R&D MANAGEMENT

Value creation in the quadruple helix: a micro level conceptual model of principal investigators as value creators

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Conceptual models of the quadruple helix have largely taken a macro perspective. While these macro perspectives have motivated debates and studies, they fall short in understanding value creation activities at the micro level of the quadruple helix. The purpose of this paper is to address this deficit by focussing on the fundamental research question how value is collectively created, captured, and enhanced at the micro level of the quadruple helix. Drawing on theoretical considerations centred on simmelian ties, boundary work and value postures (motives, creation, destruction and drivers), we develop a micro level conceptual model of principal investigators (PIs) as value creators in the quadruple helix. Scientists in the PI role engage in boundary spanning activities with other quadruple helix actors. This engagement builds strong simmelian ties with these actors and enables PIs to develop collective value motives by bridging diverse knowledge and creating common value motives. Our conceptual model extends understanding of the quadruple helix at the micro level and highlights the importance of PIs having strong simmelian ties in order to realise collective and individual value motives. The paper concludes with some suggestions for future avenues of research on this important topic.

1. Introduction

Public science is considered a public good and a source of 'diversity and flexibility' (Callon, 1994) and has moved towards a networked model where public and private actors play complementary roles (Callon, 2003). Against this backdrop, several conceptual models, that is, triple, quadruple and *N*-tuple helices, have emerged as a conceptual means to better understand the evolution of the increasing complex relationships between university, industry, government and society in a public science context (see Etzkowitz and Leydesdorff, 2000; Carayannis and Campbell, 2009; Afonso et al., 2012; Leydesdorff,

2012; Miller et al., 2016). Within this stream of literature, universities and research institutions have been described as knowledge factories and the nucleus of corresponding knowledge spillovers (Perkmann et al., 2013), whereas new ventures and incumbent firms are proposed as the exploiters of scientific knowledge (Acs and Plummer, 2005), with governments and society shaping respective innovation mechanisms.

Although valuable, present conceptualisations and perspectives are too simplistic to address the value creation in the quadruple helix – the problem being that it is not the institutions, but rather individual scientists and academics, who generate innovative ideas and novel research trajectories that can form the basis of value creation for other helix actors such as firms, government regulators, etc. It is surprising therefore that little if any research attention has focussed on these micro level value creation mechanisms of the quadruple helix (see Caetano, 2017). In this paper, we begin to address this paucity of research attention at the micro level by focussing on the interactive boundary spanning and brokering role of a key agent of increasing importance for the quadruple helix and publicly funded science, namely the publicly funded principal investigator (PI). PIs are the lead scientists on publicly funded large-scale research programmes. It is the scientist in the PI role that has to create and capture value for multiple helix stakeholders simultaneously, and often co-create value with their own research teams and academic collaborators in other institutions while dealing with scientific and market uncertainties (Baglieri and Lorenzoni, 2014).

The purpose of this paper is to conceptualise how value is collectively created, captured and enhanced at the micro level of the quadruple helix through the simmelian ties that scientists in the PI role create with other helix actors when they lead large-scale publicly funded projects. While measures of science impact are already well established, we expand these by drawing on value creation research (see Bowman and Ambrosini, 2000; Ulaga, 2003; Lepak et al., 2007) together with work on role transitions and boundary work. We highlight the role of PIs in creating value through simmelian ties, thus conceptualise, at the micro level, value creation within the quadruple helix. We thereby contribute to the increasing calls for further conceptualisations and developments within the quadruple helix literature (see Chesbrough, 2011; Carayannis and Rakhmatullin, 2014; Miller et al., 2016).

Our conceptual model suggests draws attention to the existence and benefits of strong simmelian ties among quadruple helix actors, and how these are created and enabled through the boundary spanning activities of PIs. Strong simmelian ties maximise the public good aspect of public science, underpin value motives and value creation for public science and mitigate against value destruction as well as the loss of public good impacts. These strong simmelian ties further help the PI to deal with friction effectively and balance individual helix actor's self-interest and value motives against the collective value motives for large-scale funded public science research programmes. Thus, our research opens up several fruitful areas of research centred around scientists in the PI role.

The remainder of the paper is structured as follows: Section 2 presents a theoretical background focussing on the quadruple helix, role transitions, boundary work and associated simmelian ties. Section 3 considers the value motives (individual and collective), value creation and destruction, value drivers as well as friction and conceptualises these value postures at the micro level value of the quadruple helix. A final section concludes and highlights future avenues of research.

2. Theoretical background: quadruple helix and role transitions

The aggregation of local resources and factors as well as respective entrepreneurial activities of key stakeholders determine value creation processes, that is, the transformation of various inputs into valuable outcomes (see Autio et al., 2014). A large body of literature has dealt with entrepreneurial universities and their specific role within innovation systems, highlighting the importance of academic knowledge in generating commercial innovation (Etzkowitz et al., 2000; Gunasekara, 2006; Bozeman et al., 2013; Guerrero et al., 2015). Scholars have utilised various approaches to break down the inherent complexity of the entrepreneurial paradigm of academia by analysing innovation systems from consecutive perspectives. Leydesdorff and Etzkowitz (1996) developed the 'triple helix' of university-industry-government relations, indicating the interrelatedness and interdependence of the three dimensions: entrepreneurial universities as the source of knowledge and industry as the exploiter of knowledge interact within innovation trajectories provided and shaped by the government. More recently, end users/customers have been identified as a further key stakeholder grouping within these innovation systems, leading to an extension of the triple helix framework towards a quadruple helix framework (Carayannis and Campbell, 2012; Leydesdorff, 2012). This approach resulted in a re-evaluation of knowledge-based development processes and policies (Kolehmainen et al., 2016), strategic decision-making (Paredes-Frigolett, 2015) and

role models of respective quadruple helix stakeholders (McAdam et al., 2016). Missing from these discussions, however, was consideration of the value creation dynamics at the micro-level of these evolving innovation systems.

2.1. Role transitions and PIs

A professional role is characterised by one's actions and interactions within a work environment. In academic science, the role of scientists is characterised by scientific independence (Nelson, 2004) and guided by norms related to scepticism, universalism, communism and disinterestedness (Merton, 1973). Scientists are motivated by discovery and rewarded through career standing (Siow, 1998), as well as awards and research dissemination (Partha and David, 1994). Traditionally, the purpose of science work stems from roles undertaken during a rigorous training and an extended socialisation process (Van Maanen and Schein, 1979).

However, in recent decades, university scientists have experienced role transitions, largely due to significant changes in their institutional environment. Role transitions occur when there is a change in work content or the status of one's role (Glaser and Strauss, 1971). Theory on work role transitions captures how changes in organisation goals and structure significantly impact individuals and their organisation (Nicholson, 1984). It is suggested that work adjustments link characteristics of the person (i.e. motivations), roles (i.e. job requirements) and the organisation (i.e. previous and current induction or socialisation practices) with two outcomes namely, the extent to which the individual absorbs change (i.e. personal development) and the extent to which the organisational tasks are proactively shaped to align with the individual (i.e. role development). Although some research attention has been directed at the impact of such role transitions on the nature of academic work at the micro-foundations of science (e.g. Henkel, 2005; Jain et al., 2009; Lam, 2010), scholarly attention on transitions to the role of publicly funded PIs has received much less attention. Attention to this segment of the scientific community is yet important to understand how value is created through their shaping of scientific, technological and business avenues.

Within the quadruple helix, PIs as part of their value creating endeavours interact with a multitude of helix actors to bridge the gaps across multiple boundaries (Cunningham et al., 2016a). In doing so, PIs can shape and reshape their own knowledge, work boundaries and that of their organisation. Mangematin et al. (2014) argue that PIs, through their articulation of research programmes, the shaping of research avenues and the bridging of academia and industry, can be categorised as the linchpin of knowledge transformation. In undertaking these activities, PIs also experience barriers that can impede or even destroy value within the quadruple helix (Cunningham et al., 2014). At a project level, PIs experience managerial challenges that also potentially can enhance or destroy value (Cunningham et al., 2015). Each individual actor's value posture (creating value, adding value or appropriating value) has the potential to capture and enhance value in their helix context, but can also undermine or destroy value for other helix actors. The growing research on PIs (see Baglieri and Lorenzoni, 2014; Casati and Genet, 2014; Menter, 2016; Cunningham et al., 2017b; Del Giudice et al., 2017) highlights that the role of the PI is still emerging, very fluid and that PIs are less restricted by role parameters that enable them to boundary span effectively to contribute to value creation at the micro level of the quadruple helix. Consequently, the role transition of the scientist in the PI role enables them to become more integrated with other helix actors.

When scientists transition to the role of a PI, they must undertake new work tasks. O'Kane et al. (2015) provide an overview of role definitions from a range of prestigious international research institutions and universities that outline the wide range of managerial responsibilities bestowed on PIs including: designing and scheduling the research project; financial management and sign-offs; recruitment, supervision and mentoring of staff; preparing progress reports and ensuring project deliverables are met. Despite such practical insights, the professional role identity of PIs is not yet defined and there remains a high level of discretion and novelty in the role (Nicholson, 1984). Thus, when considering PIs' ability to create value at the micro-foundations of the quadruple helix, one must consider that their role is (relatively speaking) at an early stage of development within the quadruple helix. This presents an opportunity for PIs as their role parameters are fluid and not yet defined (Cunningham et al., 2014). The new role model of PIs is thereby accompanied by a paradigm shift within academia, breaking up inherent ivory towers and enabling the creation of new boundaries and networks inside and outside academia, hence the growth of new helix structures among quadruple helix actors. Role transitions within academia consequently form the basis for boundary spanning activities in the context of publicly funded science that ultimately create and enhance value.

2.2. Boundary work and simmelian ties

In order to fulfil the value-creating potential of their emerging role at the nexus of university-industry-

government-society interactions, PIs can undertake 'boundary work' (Gieryn, 1983; O'Kane, 2016). Boundaries have been conceptualised as mental fences (Zerubavel, 1991, p. 2). However, when boundaries between roles become too strong, they can inhibit knowledge sharing and value creation (Ferlie et al., 2005; Hsiao et al., 2012). Theory suggests that boundary work is particularly important during role transitions (Ashforth et al., 2000). More specifically, if a role is highly segmented, it becomes inflexible, impermeable and has a high level of contrast to other roles. Flexibility captures how relevant a role is across place and time, while permeability denotes how involved one can be in work that is professionally/psychologically distinct from their core work-role (Ashforth et al., 2000). When roles have a sharp contrast, it means the values, norms, time lines and beliefs are in conflict with other role identities (Ashforth et al., 2000). Thus, if scientists are too segmented in their new PI role, it is unlikely to be favourable to their ability to create value in their work. For PIs to create value, they need to undertake boundary work that helps their role become better integrated with other actors in the quadruple helix. When roles become more integrated in place, time and role nature, boundary crossing and interactions with other quadruple helix actors is more seamless and value creation therefore more likely. Specifically, when PI are more integrated in the quadruple helix, their involvement in potentially productive and value creating interactions will be enhanced as they can contribute in multiple work environments and settings as well as across multiple stages (flexibility) of the research and innovation process. Moreover, being more integrated will allow PIs to be involved in multiple activities that are psychologically and/or behaviourally distinct (permeability) but also potentially complementary to their core scientific role.

A number of perspectives in the literature help to understand how PIs might become more integrated in their role within the quadruple helix. Tortoriello and Krackhardt (2010) draw attention to simmelian ties and value creation in boundary work. Simmelian ties exist when two actors are jointly and strongly tied to each other and at least one common third party (Krackhardt and Kilduff, 2002). Tortoriello and Krackhardt (2010) show that the innovative potential of collaborations between R&D scientists and engineers is primarily explained by bridging ties that not only bring together diverse knowledge, but that also help to develop shared goals and lesson competition and self-interest in the relationship. O'Kane (2016) finds that funding bodies act as simmelian ties that reduce role boundaries, foster engagement and increase the likelihood of value creation in boundary-spanning relationships between university TTO executives and PIs. Simmelian ties are thus closely related to value postures within the quadruple helix as they help to reinforce helix structures and reduce friction, hence facilitating value creation among quadruple helix actors. However, in the context of public science, simmelian ties require PIs engaging in boundary work with other quadruple helix actors. Both the concept of role transitions as well as boundary work and associated simmelian ties are therefore interrelated and prerequisites for value postures within the quadruple helix.

3. Value postures: motives, creation, destruction and drivers

In building simmelian ties within the quadruple helix, PIs have to be capable of differentiating between the value postures of other helix actors. While value creation has been the focus of research in different fields such as management, marketing and strategic management (see Tsai and Ghoshal, 1998; Bowman and Ambrosini, 2000; Amit and Zott, 2001; Prahalad and Ramaswamy, 2004), there is no universally accepted definition of value (Pitelis, 2009). How value is defined is contentious. It depends on who is creating the value and for whom. Taking the various definitions of value creation in the literature, Lepak et al. (2007, p. 182) suggest that 'value creation depends on the relative amount of value that is subjectively realised by a target user (or buyer) who is the focus of value creation – whether individual, organisation or society – and that this subjective value realisation must at least translate into the user's willingness to exchange a monetary amount for the value received'. Lepak et al. (2007) note two further conditions, monetary value and perceived performance difference. For public science, value creation is driven by creating a public good (Callon, 1994) and this is measured individually by different helix actors depending on their value motives. It is also measured collectively to ascertain what have been the economic, social and technological impacts of government investments in public science. Individuals such as PIs can create and be the source of value creation (see Felin and Hesterly, 2007). For the purposes of this paper, we focus on value motives (individual and collective), value creation, value destruction, value drivers as well as friction.

3.1. Value motives

3.1.1. Individual value motives

Taking the individual as a unit of analysis for value creation, Lepak et al. (2007, p. 183) posit that 'the

focal process is the creative acts displayed by individuals and a select set of individual attributes, such as ability, motivation and intelligence, and their interactions with the environment'. Sveiby (2001, p. 344) argues that individuals use their 'capacity to act in order to create value in mainly two directions: by transferring and converting knowledge externally and internally to the organisation'. Hence, there is a recognition that employees create value (see Pulic, 2004).

Several factors motivate scientists including the quality of work itself, job satisfaction, publications, peer recognition, working on new ideas and increasing technological and human capital (see Miller, 1986; Mansfield, 1995; Jones, 1996; Keller, 1997; Agrawal and Henderson, 2002; Owen-Smith and Powell, 2003; Thursby and Thursby, 2004). Individual motivations of scientists thereby differ across research fields (Sauermann et al., 2010).

For scientists in the PI role for publicly funded science, Cunningham et al. (2016b) identified three pull motivations factors: control, career ambition and advancement, as well as personal drive and ambition. Scientists are motivated at an individual level to become a PI as it gives them greater control over their research and resources, that is, expands their research autonomy. Becoming a PI enables scientists to grow and maintain their standing and reputation within their field and also internationally. This status also enables them to grow their international networks and develop relationships with other quadruple helix actors. This boundary expansion for the individual scientist in the PI role supports more integration and productive interaction with other quadruple helix actors. Becoming a PI allows scientists to grow and strengthen their simmelian ties with other helix actors and to become transformative agents for publicly funded research (Cunningham et al., 2016a).

Through their boundary crossing expansion activities and the development of strong simmelian ties with other helix actors, PIs are able to meet their own value motives needs and to understand and even address the value motives of other quadruple helix actors in a more effective manner centred on a common or shared purpose or what is termed collective value motives. The building and brokering of simmelian ties makes the PI aware of value motives of other helix actors and enables them to bridge devise ways to build common purpose that is necessary for large-scale multi actor publicly funded research programmes. With stronger simmelian ties built between the PI and other helix actors, PIs can better anticipate, plan for, and meet individual value motives and balance these against collective value needs and public good requirements in large-scale publicly funded research programmes. Typically, for industry, the individual value motive centres on profit, technological leadership and sustaining a competitive advantage. For government, it centres on economic development and growth as well as a return on investment, whereas end users'/customers' individual value motives centre around price. For academic actors, individual value motives centre on the reputational status of institutions that is typically based on the scientific standing of their academic communities.

3.1.2. Collective value motives

The PI role, while commonly understood in practice, is very fluid so there are less restricted role parameters. This is particularly advantageous to PIs as they seek to build collective value creation through commonality of purpose as codified and expressed in a publicly funded research proposal and implementation plan. Part of simmelian ties involves brokerage and through this group norms for groups of three or more becomes the means of effective co-ordination (Coleman, 1990). Very strong simmelian ties endure longer than those that do not due to more effective conflict resolution, less individuality and reduced bargaining power (Krackhardt, 1999). PIs having strong simmelian ties through their boundary spanning activities and engagements with other helix actors help with the development of collective value creation and processes that are essential for large publicly funded programmes that drive collective value creation for all actors. It is also essential in addressing the public good of public science particularly diversity and flexibility.

PIs have to increasingly demonstrate in large funding proposals collective value creation and public good impacts. Strong simmelian ties mean that the PI can for collective value creation meet individual value motives actor needs and balance this against collective value motives. This means that individual actor value motives do not override the collective value motives or interest of other helix actors or the public good dimensions for large-scale publicly funded research programmes. The simmelian ties that the PI builds with other helix actors balances delicately the individual and collective value motives of all helix actors. Having multiple parties with strong simmelian ties means that PIs can deal with frictions that arise more effectively because of other helix actors' presence as well as mediating actions that they can take to resolve any friction that arises. In essence, when it comes to collective value creation, simmelian ties enhance and deepen the bond between the PI and other helix actors, impose group norms and ensure that the public good dimension is considered adequately and effectively.

3.2. Value creation

The process of how value is created as well as the measuring and the capture of value can be challenging and difficult (see Gray, 2006; Nickerson et al., 2007). The creation of value for end users and buyers requires, for example, tangible resources, engagement of people, information and the actions of individuals transforming inputs into valuable outputs (see Bowman and Ambrosini, 2000). Within the management and marketing literatures, there are some countering views. Researchers in the management field have predominately focussed on value capture (see Priem, 2001; Priem and Butler, 2001) which has been shaped by the resource-based view of the firm (Barney, 1986). Strategic management literature views value as being created by producers of products and services and one of the main purposes of strategy being the creation of shareholder value (Priem, 2001). While in the marketing literature, there has been more of a focus on value creation taking account of the consumer (see Makadok and Coff, 2002). Value creation can also be viewed from two sides, that of the firm and the customer (Gutpa and Lehman, 2005).

Value creation processes for public science usually involve formal value creation mechanisms that are typically triggered by government public science calls that outline the process and the end outcomes that are being sought. An example of this at the EU level is the grand challenges focus of Horizon 2020. PIs that have created strong simmelian ties with other helix actors mobilise resources, capabilities and actors to address such public science calls. The informal activities that PIs have done such as networking and bridging activities with other helix actors such as the sharing of knowledge and expertise contributes to building strong simmelian ties and enables them to assemble the best possible group of helix actors to respond effectively to meeting the envisaged outcomes of public science research calls. This assembling of the best group of helix actors also contributes to the public good of public science particularly having project diversity. A fundamental way that scientists in the PI role contribute to value creation of public science is by converting their human capital (reputation and scientific standing). Catherine et al. (2004) therefore note that they bring their science and technology human capital to the firm.

Public science value creation research programmes can simultaneously address the two sides of value creation – firms and end users – or some public programmes can focus on just one side of value creation. This is very much driven by the value motives of government and industry in the quadruple helix. For value creation to take place at the micro level, it requires the PI's use of boundary spanning capabilities to transform available resources such as human, structural and relational capital – coupled with their scientific and human capital, to create value for producers and end users in the quadruple helix. The strength of the simmelian ties that the PI has built with other helix actors fosters greater engagement and bridges differences, lessens individual self-interest and competition among parties around a mutually beneficial shared common good. During the project formation stage in responding to the two sides of value creation, the PI envisions the scientific and market shaping potential that will result from the delivery of their project alongside the public good aspects. The simmelian ties that the PIs have built are critical in responding effectively to public funding calls. The activities that PIs engage in, such as envisioning (see Casati and Genet, 2014) and strategising in relation to their public science projects (O'Kane et al., 2015), help support and expand their boundary spanning activities, increase their awareness of the value creation processes of other helix actor environments as well as their individual value motives. The PIs' boundary spanning activities and the development of strong simmelian ties support value creation, additionality and appropriation. Directly and indirectly, PIs are impacting the value creation potential between buyers and suppliers and their willingness to pay as well as the opportunity costs of suppliers.

3.3. Value destruction and friction

The issue of value destruction has been the focus of studies in different fields such as finance (Graham et al., 2006; Harford et al., 2012) and strategic management (Campbell et al., 1995). Value destruction can thereby be avoided by adopting learning through failure (Gauthier, 2014), by deviating (component, interface, concept and scope) (Munthe et al., 2014) and non-participation in firm organisational innovation (see Wendelken et al., 2014). Echeverri and Skålén (2011) argue that with value co-creation there is value co-destruction in their case study of Swedish public transport organisations. Moreover, Pulic (2004, p. 67) suggests that value destruction can happen in two ways: 'If a fall in value creation efficiency occurs and when efficiency is below the average of the environment'.

With value creation comes value destruction and both activities can be intentional and unintentional. At the micro level, value destruction can occur intentionally where, for example, PIs do not follow the prescribed invention disclosure procedures of their institution and take the Intellectual Property (IP) out of the back door of university or what Gianiodis et al.

(2016) term as 'privately leak discoveries'. This intentionally destroys value for other helices actors involved in the project.

Also, friction can occur between parties where the value added that is anticipated is not realised by one or all the parties. This may mean that not all public good dimensions for a publicly funded research project are reached. Some empirical evidence from PIs highlight that friction can occur, when the industry partners' individual value motives change and they lose interest in the project (see Cunningham et al., 2014) or economic conditions worsen thereby putting pressure on PIs to deliver more economic outcomes quicker than intended or where the end user becomes more price sensitive due to reduced income and affordability.

Through their boundary spanning activities and building strong simmelian ties with other quadruple helix actors, the PI encounters or has to deal with friction. Such friction means that the PI at a micro level has to deal with tensions including scientific versus economic activities and impact, governance and fiduciaries responsibilities and market shaping expectation (Mangematin et al., 2014; Cunningham et al., 2016a). Strong simmelian ties with key helix actors means that during the proposal and project implementation phases, the PI can shape group norms and expectations that can address any such frictions effectively. Moreover, simmelian ties create less of an individual focus as the presence of other actors reduces individual bargaining power. The ties create a bond that combines all these elements and provides PIs with contextual dynamics and capabilities that support the effective dealing with friction that does enviably arise among quadruple helix actors.

Strong simmelian ties can moderate deliberate value destruction given such ties lessen the individual focus and create group norms that are necessary for large-scale public science projects. Some existing empirical studies suggest that publicly funded PIs attempt to avoid deliberate value destruction (see Cunningham et al., 2014). PIs do this through project adaptability by seeking ways through their funded projects to explore ways to ensure that their research is relevant and has market potential. In other words, they seek new ways of adding value that are different to what was originally stated and intended. They do this through constant environmental scanning and examining new uses and applications for their IP generated from public science (Cunningham et al., 2014). Institutional support of technology transfer activities, strong linkages with industry and clearly defined commercial opportunities were also found as factors that stimulate technology transfer mitigating again value destruction of public science by PIs (Cunningham et al., 2016a). In essence, PIs establishing strong simmelian ties with key helix actors through their behaviours, attitudes and actions can create value for all actors and put in place processes that are designed to enhance rather than destroy value such as environmental scanning activities as part of their research programme. Moreover, value destruction at the micro level can undermine and erode the public good of public science.

3.4. Value drivers

Identifying and measuring value drivers, particularly intangible value drivers for firms, can be complex and challenging (Marr, 2007). Bose and Oh (2004) ranked value drivers as profitability, uniqueness of innovation, reputation of research team and firm, growth prospects, quality of management, economic factors and risk. Pike et al. (2005) categorise the resource categories that underpin value drivers for R&D as human, organisational, relational, physical and monetary capital. The value drivers of public science are typically measured by research impact (see Narin et al., 1997) and increasingly a range of value drivers is being used to assess the performance of other helix actors such as universities (see Guerrero et al., 2015). Through their boundary spanning role and their actions, PIs support other helix actors to address and meet specific value drivers to their context. The simmelian ties help the PI to bring together diverse knowledge that can shape how end users/customers will ultimately benefit. However, the PIs is reliant on other helix actors to understand what the specific helix actors value drivers at the micro level rather than macro level value drivers are. One of the challenges for PIs is to directly have access and depth of knowledge of the value drivers for end users. Strong simmelian ties also shape PIs' simultaneous and synergistic role as scientists and (lead) users that close the divide between academia and market (Baglieri and Lorenzoni, 2014).

Finally, with respect to value orientation, governments', academic institutions' and the PIs' value orientation is focussed on both the producer and buyer, whereas the industry and end user value orientation is focussed on producer and buyer respectively. Consequently, the individual actions, the boundary spanning behaviours and motivations of PIs do influence the value creation of public science. Figure 1 summarises the value motives and drivers of quadruple helix actors as well as value co-creation and co-destruction and depicts the orientation of value creation. Both, PIs' boundary work and associated simmelian ties enable the creation of value as well as the reduction of friction. Our conceptual model thus integrates and

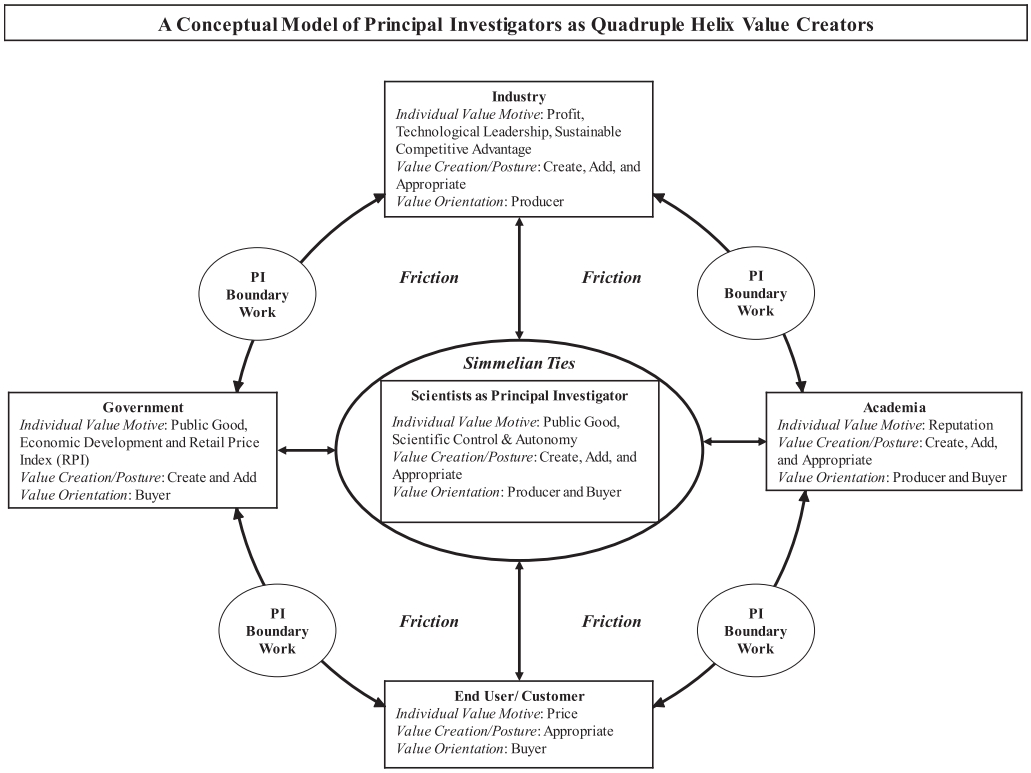

Figure 1. A Conceptual Model of Principal Investigators as Quadruple Helix Value Creators and remove the heading in line A Conceptual Model of Principal Investigators as Quadruple Helix Value Creators.

recombines these previously described theoretical concepts.

4. Conclusion

Public science involves the complementary collaboration between public and private institutions and their associated individual actors that have the public good as a central focus. Current conceptual models of the quadruple helix take a macro level perspective. However, growing studies on the role of PIs indicate that PIs play a boundary spanning role and are transformative agents in developing and leading large-scale publicly funded research programmes at the micro level (Cunningham et al., 2016a). The PI role is still emerging, very fluid and less restricted by role parameters. Taking simmelian ties as our main theoretical lens complemented by our focus on value postures (motives, creation, destruction and drivers), we develop a micro level conceptual model of PIs as value creators in the quadruple helix.

The contributions of this paper are threefold. First, our conceptual model extends our understanding of quadruple helix at the micro level by illustrating how boundary spanning activities of PIs building strong simmelian ties with other quadruple helix actors shape and drive public science value creation. Strong simmelian ties enable the PI to balance individual helix actor's self-interest and value motives against the collective value motives for large-scale funded public science research programmes while also addressing public good dimensions. Furthermore, our conceptual model suggests maximising the public good aspect of public science particularly diversity and flexibility, making it essential that scientists in the PI role have built strong simmelian ties.

Second, our conceptual model highlights that strong simmelian ties underpin value motives and value creation for public science. On the one hand, simmelian ties enable the bridging of different helix actors' knowledge and individual motives around a collective value motive while on the other hand provide the PI with the capacity to overcome such issues as individual self-interest or increased bargaining power that could potentially undermine the public good of public science.

Third, we identified friction as part of the value posture for public science. When friction occurs in large-scale publicly funded science programmes, the strong simmelian ties that the PI has created can mitigate against value destruction, loss of public good impacts and the danger of attaining sub-optimal value creation outcomes for individual quadruple helix

actors. Strong simmelian ties and strong social bonds with other helix actors thus provide the basis and enable the PI to deal with friction effectively.

As a nascent strand of literature, our micro level conceptual model is likely to generate as many questions as it answers. For example: What boundary work and behaviours do PIs need to engage with other helix actors to build strong simmelian ties? How do PIs at the micro level build strong simmelian ties with end users beyond relying on other helix actor information or through research commercialisation? What levels of value destruction and loss of public good impacts are acceptable and sustainable at the micro level and what actions do PIs need to undertake to prevent this from occurring in public science programmes? What are the core capabilities and skills that are necessary for PIs to shape and moderate value postures simultaneously between different helices in the quadruple helix at the project conceptualisation and implementation stages? Future research should address these and further questions. Our conceptual model provides a starting point and opens up the debate that can form the basis for further empirical investigations at the micro level that may lead to more in-depth insights into the quadruple helix, PIs, value postures and public science. A necessary first step therefore is the operationalisation of simmelian ties and boundary work undertaken by scientists in the PI role. Both the quality and quantity of network ties among quadruple helix actors directly influence value creation activities. Thus, the context of quadruple helix interaction becomes essential, indicating the boundaries of our conceptual framework. Future studies should consequently examine selected case studies in the context of publicly funded science, utilise a plurality of data collection methods, and make use of both qualitative and quantitative research designs to create further insights into to processes and mechanisms of quadruple helix interactions and the key role of PIs (see Cunningham et al., 2017a). For future empirical studies using our conceptual model, researchers should consider taking a specific publicly funded scheme such as the European Research Council Advanced Scholar Scheme or EU collaborative research programmes (see Nepelski and Piroli, 2017) or PIs support by a public funding agency such as the ESRC in the United Kingdom to operationalise the simmelian ties and boundary works of PIs. Comparative studies at the micro level across different research and innovation systems as well as a variety of institutional settings are necessary. This will yield further critical insights into value postures in the quadruple helix that will have significant academic, policy and practice contributions. Ultimately this is beneficial for scientists in the PI role, those involved in supporting PIs in leading large scale publicly funded research programmes, firms and end users who can exploit and use knowledge generated for commercial or societal outcomes.

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