they disrupt (transform) themselves to show the way to create smart operations for this modern digital age. Another sub-revolution is nimbleness by deploying a multitude of agile teams is separately included in the QH model with its four primary dimensions.

The QH model is illustrated in Figure 1. The four dimensions of the model are the TH ecosystems, the epochal society, upscaling agility and TMT. While it may seem to be an oversimplification of the forces behind innovation (and the 4IR), each of the four primary dimensions is comprehensive and will be discussed and summarised below. The model also illustrates the interplay of the physical, digital and other worlds, driven by a new type of innovation leadership (also known as exemplary foxy leadership).

Triple management theory

The 'modern management' concept for interoperability is encapsulated by the TMT introduced by Raheem (2018) regarding process intelligence inherent to operations management excellence. The theory concerns the principles for a broader view of technology with respect to operational flexibility, technological flexibility, workflow orchestration and system interoperability. This holistic view uses a combination of process-centric and human-centric management theories to be in pace with technology flexibility.

This dimension is the hidden intellectual properties (IPs) needed to be smart for a 'triple edge'. It may be a combination of blockchain security, augmented realities and unique cyber-physical systems for interoperability. The smart and exponential organisation of the future will seek cumulative advantage and synergy for the triple bottom-line. This is the 'triple' dimension of the QH model: leadership induced with unique, practical, competent and specialised managers. Competitive organisations who engage in the arrival of new markets need to face the velocity, scope and exponential pace of processes. This demands unique and new skill sets in terms of combined knowledge and management approaches. Triple management theory is therefore a combination of business process management (BPM), adaptive case management (ACM) and human interactive management (HIM), which facilitates change support and interoperability, relating to 'triple technology theory' (TTT), discussed in section 'Upscaling agility' of the results.

Epochal society

Audretsch (2014) predicted the entrepreneurial university for an entrepreneurial society, while Reischauer (2018) commented on technology and social change. Moreover, Etzkowitz (1994) anticipated what we see today with respect to academia engaging with industry, defined as a sociological paradigm for economic development. Caruso (2018) asserted that the modern epochal society demands customer intelligence (CI) and new models for service quality in the digital economy. The author envisions a society with an improved work–life balance within a knowledge-based economy (KBE), a virtual society and a network society. This will characterise an educated society of digital capitalism, balancing small and large companies and blurring boundaries between entities. It will entail the growth in autonomy, freedom and creativity (Caruso 2018).

This intelligent society demands smart security systems, generation 'Y geo socialisation' and smart cities. The modern society is knowledgeable and actively involved as informal students of the knowledge society. This prominent actor of the QH model is more sophisticated and more involved in the supply chain of things. Customer intelligence and artificial intelligence (AI) are integral to this dimension. Section 'Epochal society' of the results section will further explore this aspect.

Upscaling agility

The *Harvard Business Review* noted agility as the distinctive skill of our time (Rigby, Sutherland & Noble 2018). Holbeche (2018) also views agility as a requirement for organisational effectiveness of the modern institution, as it enables an organisational culture and structure that facilitate change, willing and able staff and a continuous learning mind-set in the mainstream. To be organic and in flux can be a huge advantage for any organisation. Evidently, the upscaling of agility is a significant force and thus included as a separate dimension of the QH model with respect to a new skill related to nimbleness, flexibility, responsiveness and adaptive leadership. The resiliently agile organisation needs a culture and structure that facilitate change, with willing and able staff. This aspect is further highlighted in section 'Triple management theory (TMT)' of the results section.

The triple helix ecosystems

Briefly, this dimension describes a sub-revolution based on academic, government and industry relations in terms of a sociological paradigm for economic development. This integrative view of academic entrepreneurship and innovation of the QH model places a major emphasis on university–business cooperation (UBC). The invisible and underlying power of academia relates to the work by Dovey and Remback (2015) with respect to action learning, intrapreneurship within the academy, invisible practices and innovative outcomes. This dimension is further highlighted in section 'Epochal society' of the results.

The next sections will underline the research problem, the research methodology, the results (discussed under sections 'Triple management theory (TMT)', 'Epochal society', 'Upscaling agility', and 'The triple helix (TH) ecosystems') followed by the conclusion.

Research problem

The paucity of innovation models forging innovation has reference. The usefulness of the QH model for innovation could develop and become exemplary after further improvement. The complex process of innovation modelling and a changing society call for continuous improvement of current models. Overly complex models are non-user friendly, signalling the need for a balanced model synthesising strategic, current and practical perspective. Refining the QH model may contribute to the need for a well-balanced exemplary model encompassing all significant sub-revolutions underpinning the advent of innovation.

Methodology

The works by Corley and Gioia (2011) and Meredith (1993) about theory building through conceptual methods have a reference. Conceptual research focuses on the concept or theory that explains or describes the phenomenon being studied. Conceptual research can bring about new theories or interpret existing theories in a different light to answer business questions and to solve real-world problems.

Research conducted by Jaakola (2020) provides templates for conceptual papers on theory synthesis, theory adaptation, typology and model. The model approach used in this article studies a theoretical framework that predicts relationships between concepts. The conceptual model describes the dimensions, objects and processes in the theoretical framework and explains how it works by disclosing antecedents and forging outcomes of the focal construct.

Cooper and Endacott (2007) refer to generic qualitative research and the process of qualitative exploration which seeks to discover and understand a process, phenomenon, perspectives or worldviews. Conceptual research can indicate the value of developing standpoints and practical influences through new theoretical perspectives. These may include a gap in the knowledge or new perspectives of old theories (Trafford & Leshem 2012). Concept-driven data is a primary category of qualitative data, derived from existing theory, literature and publications from other sources (Saunders, Lewis & Thornhill 2012). Several dimensions of this methodology were used to review the QH model of innovation and to produce a hypothetical improvement of

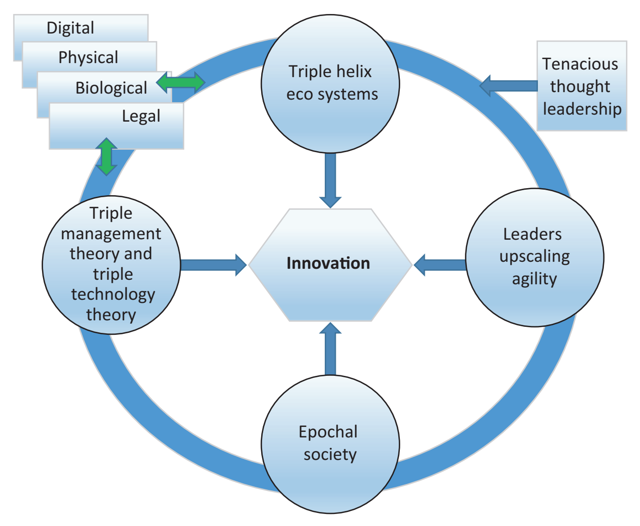


FIGURE 2: A hypothetical improvement of the quadruple helix model.

the QH model (see Figure 2 as part of the conclusion). The variety of conceptual narrative data used to refine the QM model is indicated in Table 1.

Conceptual thinking demands effectively bringing things into relation and interconnecting groups of ideas for synthesised theories. This approach showed 'explicating' ideas, either by delineating or by summarising ideas. Conceptual research implies philosophical discussion, argumentation and studies of other's work and may develop new hypotheses. The possible limitation of the study is to utilise more experts for the review although the current study did not attempt to provide a final account of the QH model, as qualitative exploration is primarily narrative at both the nominal and ordinal levels (Plowright 2011).

Ethical considerations

Ethical clearance to conduct this study was obtained from the University of South Africa Department of Operations Management Ethics Review Committee (No. OM/2018/007).

Results

The theoretical concepts of innovation are discussed below in sections 'Triple management theory (TMT)', 'Epochal society', and 'Upscaling agility'. Section 'The triple helix (TH) ecosystems' comprises the concepts from the critical reviews and perspectives from experts. The results are presented in the sequence indicated in Table 1.

Concepts regarding innovation leadership, agility and other innovation essentials

This section discusses the most important innovation essential, namely innovation leadership.

Leaders driving small scope innovations

Innovation leaders will not despise limited scope inventions. It is myth that inventions and innovation are only about large

TABLE 1: Conceptual data used for this research.

A. Concepts about innovation leadership, agility and other innovation essentials	B. Concepts of the triple-helix ecosystem and epochal society
C. Concepts about technological intensity and TMT	D. Reviews and perspectives from experts

TMT, triple management theory.

scope outcomes and breakthroughs. Innovation models must acknowledge small innovations too, embracing the forces that bring them about as well. Wild (2015), whose work is underpinned by her views on physics and electronics, sees innovation as a celebration of ideas finding traction in a global world. She reports on innovation in South Africa and indicates how the QH model also applies to 'small innovations'. The author sees science shaping South Africa through of a networking approach for environmental innovation, energy innovation (biofuels, coal gasification and sun power), health innovation and industry (robots in our mines, fingerprinting diamonds, ultrasonic transducers and titanium in a test tube).

Radical innovations, such as those from Silicon Valley (the home of innovation) with reference to 3D graphics (Silicon Graphics) and integrated circuit (Intel) (Smith 2010), are incomparable to the South African examples given by Wild (2015) of innovation that seem to be unremarkably small. Yet, it is evident that both basic and complex inventions can use aspects and combinations of the QH model dimensions. While modelling formation and innovation are usually associated with more complex processes, the QH model simplifies the interplay of complex and multiple forces.

Thought leadership

Upscaling agility is viewed as inherent to thought leadership. The work by Addison (2005) refers to the agile leader in the context of 'thought leadership' networking out of the box with new thinking applied through higher-order routines. Addison (2005) defines this type of leadership broadly as a holistic, systemic, coordinating role with respect to an integrating force in the whole intellectual life of the organisation. Such leaders refine group ideas into wisdom and express the mission of the organisation. The author also refers to leaders having the mind of a fox (also termed 'foxy leadership') and to 'value-centred leadership' with respect to collective involvement, joint problem solving and communal benefits for stakeholders. This type of leadership is holistic and may fit the QH model ideally.

Tenacity leadership

Suffering may be too harsh an explanation although innovation resulting from pressure and disruption is noted by Meyer (2010:3–24) who indicates 'how great innovative companies were established in terrible times'. The author lists multiple historic examples of great companies that began during the depression of 1807, the panic of 1819, 1837, 1857, the long depression during 1873–1879 and many more examples up to the recession of 2001 and 2008.

Hence, the QH model of innovation must focus on the innovation paradox, namely faith leadership for perseverance. Meyer (2010) reveals that the passion for and creative forces of innovation are the underlying power of innovation. Yet, the talented creative (or the technological intensive) is not the only source. While disruption is inherent to innovation, suffering, perseverance, the recession (2008–2010) and even the Great depression (1929–1939) underline the principle of survival when things get tough, seeing how many companies were born during difficult economic times.

The innovation paradox is based on the work of Meyer (2010), which provides a powerful source of innovation. His work elaborates on the perseverance of Thomas A Edison (General Electric Company) and the power of patience (Walt Disney). He also reports on several cases related to the power of competition and the power of managing disaster. The power of failure is described by lessons of the power of quitting school, asking for help, rejection and scalability. His work inspires further with an expressed need for tenacious leadership and the power of keeping the faith. Meyer even teaches about the power of impracticality and the power of organic design. Every lesson is a paradox – when you are weak you gain more, becoming recession proof. He concludes with his passion for the TH concept (St Louis University) with respect to academic intrapreneurship, the 'sandbox universe' of integrity, inspiration, imagination, innovation development and industrialisation.

Multi-dimensional innovation leadership

While tenacity is a crucial leadership characteristic, innovation essentially also needs change, talent and practical characteristics. Kotsemir and Abroskin (2013) provide a useful framework of innovation essentials in terms of leadership categories, containing 12 concepts: (1) innovation is a practical process (imitation, invention and discovery); (2) innovation needs special talent and human abilities (creativity, ingenuity and imagination) and (3) innovation embraces change (cultural-social change, organisational change and technological change).

These three dimensions of innovation leadership strongly relate to the perspective of De Jong, Marston and Roth (2015), obtained from 2500 executives of 300 companies regarding the importance of being practical, talented and being a change agent. De Jong et al. (2015) firstly note sound decision-making with respect to differentiating between business, market and technology insights that translate into winning value propositions and to investing in risk-balanced initiatives. The other three synthesised characteristics of innovation leaders are that they:

- aspire, motivate and mobilise – having vision for innovation-led growth and organising and rewarding people to innovate repeatedly
- scale and extend – launching innovations in the right scale in the relevant markets and winning by creating and capitalising on external networks
- evolve and accelerate – creating new innovation models that provide defensible and scalable profit sources and beating competition with time to market.

Summary of section 'Triple management theory (TMT)' with respect to the quadruple helix model

To encapsulate multiple characteristics for QH leadership is very complex. Most critics as well as the WEF suggested that the QH model must create an appropriate term for 'a special kind of innovation leadership' as a fundamental innovation essential. Foxy leadership and other attempts seem not to suffice and in search of an appropriate terminology for QH leadership, 'tenacious thought leadership' may fit the model.

Concepts regarding the triple helix ecosystem and epochal society

The QH model emphasises that the triple-helix ecosystem actively interacts with society, and this section confirms academic and TH power.

Academic power

The academic revolution (Etzkowitz & Viale 2010) is changing higher education. In his paper, Steenkamp (2019b) noted Sam and Van Der Sijde (2014) who:

> Reviewed the three European higher education models and noted the emergence of the Anglo-Saxon model of higher education. This model focuses on personality development through liberal education that will enable students to act flexibly and intelligently in a changing environment. (p. 520)

Literature provides evidence of the important emergence of entrepreneurial higher education. For instance, Audretsch (2014) links the entrepreneurial university for the entrepreneurial economy, while Van Looy et al. (2004) show how research outputs is promoted by scientific performance and entrepreneurial activity among academia. Van Looy et al. (2004) point towards a Matthew effect as opportunity and this interaction becomes more significant. Furthermore, the science parks in the Netherlands are known for academic power, and Hofste-Kuipers (2016) indicates how the University of Twente (UT) located in Enschede next to the 'Kennis park' became top ranked in valorisation of all universities in the Netherlands. The common denominator is the power imbedded in academia.

Another Dutch example is the University of Amsterdam with an intellectual hub 'where curious minds meet' and where academia and students dare to adapt to the epochal society by thinking differently. They look for ways to apply academic knowledge for the greater good. They engage with businesses and public institutions and prefer to engage deeper through world-class global research, including Astro particle physics studies. They work at locations where disciplines converge in state-of-the-art buildings and facilities. Their science park, one of the largest campuses of its kind, is a TH ecosystem for innovation, research and entrepreneurship. Their two year Science Research Masters (Tesla Minor) connects students with science, business and society.

Academic power is also inherent to the University of Leuven (KU Leuven), a technology hotspot and ecosystem with various campuses in 11 Belgium cities. With an active technology transfer office (TTO), it fosters a creative climate for research and innovation and is particularly renowned for healthcare technology. VentureLab (University of Twente, Netherlands) is a one year development programme that offers companies an environment where all the ingredients of success are readily available. The system is a virtual business and innovation incubator that enriches companies to facilitate growth.

Cambridge University (United Kingdom) is another higher education institution with academic power as it holds an outstanding record of remarkable breakthroughs, such as the discovery of the electron, splitting the atom, and the identification of the structure of DNA (Smith 2010). Universities that support intrapreneurship by several means such as contract research developed into institutions becoming inherent part of innovation ecosystems. The modern university of which MIT in Stanford and the University College of London serve as examples adopts several strategies of KM with TTO's (such as with Leuven university) and several industry–science links actively engaging in different ways of cooperation between industry and higher education (UBC).

Formal ties between companies and universities in Australia indicate hundreds of industry partners for every university. Woolley and Diriba (2018) describe the example of Telecom Italia (TIM) who redefines knowledge and technology transfer through open labs and filed near 30 applications for patents and more than 60 PhDs graduated as part of this collaboration.

Meyer (2010), chief innovation officer of St Louis University, serves as an example of an entrepreneurial academic, having founded four successful companies and being a pioneer of managing IPs. His passion is to build bridges between industry and universities. His tenacious leadership is characterised by disruption and a 'never say die' attitude, forging innovation and establishing great companies in tough times, such as Procter & Gamble, Mobil and Applebee.

Although complex, the entrepreneurial academic is a phenomenon confronting the core tuition mission of the university. This third mission of universities is regarded as an invisible revolution for an epochal society by Loi and Chiara Di Guardo (2015).

Clearly, modern society rejects the old view of valorisation as unfit for the modern academic calling. It is now regarded as a responsibility of many universities to develop academic power as a valorisation track record distinguishes academia and provides a competitive edge. This process entails the creation of value from knowledge by making knowledge applicable and available for economic and societal utilisation with respect to innovative outcomes.

Triple helix power

The academic revolution of academic power is inherent to TH partnerships. In his paper, Steenkamp (2019b) refers to this concept:

> [*A*]s a body of thought referring to knowledge spaces brought about by three (triple) inter-related roles of engagement by government, academia and the business sector and the TH Association originated at Stanford University under the leadership of Professor Henry Etzkowitz. (p. 521)

The benchmark is the Massachusetts Institute of Technology (MIT) and therefore a standard for TH training on the development of innovative markets and to cross the spheres of society (Etzkowitz & Viale 2010). The frequent seminars and conferences hosted by the University Industry Interaction Network (UIIN) are a good indication how more traditional universities are part of UBC and therefore getting out of the complacent zone of a conservative ethos and slowness. Etzkowitz (1994) envisioned this phenomenon as an epochal social revolution in his work titled 'Academic-Industry Relations: A Sociological Paradigm for Economic Development'.

The power of TH seems to be endless with respect to its evolution and operational configurations. Leydesdorff (2018) indicates these possibilities and how the TH model changed. Good practice case studies in UBC that portray the value of TH are published by Davey et al. (2011). The following serves as good examples:

- Leuven eco-system, Belgium; TU Innovation lab, Eindhoven University of Technology and the Technology Centre, University of Amsterdam.
- Aalto University in Finland, a country that supports UBC, is known for brain simulation technology and producing more than 3000 doctoral students. Typical to the Netherlands, Maastricht University in the Brightlands ecosystem has a core philosophy for collaborative open research education with TH hotspots at the campuses. Another prominent example in the Netherlands is the Kennispark Twente, an innovation campus amid a high-tech ecosystem. The ecosystem of this region has several innovation centres such as for wireless sensors, road safety and research centres such as Apollo Global R&D.
- Similar to the science parks in the Netherlands is the Leuven ecosystem in Belgium with incubators such as the Haasrode Science Park and the Renberg Science Park.

Central to this innovation ecosystem is the international KU Leuven research university, known for its TTO, research valarisation and the global leader in anti-HIV drugs.

Summary of section 'Epochal society' with respect to the quadruple helix model

This section confirms the dimension of the QH model without any new perspectives other than using the term 'academic power' to emphasise the outcome of universities empowering 'academic intrapreneurs' to become university entrepreneurs within a collective entrepreneurial institution actively engaging with a usually strategically located ecosystem.

Concepts regarding technological intensity and triple management theory

While the QH model addresses technology in the broadest sense, this section provides an even more holistic perspective.

Beyond technological intensity

A conventional view of technology is to associate it with machines and equipment. This narrow perspective is related to the historic eras of technology intensity. However, technology today is concerned with practical knowledge of how to do or make things or solve problems in the broadest sense. Simon (in Smith 2010) defines it as knowledge stored in millions of books, human heads and artifacts themselves.

Although radical innovations are usually driven for new technology (Smith 2010) such as the digital camera, jet engine for mass travelling and the MP3 player, technological intensity is not the only proxy for innovation capability. Differently put, the ability to innovate is not limited to the stratum of high technological intensity. Based on four case studies, Zawislak et al. (2018) confirm the principle that firms belonging to one stratum of technological intensity have innovation capability based on a balance of additional technological, operational, managerial and transactional capabilities. It is for this reason that the QH model displays a much more holistic view of forces of innovation with reference to TMT (Raheem 2018).

Firms can therefore be innovative regardless of their stratum of technological intensity, which shows the importance of combining multiple capabilities to ensure innovation success. Smith (2010) concludes that innovation involves several theories (descriptive, analytical and predictive) of innovation, different sources of innovation (epochal society, corporate undertakings and process needs), processes of innovation (push or pull) and IP (trademark, copyright and patent). This clearly indicates a broader view and paradigm of technology.

Improving the conventional technologies

It is also important to acknowledge small-scope inventions based on traditional principles of improvement. Hansen and Goelzer (1996), for example, note the importance of technology management with respect to adjustments or replacements of parts, alignment and balancing of equipment, lubrication of sub-assemblies and the utilisation of appropriate cutting tools. They also refer to the substitution of components and processes.

Basic operations management and the science of industrial engineering can bring about remarkable outcomes when old principles bring new developments to the fore:

> [*D*]ifferent materials with unique chemical properties produce new composite (materials) when combined. Traditional money sees the lure of crypto and investors going into the cryptocurrency world. Human creativity will see normal buildings become intelligent building systems. Conventional machinery becomes intelligent machinery where 'electro spindles' are manufactured for mechatronics. Also, early leak detection equipment is installed at power plants, and so the list goes on. (Steenkamp 2019:516)

The new modern economy with the sophisticated customer demands of an epochal society sees CI and mass customisation. For instance, the common service quality challenge with respect to the queuing problem is another example of technical capability as noted by Aylak, Hofste-Kuipers (2016) who improved traditional simulation principles for cash registers of a giant retail company.

While technical excellence and operational capability are important, they are not always requirements for innovation. Phiri, Oladijo and Akinlabi (2018) studied friction, wear and lubrication and the advantages of the thin film deposition method because wear degradation is one of the most failure mode incurring realities in modern industries. Also, Solilo and Doorsamy (2018) addressed power line maintenance with a technically commendable design of power line tracking unmanned arial vehicles.

In the conference proceedings, Steenkamp (2019:520) noted that sensor technology is nothing new, the integration of sensors is. He stated that:

> [*S*]ensor readings are now processed by the product and the product will have types of connectivity such as industrial ethernet interfaces. So, besides data storage and exchange, the toolbox will dramatically improve in terms of monitoring (detection of failures) and additional possibilities (models) around the product. The Helsinki Institute of Information Technology, for instance, founded a company for all touch tracking software. The technology can pick up and track an unlimited number of fingers, hands and objects Steenkamp (2019b:520).

A modern paradigm of technology

According to Zawislak et al. (2018), the full stratum of technology shows the importance of combining multiple capabilities to ensure innovation. This introduces another triple concept, namely TTT. This holistic view of technology is also encapsulated by TMT, including a new kind of business intelligence to better understand the epochal society with the idea of CI and real-time customer information. Detailed customer data provides information, which indicates the ideal way to interact with the individual client/customer. This principle brings another dimension of technology to the fore with respect to an emotional hyperbole of optimism that elicits amazement. The faith is established that 'anything is possible' with 'smart factories performing near-miraculous feats because robots can think, machines communicate, cameras fly and inventory is available just-in-time' (Steenkamp 2019:518).

The modern paradigm of technology or TTT will see a new focus on technology partners, digital transformation, operations excellence and the growing importance of the integration of business functions through enterprise resources planning (ERP). Information and communication technologies will merge with conventional processes and the internet of things (IoT) will be central to the shifting of paradigms.

The digital force brings a blending of technologies that is pixilating the lines between the physical, biological and digital spheres. However, the ethical and/or moral threat for human society to be controlled or 'robotised' must be considered with care as larger amounts of data increase society's hope for more data with respect to 'big data'.

This TTT paradigm therefore has multiple dimensions, including digital disruption, quantum computing and AI. It does not necessarily predict a utopia and the negative emotions, fear, celerity and unpredictability of the impact of technological changes predicts several complications for the way we will live. Still, many entrepreneurs will not shy off from this new technological paradigm.

Summary of section 'Upscaling agility' with respect to the quadruple helix model

Innovation is not conventional 'technology intensity' per se; hence, this section provided a good perspective of a more holistic view of technology. It does not disregard technology intensity but confirms TMT and introduces a new concept with respect to TTT. This may be included in the hypothetical new QH model (see Figure 2).

Reviews and perspectives from experts

The following are the perspectives of five expert reviews of the QH model, indicating confirmation and improvement recommendations (Table 2).

TABLE 2: Expert reviews of the quadruple helix model and recommendations.

Expert reviews	Specific comments and suggestions	Summary with respect to QH model
The first reviewer's report concurs with the design	This report of a senior professor from a private university concurs that the QH model contains the main components. He suggested it may consider epochal society in need of blockchain security (smart security systems), generation 'Y geo socialization' and smart cities. The reviewer also noted that TMT relates to artificial intelligence (AI), robotics and virtual and augmented realities.	In essence, the review confirms the model without drastic changes.
The second reviewer's report focused on the triple helix ecosystem	The review from a practical engineering perspective noted that the TMT dimension is a necessary outcome for competence by default. He noted the irony how the 4IR takes us back to apprenticeships associated with the First Industrial Revolution. He made four valuable statements that without a TH ecosystem each institution (or individual) will capture and isolate its own IPs to the detriment its potential for society. Some universities and industry even move further from each other because of this silo phenomenon. Many students therefore need to start to equip themselves from scratch when employed and many of these 'millennials' obtain unfamiliar jobs before they can add significant value. The epochal society is empowered (and therefore more demanding) and he referred to examples such as Alexa and Siri systems helping households to respond to verbal commands. The standards are higher but also unrealistic at times (by giving an example of unrealistic customers from Australia with respect to a power station simulator).	The reviewer focused on the importance of the TH ecosystem. In essence, the review confirms the model without drastic changes.
The third reviewer's report focused on the value of the WEF perspective	The review from an industrial engineer noted that the QH model makes a valuable contribution to the body of knowledge on innovation models. Although the authors of the model proposed further validation of the model, it will certainly stimulate thought for application and further research on the theme. The research for the model was found to be developed from a strong and recent body of existing knowledge in the field. The perspectives from the WEF obtained by the authors should enhance the validity of the model.	The report confirms the model without recommended changes.
The fourth reviewer's report focused on the legal dimension	The reviewer from an African university confirmed that the QH model articulates the push–pull dimension of innovation which is crucial for influencing practice, scholarly debate and potential limitations. She identified the following aspects as 'silent in the QH model': a. The legal dimension Legal issues are not limited to the epochal society but are cut across every dimension of the QH model. From an epochal society viewpoint, the privacy issue is serious with respect to the collection, use and storage of data (e.g. the recent Facebook case). The advent of innovation is not above moral and ethical issues. Legal, ethical and policy frameworks play catch up to innovation. Yet, the cumbersome ethical 'movement' itself is sabotaging research at universities (referring to the University of South Africa) and is a good example of an issue in need of innovation. The legal vehicle must add value and not be a hindrance. The Uber driverless car case illustrates the legal imperative of innovation. It affects the dynamic process of driverless cars and auto flights innovation. Issues of machine evidence become centre stage as they pose procedural challenges in criminal justice across the world. b. The infrastructure dimension It was noted that excellent infrastructure should strengthen the TMT and agility dimensions of the QH model (the TH ecosystem dimension of the QH model, however, does imply massive utilisation of existing incubators, resources, skills, process technologies, cloud availability, mobile infrastructure and other facilities to eliminate the duplication of what already exist).	From the above, the legal dimension seems to be the aspect that requires consideration for the new hypothetical QH model (see Figure 2). As the new technological paradigm with its significant digital force brings a blending of technologies that is pixilating the lines between several worlds (digital, physical and biological), and cyber-physical technology brings the real and virtual worlds closer together; the reviewer recommends that the real world must include the legal (moral and ethical) dimension.

Table 2 starts on the next page →

TABLE 2 (continued ...): Expert reviews of the quadruple helix model and recommendations.

Expert reviews	Specific comments and suggestions	Summary with respect to QH model
	c. The commercialisation dimension Although the QH model highlights this aspect in the TH context, it was suggested that the model could explain the value chain principle where industry, academia and government are the leading adopters of innovation. While not a simple matter, commercialisation opportunities increase even if geo-dimensions reveal that the triple stakeholders are the adopters of foreign IP at the expense of their local IP. The challenges do not defeat the opportunity if there are lighter regulations and accessible value chains. d. New type of leaders As noted by several reviewers, the QH model should provide an identity for the new type of QH innovation leader. Currently, it offers little direction to government, academia and industry on who should tackle the weight of each dimension (or all dimensions as a whole). The reviewer finally notes that this will bring the QH model to a practical level.	
The fifth review focused on thought leadership	The perspectives of the award-winning work of Addison (2005) provided valuable insight to the QH model. Unsurprisingly, he does not refer to the current 'epochal society', as his work dates to 2005; yet he explains the innovation generations of which the technology-intensity era was the first, and collaboration and state enablement the fourth and fifth. This relates to the TH ecosystem dimension of the QH model with the strong emphasis on cross-functional networking, the team sociability concept with both solidarity and close-distant relationships in line with this dimension of the QH model. The author's four innovation essentials, namely netting strategy, churn of ideas, leverage and sustainability, are also related to this dimension. The terms 'sector collaborations' and 'enablement' are used with respect to strong, vibrant and relevant academic research in the management of technology, using the Cambridge phenomenon as example for commercialising research outputs. The author's work refers to the ecosystem of knowledge capital in the laboratory of the world. The TMT dimension of the QH model is indirectly highlighted with respect to the 'community of practice' as the incubators of experts combining their skills. Addison notes that this 'community of practice' comes into being when experts, similarly, trained and sharing professional values, combine their skills and breach the walls of the firm. Finally, Addison supports small companies in the sense that they are nimble, flexible and fast. He stresses the upscaling agility of the QH model in the context of 'thought leadership' networking out of the box with new thinking applied through higher order routines. Addison (2005) defines this type of leadership as having a systemic coordinating role in creating an integrating force in the whole intellectual life of the organisation. Such leaders refine group ideas into wisdom and express the mission. He refers to the mind of a fox ('foxy leadership') and elaborates on this agile leader, able to work within systems in order to break out of them (Addison 2005). In this context, the author notes the importance of resolving the innovators paradox: to know the dangers of routines that reduce uncertainty. Routines can be inimical to innovation because they impose bureaucracy where there should be freedom, requiring rigmaroles instead of intellectual rigour. Rules and creativity are not in conflict, but the skill is to turn standard behaviours into creative interaction.	This perspective confirms the model without changes. However, it contributed to the term for a special kind of innovation leadership, namely 'thought leadership' combined with tenacious leadership (see Figure 2).

QH, Quadruple Helix; WEF, World Economic Forum; TMT, Triple management theory.

Conclusion

The QH model is one of a few preferred innovation models that encapsulate the primary forces, sub-revolutions and movements forging innovation. Part of the modern economy is a social sub-revolution requiring a new kind of innovation leadership as an inherent innovation essential. The purpose of this study was to improve the usefulness of the QH model that may develop to be exemplary after further review, adhering to be balanced, synthesising strategic, current and practical perspectives. The study showed that the model can be improved without too many complexities, displaying the interplay of significant sub-revolutions underpinning the advent of innovation.

In essence, the article confirmed the usefulness of the QH model of innovation although it showed (as for any model) that the QH model may still develop further. Reviewing several innovation concepts and innovation essentials underlined how complex it is to encapsulate multiple forces of innovation and multiple characteristics for QH leadership. In search of appropriate terminology for this 'special kind of QH innovation leadership', the study proposed 'tenacious thought leadership' as a possibility (noted by experts in section 'The triple helix (TH) ecosystems'). After reviewing the concepts of the TH ecosystem and epochal society, this dimension of the QH model was confirmed without any new perspectives other than using the term 'academic power'.

Upon the exploration of concepts regarding the stratum of technology, technological intensity and TMT, a more holistic view of technology was identified. Without disregarding conventional technology intensity, the article portrayed innovation in a much broader sense, confirmed TMT, and introduced a more holistic concept with respect to TTT included in the hypothetical new QH model (see Figure 2).

Finally, the reviews and perspectives from four experts confirmed the model, while one expert suggested that the improved hypothetical QH model also includes the legal dimension. The digital force brings a blending of technologies, blurring the lines between the physical, biological, digital and the legal (moral and ethical) worlds. The theoretical and practical implications of the changes are illustrated as hypothetical improvements in Figure 2.

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