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Managing circular economy-oriented niche innovation networks within a triple helix-based governance framework

The cases of industrial biotechnology and remanufacturing in Scotland

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A Thesis presented in fulfilment of
the requirements for the degree of
Doctor of Philosophy

2019

This thesis is the result of the author’s original research. It has been composed by the author and had not been previously submitted for the examinations which has led to the award of a degree.

Signed: Jack Barrie Date: 11.08.19

Abstract

Transition from a linear to circular economy requires fundamental restructuring of the global production-consumption systems. Such restructuring is dependent on the development and proliferation of niche technologies and innovations which promote ‘inner loop’ activities necessary to achieve such a transition such as reuse, repair and remanufacturing. To achieve this, the approach to managing innovation must be redesigned to cope with the increased complexity of moving from linear *value chains* to circular ‘inner loop’ *value webs* of material reuse. This thesis therefore examines a novel innovation policy tool which employs a triple helix-based niche manager to strategically manage ‘inner loop’ niche innovation networks in-line with the broader circular economy transition.

This thesis undertook in-depth studies of two triple helix-based niche managers in Scotland (the Industrial Biotechnology Innovation Centre and the Scottish Institute for Remanufacturing) between September 2015 and March 2018. A novel methodological approach using social network analysis was developed. This allowed each triple helix-based niche manager’s impact on their respective niche innovation networks’ structure and composition to be empirically measured; and as such, the network members’ capacity to develop ‘inner loop’ innovations. By combining the social network analysis of 86 network members with 173 network member surveys and triple helix-based niche manager focus groups, the reasons behind the changes in network structure and composition are explored in depth.

This thesis finds that the triple helix-based niche managers were able to perform key nurturing and empowering roles necessary for steering the innovation networks in-line with a circular trajectory. In terms of nurturing, they were able to build diverse networks, increase shared learning and raise expectations of the niche. In terms of empowering the innovation networks, they were able to connect niche actors with regime actors, direct circular economy funding into the niche and lobby policy makers in terms of niche requirements.

Acknowledgements

Firstly, I would like to express my sincere gratitude to my supervisors, Elsa João and Girma Zawdie for offering continuous support and motivation of my Ph.D. study. I would especially like to express my gratitude for the total freedom they provided to me to explore and draw from a wide range of theoretical areas which has resulted in this unique piece of research. I could not have imagined having a better pair of supervisors.

I would also like to thank the Ellen MacArthur Foundation for awarding me with the Schmidt-MacArthur Fellowship. The opportunity to work and learn from leading circular economy academics and thought leaders including Ellen MacArthur, Ken Webster, Walter Stahel and Janine Benyus were invaluable in shaping my fundamental understanding of the circular economy and my approach to this thesis.

My sincere thanks also go to all the staff at IBioIC and SIR, particularly Roger Kilburn and Jacqueline Balfour for allowing me to freely interview their network members and assess their performance across a broad spectrum of areas. Without their precious support it would not be possible to conduct this research. The unique dataset collected for this thesis was only possible due to the generosity of the individual industrial biotechnology and remanufacturing network members in terms of giving their time to complete my challenging interviews and surveys as well as demonstrating a willingness to contribute to the greater good.

I would like to thank my family for supporting me throughout writing this thesis and my life in general. Last but not the least, I would like to thank my lifetime partner, Ellie Murtagh, for supporting me and believing in my aspirations for this thesis.

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Abbreviations

ASLEE	Algal Solutions For Local Energy Economy
C2C	Cradle to Cradle
EPR	Extended Producer Responsibility
EU	European Union
GDP	Gross Domestic Product
IBioIC	Industrial Biotechnology Innovation Network
ICT	Information and Communication Technologies
IPCC	Intergovernmental Panel on Climate Change
IoT	Internet of Things
ILG	Industry leadership group
ITI	Intermediate Technology Initiative
KTN	Knowledge Transfer Network
MLP	Multi-Level Perspective
OEM	Original equipment manufacturer
RFID	Radio frequency identification device
SDG	Sustainable Development Goals
SIBDG	Scottish Industrial Biotechnology Development Group
SIR	Scottish Institute for Remanufacturing
SNA	Social Network Analysis
SNM	Strategic Niche Management
SMAS	Scottish Manufacturing Action Service
SME	Small to Medium sized Enterprise
UN	United Nations
VAT	Value Added Tax

Chapter 1: Introduction to thesis

> "Infinite growth of material consumption in a finite world is an impossibility"
> (Schumacher 1973, p.88)

Ecosystem destruction, biodiversity loss, climate change, ocean acidification, increasing price volatility and resource depletion are all fatal symptoms of the current linear production-consumption system which drives the global economy. There is a now increasing global awareness on the urgent need to redesign the economic system to be one which is more restorative and regenerative by design and therefore avoid potential ecological and societal collapse. An economy which decouples societal prosperity from material consumption. Such a system would slow and narrow the flow of materials through the economic system and loop all end-of-life resources back into the system to be reused. The transition to a more 'circular economy' is therefore reliant on the transition from todays linear value 'chains' of production and consumption to circular value 'webs' of continuous material and energy flow. A societal transition of this scale is, in part, dependent on the development and proliferation of new technologies which promote circularity combined with greatly enhanced collaboration and coordination between all of society's actors. Using Scotland as a case study, this thesis evaluates a novel policy approach which employs a triple helix governance model to strategically manage national innovation networks of circular technologies to stimulate the formation of circular value webs.

This thesis explores the dynamics of a societal transition towards a circular economy. As such, the research approach draws predominantly from transition theory. Transition theory offers a framework to assess the transformation of societal systems at a large scale and over long time periods (Kemp *et al.,* 1998). It excludes the use of linear models to describe complex systemic change. As such it is based around systems thinking. Transitions theory has also been described as a meta-theory as it draws from a wide range existing models, theories and even opposing approaches. The inclusivity of transitions theory provides a valuable theoretical sandbox for the integration of scientific theories and insights.

Transition theory has evolved from within a research paradigm which has grown in popularity over the past two decades. This paradigm recognises the inherent uncertainty linked to sustainable development and that scientific knowledge alone does not provide the full answer when it comes to understanding messy and wicked societal problems. Ravetz (2006, p.80) called this new research paradigm ‘a revolution in epistemology: science does not deliver certainty’. By recognising that science cannot deliver all the answers in the study of sustainability, this new research paradigm has attempted to the bridge the gap between fundamental and applied research through using integrated approaches and complexity thinking (Rotmans 2005, 21).

Fundamental research, as described by Gibbons et al. (1994), is science driven, single disciplined and undertaken through formal scientific procedures whereas applied research is multi-disciplinary, oriented towards society and based on new roles and approaches to research. In reality, there exists a continuous iterative loop between the two types of research, each informing the other. Transitions studies attempt to rest within the overlap between fundamental and applied research. As such, transitions studies tend to be multi and inter-disciplinary whereby they combine and integrate skills, techniques and knowledge from different disciplines. They are also transdisciplinary in that they combine tacit knowledge derived from applied research with scientific knowledge derived from fundamental research. Finally, transitions studies are normative in terms of their ambition to contribute to achieving sustainability.

The study of societal transitions, or the circular economy transition in the case of this thesis, requires new types of research methodologies which allow the researcher to embrace the ambiguity of the topic and bridge the gap between fundamental and applied research. The transition to a circular economy is an example of a research topic that cannot be considered from a traditional scientific sense. Researchers are unable to study existing circular economy transitions because it is a relatively new concept that is yet to be fully defined both theoretically and in practice. The methodologies used must therefore be integrative by design and be normative in their desire to contribute to the transition under study.

This thesis is particularly predicated upon the normative concept that scaling ‘inner loop’ activities is critical to achieving a circular economy. The notion of inner loops is built on the rationale that the shorter the path of a product or material from its end-of-life to a new user, the more the embedded energy, labour and resources which went into producing it (and hence the economic value) are retained. As the embedded value is eroded, through increasingly inefficient outer loop activities, such as downcycling or combustion, more value and material leaks out of the economic system. In addition to lost economic value, this leakage also leads to a wide range of negative societal and environmental impacts such as biodiversity loss, climate change and polluted land and oceans. Therefore, retaining products and materials within the inner loops (such as reuse, repair and remanufacturing activities) for as long as possible is seen as a fundamental requirement to achieve a circular economy (Vanner *et al.*, 2014).

Currently, inner loop activities remain niche economic activities in to which only a small percentage of products and materials flow. It has been estimated that only 9% of the global economic system is circular (Circle Economy 2019). This is due, in part, to the technological complexity associated with restructuring a value chain to become more circular. For instance, closing loops in a value chain requires the real time tracking and monitoring of products and components as they move through the entire supply chain and reverse logistics technologies are required to aggregate and capture end-of-life products to be prepared for reuse. Once captured, it is necessary to have technologies which can accurately inspect, dissemble, repair, refurbish and reassemble components to make new products. If the material stream is organic, there is the need for industrial biotechnologies to break down organic wastes into the building blocks to make new bio products such as plastics, fuels and chemicals. As such, there is a need for innovation policy to support the development of such technologies to accelerate the shift towards more circular value webs (Milios 2018).

Current circular economy innovation research remains highly focussed on how the individual businesses and the wider private sector can become more circular. There is therefore sufficient knowledge on help to build tools and guidance for innovation for a business or even how a business can build a bigger ecosystem of partners to enact change. However, restructuring the entire production-consumption system far exceeds the capabilities of any one business and even the private sector as a whole. It requires collaboration and coordination from a wide range of different stakeholders operating at different scales and levels of the economic system. As such there exists a knowledge gap in terms of understanding how multi-stakeholder networks of collaboration can be established and governed to achieve such systemic innovation. In particular, there is currently no guidance on how innovation policy can be redesigned to better coordinate wider networks of circular innovators to build strategic inner loop value webs which cannot be achieved by any one business alone. This thesis therefore empirically explores a novel innovation policy tool introduced in Scotland to strategically manage networks of ‘inner loop’ innovation in line with the wider CE transition. The first section in this chapter explores the need to redesign innovation policy to better suit the complexity of a circular economy transition. Subsequently it details the unique Scottish approach to circular economy innovation policy. Finally, it outlines the aims and objectives of this thesis and its structure.

1.1 Redesigning innovation policy for a circular economy transition

A circular economy is an economy which is restorative and regenerative by design (Ellen MacArthur Foundation 2015a). It is therefore an evolution from the current linear ‘take, make, dispose’ model whereby virgin materials are extracted from the earth, made into products, consumed and then burnt or thrown into landfill or the environment to be lost forever. The linear economy evolved under the paradigm of ‘illimitable plains’ (as phrased by Boulding (1966)) which assumes the infinite availability of earth’s resources and economic growth. In contrast, the concept of a circular economy evolved from the recognition that earth’s resources are finite and therefore if economic growth is to continue, it must be absolutely decoupled from material consumption.

The transition from a linear to circular economy involves fundamental systemic changes to the current linear production-consumption system in which deeply embedded path dependencies and lock-ins which underpin the traditional linear ‘make, use, dispose’ economic model are disrupted. Thus, in the transition process, major shifts would be expected to occur in technological trajectories due to innovation, and in market trajectories as a result of changing socio-economic trends. These trajectories would also be expected to align in a systemic framework to ensure that the use of resources across the economic spectrum increasingly leads to a ‘zero waste’ situation.

Innovation policy can therefore play a key role in favouring the development and uptake of technologies which enable inner loop activities and business models to be implemented. However, traditional policy approaches to technological innovation have evolved under the auspices of the linear economic paradigm and therefore tend to promote innovation which is geared towards furthering linear economic growth. Transition theory evolved in recognition that innovation policy has also largely failed to acknowledge that innovations are developed within wider socio-technical and socio-economic systems resulting in poor uptake and unintended consequences. As such, current approaches to technological innovation are unlikely to be adequate to realise a circular economy which requires shared consensus, coordination and collaboration between all actors in the supply chain. As such, there is a need to explore new ways to strategically manage innovation to support a circular economy transition which acknowledges the messy and complex nature of such a transition.

This thesis draws from the field of transitions theory to explore potential new approaches to innovation policy. The field of transitions originated from the recognition that societal transitions are complex and difficult to govern. The field of transitions theory houses many different frameworks and heuristics which were developed to help researchers and policy makers frame the problem in questions. This thesis explores the potential of Strategic Niche Management (SNM) as a policy tool to strategically manage technological innovation in line with a circular economy transition trajectory.

SNM was originally developed form the recognition that new innovations which have the potential to challenge the status quo will likely fail to scale out of their current niche without some form of external support. This is based on the premise that societal systems (food, water, energy systems for example) have evolved over long periods of time to become stable systems which will strongly resist anything that will disturb the status quo. SNM sets out a framework to help nurture the innovations by building support networks around them, increasing shared learning as well as raising external expectations of the innovation. The framework also explores how to empower the niche innovations by finding potential opportunities where the innovation conforms with the existing societal system or altering selection environments of the existing system in favour of the niche innovation.

However, studies have shown that the application of SNM to niche innovation networks, while providing the necessary condition for niche innovation, lacks the consensus, network reflexivity and social capital base with which to disrupt incumbent socio-technical regimes. This is largely attributed to the fact that SNM has traditionally adopted a top-down governance system which invokes network tension for lack of reflexivity. Such an approach makes it restrictive in terms of its contribution to enhancing innovation and possibilities for accelerating the diffusion of inner-loop activities.

The task of SNM is likely to increase in complexity as the circular economy transition requires the formation of protected spaces with much wider network boundaries to promote the cross sectoral uptake of disruptive circular economy enabling platform technologies such as industrial biotechnology and the blockchain.

As such, this thesis argues that the problem of SNM governance within circular economy-oriented niche innovation networks is likely to be mitigated when SNM is applied in the context of the triple helix approach to innovation. The triple helix approach posits that for system innovation to occur, there needs to be increased collaboration and coordination between three key societal institutions, government (knowledge regulators), industry (knowledge users) and academia (knowledge creators). Incorporating the triple helix approach to innovation within SNM would enhance consensus, network reflexivity and social capital base between the triple helix actors. The issue of triple helix-leveraged transition to circular economy, however, raises questions about how the triple helix approach can be operationalised within the niche. The notion of a triple helix-based niche manager was proposed as a new form of SNM manager with the mandate to stimulate the formation of a triple helix consensus space and ultimately lay the networks capacity to generate and scale inner-loop-oriented innovation. However, the concept of a triple helix-based niche manager has not been empirically evaluated in practice.

1.2 The Scottish approach to circular economy innovation policy

Scotland is currently viewed as one of the leading countries in terms of implementing approaches to transition to a circular economy (Ecopreneur 2019). In 2016, the Scottish Government was the first government in the world to publish a national circular economy strategy titled ‘Making Things Last’ which targeted the expansion of ‘inner loop’ activities (Scottish Government 2016). Building on the Making Things Last strategy, Scotland was subsequently awarded £18 million funding from the European Union in 2016 to undertake a programme of supporting ambitious circular economy innovation and experiments within Scotland (Zero Waste Scotland 2019). The trailblazing work undertaken was recognised by the World Economic Forum in 2017 whereby Scotland was awarded the prestigious Circular Economy Award (Scotland Europa 2018).

A key narrative within the Making Things Last strategy was the need to stimulate the development and adoption of cutting-edge technologies which would enable the establishment of key ‘inner loop’ value webs such as biorefining of organic waste into plastics, fuels and chemicals or remanufacturing high value goods. Scotland hosts a number of world leading universities and research institutes which have traditionally been poor in transferring their knowledge to industry (Lyall 2007). The Scottish Government recognised that such a systemic transition would therefore require more effective knowledge generation and transfer between government (knowledge regulators), industry (knowledge users) and universities (knowledge producers) – otherwise known as the ‘triple helix’. Subsequently, the Scottish Government launched two ‘triple helix’ based organisations in 2015 which were publicly funded but co-governed by leading academic and industry actors. These were the Industrial Biotechnology Innovation Centre (IBioIC) and the Scottish Institute for Remanufacturing (SIR). IBioIC and SIR were set up with the mandate to build and manage national innovation networks and foster the development of niche innovation through university-industry collaboration to build the key circular economy inner loop value webs of biorefining and remanufacturing.

IBioIC and SIR employ a triple helix co-governance model rather than the traditional top-down innovation governance approach. In addition, they are also set up with the normative agenda to manage a national network of niche innovators in line with the national circular economy transition. In recognition of the unique nature of these organisations, this thesis refers to them as triple helix-based niche managers. This thesis therefore sought to assess how effective SIR and IBioIC were as triple helix-based niche managers where in terms of building such networks and steering them in line with the broader circular economy transition.

1.3 Thesis aim and objectives

The aim of this thesis is to evaluate the ability of a triple helix-based niche manager to perform key nurturing and empowering activities within a circular economy-oriented niche innovation network.

Due to the novelty of the triple helix-based niche manager proposed in this thesis, it is critical to assess their potential in a real-world context. This thesis therefore addresses such a knowledge gap by undertaking detailed empirical case studies of two triple helix-based niche managers within two separate circular economy-oriented niche innovation networks. The following objectives were used to achieve the thesis aim:

Objective 1: With regards to *niche nurturing activities*, assess through the combination of a complete social network analyses and qualitative research methods, the impact a triple helix-based niche manager may have on a circular economy-oriented niche innovation network with regards to the following niche empowering activities:

a. Building of the social network
b. Raising shared expectations
c. Facilitating shared learning

Objective 2: With regards to *niche empowering activities*, assess through the combination of a complete social network analyses and qualitative research methods, the impact a triple helix-based niche manager may have on a circular economy-oriented niche innovation network with regards to the following niche empowering activities:

a. Supporting niche innovations to compete against incumbent technologies
b. Altering selection environments in favour of the niche innovation.

1.4 Thesis structure

The thesis is structured as follows. Chapter 2 introduces the current global sustainability challenges society faces. It explores the reasons for these challenges, particularly the expansion of the linear ‘take, make dispose’ economy. It subsequently discusses the concept of a circular economy, the potential environmental, social and economic benefits thereof and current circular economy initiatives occurring around the world. It concludes with an assessment of the challenges associated with transitioning to a circular economy and the importance of targeting the growth of inner-loop circular activities.

Chapter 3 introduces the concept of transitions thinking and the benefits of applying transitions frameworks for conceptualising the dynamics of a circular economy transition. It revises one of the most popular transitions heuristics, the Multi-Level Perspective (MLP), to set the conceptual framework with which this thesis is bound within. By highlighting the limitations of the MLP as a policy tool to grow inner-loop activities, Strategic Niche Management (SNM) is proposed as a potential alternative. An overview of SNM is therefore provided which outlines the potential benefits SNM brings to stimulating circular niche innovation. The chapter concludes with the current limitations of the tool and the need to revise it to allow for the polycentric management of the wider niche rather than top-down individual innovation experiments and to increase the level of reflexive knowledge transfer between the niche and policy makers and enforcers as well as external actors.

The first half of Chapter 4 introduces the concept of the triple helix approach to systemic innovation. It then proposes that there is a natural symbiosis between the triple helix approach and SNM in which the triple helix approach offers a conceptual model for developing a form of polycentric governance within the niche between universities (the knowledge producers), industry (the knowledge users) and government or public-sector stakeholders (the knowledge regulators). Whereas the formation of a niche creates a shared normative space where triple helix actors can coordinate and collaborate based on the shared normative goals of the niche succeeding. The second half of Chapter 4 proposes the use of system intermediation as a mechanism with which to operationalise triple helix co-governance of SNM within the niche network. As a result, the chapter concludes by proposing the theoretical concept of a triple helix-based niche manager as a novel policy tool with which to simultaneously nurture the niche network as well as empower the niche by aligning it with the wider circular economy trajectory and initiatives and outlines the need for robust empirical research into the viability of such a policy tool.

Chapter 5 provides the background and context to the research. The chapter is divided into three sections. The first section provides the context the Scottish circular economy transition. The second section provides an overview of the case studies of two triple helix-based niche managers undertaken in this thesis, the Scottish Institute for Remanufacturing (SIR) and the Industrial Biotechnology Innovation Centre (IBioIC) and explains how they are embedded within the wider Scottish circular economy transition. The final section outlines the aims and objectives of the thesis.

Chapter 6 presents the methodology used to achieve the aim and objectives of the thesis. The two initial sections cover the main methodological approaches to assessing the ability of SIR and IBioIC to nurture and empower their respective niche innovation networks. These are complete social network analysis and additional supporting data with which to compliment the social network analysis (collected through network member surveys and interviews as well as focus groups with SIR and IBioIC staff). The chapter provides an in-depth rationale for the selection of social network analysis as a research tool for measuring the impact of IBioIC and SIR on their respective networks.

Chapters 7 and 8 present the results, analysis and discussion of the IBioIC and SIR case studies. The first section presents the results of the complete social network analysis. The first of which are the impact of IBioIC and SIR on the overall network characteristics (network cohesion, presence of cohesive subgroups and network centralisation). Secondly, the impact of IBioIC and SIR on the level of interaction, collaboration and knowledge and resource transfer within and between the triple helix groups within the niche. Thirdly the level of network centrality of IBioIC and SIR within the network. The second section presents the additional supporting data. It presents and discusses the results from the network member surveys and interviews as well as focus groups with SIR and IBioIC staff.

Chapter 9 compares and contrasts the results from the two case studies and offers a discussion why such similarities and differences in the results occurred and the subsequent ramifications for the potential for using a triple helix-based niche manager as a policy tool for nurturing and empowering circular economy-oriented niche innovation networks.

Chapter 10 presents the conclusions of the thesis. The chapter is divided into four sections which cover the conceptual, methodological, empirical and applied learning contributions made by this thesis as well as the recommendations for future studies.

Chapter 2: The need to transition from a linear to circular economy

> “Ours is an economy at war with many forms of life on earth, including human life. What the climate needs to avoid collapse is a contraction of humanity’s use of resources; what our economic model demands to avoid collapse is unfettered expansion. Only one of these sets of rules can be changed and it’s not the laws of nature.”
>
> (Klein 2014, p.21)

This chapter outlines, through a literature review, the contextual setting with which this thesis is embedded. Firstly, it outlines the current existential crises facing humanity and sheds light on the role of the linear economy in driving such crises. Secondly, it introduces the notion of a transitioning to a circular economy as an opportunity to address such crises. It provides detailed background on the theoretical foundation of the circular economy and how it emerged as a global movement. Following this, the current knowledge gaps and research opportunities pertaining to how such a transition may take place are outlined.

2.1 The linear economy versus planetary boundaries

Since the beginning of the industrial revolution, society has experienced a period of exponential economic growth, often referred to as the great acceleration (Steffen *et al.*, 2015). Global gross domestic product (GDP) is 10 times bigger than it was in 1950 and the world economy is excepted to more than double by 2050 (PWC 2017). This growth has led to a significant rise of living standards for billions of people. The average human lifespan has increased from 48 in 1950 to 71 in 2016 (Roser 2019). Since 1990, the number of people living in extreme poverty has halved and 2 billion people have gained access to clean drinking water (UNDP 2015).

This staggering economic growth has predominantly been fuelled by the combination of rapid population growth and the rise of a globally integrated linear economic system. A linear economic system, also referred to as the ‘take, make dispose’ system, is an economic system whereby earths mineral and biological resources follow a linear path from extraction to processing, manufacturing, use and eventually to 'non-economic reservoirs' (as discussed in Boulding (1966)) such as landfill or the environment.

Although the linear economic model has significantly contributed to the advancement in the quality of human wellbeing and has raised millions of humans out of poverty, it has done so by exponentially increasing natural resource consumption. As such, the material consumed globally has increased threefold over the past forty years, whereby material extraction increased from 22 billion tonnes in 1970 to 70 billion tonnes in 2010 (UNEP 2016). The quest for endless economic growth, driven by material throughput, has meant that environmental and social degradation have been classed as 'externalities' that should not and cannot be accounted for within the economic system (Webster 2015).

The externalisation of the environment, with which the economy is ultimately bounded within, has brought many of earth's systems, with which all life on earth depends, to near collapse. Biomass extraction has accelerated large scale deforestation and biodiversity loss and has led to roughly 80% of global agricultural land experiencing moderate to severe erosion (Pimentel and Burgess 2013). The extraction of minerals through intensive and large-scale mining and the processing of the ores are associated with toxic emissions to the land, air and water. Their use in consumer products results in large volumes of hazardous waste. The movement and processing of all these commodities around the globe requires considerable amounts of energy which has typically been derived from fossil fuels and as such produces vast amount of dangerous greenhouse gas emissions. A study assessing material flows, waste production, and recycling in 2005 estimated that approximately 94% of the materials (excluding biomass) that flow through the global economy are not recycled and as such are discarded into landfill, burned or dumped into the environment (Haas *et al.*, 2015).

Drawing inspiration from the world renowned research by Rockström et al. (2009), which assessed humanity's impact on the nine critical planetary boundaries[1], Raworth

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[1] The nine planetary boundaries include: Stratospheric ozone depletion, Loss of biosphere integrity (biodiversity loss and extinctions), Chemical pollution and the release of novel entities, Climate Change,

(2017) introduced the concept of a ‘doughnut’ economic system (Figure 2.1). The doughnut represents a theoretical safe band for human prosperity in a flourishing web of life. To remain within this band, humanity must not exceed the nine environmental planetary boundaries (the outside of the doughnut) and ensure that every human does not fall short of life’s basics for human wellbeing (the inside of the doughnut).

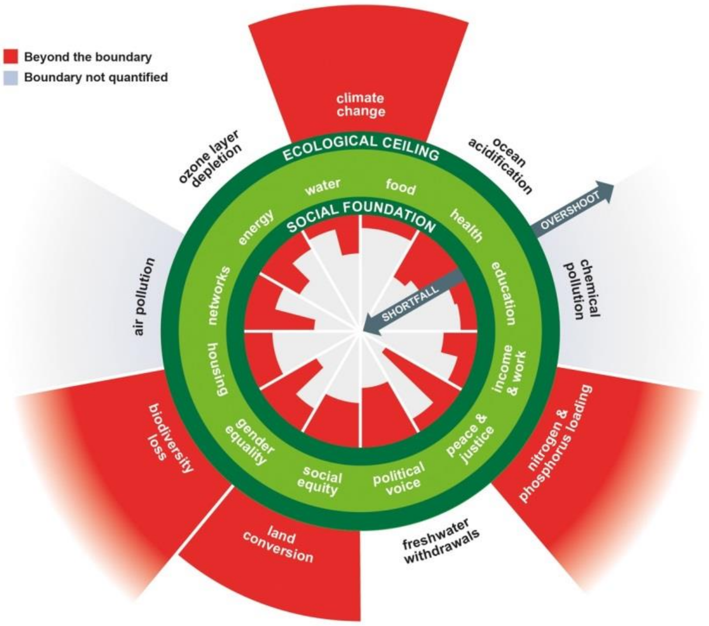

Figure 2.1: The doughnut economy – a graphical representation of the challenges faced in the 21st century, showing that four planetary boundaries have already been exceeded (Raworth 2017).

Alarmingly, as outlined in Figure 2.1, humanity appears to have already exceeded four of the nine planetary boundaries (Raworth 2017). These include climate change, biodiversity loss, land conservation and nitrogen and phosphorous loading. To put this into perspective, atmospheric CO^2 has shot past the theoretical safe limit of 350ppm to 410ppm as of May 2018 (CO2.Earth 2018). If this trend continues, the planet will see a 4 degrees Celsius increase in temperature and sea level rise of 85cm by the end of the century (Brown and Caldeira 2017; Nauels *et al.,* 2017). Such a sea level rise would threaten nearly all major coastal cities, creating over 140 million climate refugees as early as 2050 (Rigaud *et al.,* 2018). The most recent intergovernmental panel on climate change (IPCC) report estimated that if humanity did not significantly

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Ocean acidification, Freshwater consumption and the global hydrological cycle, Land system change, Nitrogen and phosphorus flows to the biosphere and oceans and Atmospheric aerosol loading.

reduce emissions by 40% in the next 12 years, the 1.5 degree Celsius temperature increase above pre-industrial levels threshold would be missed (IPCC 2018).

Furthermore, 14.2 million tonnes of phosphorous per year is spread on the earth as fertiliser, which is far above the estimated boundary limit of 6.2 million tonnes (Steffen *et al.*, 2015). Roughly 80% of earth's natural forest has disappeared (WWF 2015) and the percentage of fish stocks being harvested at unsustainable levels rose from 10% in 1974 to 33% in 2015 (FAO 2018). Further stress is put on marine life through 8 million tonnes of plastic entering the world's oceans each year, which is choking, starving and poisoning millions of marine animals and birds every year *(*Jambeck *et al.*, 2015). Since 1970, the number of mammals, birds, reptiles, amphibians and fish have halved (WWF 2014). To make matters worse, the human activities that are directly causing this destruction show little evidence of slowing and many are, in fact, accelerating.

In addition to ecological limits, the 'doughnut' also incorporates social wellbeing criteria such as access to energy, water, food and shelter as well as gender equality, education and a whole host of other factors. It is evident that the current economy is failing humanity in every single one of them. One in nine humans are undernourished, one in three has no access to a toilet and one in two lives in countries in which people severely lack a political voice (Raworth 2017). Based on these statistics, the current economic system is pushing modern civilisation to the edge of both ecological and social collapse.

The doughnut (Figure 2.1) is a strong warning signal of the precarious state of human civilisation. Unfortunately, such threats are expected to increase in the next half century. It is estimated that by 2030, three billion people are likely to transition from low to middle class status, spending between USD$10 and USD$100 a day (Ellen MacArthur Foundation 2013). The global economy is set to double by 2050. Such growth is based upon an increase in raw biological and mineral material extraction to meet the demand for public infrastructure, housing, transport, energy, food and a wide range of other commodities. An increase in resource demand over such a short time frame combined with a global population growth of one billion people is a ticking time bomb for the environment, civil society and the global economy (Ellen MacArthur Foundation 2013).

Material scarcity is a concern. If all countries achieve the level of consumption which is even half of that of the USA today, then copper, tin, silver, chromium, zinc and a range of other minerals will be depleted in only four decades. The uneven distribution of scarce resources will likely lead to conflicts and trade wars between competing countries (Bunker and Ciccantell 2005). Lee et al. (2012, p.xiv) suggested that society’s insatiable consumption habit means that we are ‘sleepwalking into a prolonged era of resource-related strife’.

The challenge for humanity to fit within the safe band of the doughnut is two-fold. Developed nations must drastically reduce their ecological footprint per capita whilst retaining high standards of living and developing nations must increase their standard of living without increasing their ecological footprint per capita. Unfortunately, even the most sustainable nations are not even close to achieving this (Figure 2.2). To realise such a lofty goal, a fundamental restructuring of the linear extractive economic model must occur; to one which is restorative and regenerative by design and which mimics natural ecosystems and closes material resource loops. The new economic system must achieve an absolute decoupling of economic and social growth from material consumption if humanity is to remain within the safe band of the doughnut. One solution that may help contribute this goal is to transition to a circular economy.

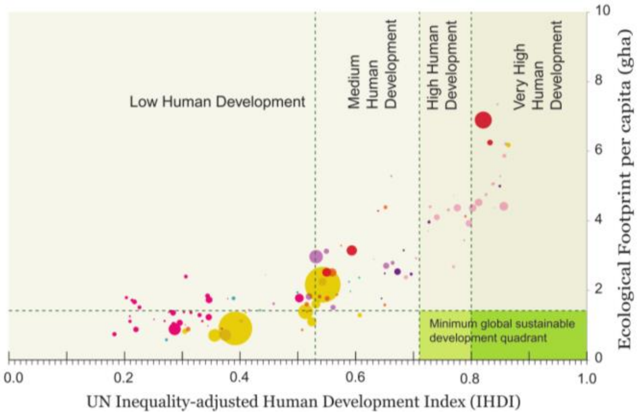


Figure 2.2: Ecological Footprint per capita vs. Human Development Index (HDI) demonstrating need for developed nations to reduce ecological footprint and developing nations to increase HDI without increasing ecological footprint (World Wildlife Fund (2014))

2.2 The need to transition to a circular economy

As outlined above, the environmental, economic and societal consequences associated with the continuation and expansion of linear extractive economy are alarming. There is an urgent need, therefore, to change the goal of the economic system from one which is linear and extractive in nature towards a model based on the cyclical flow of materials and energy, in which every activity restores and regenerates the overall health of the system. As such, the notion of a 'circular economy' has been argued by many to be an important contributing solution to current global challenges (Peters *et al.*, 2007; Yuan *et al.*, 2008; Allwood *et al.*, 2010; Chen and Graedel 2012; Ellen MacArthur Foundation, 2015c; Ghisellini *et al.*, 2015). The following section describes (i) the concept of a circular economy, (ii) the need to support the growth of inner-loop circular activities, (iii) current circular economy initiatives and (iv) gaps in the literature and practice.

2.2.1 The origins of the circular economy concept

The term 'circular economy' was formally coined by the economists David Pearce and Kerry Turner in recognition that the linear conveyor belt format of the economy treated the environment as a sink for pollution and waste (Pearce and Turner 1989). However, the notion of an economic system dependent upon cyclical material flows cannot be fully attributed to a single originator. Rather, it has evolved in-line with the environmental movement reaching as far back as 1966. For example, Boulding (1966, p.7) theorized that society must transition from a 'cowboy economy' (which is associated with 'illimitable plains and reckless, exploitative, romantic, and violent behaviour) to a 'spaceship economy' in which 'the earth has become a single spaceship, without unlimited reservoirs of anything, either for extraction or for pollution, and in which, therefore, man must find his place in…'.

It was the European Commission report titled 'The potential for substituting manpower for energy' written in 1976 by Stahel and Reday-Mulvey (1976) that laid the conceptual foundations for the circular economy concept as it currently stands. The report highlighted the potential impact such a transition could have on promoting sustainable jobs (in the handling, sorting, cleaning, repairing and refurbishing of discarded goods and materials) as well as national economic competitiveness through the decoupling of resource consumption from profit. Stahel and Reday-Mulvey (1976) argued that the shorter the loop or path from a materials end-of-life to its new use, the more profitable and resource efficient it is. As such they sketched out the idea of cascading material loops of re-use, repair, reconditioning and then recycling.

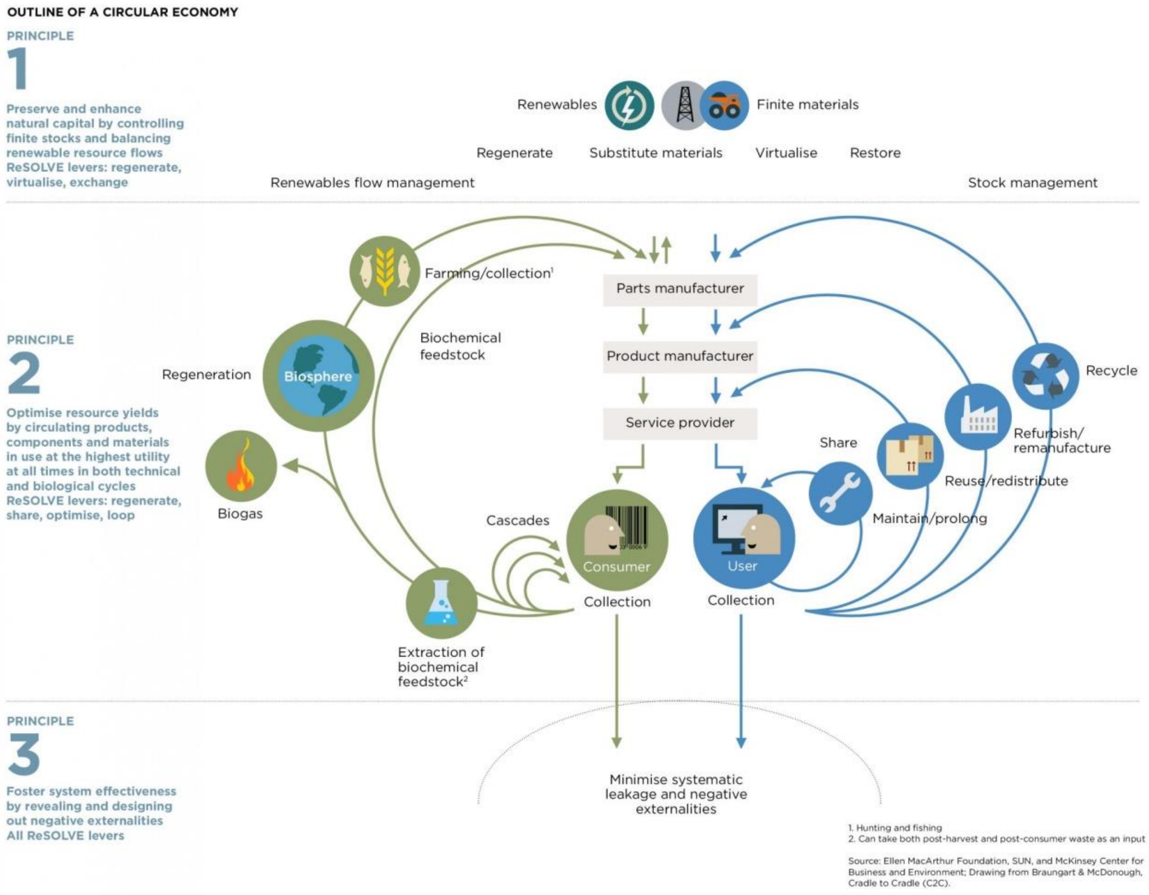
Stahel (2010) also promoted the idea of a performance economy whereby the transition to a circular economy reinforces the need for low energy high labour activities such as repairing or refurbishing. Governments should therefore move towards a sustainable tax policy in which non-renewable resources (such as metals and fossil fuels) are taxed and renewable resources (such as labour) are not taxed. Stahels' work on the performance economy and resource cascades led to him advocate for the transition from a 'cradle-to-grave' economy to a 'cradle-to-cradle' economy. The notion of a cradle-to-cradle economy was further expanded and promoted by McDonough and Braungart (2009) via their book 'Cradle to Cradle: Remaking the way we make things'.

McDonough and Braungart (2009) describe Cradle-to-Cradle (C2C) as a holistic design philosophy inspired from the regenerative way nature continually circulates nutrients throughout ecosystems. To ensure a fully restorative system is designed, the C2C concept sub-divides material components into two categories: (i) consumables or 'biological nutrients'; and (ii) durables or 'technical nutrients'. Consumables are biological ingredients that can be safely returned to the earth and at minimum do no harm, such as cotton or wood. These nutrients have the capacity to regenerate living eco-systems, such as soils, as well as provide a source of renewable energy through the likes of anaerobic digestion. A durable is any material that is not suitable to be returned to the earth directly such as metals and plastics. The technical recovery cycles should therefore be designed so that they can be re-used with little to no loss of quality or value of the component. Although the C2C philosophy incorporates several other design principles including renewable energy, water stewardship, social welfare and material health, the notion of material re-utilisation, i.e. closing material loops, remains the backbone of the concept.

In addition to the performance economy and C2C, several other fields of thought related to closing material loops have also contributed to the development of the circular economy concept including industrial ecology (Graedel 1996), industrial ecosystems (Jelinski *et al.* ,1992), industrial symbiosis (Chertow and Ehrenfeld 2012) and cleaner production (Stevenson and Evans 2004). More recently, the circular economy has expanded into broader schools of thought including biomimicry (Benyus 2002), ecological economics and natural capitalism (Lovins *et al.,* 2006) and taxing resources instead of labour (Cambridge Econometrics 2016).

In an attempt to synthesize the narrative surrounding what form a circular economy may take, the Ellen MacArthur Foundation produced the ‘butterfly diagram’ (Figure 2.3), which has grown to become the most widely used visual representations and heuristics to describe the circular economy (Ellen MacArthur Foundation 2013). The butterfly diagram highlights the traditional linear economic system in the middle of the system where natural resources are traditionally extracted from the earth, manufactured, used and then discarded. The diagram represents a butterfly by highlighting two potential pathways (or loops) for resources to be captured and re-absorbed into the economic system rather than being discarded to the environment. The shorter the loop the more value is retained within the product or resource. The loops to the left of the diagram are the flow of biological nutrients back into the economic system and on the right of the diagram are the flows of technical nutrients (as advocated for in the C2C approach).

Although the notion of what constitutes a circular economy remains a heated debate within academic literature, there is a consensus that a circular economy recognises that the economic system is embedded within society, which is in turn embedded within the natural environment. Rather than being driven by material throughput, it should therefore be driven by cyclical material flow and promote the designing out of waste and pollution, keeping products and materials at their highest utility for the longest possible time and regenerating natural ecosystems. The idea of the hierarchical cascading flow of materials is central to the model. A second, but no less critical element of the butterfly diagram is the recognition that in order for materials to flow around the economy, the system must run on abundant renewable energy rather than finite polluting fossil fuels.



1. Hunting and fishing
2. Can take both post-harvest and post-consumer waste as an input

Source: Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment; Drawing from Braungart & McDonough, Cradle to Cradle (C2C).

Figure 2.3: Material Flow Diagram of the Circular Economy (Left = Biological cycle and Right = Technical nutrient cycle). This diagram is often referred as the 'butterfly diagram' (Source: Ellen MacArthur Foundation (2012)).

An attempt to synthesise what may constitute as a circular economy, based on a detailed literature review, Korhonen et al. (2018, p.39) offered the following definition of a circular economy:

> 'Circular economy is an economy constructed from societal production-consumption systems that maximizes the service produced from the linear nature-society-nature material and energy throughput flow. This is done by using cyclical materials flows, renewable energy sources and cascading energy flows. Successful circular economy contributes to all the three dimensions of sustainable development. Circular economy limits the throughput flow to a level that nature tolerates and utilises ecosystem cycles in economic cycles by respecting their natural reproduction rates'.

2.2.2 The importance of entropy and the inner-loops

The argument for the economic and environmental advantages of the hierarchy of material cascades from inner-loops to outer loops is based on the well-known principle of material entropy and the second law of thermodynamics (Georgescu-Roegen

1971). Material entropy is a measure of the distribution and uniformity of material elements. The second law of thermodynamics outlines that for anti-entropic processes to occur, such as nitrogen fixation from the atmosphere or the production of aluminium from bauxite, an external energy source is required (Boudling 1966).

Although the concept of entropy has been known and understood for the past two centuries, the current linear economic system fails to take full advantage of it. For instance, the linear economy has evolved highly effective anti-entropic approaches to extracting the earth’s natural resources and turning them into products. However, it has failed to realise the economic potential of retaining the materials entropy at the highest possible level for as long as possible, thereby increasing the margin between revenue generated and the cost of energy, labour and resource required to initially make the material (Stahel 2013).

The biological and technical nutrient flow hierarchy, as developed by the likes of Stahel and Braungart and visualised by Georgescu-Roegen (1971) and more recently by the Ellen MacArthur Foundation in the form of the butterfly diagram, is based on the principle of entropy. It argues that a product or material should be kept at its highest quality for as long as possible to retain the highest level of embedded value gained from the labour, capital, energy and resources that went into building the product. Stahel (2013, p.3) theorized that by targeting the inner-loop material cascades, value is retained and “performance of stock replaces value added of flow, and utilization value replaces exchange value as a central notion of economic value”.

Herman Daly’s notion of a steady-state economy has also profoundly influenced the idea of cascading loops. Daly (1991, p.286) suggested that the global economy should be re-structured to exist in a steady state whereby “constant stocks of people and artefacts, [are] maintained at some desired, sufficient levels by low rates of maintenance throughput, that is, by the lowest feasible flows of matter and energy from the first stage of production to the last stage of consumption.”

The butterfly diagram, Figure 2.3, outlines the differing hierarchy of loops for biological and technical nutrients. Each additional loop or cascade may be considered as an extra link in the value chain (Braungart *et al.,* 2007). For technical nutrients, reuse and sharing of products would be considered the ‘shortest’ loop as it does not reduce the product's entropy and extends its lifetime. Following re-use is product maintenance, repair, refurbishment, remanufacturing and finally recycling. Recycling is regarded as the last resort for a material in which the material entropy significantly drops compared to the other loops for many materials (Korhonen *et al.*, 2018). For biological nutrients the loops may take the form of redistribution, bio-refining, energy extraction and composting before returning to the earth. It is important to note that, for durables, the concept of 'consumer' is replaced with 'user'. This highlights that technical nutrients are 'used' not 'consumed' thus highlighting a shift towards business models that are built on revenue from providing a service to the 'user' not a product to the 'consumer'.

2.2.3 Arguments for a rapid circular economy transition

The Ellen MacArthur Foundation (2006, 2013, 2015) argue that the transition to a circular economy promises numerous economic, environmental and societal benefits. The theoretical environmental benefits are many, ranging from reduced virgin material demand and energy inputs as well as toxic waste and emissions outputs. Through applying the C2C approach consumer products are less likely to contain toxic contaminants.

One of the key environmental benefits of transitioning to a circular economy is the estimated reduction in climate affecting emissions. The report by Material Economics (2018), calculated that in an ambitious scenario, the transition to a circular economy would result in as much as 296 million tonnes CO^2 per year out of a total of 530 million tonnes CO^2 in heavy industries in the EU by 2050. The Ellen MacArthur Foundation (2018) claim that a CE transition in China could reduce emissions of fine particulate matter by 50% and greenhouse gases by 23%. As such, the transition to a circular economy appears critical for meeting the Climate Paris Agreement targets.

It is however, the economic benefits that a circular economy offers which are most widely discussed in the literature. Accenture identified the transition to a circular economy as a USD$4.5 trillion global opportunity before 2030 (Lacy and Rutqvist 2015). A report by the European Commission highlighted that the transition to a circular economy can offer savings for European businesses of up to EUR 600 billion, create an additional 2 million jobs and boost GDP by nearly 1% (European Commission 2014).

The cascade system offers four economic value propositions over the standard linear product design and consumption mode (Accenture 2014). Firstly, it promises to decouple the link between resource scarcity and economy activity. Secondly, markets become more liquid by reducing the idle time of products which in turn increases the number of users that can benefit from the same volume of resources. Third, value chains are made more resilient by converting waste outputs in one part of the chain into useful resources in another part of the chain. Finally, keeping economic assets in use for as long as possible allows for the satisfaction of greater demand without using more resources. Drawing from Walter Stahel's notion of the performance economy, there is also the opportunity for job creation with regards to manually sorting, inspecting, stripping down, cleaning and handling used products.

The economic benefit to companies is that they can provide the same product or service with less material and energy input, and as such, should out-compete rival businesses. Through employing circular business models, such as converting a product to a service, businesses can retain customers for longer and increase their profit (Boons *et al.*, 2013; Urbinati *et al.,* 2017). There would also be reduced waste management and emissions controls costs to companies and local authorities. Through the rise of the sharing economy, citizens are likely to gain access to products and services they previously may not have been able to afford.

2.3 Circular economy activities in the policy arena

The notion of transitioning to a circular economy has begun to make inroads into mainstream political and economic spheres and is already impacting supranational economic strategies (Preston 2012). In 2015, the United Nations launched the Sustainable Development Goals (SDGs) consisting of a broad set of 17 goals with the aim of transitioning to a sustainable world by 2030. Goal 12 focuses specifically on developing a global circular economy with the aim of ensuring sustainable consumption and production patterns. This goal will be met through the implementation of a ten-year framework of coordinated programmes in all countries.

In 2015 the European Union, the largest global economic trading block, launched a Circular Economy Strategy which outlined ambitious targets for all EU member states (European Commision 2015). This transition is argued by the European Commission as a promising pathway for “boosting the EU's competitiveness by protecting businesses against scarcity of resources and volatile prices, helping to create new business opportunities and innovative, more efficient ways of producing and consuming” (European Commision 2015, p.7).

Supranational circular economy goals, such as the SDG’s, are ultimately operationalized at the national and regional levels where policies and laws can be enforced. The advantages of a national transition to a circular economy are becoming increasingly evident, particularly for countries with advanced economies, due to the need to operate at increasingly higher resource and labour efficiencies and innovate faster than their counterparts to stay competitive (Webster 2015). Many national governments therefore view the transition to a circular economy as an opportunity to gain competitive advantage, reduce reliance on material imports as well as boost domestic jobs and revenues. In his opening keynote speech at the Circular Economy Stakeholder Conference, Frans Timmermans (first vice president of the European Commission) stated: ‘we cannot compete on wage costs; we cannot compete on cheap natural resources as other parts of the world could. But with resource efficiency, leadership in green technologies and modern waste management, we can build a competitive edge, generate new business opportunities and create jobs’ (European Commission 2018a). It is based on this premise of economic competitiveness that many countries have actively embraced the goals set at supranational levels.

China was one of the first countries to enshrine the circular economy in law in 1998 and in 2002 Japan passed a law titled the ‘Promotion of Efficient Utilization of Resources’ (Su *et al.*, 2013). The law requires that all manufacturers are legally mandated to recover materials and run disassembly plants. Subsequently, Japan introduced the ‘Law for Establishing a Recycling-Based Society’ in 2002 (Geissdoerfer *et al.*, 2017). In 2009, China introduced the Circular Economy Promotion Law (McDowall *et al.*, 2017) and has targeted the circular economy as a key strategy for industrial development (Feng and Yan 2007; Yong 2007; Yuan *et al.*, 2008).

Many countries, particularly in Europe, are implementing national circular economy initiatives and roadmaps. The Netherlands, Scotland, Sweden, Norway, Denmark and Slovenia have all produced national circular economy roadmaps and strategies (Ecopreneur 2019).

The Netherlands and Scotland are viewed as the forerunners to become global circular economy leaders. Scotland has set some of the most ambitious waste reduction targets in Europe and has launched a high level national policy strategy titled 'Making Things Last' to reach these goals with a £18 million circular economy innovation fund to match (Scottish Government 2016). The Scottish Government was also the first government to join the Ellen MacArthur Foundation CE100, a global platform for industry, universities and governments to collaborate to accelerate the transition to a circular economy (Ellen MacArthur Foundation and Scottish Enterprise 2014).

The Netherlands made the circular economy a centre piece of its presidency of the Council of the European Union for 2016 in which they have launched a specific programme titled 'Realisation of Acceleration of a Circular Economy' achieve the goal (Ellen MacArthur Foundation 2015b). The Dutch Government is also currently running the Realization of Acceleration of a Circular Economy (RACE) project which has the aim of making the Netherlands a global hotspot for circular activities (Kalmykova *et al.*, 2018).

The circular economy is also beginning to gain a foothold in the corporate strategies of the world's biggest companies. A global initiative, Factor10, was launched at the World Economic Forum 2017 (WBCSD 2019). The aim of Factor10 is to restructure the value chain of global trade from linear to circular. The CE100 network, facilitated by the Ellen MacArthur Foundation, is another example of growing business interest in the circular economy. The CE100 network members include some of the biggest companies in the world including Google, Coca-Cola, Nike and Unilever and aims to close global resources loops (Ellen MacArthur Foundation 2019).

2.4 Circular economy innovation policy: an important research and knowledge gap

The circular economy literature review by Geissdoerfer et al. (2017) demonstrated a tenfold growth in academic publications covering the topic of the circular economy from under 10 publications per year in 2008 to over 100 in 2016 (Figure 2.4). A separate literature review by Merli et al. (2018) found that approximately 70% of circular economy publications identified individual businesses as the key driver for change and therefore sought to examine the most effective tools, frameworks, business models and management processes across different sectors (Figure 2.5). In contrast, only 11.55% of articles were found to explore how such a transition may be governed in a more systemic approach at the national and international level (Bigano *et al.*, 2016; McDowall *et al.*, 2017).

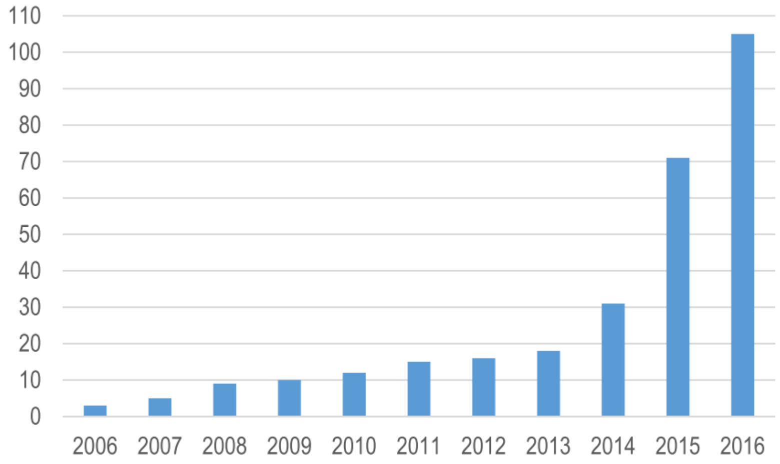


Figure 2.4: Number of academic publications on the topic of circular economy (Geissdoerfer et al., 2017)

Research on individual businesses is necessary to support businesses to proactively drive change towards circularity. However, a national or global circular economy transition will ultimatley require the reconfiguration of entire value chains and as such the coordination and collaboration between a diverse set of stakeholders (European Environment Agency 2016; Lieder and Rashid 2016). This is a challenge since individual businesses are constrained in their ability to influence the wider social and economic systems that they are bounded within (Korhonen *et al.,* 2018). This is due to the structure and dynamics of the global economic system being heavily influenced by societal systems for production and consumption which have evolved to be highly resistant to change (Hegger *et al.*, 2007a). Furthermore, Meadowcroft (2009) suggests that the open market is unlikely and unable to respond quickly enough to the growing social, economic and environmental pressures due to the recognition of the short sighted nature of private sector firms. It is therefore evident that additional research is required on how national circular economy transitions may be goverened to overcome the pre-exisitng linear socio-technical regime lock-ins.

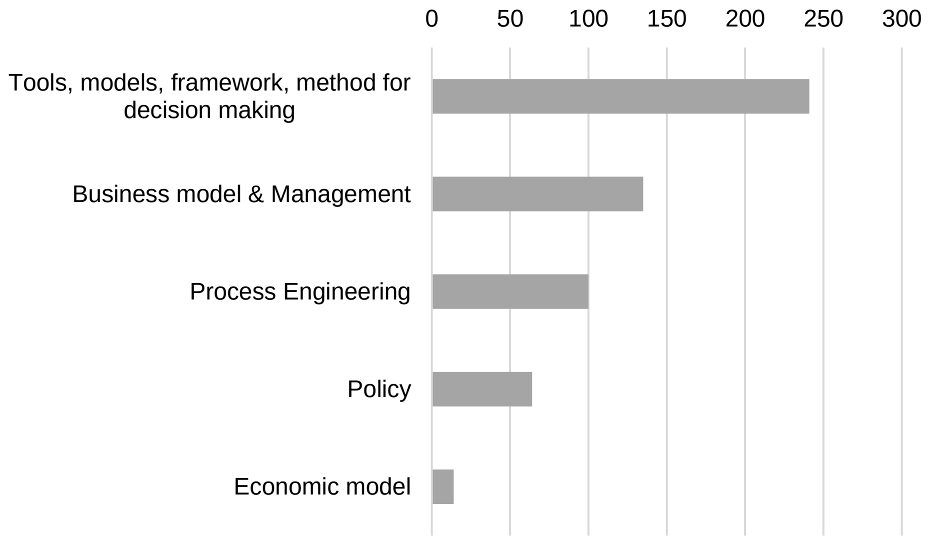


Figure 2.5: Current circular economy literature focus areas demonstrating knowledge gap with regards to broader systems thinking (Merli *et al.*, 2018)

As discussed above, any circular innovation developed by individual companies which challenges the status quo, will likely experience significant resistance from well-established powerful incumbent actors as well as institutions, policy and infrastructure that are aligned with a linear economy (de Jesus and Mendonça 2018). Therefore, although necessary, the current focus on tools and models for individual businesses to become more circular may be compared to shuffling the deck chairs on the titanic, to paraphrase Meadows (2008). Such research focuses on targeting 'shallow' leverage points on a system which ultimately have little influence on the system itself. Further research is therefore required on how deeper system leverage points can be targeted such as changing the rules and goals of the economic system.

In recognition of the risk of linear 'lock-in', there has been increasing emphasis within the circular economy literature on the need to develop a suite of public policy measures to address legal frameworks (such as the definitions of waste) and provide tax breaks and incentives. Huamao and Fengqi (2007) argue that policy is a fundamental driver in realising a circular economy. Genovese et al. (2017) argue government bodies must play the role of facilitator with regards to overcoming the key lock-ins in the current economic and industrial systems. Esposito et al. (2015) identified practical levers government can use to drive increased circularity through the likes of tax, laws and regulatory frameworks within specific industrial sectors or the society at large.

In a review of circular economy policy introductions, de Jesus and Mendonça (2018, p.78) argue that current circular economy policies have, in themselves, been applied in an inherently linear fashion as such have led to “misaligned incentives, lacking of a conducive legal system and a deficient institutional framework”. As such, de Jesus and Mendonça (2018, p.85) suggest that a redesign of current policy approaches towards a ‘multidimensional, multi-actor systemic innovation approach to CE’ is required. In a scan of current circular economy policy mixes in Europe, Milios (2018) also identified that research gaps exist on policy interventions which specifically target the growth of inner-loop activities such as reuse, repair, refurbishing and remanufacturing. Milios (2018, p.862) also highlighted that those policy measures which did focus on inner-loop activities were not effective on their own and suggested that “a novel approach in policy development is required; one that dictates a rather holistic policy view at systems level”.

Stahel (2013) argues that a more holistic approach to circular economy policy has not yet come to fruition as policymakers fail to understand the basic principles of the circular economy. These principles, as suggested by Stahel (2013), include (i) continuous material loops feeding into the production process; (ii) maintain the material quality and performance for as long as possible; (iii) extended ownership of products through reusing, repairing and remanufacturing is cost efficient; (iv) a functional market for second hand material and products is necessary to realise a circular economy; (v) the shorter the path of resource circulation (geographically and activity-wise) the more profitable it is.

Considering the current limitations of current circular economy policy approaches, Milios (2018) argued that policy makers must broaden their scope to consider the interactions between a broad suite of policies spanning the entire lifecycle of a product.

This would include five main stages including (i) production systems (eco-design, remanufacturing, product policy); (ii) consumption systems (Green Public Procurement, Labelling, certification, warranties, waste prevention); (iii) waste management (increased recycling targets); (iv) reuse/second hand market (extended producer responsibility); and (v) waste markets (resource tax, Value Added Tax (VAT), standards, waste shipment regulations).

Figure 2.6, adapted from Milios (2018), illustrates that a broad spectrum of different policy mechanisms across the entire product lifecycle of the production consumption system are currently being explored in various policy arenas – albeit not in a coordinated manner. Nonetheless, there are numerous policy tools available with which to perform the carrot and stick pressures to drive change towards a circular economy. A policy mix will put pressure on producers, users and waste recyclers to alter their activities to become more circular.

Such policy measures push for a fundamental restructuring of existing value chains. Yet such a restructuring requires coordination and collaboration between stakeholders across the full length of the value chain, and in many cases inter-supply chain collaboration (Ruggieri *et al.*, 2016). Furthermore, the physical restructuring of the value chain requires collaborative innovation (both in terms of new technologies and business models) and experimentation on how best to achieve such change - the learnings of which need to be effectively transferred around the value chain and to policy makers.

Park and Chertow (2014, p.47) argue that 'what determines the 'possibility' of reuse for a material is the extent of knowledge that has led to technological innovation for reuse. (…) The reuse potential increases as technological options increase, enabling more material recovery'. Su et al. (2013) also identified the shortage of advanced technologies, combined with weak economic incentives, as a key barrier to China realising its circular economy goals.

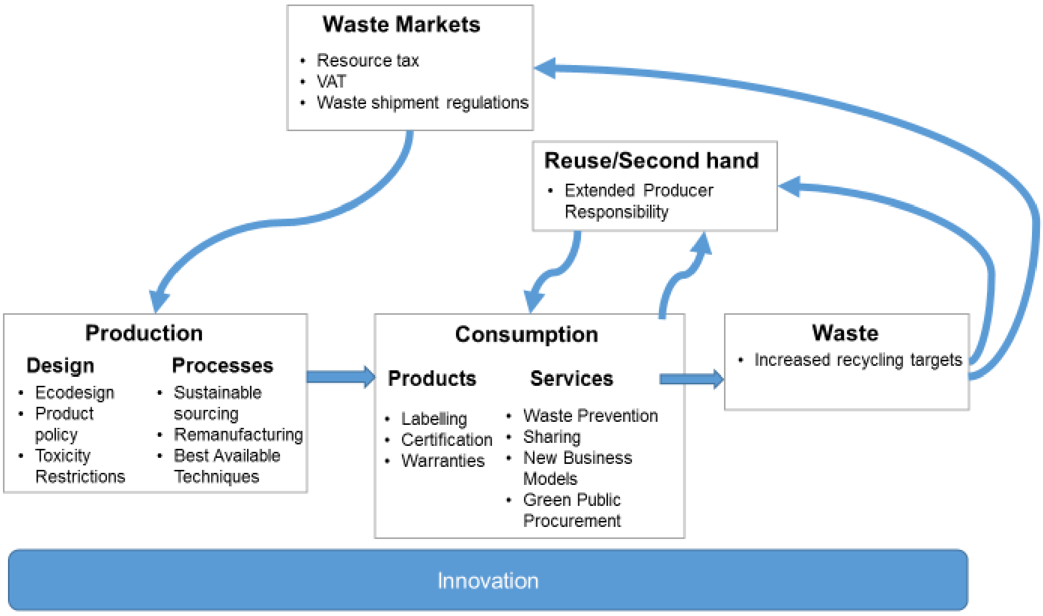


Figure 2.6: Overview of different types of circular economy oriented policies (adapted from Milios, 2018)

The enabling of circular economy activities is dependent upon the successful diffusion of several cross sectoral 'inner-loop' enabling technologies such as the blockchain[2] (Ellen MacArthur Foundation 2016), big data and the internet of things (IoT) (Lopes de Sousa Jabbour *et al.*, 2018; Nobre and Tavares 2017), bio-refining (Venkata Mohan *et al.*, 2016; Zabaniotou 2018), and additive manufacturing (Matsumoto *et al.*, 2016; Despeisse *et al.,* 2017). The combination of disruptive technologies with new circular business models, such as offering a product as a service, will likely lead to the messy and unpredictable re-configuration of existing *or* establishment of entirely new value chains (Boons *et al.*, 2013; EEA 2016; Urbinati *et al.*, 2017). It is therefore evident that there are enormous technological hurdles with regards to achieving widespread application of resource efficiency technologies. Therefore, the current policy mix, as outlined in Figure 2.6, only addresses one side of the problem – it provides the pressure for businesses to change. However, systemic change cannot occur without innovation, particularly technological innovation which enables inner-loop activities to occur. Little research exists on the use of policy to enable systemic circular innovation to occur. Innovation policy which support circular innovation does exist, such as the Horizon 2020 programme or Innovate UK. The Horizon 2020 work programme launched the call "Industry 2020 in the circular economy". The programme aims to

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[2] The blockchain is a technology which allows an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way.

support projects that promote innovation through CE, with an investment over €650 million (European Commission 2018b).

However, little evidence exists of policy being developed which implicitly targets the establishment of inner-loop value chains through multi-stakeholder collaboration and coordination – especially at a regional or national level. As highlighted above, much of the academic literature on circular innovation is focussed at the business level exploring how business model and product innovation can occur. However, no literature was evident on how to coordinate and enable wider inner-loop activities.

Based on this knowledge gap, this thesis argues that there is a need for a more holistic approach to technology innovation policy to complement the existing circular economy policy mix outlined in Figure 2.6. Such an approach should acknowledge the multi-actor systemic nature of innovation and target the re-configuration of entire value chains through the successful diffusion of circular economy enabling technologies. The introduction of such technologies must be able to overcome the inherent linear lock-in within existing socio-technical regimes if they are to achieve scale.

By drawing from the sustainability transitions literature, the following chapter explores the challenges of successfully scaling such inner-loop technologies and explores the potential for adopting Strategic Niche Management (SNM) as an innovation policy for scaling circular economy enabling technologies using multi-stakeholder collaborative approach to systemic innovation.

Chapter 3: Applying transition theory to understand the circular economy transition[3]

The circular economy has been promoted by several global institutions as an opportunity to build an environmentally sustainable and socially just economic system. A recent study by the Ellen MacArthur Foundation and McKinsey suggested that Europe could create a net benefit of €1.8 trillion by 2030 if a circular economy path is followed (Ellen MacArthur Foundation 2015b). Accenture estimated the benefits to be up to USD$4.5 trillion globally by 2030 (Lacy and Rutqvist 2015). Although such claims have been made, how to overcome path dependency and technological lock-in to achieve systems change is yet to be fully understood. Furthermore, as outlined in Chapter 2, if a global circular economy were to be realised, local, national and supranational production-consumption systems would need to be entirely reconfigured. This would require a re-design of how current technological innovation policy is designed and implemented. It is therefore logical to draw from pre-existing literature which has explored the complexities of governing societal transitions.

This chapter will therefore introduce the scholarly field of transition theory and outline its relevance in helping both academic scholars and policy practitioners understand the complex dynamics associated with a circular economy transition and it potential impacts on how such a transition may be governed. Firstly, it describes the emergence and growth of the research field and subsequently the different types of transition frameworks developed to analyse past transitions as well as operationalize future ones. Following that, it discusses the need to revisit and revise a popular sustainability transitions policy framework to accelerate a circular economy transition, that of Strategic Niche Management (SNM).

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[3] Sections 3.5 and 3.6, which discuss the Strategic Niche Management as a potential policy tool to accelerate the circular economy, are published in: Barrie et al. (2017).

3.1 Sustainability transitions: an emerging field of research

The growing sustainability challenges over the past few decades, as outlined in Section 2.1, coupled with the complex lock-in dynamics associated with socio-technical regimes, have brought to the fore a discussion on the role of national governments and multi-lateral organisations in governing or steering societal transitions towards sustainability (Elzen and Wieczorek 2005). As such, there has been increasing attention on the topic of sustainable transitions within social-science research (Frantzeskaki and Loorbach 2010; Smith *et al.*, 2005, Grin *et al.*, 2010) and it is beginning to permeate into national and supranational policy arenas *(McDowall et al.*, 2017).

Transitions literature is based on the notion of a *transition*. A transition is a process of deep change in the structure of society. It is the evolution from one stable societal system to another. The transition process is driven by the co-evolutionary dynamics existing between individual citizen behaviour, policy and legislation, technological innovation, markets, public institutions and infrastructure (Kemp *et al.*, 1998). Transitions are not instantaneous events, rather they play out over decades (minimum one generation) and are influenced by interactions between different societal and geographical scales (Rotmans and Kemp 2003). A transition can therefore be described as a complex societal phenomenon and understanding how to steer or govern a transition towards sustainability may be considered a wicked problem[4] (Peters 2017).

The transitions field has expanded around a handful of foundational theoretical frameworks and heuristics. These include the multi-level perspective on socio-technical transitions (Geels 2002; Geels and Schot 2007; Smith *et al.*, 2010), strategic niche management (Kemp *et al.*, 1998; Raven and Geels 2010); transition management (Rotmans *et al.*, 2001; Loorbach 2007; Loorbach and Rotmans 2010) and technological innovation systems (Bergek *et al.,* 2008; Hekkert *et al.*, 2007).

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[4] A wicked problem may be defined as a problem whose social complexity means that it has no determinable stopping point (Tonkinwise 2016).

Alongside these heuristics and frameworks, several theoretical approaches have been advanced to explain different aspects of societal transitions. These range from more general theories such as actor network theory (Latour 2017), evolutionary economics (Metcalfe 1994; Nelson and Winter 1982), reflexive governance (Smits *et al.,* 2010), and sociology of expectations (Borup *et al.,* 2006; Brown and Michael 2003) through to more technocratic theories such as technology futures and constructive technology assessment (Porter *et al.*, 2004). Due to the particular focus of transitions literature on sustainability, a number of sustainability oriented approaches have also been incorporated into transitions thinking including eco-innovation (Kemp 2010; Rennings 2000), ecological modernization (Jänicke 2008), and industrial ecology (Ehrenfeld 2000).

3.2 The circular economy as a sustainability transition

The trajectories of societal transitions are inherently messy and unpredictable as they take place within complex systems that exhibit and respond to emergent properties. In an attempt to bring clarity to this ‘messiness’, Berkhout et al. (2004) and Smith et al. (2005) developed a heuristic of four archetypal societal transformations based on the coordination of actors and whether resources are mobilized internally or externally to a socio-technical regime.

Box 1: What is a socio-technical regime?

Socio-technical regimes evolve to address fundamental societal needs such as water, energy and food supply. These regimes form through the co-evolutionary build-up and alignment of knowledge, resources, practices, infrastructure, values and norms (Rip and Kemp 1998). It is due to this co-evolutionary formation that technological lock-ins exist in which well-established technologies become deeply intertwined with culture and lifestyles, business models, infrastructure, regulations, institutional practices and politics. Such complex lock-ins induce incremental and complementary changes to socio-technical regimes (Markard and Truffer 2008). In most cases, the incremental changes do not lead to systemic change, such as transitioning to a circular economy, within an appropriate timescale (Markard and Truffer 2008). It is therefore evident that radical innovation arising out with existing socio-technical regimes must be promoted to ensure a timely transition.

The four types of societal transformations are: (i) re-orientation, (ii) emergent transformation, (iii) endogenous renewal and (iv) purposive transition (Figure 3.1). The framework suggests that as the resource locus (the creation and supply of resources) becomes increasingly externalised to the incumbent socio-technical regime and the coordination between actors is low, an emergent transformation will likely occur (Figure 3.1 Bottom Left Quadrant). Such transformations have been observed to occur directly after a rapid decline in economic growth, otherwise known as a recession, or worse a depression. Recession affects every part of the economy hence the uncoordinated drive for systemic change by a range of different actors external to the incumbent regimes (which are reliant on the failing economic model) and the emergence of multiple new socio-technical regimes (Smith *et al.,* 2005).

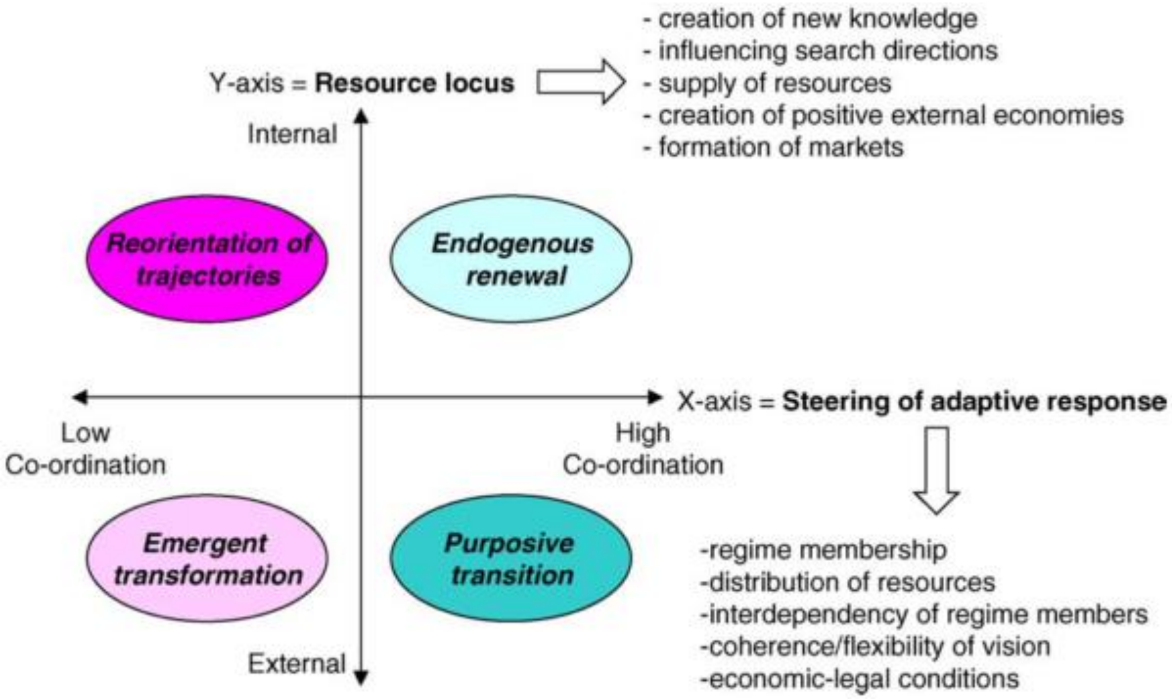

Figure 3.1: Four types of societal transitions with respect to the level of coordination and locus of resources. Circular Economy is now evolving from emergent to endogenous and purposive transformation (Smith *et al.,* 2005)

The 2008 global financial crisis combined with the increasingly volatile commodity markets saw global productivity grind to a halt and wages stagnate (Webster 2015). A fundamental restructuring of the global economy was therefore required where growth became decoupled from finite resources. This need for a fundamental restructuring of the entire global production-consumption system sparked the beginnings of an emergent transformation and led to a series of seemingly uncoordinated attempts from ‘external’ actors to the linear regime to create such systemic reconfiguration of the production-consumption system. These ranged from the ‘Fossil Fuel Divestment’ campaign run by 360.org which has seen the divestment of over USD$6.24 Trillion from the fossil fuel industry (The Guardian 2018), to the renewables revolution and even the rise of the sharing economy in which companies such as AirBNB have obtained over 60 million customers in the space of a few years and now have more rooms available than the three largest hotel chains combined (Byers *et al.,* 2013). Although seemingly unrelated, the rise of these movements appear to have been in response to the failings of the linear extractive economy and an attempt to re-design the production-consumption system to be more circular in nature (Webster 2015).

Governance of emergent transformations is challenging as the selection pressures are poorly articulated or aligned and as such obscure the end-point of such a transition. This significantly restricts coordination between regime and external actors. Smith et al. (2010) suggest that, due to the combination of growing selection pressures and increased activity, it is common for initially uncoordinated initiatives to begin to converge over time towards a more consistent and aligned trajectory (Figure 3.1).

When an emergent transformation becomes more coordinated over time but remains largely external to incumbent regimes then a purposive transition is likely to occur (Figure 3.1). A purposive transition radically challenges, in most cases replaces, incumbent regimes such as the transition from a centralised electricity grid fuelled by fossil fuels to decentralised and locally owned renewable energy generation (Figure 3.1 Bottom Right Quadrant). Endogenous renewal leads to significant internal reconfiguration of regimes such as the shift from coal fired power plants to natural gas power plants (Figure 3.1 Top Right Quadrant).

Purposive transitions offer the greatest governance challenge as they force incumbent regimes to adapt in a way that leads to the current technologies becoming obsolete (Smith *et al.,* 2005). Whereas endogenous renewal offers less challenges to the status quo. Berkhout et al. (2004) warned, however, that a purposive transition is not guaranteed to ensure environmental or social benefits and thus requires an effective correcting mechanism to ensure that these factors are taken into consideration.

A ‘sustainability transition’ is considered a type of purposive transformation (Farla et al. 2012). The notion of a sustainability transition is inherently normative. Examples of sustainability transitions may be considered as the overhaul of current food, waste or energy systems towards more sustainable alternatives (Elzen and Wieczorek 2005). Geels (2011) outlined that sustainability transitions have three unique characteristics. Firstly, they are goal oriented or ‘purposive’. Secondly, they do not offer obvious user benefits and therefore any environmental innovations that require special support. Finally, the empirical domains which sustainability transitions cover are dominated by large firms who will likely defend the status quo to retain their powerful positions.

Since the financial crash in 2008, it can be argued that the circular economy has evolved from an uncoordinated emergent sustainability transition to one which is more purposive in nature. The emergence of the circular economy as a dominant narrative for the current sustainability transition is evidenced through numerous global initiatives beginning to emerge that use consistent circular economy vernacular such as the United Nations led Sustainable Development Goals, the European Circular Economy Package (European Commission 2015), China’s five year national plan (Murray *et al.*, 2017), several national circular economy strategies launched by Swedish, Danish, Finish and Scottish Governments (Ecopreneur 2019), and the Ellen MacArthur Foundation CE100 Network (Ellen MacArthur Foundation 2019).

The limitation of purposive sustainability transitions research is that is has tended to focus on the transition of an individual socio-technical regime, such as energy or food, rather than deeper transitions which transform the entire economic system. Adopting the terminology from Schot and Kanger (2018), the circular economy may be thought of as an articulation of a new techno-economic paradigm which stimulates the formation of a meta regime; a coordinating mechanism that creates new interconnections between multiple technologies and industries. It advocates for the structural change of the entire production-consumption system and therefore spans multiple socio-technical regimes such as food, water, energy, manufacturing, transport, construction and resource extraction models (Lachman 2013). In addition, the circular economy is a movement away from a linear value chain towards value webs where technical and biological nutrients flow amongst and between multiple socio-technical regimes and therefore raises a unique governance challenge. This makes the circular economy, as a purposive transition, particularly difficult to govern.

Although the transition to a circular economy appears to be being normatively driven through publicly funded national and supranational initiatives, very little exists in the literature with regards to how national governments can successfully operationalise such purposive goals. Therefore, as in the studies by Geels (2011) and Kivimaa (2014) the remainder of this chapter will focus on the role of national government in facilitating and steering a purposive circular economy transition using policy as a correcting mechanism.

The following section will provide an overview of two widely used transitions frameworks which offer policy practitioners and researchers an increased ability to interrogate and ultimately develop circular economy steering mechanisms. These are: (i) the multi-level perspective; and (ii) strategic niche management.

3.3 Understanding the circular economy transition through the multi-level perspective

The most widely adopted framework to understand the dynamics of societal transitions is the Multi-Level Perspective (MLP) (Geels 2002). This section introduces the MLP and discusses the benefits of applying it to governing and understanding the circular economy transition. It concludes with the limitations of the MLP and need for additional tools to be used.

Geels (2002) proposed the multi-level perspective (MLP) on transitions as a heuristic to comprehend and analyse the complex dynamics associated with societal transitions. The MLP frames transitions as system innovations, in other words a reconfiguration from one socio-technical system to another. The MLP postulates that there are three main levels within a transition as outlined in Figure 3.2. The middle or meso level is the socio-technical regime which provides a specific societal need such as food, water or energy supply. Above this level at the macro scale is the socio-technical landscape. The landscape is a catch all for dominant macro scale trends that put pressure on the sociotechnical regimes to reconfigure. The bottom or micro-level is that of technological niches which produce radical innovations that put bottom-up pressure on the regimes. The real benefit of the MLP is that it serves as a framework to contextualise the dynamic interplay between the three levels during a transition. It also highlights broadly how the trajectory and configuration of regimes can be altered by niche or landscape external pressures.

MLP Level 1: Socio-technical regime

The middle or meso level in the MLP (Figure 3.2) is comprised of socio-technical regimes. Socio-technical regimes are the stable and dominant way of addressing a particular societal need such as food, water or energy supply. The niche and socio-technical regimes experience a complex dynamic as the characteristics of a socio-technical regime tend to only lead to incremental change over time, whereas, more often than not, niche innovations present radical changes that will alter the path of the socio-technical regime. Sustainable niches must overcome this lack of willingness to change structure if they are to change the path of the regime and seed a transition. The MLP infers that socio-technical regimes can be reconfigured over time by two external forces; (i) landscape pressures; and (ii) niche innovations.

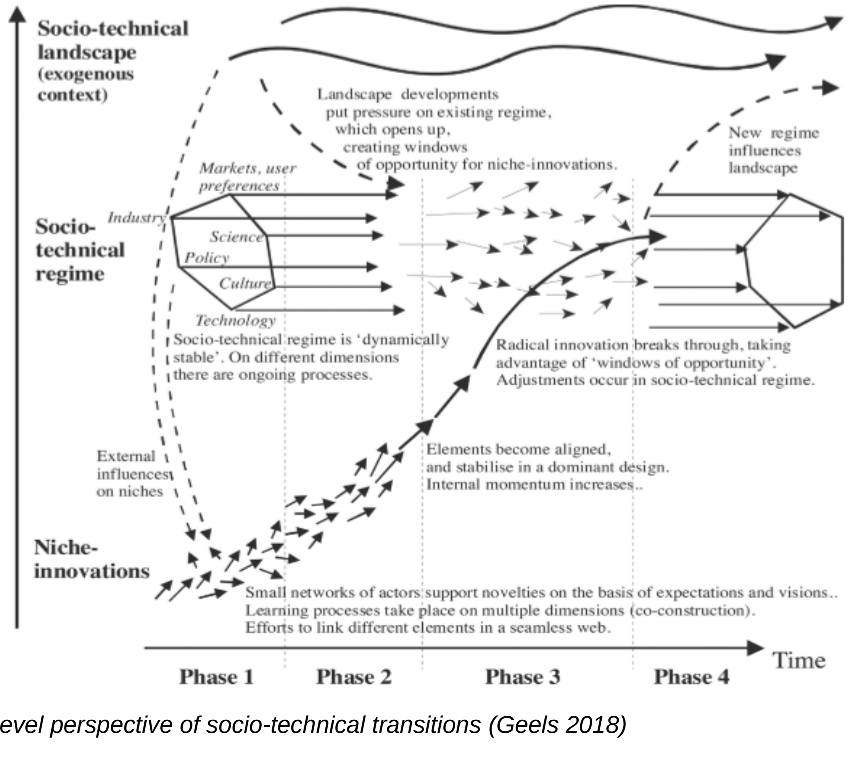

Figure 3.2: Multi-level perspective of socio-technical transitions (Geels 2018)

MLP Level 2: Socio-technical landscape

The socio-technical landscape accounts for changing macro level trends which exert forces upon sociotechnical regimes from the macro level. Geels (2018) suggests that trends come in two forms: (i) slow changing; and (ii) exogenous shocks. Slow changing trends include changes in demographics, spatial structures, climate change, infrastructure and even political ideology. Exogenous shocks include economic recession and depressions, war, natural disasters or political revolts. Changes in the landscape are a continual source of pressure on regimes and cannot be controlled by Governments (Smith *et al.*, 2010; Farla *et al.*, 2012).

MLP Level 3: Niche innovation

The niche innovations level sits at the micro level of the economy. Within the niche level exists innovations that fundamentally challenge the configuration of established regimes and are a major source of creative destruction. The actors within the niche level tend to be perceived as 'outsiders' to the regime such as the environmental campaigners developing early forms of wind turbines (Hermans *et al.*, 2013). If a niche innovation is to grow and eventually reconfigure existing regimes, buy-in from actors within these regimes is essential, for instance energy utilities in the growth of wind energy (Verbong *et al.*, 2008). As such the niche level can be considered as a continual source of transformative ideas who's potential is controlled and interpreted through the more powerful force of the regime (Smith *et al.*, 2010). Raven (2005, p. 50) defined a technological niche as 'a loosely defined set of formal and informal rules for new technological practice, explored in societal experiments and protected by a relatively small network of industries, users, researchers, policy makers and other involved actors'*.*

Sustainable niche innovations face many barriers to success. Asides from having to compete with more established better resourced incumbent regimes existing within a system that is resistant to change, they also compete on an uneven playing field with other niches whose interests are more closely aligned, in other words complimentary, with the established regimes. In the context of sustainability transitions, Geels (2011) and Geels et al. (2016) argue that government policy plays the predominant role in helping niches to overcome these barriers.

3.3.1 Adopting the multi-level perspective as a policy and research tool

The MLP is a mid-range framework which has been adopted by transition scholars to analyse a number of historical case studies of historical socio-technical transitions. Geels (2002) undertook an empirical analysis of how steamships replaced sailing ships and transformed global trade between 1780 and 1900. Geels demonstrated their rise from a niche market of tug boats to pull cargo ships along inland canals before expanding out to harbours ports and estuaries and eventually to long distance freight shipping and widespread replacement of sailing ships. The MLP has also been applied to a range of modern transitions. One example would be the study by Raven (2004) on the implementation of manure digestion and co-combustion in the Dutch electricity regime. By adopting the MLP, Raven (2004) was able to develop a coherent narrative around the mismatch in rules between the agricultural and energy regimes and the biomass niches. Hekkert et al. (2007) surmised that the MLP has significant potential for policy making. The MLP has since been observed to have a strong influence on European policy making, particularly in the Netherlands from where the concept emerged.

Nonetheless, the MLP suffers from certain conceptual limitations which transition scholars (Berkhout *et al.,* 2004; Voß *et al.,* 2009; Smith *et al.,* 2010) argue will likely restrict its use as a policy analysis tool. Such limitations are exacerbated when applied to the context of a circular economy transition. The following sections outlines these limitations and proposes a revision to the MLP framework to fit with the complexities of a circular economy transition.

3.3.2 Limitations of the multi-level perspective as a circular economy policy tool

Although the MLP has proved to be an effective heuristic for offering a more general understanding of the dynamics of societal transformations, the ability to apply it as a policy tool to facilitate and incite socio-technical change towards sustainability remains limited (Geels 2011).

Smith et al. (2010) outlines three key challenges for adopting the MLP as a transition policy tool. Firstly, the MLP does not allow for an explanation of how and why links between the conceptual levels of niche, regime and landscape occur. Without understanding the links between the levels, it is difficult to identify the key leverage points with which to accelerate and steer the formation of niche-regime circular economy-oriented links. Secondly, the two-dimensional construct of the MLP does not easily allow for the exploration of the plurality of regimes and niches. Although the majority of MLP studies focus on the transition of a specific regime, such as the energy or transport sectors, the meta-regime nature of the circular economy transition (i.e. it requires the reconfiguration of multiple regimes) means it will be comprised of a complex web of overlapping socio-technical regimes and niches – each influencing the other. This makes governance of a circular economy transition through traditional top-down targeted interventions and policies challenging and unpredictable.

The MLP also offers no way to understand the effectiveness of governance mechanisms. Schot and Geels (2008) highlight that socio-technical regimes can be highly resistant to targeted government initiatives such as the congestion charge or extended producer responsibility. Policies also tend to create an ‘us and them’ dynamic. The need for a broader portfolio of policy measures is recognised within the MLP however there is a lack of guidance on how to coordinate such a portfolio (Voß *et al.,* 2009).

Finally, the MLP in the form of an operational policy tool, does not directly account for current paradigmatic shifts in the way society and the economy functions such as the rise of open innovation (Chesbrough 2003) or the changing roles of institutional actors such as the third mission of universities (Etzkowitz and Leydesdorff 2000) and even the transition of advanced nations to a knowledge-based economy (Powell *et al.*, 2004). It can therefore be argued that the MLP represents a historical model of past transitions as opposed to projecting a possible future model of how transition dynamics may occur and how they may be governed. This is echoed by Smith et al. (2010, p. 440) which state that the ability to “catch [paradigms] as they form, and manage the formation and establishment of new ones, remain very poorly understood and under researched”.

This opens a broader debate around the tools and mechanisms for governing regime change which was highlighted early on in the development of transition management concept by Berkhout et al. (2004, p.11) who suggested that there is still no theory of how to 'link' together the development of niche innovations in combination with a purposive style of transition management. A critical question in the circular economy transition is how such niche technologies can scale rapidly, however the MLP does not provide an operational framework with which to achieve this.

Although critics of the MLP have highlighted obvious shortcomings in the model, it remains the most commonly applied framework within the transitions literature. This is partly due to its ability to offer clarity and structure to the complex and multifaceted nature of socio-technical transitions. But more importantly, it is generalizable enough that it allows flexibility to the researcher or practitioner to define the topic and scale of analysis, define system boundaries and employ the three levels of the framework based on the subject under study (Geels *et al.,* 2016). Due to the adaptability of the MLP framework, there is merit in applying it as a heuristic for framing the complex dynamics of a circular economy transition and the governance challenges thereof. The following section therefore offers a revision of the MLP for the context of a circular economy transition – the purpose of which is to identify the key transition challenges that national governments need to understand and overcome.

3.4 Revising the MLP to fit the complexity of a circular economy transition

By combining the MLP narrative with Schot and Kanger's (2018) idea of a techno-economic paradigm, a re-conceptualisation of the MLP from 2 to 3 dimensions can be developed to help visualise the multi-level dynamics of a circular economy transition (Figure 3.3). Starting with the regime level, the current linear economy can be described as a system which is made up of multiple distinct but inter-dependent socio-technical regimes (such as energy, mobility and food regimes). The continuous reconfiguration of these regimes, which are comprised of components such as technologies, markets, users, legislation, can be observed via the x-axis which represents time. The resultant transformation of each individual incumbent linear regime would be a transition to a circular regime in which all socio-technical regimes become and remain aligned with circular economy principles.

Linear regimes currently experience multiple landscape pressures including climate change, biodiversity loss, resource constraints, pollution and many more. The linear regimes are also under pressure from a range of different circular economy enabling niche technologies. The pressures on the regimes from the landscape and niche levels can be observed via the y axis. The initial MLP diagram developed by Geels (2002) only represented the interplay between a single socio-technical regime and the external landscape and niche pressures – in other words the X and Y axis (See Figure 3.3).

Yet, the transition to a circular economy requires the reconfiguration of the entire global production-consumption system and as such the reconfiguration of all societal regimes. The original two axis MLP diagram is arguably overly simplistic for framing the complexities of a circular economy transition. Therefore, in addition to the traditional representation of the MLP with a single x-axis (time) and y-axis (scale), an additional z-axis (economic breadth) is included in Figure 3.3 to offer greater clarity on the complex inter-niche, niche-regime, inter-regime, landscape-regime and landscape-niche dynamics associated with a circular economy transition.

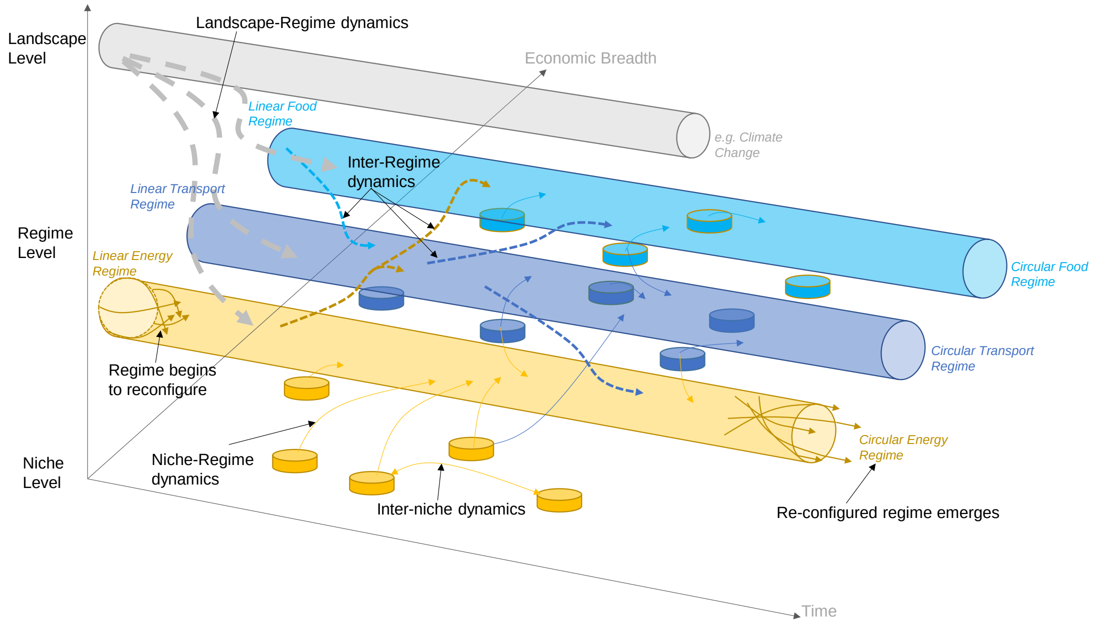

Figure 3.3: Graphical representation of niche, inter-niche, niche-regime, inter-regime, landscape-regime and landscape-niche dynamics for a transition to a CE using a revised MLP framework from Geels (2018).

Firstly, the additional z-axis allows for the representation of multiple linear regimes and their respective co-evolutionary reconfiguration from linear to circular regimes – this is particularly important for a circular economy transition where the lines between incumbent regimes become increasingly blurred. Secondly, the z-axis also allows for the representation of technological niches that are aligned with circular economy principles which threaten to reconfigure several linear incumbent regimes. For example, electric cars as a technological niche align closely with the mobility regime. However, the success of electric cars may also lead to a significant reconfiguration of the currently centralised electricity regime to a more decentralised regime due to their energy storage capacity. Thirdly, the z-axis allows for the representation of inter-niche dynamics, not only for closely aligned or competing niches, but also between niches emerging under different regimes. Finally, the additional z-axis also allows the representation of landscape pressures impacting multiple regimes in different ways.

Although this thesis acknowledges the critical role of understanding landscape-regime and landscape-niche dynamics, this thesis explicitly looks at the area of the MLP where national governments and national policy can exert a normative influence and steer the transition towards circularity. As such, the remainder of this thesis will be framed within the interstitial space between circular niche innovations and incumbent linear regimes.

The following sections develop Figure 3.3 in further detail with regards to the notion of the increased complexity of a circular economy transition, relative to a singular regime change, and identifies the governance challenges associated with such increased complexity. In particular, it explores the need for technology innovation policy to build reflexivity with regards to: (i) inter-regime; (ii) inter-niche; and (iii) niche-regime dynamics.

3.4.1 Inter-regime dynamics: reconfiguration and overlapping of multiple regimes

The combination of disruptive technologies with new circular business models, such as offering a product as a service, will likely lead to the messy and unpredictable re-configuration and blending of previously distinct value chains existing within different regimes (Boons *et al.,* 2013; Urbinati *et al.,* 2017). Take the transport regime and electricity regime as an example. Electric and hydrogen vehicles are estimated to replace the one third of internal combustion engines by 2030 (International Energy Agency 2017). The transition to electric and hydrogen powered vehicles will not only significantly reconfigure entire value chains within the incumbent automotive regime but may also have significant effects on the fossil fuel-based electricity regime. This is because they can be used as temporary storage devices which can draw from or supply power to the grid. This potential significantly increases the chances of the transition to a renewable electricity regime as the cars will be able to act as storage buffers to cope with the intermittency of renewable energy technologies such as wind turbines (Zhao *et al.,* 2017). Furthermore, the planned mass scale roll out of decentralised renewable energy systems will likely make it even cheaper for households to charge their electric cars. As such the internal reconfiguration in the electricity regime currently taking place via renewables will also have an impact on the success of electric cars – which was traditionally thought of as a ‘mobility’ niche. There is therefore a much greater need for alignment between the electricity and automotive regimes to ensure such a transition remains smooth.

3.4.2 Inter-niche dynamics: reconfiguration of value chains requiring alignment of multiple niche technologies

The circular economy transition is dependent upon the widespread diffusion of several enabling technologies which currently sit within the niche level of the MLP. Such technologies include the blockchain (Ellen MacArthur Foundation 2016), big data and the internet of things (IoT) (Lopes de Sousa Jabbour *et al.,* 2018; Nobre and Tavares 2017), bio-refining (Venkata Mohan *et al.*, 2016; Zabaniotou 2018), and additive manufacturing (Despeisse *et al.*, 2017; Ford and Despeisse 2016). Each individual technology, if scaled successfully, will likely have a significant impact on the structure of multiple regimes. Therefore, with the rate of technological development ever increasing, and the parallel growth of these technologies, the potential relationships and interfaces between such disruptive technologies need to be carefully understood and managed to ensure they steer the regimes in-line with circular economy principles.

Take biorefining and additive manufacturing as two niche circular economy enabling technologies. Biorefining offers the ability to convert waste organic matter (e.g. from food or agricultural waste) into valuable fuels, chemicals and plastics. Biorefining is seen as a key technology for enabling the transition to a bio-economy and replacing fossil fuel derived fuels, chemicals and plastics. Additive manufacturing (such as 3D printing) is seen as a key enabling technology for scaling distributed or localised manufacturing of goods and products thereby eradicating the need to transport products and components around the globe to be assembled and eventually delivered to the customer (Matsumoto *et al.*, 2016). The combination of biorefining and additive manufacturing would allow businesses and individuals to make a vast array of products from locally derived waste organic material for a very low cost. Therefore, there is significant need for coordination and collaboration between the two technological niches to increase the chances of success.

In addition, the reconfiguration of many established value chains from linear to circular is dependent on the simultaneous scaling of several of these niche technologies. Take for example a manufacturing value chain being reconfigured to close its material flow loops and remanufacture all its products. For this to be viable, it is necessary to utilise IoT technology to track and predict material flows throughout the entire supply chain all the way to the user, adopt material passport technologies such as radio frequency identification devices (RFID) to quickly identify product and inspect component quality and even use additive manufacturing to remanufacture products where the spare parts supply chain has been discontinued. Therefore, it is necessary that separate technological niches are better coordinated to ensure the best opportunity to reconfigure existing linear value chains.

3.4.3 Niche-regime dynamics: enabling technologies impacting multiple regimes

Finally, many circular enabling technological niches will likely straddle the boundary between several regimes making it challenging to manage the development of the niche in-line with the needs and demands of a single regime. Industrial biotechnologies are one such example, as they hold the potential to disrupt the agricultural, chemicals, fuels and plastics regimes. Therefore, there is the increased complexity of supporting the growth of such a technological niche through traditional top-down policy mechanisms in a way that it becomes absorbed and accepted by the respective regimes.

The revised MLP framework presented in this section highlights that the transition to a circular economy is a complex governance challenge as it requires the simultaneous reconfiguration of numerous linear sociotechnical regimes. Furthermore, the reconfiguration is also dependent on the scaling of numerous technological niches, the successes of which are independent and will affect multiple regimes. As such, it is unlikely that traditional top-down policies, which focus on a single niche or regime, without accounting for the complex multi-niche-regime dynamics, will be sufficient for such a transition. There is therefore the need to develop innovation governance tools which are better suited to such complexity.

The following section introduces Strategic Niche Management (SNM), an analysis tool developed to address the limitations of the MLP with regards to fostering the growth of sustainable technological niches. It explores the potential use of SNM as a policy tool for steering the transition to a circular economy and necessary revisions required to cope with the complexity described in this section.

3.5 Strategic Niche Management as a circular economy innovation policy tool

The revised MLP (Figure 3.3) sets the scene for the broader dynamics associated with a circular economy transition. However, it does not offer practitioners working within the policy arena a practical framework with which to stimulate the coordinated growth of niche inner-loop enabling technologies which are central to a successful circular economy transition. This section therefore introduces Strategic Niche Management (SNM) as a potential governance tool for stimulating circular oriented niche innovation. It then discusses the revisions to the SNM framework required to cope with the complexity of a circular economy transition.

The concept of SNM was first presented by Kemp et al. (1998). It was defined as “the creation, development and controlled phase-out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of (1) learning about the desirability of the new technology and (2) enhancing the further development and the rate of application of the new technology” (Kemp *et al*., 1998, p.186). The definition of which was derived from the first EU SNM project titled ‘Strategic Niche Management as a Tool for Transition to a Sustainable Transport System’.

SNM was developed as an evolutionary policy tool to facilitate the growth of radical and sustainable technological niche innovations in-line with a wider sustainability transition (Kemp *et al.*, 1998). It is based on the rationale that if radical innovations were to successfully destabilise unsustainable technology regimes, they would require initial protection from the competitive pressures of the market through the formation of protected spaces (Raven 2006; Schot and Geels 2008a; Verbong *et al.*, 2008; Nill and Kemp 2009). A protected space is a neutral conceptual space (or application domain) where a range of innovation stakeholders are supported and encouraged to collaborate in interactive learning processes and experiments that contribute to cultivation and scaling of a new technology or class of technologies (Caniëls and Romijn 2008).

Experimentation lies at the heart of SNM. Experiments are the mechanism that allow for expectations to be aligned, networks to grow and learning to occur. There are two forms of experimentation; demonstration experiments and replication or dissemination experiments. Demonstration experiments have the aim of demonstrating the potential benefits of such a technology whereas as replication experiments explore the viability of how widely applicable such a technology is and how it is affected by differing socio-technical contexts.

It is within these experiments, undertaken within a protected space, that a niche innovation network of technology stakeholders is nurtured and valuable learning processes to scaling the niche are obtained (Hegger *et al.*, 2007). A protected space may therefore be considered to consist of a dynamic niche innovation network comprised of organisations contributing to innovation within a technological niche.

SNM was developed to address the limitations of the MLP with regards to being a more prescriptive and objective policy tool for managing niche innovation in the context of sustainability transitions. As an analytical tool, SNM has enabled an in-depth understanding of the conditions for successful widespread adoption of niche innovations as well as the mechanisms required to protect such innovations in the nascent stages of development (Kemp *et al.*, 1998; Verbong, *et al.*, 2008; Ulmanen *et al.*, 2009; Boon *et al.*, 2014; Verhees *et al.*, 2015). Similar to the MLP framework, SNM has been adopted by academic researchers to assess historical case studies of niche innovations (Hoogma *et al.*, 2002; Elzen, *et al.*, 2012), as well as provide useful insights for policy makers and industry (Kemp *et al.,* 1998; Weber *et al.*, 1999; Hoogma *et al.*, 2002).

The SNM literature also differentiates between the maturity levels of a niche. Lopolito et al. (2011) hypothesized that there are four phases of niche maturity: (i) absent; (ii) embryonic; (iii) proto; and (iv) full. A niche may be described as absent when the there is no willingness, power or knowledge within local stakeholders or potential users with which to adopt the new technology options. To progress to an embryonic stage – the lack of interest should be addressed through policy, which subsequently attracts the attention of key producers and users and builds a core willingness to pursue the development of the niche. An embryonic niche is characterised in the addition of actors to the network who hold relevant resources with which incubation can occur and joint experiments can take place. A proto-niche is characterised by a clear and shared vision within the niche and a suitable level of powerful actors within the network with which to scale the niche. A proto-niche lacks suitable network structures and governance mechanisms with which to facilitate effective learning and knowledge transfer. As such, to progress to a Full niche, the condition of effective knowledge and learning and the convergence towards a dominant design is necessary (Lopolito *et al.*, 2011).

Harborne et al. (2007) stress that involvement of outside actors and second-order learning between niche stakeholders does not happen easily. As such, there is general agreement in the literature that there are three main (internal) processes necessary for the successful development of a technological niche: (i) shielding; (ii) nurturing; and (iii) empowering (outlined in Table 3.1) (Kemp *et al.*, 1998; Smith and Raven 2012; Boon *et al.,* 2014; Verhees *et al.*, 2015).

Table 3.1 Overview of the niche processes involved in Strategic Niche Management (modified from Kivimaa (2014))

Niche Processes	Aim	Example activities
Shielding	To hold off selection pressures present within incumbent socio-technical regimes and create a protected space for innovators to experiment.	• Mobilizing pre-existing generic support • Implementing the innovation in favourable locations • Creating financial support, temporary rule exemptions for innovation (new subsidies, research and development funds, tax incentives, green public procurement) • Tolerating poor economic/technological performance
Nurturing	Ensuring the protected space created by shielding is fully utilised. This is done by undertaking activities that will improve the socio-technical and economic performance of the niche technology/technologies so as to reduce dependency on shielding. Key objectives are to optimise shared learning, build networks and facilitate shared expectations.	• Supporting broad and reflexive learning • Articulating specific and shared expectations • Building broad and deep networks
Empowering	Helping a niche innovation to realize its path breaking potential to reconfigure incumbent socio-technical regimes by undertaking outward facing activities aimed at changing mainstream contexts.	• Fit and Conform Activities: o Promoting innovation that will be able to compete under pre-existing market pressures o Dispelling fears that that no radical change to the existing socio-technical regime would be required o Outlining that shielding and nurturing activities are temporary • Stretch and Transform o Fighting for and achieving institutional reforms o Justifying shielding based on sustainability principles o Outlining that nurturing activities are a continual learning process in the path towards sustainability

3.5.1 Shielding niches from external market forces

Shielding is a process which largely takes place outside the niche. It aims to protect niche innovations from market selection pressures by providing a protected space for experimentation. Shielding mechanisms occur in various forms, including financial support, rule exemptions, basic research funding and dedicated programs (Verhees *et al.*, 2015). Shielding can also come in the form of policies as outlined in Figure 2.6.

3.5.2 Nurturing the niche network

The aim of nurturing is to improve technological/economic performance of the shielded innovations. As such, nurturing helps the shielded technological innovations to progress from a technological niche to a market niche that suits the needs of a specific market segment without the need for shielding and nurturing support. Nurturing is essential to the health of the niche as effective learning is unlikely to occur naturally between the heterogeneous groups of niche actors (Hoogma *et al.*, 2002). At its core, nurturing aims to cultivate the network of innovators and niche actors within a protected space. Schot and Geels (2008) suggest that nurturing is achieved through the following three main processes: (i) and building of social networks; (ii) exchange of knowledge and supporting learning processes; and (iii) articulating of values and visions.

3.5.2.1 Nurturing activity 1: Network formation

The first nurturing activity of SNM is the building and maintenance of a broad social innovation network with which to carry out and articulate expectations, enhance knowledge exchange and learning and ultimately sustain niche development. In the early stages of niche development, the niche innovation network is typically narrow consisting of a few firms and little to no regulatory stakeholders. At this stage, it is imperative that the niche network attracts actors who are willing, based on their expectations of future niche success, to invest in expanding the niche.

The niche can be expanded by bringing in incumbent regime actors who tend to have the resources and power to expand the niche, but may also restrict it if these actors have a vested interest in slowing down the niche developments to prevent reconfiguration of the regime – thereby leading to more incremental innovation (Kemp *et al.*, 1998, p.191). Nonetheless, without buy-in from the regime actors, the niche is highly likely to fail. It is therefore necessary to have a balance of regime actors with actors that do not hold strong ties with the regime and who are more willing to try more radical innovations. This balance between regime and non-regime actors within the network has been shown to affect the extent to which the innovations coming out of the niche are radical or incremental in nature (Hoogma, 2000).

In addition to having a broad network, it is also important for SNM to ensure that the network experiments and initiatives are aligned to the long-term goal of the niche. Alignment must come in many forms including the niche innovation network actors' expectations, visions and longer term strategies (Schot and Geels, 2008). If the network is well aligned, all activities will complement each other, and this would broaden the scope for synergy and hence create opportunities for innovation of the radical type.

3.5.2.2 Nurturing activity 2: Enhancing broad and reflexive learning

Effective learning is a key objective in undertaking real world experiments with niche technologies (Raven, 2005). As such, a niche experiment can be designed to ensure valuable learning is obtained with regards to specific technological, economic or social performance aspects of the technology. Therefore, assuming sufficient learning is captured, experiments can drive an iterative loop of reflexive learning whereby actors taking part in the experimentation learn from and share the results, adjust the technology (either by branching finding a new application or improving on the previous limitations) and then commence a new iteration of experimentation.

Such an iterative cycle should enhance the alignment or offering of the niche technology with regards to its ability to reconfigure an incumbent regime. Hoogma et al. (2002) suggest that experiments offer the potential for wider learning on the topics. This includes the level of complementarity between the technology and existing infrastructure, user needs and demands, societal and environmental impacts, scaling issues and finally any necessary adjustment required in the Government's policy and regulatory framework.

By studying several examples of niche experiments in the Netherlands, Hoogma et al. (2002) found that effective learning that advances the technology niche to a market niche does not necessarily occur naturally. Raven (2005) suggested four barriers within the experimental learning iterative loop[5] may prevent change from occurring:

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[5] The iterative learning process within SNM involves undertaking individual experiments, the results of which are shared building a wider network and raising expectations. New experiments are subsequently designed and implemented based on the learning and expectations and the iterative process continues (Raven, 2005).

1. Actors may learn that changing their normative stance (ideas and values) may improve the likelihood of the technology succeeding – yet they may ultimately be constrained in their ability to change their behaviour to reflect such learning due to external constraints of the actors (such as laws, incentive structures and standards).
2. It is not guaranteed that the actor who learns from an experiment is able translate the learning into future use. For example, experiments tend to be highly situation and context specific and therefore it is difficult to transfer learning to another experiment – in other words they may be situationally constrained.
3. The learning from one actor is not automatically transferred to a higher level (either amongst the wider niche or even the incumbent regime). An additional risk being that if the learned actor leaves the niche – the valuable knowledge also leaves – in other words fragmented learning.
4. Even if an experiment is successful and valuable learning is captured – the experiment actors have little or no influence or ability to scale the experiment – in other words opportunistic learning.

Due to the four challenges with regards to leveraging learning within the niche to accelerate change, there is a clear need for external support, in the form of SNM nurturing, to help overcome such barriers.

3.5.2.3 Nurturing activity 3: Articulating and shaping specific and shared expectations

In addition to effective learning, the management of actor expectations plays a critical role in the early development activities of the niche technology. For instance, early promises by actors, particularly powerful ones, on the future potential of a niche technology provide the niche with some level of legitimacy. If other actors buy-in to these early promises, they will be more likely to inject time and resources to develop the technology which has yet to offer any market value. Conversely, for a complex technology such as industrial biotechnology, initial expectations between actors can be varied and fragmented. This is because the technology could in theory be applied in many different sectors and industries and as such each actor may have a different vision and expectations of the trajectory (and viability) of such a technology. Such a fragmentation can lead to niche branching where actors search in different domains for new opportunities to apply the technology.

The results from niche experiments serve as strong mechanisms for guiding actor expectations. Experimental results offer objective evidence which allows actor to either increase the robustness and specificity of their expectations or change them to fit closer with the limitations of the experiment. An experiment can also act as a mechanism to allow several actors to develop shared expectations through objective means. If the experiment has some level of excess, expectations can increase. Hoogma et al*.* (2002) demonstrated that when this occurs the niche is more likely to succeed.

The alignment of expectations, as with learning, does not occur naturally. Rather it requires a concerted effort to align a broad range of stakeholders who exhibit different institutional norms, culture, practices and goals. As such, Hoogma (2000) stated that as the alignment of the niche innovation network increases, so does the scope of niche development.

3.5.2.4 Interaction between the three nurturing processes

The nurturing processes of building networks, raising expectations and shared learning are highly interrelated and interdependent. Raven (2005) illustrated such interdependencies (Figure 3.4). The niche nurturing process goes as follows. Early promises on the future benefits of the technology raise expectations amongst actors both within and out with the niche. Raised expectations attracts actors to invest time and resources in running experiments to affirm their initial expectations. The network characteristics and structure influence the design and output of the experiment. Results from the experiments contribute to learning processes. The structure and composition of the network dictates how well learning is absorbed by the wider network. Expectations are tempered or made more robust depending on the results of the experiments. Raised expectations can lead to new actors becoming involved and new experiments increase.

The extent to which the niche technology creates incremental or radical change within the regime is dependent upon the composition of the niche innovation network with regards to the balance of regime and external actors. The process of experimentation continues until the niche technology develops into one or more market niches whereby the technology can compete with incumbent technologies under specific conditions. Market niches have barely any visible effect on the regime and the network remains relatively narrow. As the niches develop and further experimentation is undertaken the niche technology eventually emerges as the dominant technology within the regime and as such, practices and norms are reconfigured to align with the new technology (Hoogma 2000).

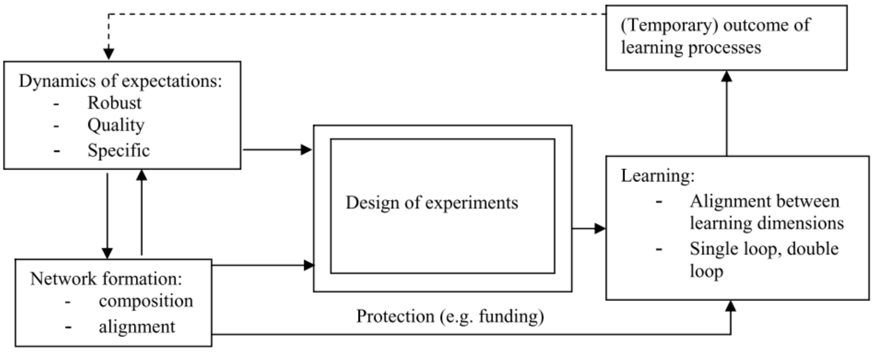


Figure 3.4: The dynamics between niche expectations, learning processes and network formation in relation to the design and implementation of experiments (Raven 2005)

3.5.3 Empowering the niche to overcome regime lock-in

Smith and Raven (2012) recognised that niche actors are unlikely to be able to individually exert influence to change mainstream selection criteria as the sphere of power tends to sit with powerful incumbent regime actors. Therefore, if the niche innovation is to expand outside the technological niche into a niche market segment and further realize its path breaking potential to reconfigure incumbent socio-technical regimes, some level of niche empowerment is required.

Empowering activities are largely outward facing from the niche and targeted towards changing mainstream contexts within the incumbent socio-technical regimes. Smith and Raven (2012) identified two forms of empowering a niche innovation; (i) fit and conform; and (ii) stretch and transform. Fit and conform empowerment develops the narrative that, if the innovation were to scale, very little reconfiguration of the socio-technical regime would be necessary to accommodate it, thereby allaying fears from incumbent actors. It stresses that shielding and nurturing of the innovation is only a temporary process. In contrast, stretch and transform empowerment promotes the notion that shielding support is not fully removed and that such shielding activities become institutionalised, thereby permanently altering the selection criteria of the market (Verhees *et al.*, 2015).

3.5.4 Inter-relationships between niche shielding, nurturing and empowering

The relationships between shielding, nurturing and empowering activities in protected spaces are considered to be iterative and co-dependent (Boon, *et al.,* 2014; Verhees *et al.*, 2015). Initial protection, for instance, leads to early nurturing and hence provides the conditions for the development of an innovation. If the innovation shows promise, then stronger protection mechanisms can be introduced which further assist nurturing and empowerment and eventually institutionalisation of the niche network. Once the network within the protected spaces builds enough momentum to compete on an equal basis against incumbent technologies, protection measures would be expected to be removed and give way to continuous knowledge exchange between policy makers and actors on the innovation network over the lifetime of the protected space (Verhees *et al.*, 2015).

3.6 Adapting SNM for governing a circular economy transition

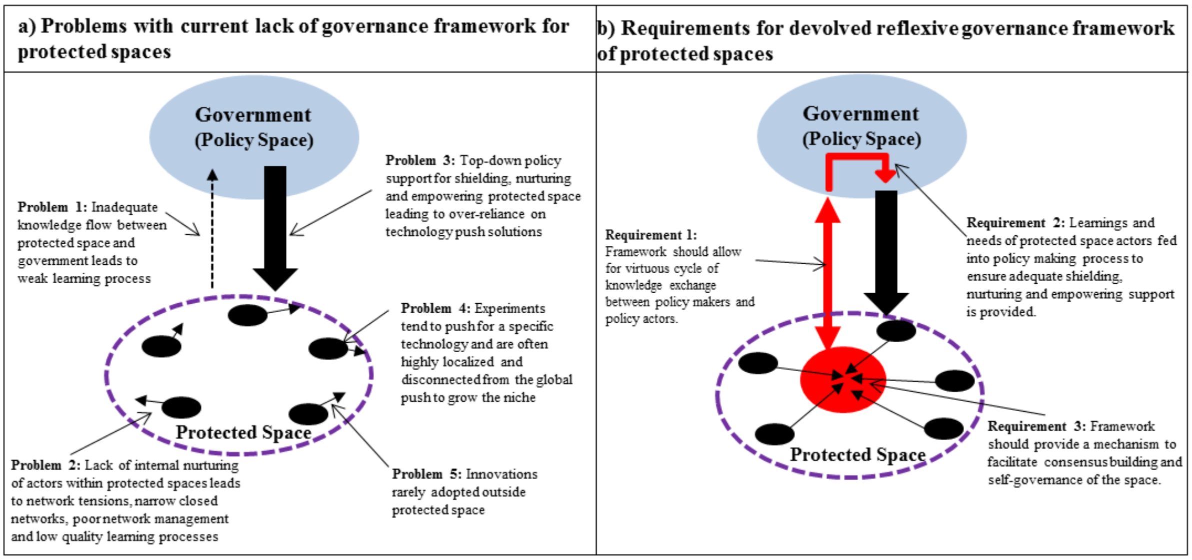
Several SNM scholars have highlighted that although SNM has proved useful as a policy analysis tool (Hegger *et al.*, 2007b; Verbong *et al.*, 2008), there is little evidence in the literature to suggest it has been applied successfully as a tool to help policy makers introduce appropriate shielding, nurturing and empowerment policies for sustainable technological niches (Mourik and Raven 2006). In addition, as outlined in Section 3.4, the transition to a circular economy will likely offer significantly more challenges to SNM practitioners as it requires managing the niche in-line with a broader circular economy transition. This section therefore proposes necessary adaptations of the SNM model, both in terms of how to nurture and empower a technological niche in line with a broader circular economy transition. Specifically, it outlines the need to introduce a niche level manager which can: (i) nurture the wider niche rather than a single experiment and through a more polycentric governance model; and (ii) empower the niche by promoting inter-niche and niche-regime interaction.

3.6.1 Managing the wider niche rather than a single experiment

SNM has predominantly been operationalized under the linear lens of managing individual innovation experiments as opposed to re-structuring value chains (Mourik and Raven 2006; Hoogma *et al.*, 2002)). Examples include trialling fuel cell busses in Japan (Harborne *et al.*, 2007). However, as outlined in Raven (2005), regime changes do not occur through single experiments. They occur through a long trajectory of numerous niche experiments.

Schot and Geels (2008) showed that undertaking isolated experiments involve learning from local practices under local conditions and is therefore not necessarily reflective of wider niche or regime dynamics. In the case of the energy sector in the Netherlands, from where the SNM concept originated, Verbong et al. (2008) demonstrated that the lack of coordinated multi-experiment niche management framework led to a ‘muddled’ linear top-down approach to innovation which produced unintended consequences such as poor learning processes, an over-reliance on technology push, narrow and closed social networks and false expectations (Figure 3.5– Problems 1, 2 and 3) (Verbong *et al.*, 2008; de Wildt-Liesveld *et al.*, 2015). Caniëls and Romijn (2008) also found that isolated experiments promoted through SNM have seldom led to the establishment of technological niches and the ones that did, rarely evolved into wider market niches. As such, the focus on single experiments had failed to realise the key nurturing processes.

In review of these limitations, Mourik and Raven (2006) strongly advocated for a mind-set shift in the approach to SNM from managing a single experiment, to managing the wider niche. This would involve fostering and supporting the implementation of multiple experiments all aligned with the longer-term trajectory of the niche. The argument for wider niche management aligns with the complexity of circular economy enabling technology niches, whereby such technologies have the potential to reconfigure several regimes and as such require a wide range of different experiments. It also aligns with the need to facilitate the occurrence of branching within the niche whereby the same technology is experimented with in different domains (or sectors) thus promoting a more natural evolutionary path to regime reconfiguration (Raven 2005). By focussing on the niche level, SNM is more likely to support such branching rather than being wedded to a single experiment.



a) Problems with current lack of governance framework for protected spaces

Problem 1: Inadequate knowledge flow between protected space and government leads to weak learning process

Problem 2: Lack of internal nurturing of actors within protected spaces leads to network tensions, narrow closed networks, poor network management and low quality learning processes

Problem 3: Top-down policy support for shielding, nurturing and empowering protected space leading to over-reliance on technology push solutions

Problem 4: Experiments tend to push for a specific technology and are often highly localized and disconnected from the global push to grow the niche

Problem 5: Innovations rarely adopted outside protected space

b) Requirements for devolved reflexive governance framework of protected spaces

Requirement 1: Framework should allow for virtuous cycle of knowledge exchange between policy makers and policy actors.

Requirement 2: Learnings and needs of protected space actors fed into policy making process to ensure adequate shielding, nurturing and empowering support is provided.

Requirement 3: Framework should provide a mechanism to facilitate consensus building and self-governance of the space.

Figure 3.5: The need for a new framework to facilitate reflexive governance of niche innovation networks and support the wider adoption of niche innovations (Verbong et al., 2008; de Wildt-Liesveld et al., 2015; Caniëls and Romijn 2008; Schot and Geels 2008; Mourik and Raven 2006; Raven 2005; Rip and Kemp 1998).

To go a step further, this thesis argues that to be fit to be used as a circular economy policy tool, it is necessary for the SNM operational framework to not only be able to manage the wider niche but also align internal niche developments and experiments with other complementary circular oriented niches and regimes. This is based on the logic that experimentation with a single niche technology will fail to leverage the symbiotic advantages associated with collaborating with external innovation networks which follow the same trajectory towards circular economy and to which the realisation of a circular economy is dependent upon (discussed in Section 3.4).

By managing the whole niche, SNM can focus on increasing shared learning between experiments, thereby widening and strengthening the niche innovation network and increasing the likelihood of the formation of shared expectations and aligned visions. However, two key questions arise as to *how* SNM should manage the wider niche. Should it follow the traditional top down policy approach? Is a niche network manager or coordinator needed and if so – what form and structure should it take and how should it be governed? The next two sections address these two questions.

3.6.2 Moving from top-down to polycentric governance of the niche

One of the underlying assumptions of SNM is that governments cannot implement protection measures effectively via a centralised or top-down policy approach (Rip and Kemp 1998, p.383). Rather, a protected space is expected to develop out of a collective co-evolutionary steering process between a range of societal actors. Elzen and Wieczorek (2005) recognised the complex and unpredictable dynamics associated with transitions and as such argue that current top down approached based on "simple steering philosophies" will not work.

Furthermore, according to Kemp et al*.* (1998), a key factor in the success of a niche, and niche experimentation, is the capacity for experimenting with the technology in various different domains and directions. Varied experimentation enhances the evolutionary selection process and increases the likelihood of the technology creating regime level re-configuration. The potential breadth of application of some circular economy enabling technologies are very wide, such as industrial biotechnology or additive manufacturing, which means that there will likely be a high-level experimentation and niche branching occurring which is difficult to predict or manage via top down policy.

Ghisellini et al. (2015) found that the success of circular experiments required the involvement of a wide range of societal actors and the ability of such experiments to create the conditions with which collaboration and exchange patterns could occur between such actors. Therefore, SNM must be able to account for multi-stakeholder interaction, adaptation to unpredictable events, niche branching, continuous monitoring and learning reflexivity. As such, SNM requires a more networked and flexible approach to niche governance as opposed to the traditional linear approach to innovation pursued by most governments. However, such a co-evolutionary steering process is rarely apparent as the steering of "niche experiments is not straightforward and is often associated with difficulties" (de Wildt-Liesveld *et al.,* 2015; p.155). If this is scaled to the steering of several experiments the challenge further increases.

Moreover, Nilsson et al. (2012; p.51) observe that the way in which “governance should be best organised to achieve both momentum and a sustainable direction is not well understood”.

Due to the complexity of the circular economy transition with regards to the need for inter-niche, niche-regime and inter-regime coordination, the future role of SNM is unlikely to involve managing isolated experiments in a top-down manner, rather nurturing and empowering networks comprising of multiple cross cutting experiments and working symbiotically with other circular economy enabling technological niches to reconfigure linear regimes.

As such, a certain level of SNM governance must therefore be devolved to the protected space innovation network to avoid information overload. As Turnbull (2002; p.41) argues, the delegation of power from government to a ‘self-governing inclusive stakeholder network’ may provide a stronger basis for the development of social capital, which Cooke and Wills (1999) consider to be critical for the vitality of innovation networks. The need to increase self-governance is also alluded to by Schot and Geels (2008; p.548) who posit that governance of a protected space “would require not only a change in the specific practice of organising experiments, but also broader institutional and cultural changes, particularly in the distribution of responsibilities and the organisation of relations between state, market, civil society and science and technology.” Devolving the day-to-day governance of inner-loop protected spaces would also minimise the amount of information that governments are required to absorb and process, and the risk of information being lost, forgotten or distorted as it filters up hierarchical and bureaucratic organisational chains of command.

Schot and Geels (2008; p.538) further suggest that although protected spaces require some level of self or ‘endogenous’ governance, there is still a role for external policy makers to play to ensure that the protected space is set on the trajectory of sustainability by providing appropriate shielding, nurturing and empowering mechanisms that would enable the protected space to thrive. Smith (2004) also notes that top-down support is essential for a niche to evolve into mainstream. Building on this, Lieder and Rashid (2016) determined that the success of circular economy implementation will likely depend on the establishment of a synchronized top-down and bottom-up transition strategy which is inclusive of all relevant stakeholders including policy makers, governmental agencies and industry.

There is therefore the need for continuous and transparent knowledge exchange between the protected space niche network and policy makers to ensure the policy making process becomes more reflexive to the changing needs of the protected space (Figure 3.5 – Requirement 2 and 3). Reflexivity is increasingly being recognised as an important criteria for modern governance (Voß and Kemp 2005). Reflexive governance is a response to globalisation creating an increasingly networked society. When systems thinking is combined with the notion of reflexivity, governance and policy evolve from singular points of intervention to a system of continual feedback in which further adjustments are made based on changing environmental conditions (Shove and Walker 2007).

The notion of building reflexivity into the SNM process is not new (Schot and Geels 2008). However, a study by Verbong et al. (2008) highlights that, in practice, SNM remains a government-led initiative of centralised policy approaches. This limits the ability of governments to adapt and align support mechanisms to shield, nurture and empower protected space networks, and to build the momentum for radical innovations needed for transition to circular economy (Figure 3.5 - Problems 1 and 5).

Governments are therefore caught between a rock and a hard place. Traditional forms of policy intervention risk significant unintended consequences, yet no intervention creates a risk of the continuation of the linear economy due to the short-sighted nature of markets. This sentiment is reflected by Derk Loorbach, a leading author of transition management theory, in which he states that…

> “[t]here seems to be an increasing degree of consensus in governance research that both top-down steering by government (“the extent to which social change can be effected by government policies”) and the liberal free market approach (“the extent to which social change can be brought about by market forces”) are outmoded as effective management mechanisms to generate sustainable solutions at the societal level by themselves, but it is at the same time impossible to govern societal change without them.” (D. Loorbach 2010)

Raven (2005) discusses the need for a new governance framework for protected spaces that seeks to balance self-governance with top-down forms of governance which is argued to be essential for a circular economy transition (Lieder and Rashid 2016) A degree of niche innovation network self-governance reduces the risk of information overload on policy makers as well as making the protected space networks more responsive to the changing market dynamics (Figure 3.5 – Requirement 1). However, while governments continue to play the critical roles of steering the protected space networks in-line with a circular economy trajectory, and introducing policies to help shield, nurture and empower these protected space networks, it is important for a revised SNM operational framework to promote reflexivity between policy makers and protected space network actors (Figure 3.5 - Requirement 2 and 3).

Thus, a governance mechanism is required to provide an institutional structure for self-governance to evolve and for the niche to be managed on a day-to-day basis as championed by Weber et al*.* (1999) (Figure 3.5 – Requirement 3). However, the mechanism must also act as a vehicle for the transfer of learning from the network to policy makers to allow for the introduction, alteration and eventual removal of shielding, nurturing and empowering polices as discussed in Raven (2005) and Ulmanen et al*.* (2009) (Figure 3.5 – Requirement 1 and 2).

3.6.3 Facilitating inter-niche and niche-regime collaboration

Niche empowerment is also critical for ensuring a niche expands and reconfigures incumbent regimes. Shove and Walker (2007, p.764) suggested, “the key idea is that change takes place through processes of co-evolution and mutual adaptation within and between the layers”. During the early stages of its development, SNM initially prioritised niche innovation on impacting incumbent socio-technical regimes. However, as the research evolved, particularly through a closer alignment from the MLP, niches have been found to breakthrough in-line with broader upper tier macro and meso processes. Schot and Geels (2008) states that although niches and experiments are crucial for achieving regime shifts, an understanding of the linkages between the niche and the broader regime and landscape levels is also important (Geels *et al.,* 2013). Schot and Geels (2008; p.550) also recognised that niches are not the only forces that lead to technology regime changes. Niches, they argue, must be developed in-line with the “on-going processes at broader regime and landscape levels”. As such, SNM must be able to foresee and react to such external forces through a range of niche empowering activities.

Empowering can be done via two approaches: (i) fit and conform; and (ii) stretch and transform (as described in Section 3.5.3). Traditionally, SNM has focused on the empowerment of a single niche to impact a single regime. However, as shown in Figure 3.3, niches can impact and be impacted by multiple regimes and niches. As such there is a need to adapt how the empowerment of a niche is undertaken to fit the demands of such a transition.

3.6.4 Revising the model of niche network manager

Weber et al. (1999) and Heidenreich et al. (2016) identified that a crucial factor for the success of an innovation network is rooted in the presence of a network manager who encourages and facilitates innovation and provides dynamic management. Traditionally, the role of niche manager within SNM has been assumed by any actor, be it an individual, a citizen group, a company, an industry association, a university, a special interest group, a regulatory agency or a policy maker (Kemp *et al.,* 1998).

The aim of the niche network manager is to drive and guide the network around a niche by shielding the network from external market pressures through mechanisms like subsidies, grants and tax incentives, nurture the networks ability to share resources and collaborate and finally empower the niche to integrate into existing and initially resistive regimes (Weber *et al.,* 1999).

These types of niche managers have all tended to be limited in their scope to affect change at the niche level. As outlined in the sections above, a polycentric governance mechanism nested within the niche is necessary to nurture the niche innovation network and steer the niche in-line with external circular economy transition processes and demands including encouraging reflexivity between inter-niche and niche-regime initiatives.

It is therefore evident that a new form of niche network manager is required to nurture and empower a niche network in line with broader circular economy transition dynamics. However, the question remains as to what form and structure such a niche network manager should take. The following chapter explores how the symbiosis of the triple helix approach to innovation and system intermediation may enable a reflexive polycentric SNM governance model geared towards the transition to circular economy.

Chapter 4: Managing ‘inner loop’ niche innovation networks via the triple helix approach and system intermediation[6]

> “Systemic and inter-connected problems need systemic and inter-connected solutions.”
>
> (Brown and Wyatt 2010, p.35)

The previous chapter outlined the benefits of applying transitions thinking to the framing of the circular economy transition. It outlined that SNM offers potential as a policy tool for steering inner-loop technological niches within such a transition. Yet, due to the complexity of the circular economy transition, a new approach to operationalising SNM is required. Firstly, the approach must encompass the wider niche rather than a single experiment through an enhanced form of polycentric governance and secondly it must promote inter-niche and niche-regime coordination and collaboration. This could be achieved through the introduction of unique form of niche network manager – however it is yet unclear how such a niche network manager may be structured or operate.

As such, this chapter explores the notion of leveraging the potential symbiotic relationship between SNM and two separate fields that attempt to address the challenge of accelerating innovation for a circular economy transition: (i) the triple helix innovation system; and (ii) innovation intermediation. Each approach is analysed with regard to their ability to allow the SNM revision requirements outlined above. This is done via a critical analysis of the literature.

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[6] A summary of this chapter is published in: Barrie, *et al.* (2017).

4.1 The triple helix approach to systemic innovation

> “A machine, for instance, originated in the mind of man, and both its construction and its use involve information processes imposed on the material world by man himself. The accumulation of knowledge, that is, the excess of its production over its consumption, is the key to human development of all kinds, especially to economic development.”
>
> (Boulding 1966, p.5)

The SNM framework requires adaptation to ensure an increased level of polycentric governance occurs within the niche, but also to ensure the niche evolves in line with the broader circular economy transition dynamics. This is due to the fact that success of a niche technology is based on the collaboration and coordination of a wide range of stakeholders existing within and out-with the niche. This section therefore explores the merit of framing SNM multi-stakeholder governance via the triple helix approach. Firstly, it provides an overview of innovation systems frameworks and their current limitations with regards to the application to niche governance. It then introduces the notion of a triple helix innovation system. Finally, it discusses the potential merit in integrating the triple helix approach into the SNM operational framework.

An innovation system can be defined as one with the goal to ‘develop, diffuse and utilise innovations’ (Carlsson and Stankiewicz 1991). The study of innovations systems offers researchers and practitioners the opportunity to understand how best to facilitate, manage and coordinate national, regional, sectoral and even technological innovation (Jacobsson and Bergek 2011).

Systems of Innovation can be traced back to Friedrich List´s idea of “The National System of Political Economy” (1841) which resurfaced in Freeman (1982). List correctly predicted the risk of Germany overtaking England in national competitiveness and attributed it to many of the features recognised in modern day innovation system frameworks such as knowledge accumulation, institutional roles and promoting strategic industries (Freeman 1995).

As Lundvall (2005) suggests, Freeman developed the concept of systems of innovation through a deep held frustration with the neoliberal Friedman-Hayek style of classical economics developed after World War II whereby low wages and devolved currency were assumed to be the key tools for enhancing national competitiveness and economic ‘catch-up’; otherwise known as the Washington consensus. This belief devalued the role of government policy in driving competitiveness as well as the dynamic process related to innovation and knowledge creation with respect to economic growth strategies.

Around 2002, the search for more tangible and theoretically robust frameworks for innovation systems increased for nation states to innovate faster. Different branches of innovation systems have subsequently been explored including regional innovation systems (RIS) and innovation clusters, technical innovation systems (TIS) and sectoral innovation systems (SIS). The development of these branches of innovation systems were an attempt to better understand the meso context of innovation systems encompassing different groupings of economic activity (Kastelle *et al.,* 2009). Hence, studies investigated more specific concepts where boundaries could be more easily drawn, system attributes more specifically defined and theories tested (Carlsson *et al.*, 2002). The critical review of NIS by Miettinen (2002) may have influenced this macro to meso level transition by suggesting that NIS was little more than a political rhetoric and postulated that future research must move towards more detail on ‘specific clusters, regions, technologies’ instead of an aggregate national level perspective.

What is evident is that innovation system theory has contributed significantly to understanding the systemic nature of innovation. It has shed light on the key functions, components and relations of an innovation system. However, it has appeared to have hit a number of conceptual barriers ranging from conceptual diffuseness, heterogeneity, boundary ambiguity, lack of ability to explain the co-evolution of key innovation actors nor why changes in the system occur (Edquist 2006; Malerba 2002). Moreover, due to the heterogeneity of the concept, it is not perceived as and easily applicable for policy makers or practitioners (Meyer ,*et al.* 2014). It is due to these fundamental limitations that Henry Etzkowitz and Loet Leydesdorff proposed the concept of the concept of a Triple Helix innovation system.

4.2 The origins of the triple helix approach to innovation

Over the past few decades, there has developed consensus that effective knowledge generation, transfer and use is the engine of innovation systems and the rapid development of advanced technologies in developed countries is underpinned by an accelerated translation of scientific and technical knowledge into to commercial knowledge. As such, understanding how knowledge can be more effectively generated, transferred and used within an innovation system is seen as far more valuable than the physical inputs (Powell *et al.*, 2004).

The accelerated rate and complexity of technological advances has meant that it has become ever more challenging for individual firms to acquire such knowledge and compete. Furthermore, such rapid and largely unpredictable advances mean that governments struggle to foresee the technological developments and as such policies tend to be reactive rather than proactive with regards to enabling industry and universities to capitalise on them. The increased reliance on universities as knowledge generators has led to universities aligning their research more closely with immediate market demands and creating university spin out offices – otherwise referred to as the Third Mission (Zawdie 2010).

It is based on these societal challenges that Etzkowitz (2002) identified the need for the hybridisation of industry (knowledge users), government (knowledge regulators) and universities (knowledge generators) (the Triple Helix) to occur which allows for more effective knowledge, transfer and use between the three. Hybridisation, in this sense, means a blurring and overlapping of the boundaries between industry, universities and government (Etzkowitz 2008).

As the boundaries between the triple helix institutions become blurred, new choice environments come into existence allowing for new forms of cooperation such as science parks, business spin out incubators, strategic multi-institutional research initiatives which are conducive to innovation (Etzkowitz 2011). By improving knowledge generation, transfer and use between the three triple helix institutions, a well-functioning triple helix system has been argued to produce several benefits including (i) increased generation of systemic innovation; (ii) inter-institutional learning;

and (iii) the ability to self-organise in the pursuit of systemic innovation (Ivanova and Leydesdorff 2014; Cai 2015; Farinha *et al.,* 2016). As such, Leydesdorff and Zawdie (2010) argue that effective triple helix interaction is crucial for the transformation of newly generated knowledge into economic gains.

The ‘triple helix’ concept may therefore be described as a multi-structural, multi-functional and nonlinear model of innovation. It offers a way to operationalize the innovation systems concepts by promoting the interactive co-evolution between knowledge generation (universities and research institutes), public-sector (Government and public-sector agencies) and the commercial application of knowledge (industry) (Zawdie, 2010). The concept also provides a clear normative heuristic for understanding and analysing the complex dynamics of knowledge generation, transfer and use within innovation systems (Marques *et al.,* 2006; Ranga and Etzkowitz 2013; Cai 2015)*.*The conceptual clarity of the triple helix concept, has meant that it has “gained an official recognition by international institutions such as the OECD and the European Commission” (Todeva and Etzkiwitz 2013, p.1).

A handful of studies have raised the debate regarding the worth of adding society as fourth helix to the model (Cooper 2009; MacGregor *et al.*, 2010; Carayannis and Campbell 2011). Yet, Etzkowitz (2003, p.312) counters the argument by stating that “to view the public as a fourth helix is to narrow the public to a private sphere, rather than seeing it as the underpinning of the entire enterprise of innovation” and that the original three helices have stood the test of time. In addition, Rieu (2013, p.21) points out; ‘…adding “society” as a four helix seems now superfluous…[as it is]…first a collective and daily experience, secondly a social system studied by human and social sciences. Universities, industrial and commercial activities, political institutions and regimes are historical constructions in the social system and of the social system.’ Farinha and Ferreira (2013) also illustrate how the sphere of society has been and can be integrated into the triple helix model for regional competitiveness, not as a fourth helix, but as representation of the environment in which triple helix evolve.

There are two distinct branches of the triple helix concept within the literature. The first is the neo-evolutionary model of a triple helix system proposed by Loet Leydesdorff (Leydesdorff 1997); whereby triple helix institutions are seen to co-evolve into new entities which interact via market selection pressures and innovative dynamics and communicate through ‘specific codes’ at their interfaces. The second model is a neo-institutional triple helix system proposed by Etzkowitz et al*.* (2000); which suggests that a triple helix system can exist in several different configurations.

Although the system characteristics are present in all triple helix systems, Ranga and Etzkowitz (2013) also recognise from the neo-institutional branch that numerous permutations of triple helix exist globally. The characteristics of which are dependent upon the mixture of the economic, social, political and social characteristics at the time as well as the policy regime (Zawdie, 2010). Three general forms of triple helix systems, as suggested by Etzkowitz and Leydesdorff (2000), include the (i) statist, (ii) the laissez-faire and (iii) the balanced or ‘hybrid’ (Figure 4.1). Statist models occur where a government takes the lead role in driving or restraining industry and academia’s capacity to innovate. Russia, China and South America could be placed in this bracket. The laissez fair model is typical where states have limited intervention in the economy such as the USA and some western European countries. Finally, the balanced or ‘hybrid’ model is a model that is emerging in the advanced knowledge economies whereby industry takes on the role of production, universities provide knowledge and technology and government acts as a regulator and stabiliser. It is within the interstitial boundaries between the actors that synergies of innovation occur.

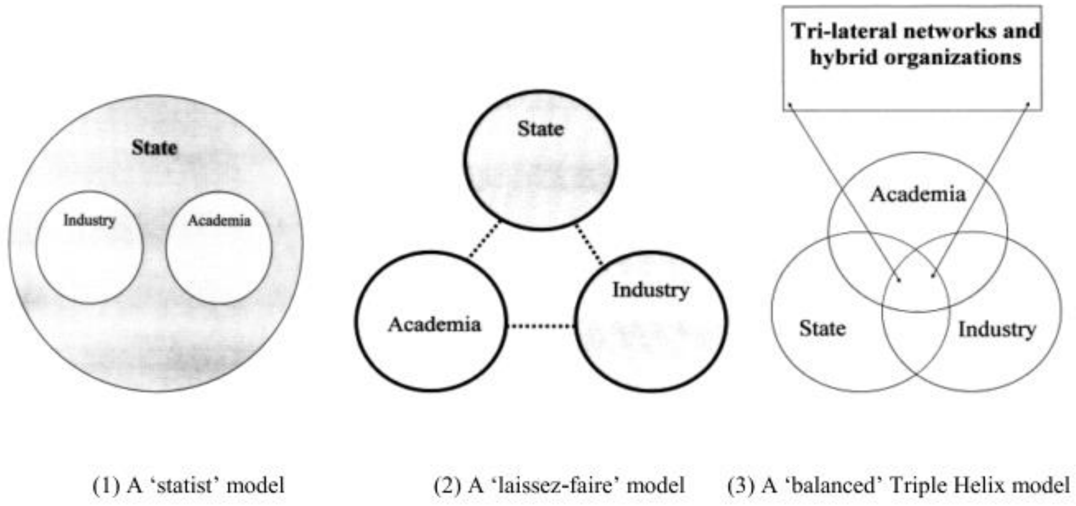


Figure 4.1: The three main forms of triple helix system as identified by Eztkowitz and Leydesdorff (2000)

The neo-evolutionary branch of triple helix scholarship perceives the relations between the triple helix institutions to be in constant flux, whereby the journey towards a knowledge society (or a laissez faire to a balanced triple helix) goes through three main phases (Figure 4.2). Firstly, actors begin to get closer together through increased interaction. Second, the boundaries between each become increasingly blurred. Finally, a stem cell phase develops where Knowledge, Innovation and Consensus spaces (discussed in further detail below) form and new institutional formats emerge. The blurring of the actor boundaries can lead to the interchanging of roles, whereby actors take up the slack from others such as universities developing spin-out and patenting offices, or joint research initiatives with industry.

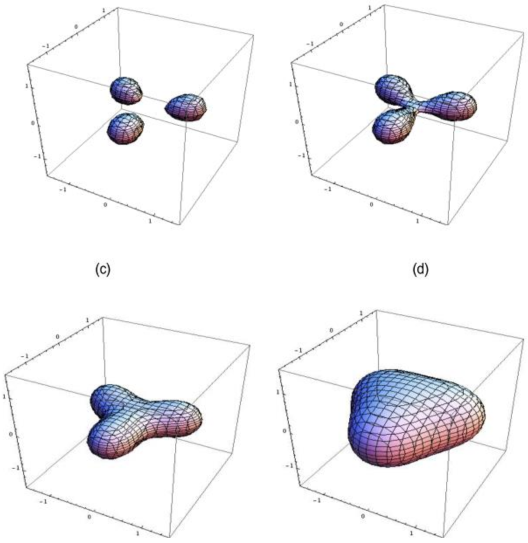


Figure 4.2: Interaction between the triple helix institutional spheres in the formation of Knowledge, Innovation and Consensus Spaces (Ranga and Etzkowitz, 2013)

An alternative view of the development of balanced triple helix system evolves over several stages is offered by Cai (2015). Cai (2015) reinterprets the formation of the ideal triple helix model in the context of institutionalisation whereby there are four stages that develop in an iterative and overlapping manner. The first stage occurs when there is a recognised need, due to the rapidly increasing complexity of the technology landscape, for university, industry, and government to form reciprocal relationships “with each other in which each attempt to enhance the performance of the other” (Cai 2015, 11). For example, “universities produce and transfer more knowledge to industry and society, while gaining additional funding sources from industry and government to strengthen the performance of research” (Cai 2015, p.11).

The second stage leads to internal transformation of each triple helix actor, in which each adopts a role of the other. This means that, in addition to their traditional roles, each actor assumes a role of the other as a secondary initiative. For example, universities retain their roles of education and research but extend their capacity to valorise their knowledge generation through patents, spin out companies and technology transfer offices. Governments retain their role in resolving market failures but begin to provide venture capital for high risk businesses. Industry retains the role of producer of goods and services, but also begin to undertake research (Etzkowitz 2011).

The third stage is the emergence of tri-lateral interactions between the triple helix actors. This stage emerges during the process of each actor assuming the role of the other, in which actors begin to recognise that simply adopting the role of the other is unlikely to lead to the desired goal and so increased collaboration and coordination between the three actors is required. These increased interactions tend to lead to the formation of hybrid organizations that exist in the overlap of two or three actors such as science parks, incubators and research institutes.

The final stage involves the institutionalization of the triple helix concept and the progression towards an ideal triple helix system. The institutionalization of the triple helix concept means that the activities of each triple helix actor within the system have become routine and practice. If these activities are retained over an appropriate length of time the concept serves as a cognitive framework for collaboration between the three actors.

The notion of the triple helix approach has matured, through numerous empirical studies, from a metaphor to a conceptual framework that is used to inform policy makers at micro, meso and even macro levels with regards to developing relevant innovation and development strategies in emerging knowledge societies (Ranga and Etzkowitz 2013). An example is the Climate Knowledge and Innovation Community (KIC) initiative, the European Union's largest public-private innovation partnership focused on climate innovation to mitigate and adapt to climate change adopted the triple helix model as a core operating approach (Climate KIC 2018). The concept is also increasingly embracing new forms of governance theory to enable this hybridization to occur, including evolutionary economics, network building, reflexivity and systems thinking (Etzkowitz and Leydesdorff 2000; Farinha *et al*., 2014).

Building on the notion of the evolution of a balanced triple helix system, Ranga and Etzkowitz (2013) attempted to develop an explicit analytical framework based on the systemic nature of innovation which lies at the heart of both. They argue that the dynamic interplay between triple helix institutions can be conceived as a system, in which it has components (Government, Academia and Industry), functions (knowledge, innovation and consensus spaces) and activities (collaboration and conflict resolution, collaborative leadership, substitution and networking).

Ranga and Etzkowitz (2013) hypothesise that the formation and co-evolution of an ideal triple helix system requires the presence of a consensus space, a knowledge space and an innovation space (Ranga and Etzkowitz, 2013). The consensus space is the set of activities that allow triple helix actors to brainstorm, debate and assess plans to advance towards a knowledge-based system through co-created practices (Figure 4.3). It requires the build-up of social capital to engender trust and effective knowledge transfer. The consensus space is seen to be essential for stimulating systemic innovation. Government usually takes the lead role in the formation and management of the consensus space. The knowledge space forms through a range of activities that allow knowledge to be generated, diffused and used amongst the triple helix actors. Academia is often recognized to take the lead role in this space. The innovation space comprises of activities undertaken predominantly by hybrid organizations spanning the boundaries between the triple helix actors and is predominantly driven by industry (Ranga and Etzkowitz 2013).

The consensus space is believed critical for driving meaningful interaction between knowledge and innovation spaces. If there is limited consensus between the triple helix actors, hybrid organizations and transfer networks that make up the innovation space are unlikely to form. As such, full advantage of the knowledge space potential is unlikely to be taken (Ranga and Etzkowitz 2013). Hence, triple helix system cannot form without the presence of a consensus space.

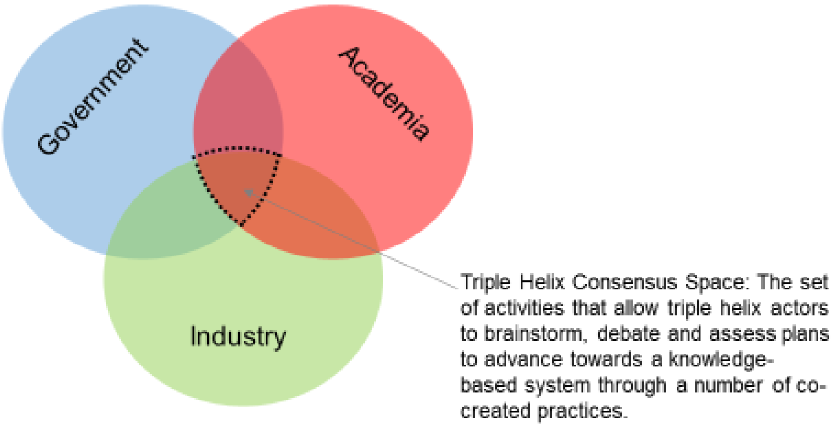


Figure 4.3: Representation of a consensus space within a triple helix system where the actors in the three spheres can come together in the spirit of mutual understanding and trust

What triggers the initial formation or evolution of the consensus space is not well understood in the literature (Anttonen *et al.*, 2018; Ranga and Etzkowitz 2013). According to Cai (2015), the formation and institutionalization of triple helix systems occur through regulative, normative and cognitive changes in the individual triple helix actors. Regulative institutionalisation of the triple helix deals predominantly with the funding agencies role in shaping and structuring the institutional order of the Triple Helix. Whereas the normative institutionalisation of the triple helix is grounded a shared belief of what is appropriate like, for example, the case for transition to circular economy. The combination of both regulative and normative institutionalisation can lead to some level of success for implementing the triple helix approach, however, as Cai (2015) argues, it is the build-up of cognitive pressures that create long lasting institutional change. This is achieved when a critical mass of individuals share consensus that the triple helix approach is the standard way of doing thing and act accordingly.

In a review of the extent to which a triple helix consensus space exists for the circular economy, Anttonen (2018), found that currently only a weak space exists. This is because discussions and activities between the triple helix mainly focus on the outer loops of the circular economy material flows such as waste, recycling and waste management. These activities are unlikely to prompt systemic innovations beyond this scope. Therefore, there is a need for a shift in the consensus space towards inner-loop activity. This thesis therefore explores how such a consensus space may be established and managed.

4.3 Applying the triple helix approach to SNM

This thesis argues that protected spaces offer the fundamental conditions for triggering the evolution of a triple helix consensus space as outlined in Figure 4.4. This is because the formation of protected spaces allows stakeholders, from all three triple helix institutions, to unite around an idea or technology with which they share the same normative beliefs and aspirations. As outlined in Figure 4.4 (Point 1), a protected space offers an area for shared normative beliefs to be transferred into shared actions and experimentation. Such activity allows the triple helix knowledge and innovation spaces to more easily align and spark discussion and collaboration between the three triple helix actors, promoting both normative and cognitive institutionalisation, albeit at a niche level (as identified in Cai (2015)). A protected space is also an artificial space established by funding agencies and therefore may be used as a mechanism for regulative institutionalisation of the triple helix system – as discussed in Benner and Sandström (2000).

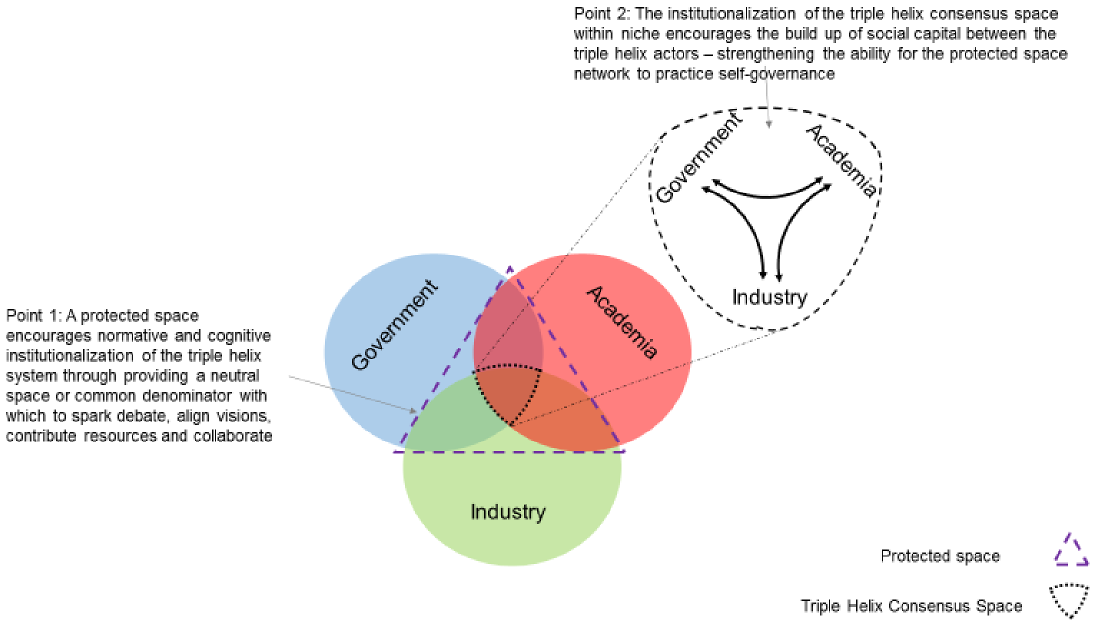


Figure 4.4: Visualisation of the benefits created through the synergy between protected spaces and the triple helix system (Source: Adapted from Barrie et al. (2017))

As outlined in Figure 4.4 (Point 2), a triple helix consensus space within the niche may provide a stabilising bridge between supply push and demand pull forces and top-down and bottom-up pressures on the choice environments, including the selection mechanism of the market; the stabilisation mechanism of policy; and the globalisation mechanism of knowledge generation and knowledge exchange (Leydesdorff and Zawdie 2010). The fostering of a triple helix consensus space within the niche innovation network may therefore allow for the emergence of a wide range of possibilities, challenging all players involved in social functions, wealth creation, organised knowledge production and the regulation and control of activities to select and shape technological trajectories recursively over time. This would help remove path-dependency lock-ins that otherwise inhibit the transition to circular economy.

Schot and Geels (2008) argue that although learning and network development in protected spaces are enhanced by diversity, there is a point at which too much diversity in networks would stunt progress, as it creates uncertainty and a reduced ability to pool resources and impedes the emergence of a stable set of rules. The formation of a triple helix system within a protected space may offer a balance between achieving diversity between innovation actors and enabling a satisfactory level of coordination by providing a clear network boundary in the form of a protected space.

Implicit in the idea of the symbiosis between protected spaces and the triple helix approach to innovation is the need to break away from the dominant logic of a national and centralised triple helix system towards a more decentralised concept of multiple and temporary overlapping triple helix systems within individual niches. The premise for this is that humans are significantly limited in the information they can receive, process and react to. Turnbull (2002, p.39) argues that, due to the complexity and rapid pace of technological development, “it has become physically implausible and economically impractical for central government to monitor and govern the dynamic complexity” of sustainability transitions.

The triple helix system can be decentralised, so that protected space innovation networks can be expected to evolve not only along their respective trajectories, but also horizontally learning from the experiences of other protected spaces and identifying opportunities that would enhance their contribution to the making of the circular economy. At the heart of the ‘horizontal learning’ process is the development of networks that increase the ability of protected spaces to self-govern, whilst accumulating systems-oriented knowledge that would equip them for participation in circular economy activities.

Conceptually, this melding of the triple helix system with the management of protected spaces can be construed as a decentralised ‘hub and spoke’ model of triple helix innovation and governance aimed at transition to circular economy. In this model, the circular economy strategy of governments constitutes the hub, and the range of protected spaces that address key circular economy challenge areas, the spokes. The interconnectedness of the players in the model and the commonality of the overarching challenges the model seeks to address would define the pathway to a circular economy end.

The concept of multiple decentralised triple helix systems is therefore a theoretical leap that may offer benefits elsewhere in the field of innovation systems theory. In the context of this thesis, the decentralisation of the triple helix system appears crucial for enabling polycentric governance of protected spaces for the development of activities across the economic spectrum aligned to circular economy objectives.

Although the triple helix approach appears to offer a framework for enhancing the level of self-governance within protected spaces, the question therefore remains as to how the operationalization of governance within a triple helix-based niche innovation network remains.

4.4 Triple helix-based niche management of inner-loop niche innovation networks

As outlined in Section 4.1, the application of the triple helix approach to the governance of inner-loop niches appears beneficial with regards to addressing the current limitations of SNM in governing inner-loop-oriented niche innovation networks. However, to succeed, the triple helix approach needs to be institutionalised and operationalised within the protected space in some form.

Nakwa and Zawdie (2013) highlighted that the implementation of the triple helix as a strategy for operationalising innovation has commonly been impaired by dysfunctional knowledge and information networks which has served to constrain relations between the triple helix groups. Johnson (2009) suggests that poor knowledge transfer between the three institutions occurs for two main reasons. Firstly, there are inherent cultural differences between the institutions and secondly there exists a lack of willingness to undertake collaborative activities due to mistrust. In light of these challenges, Dzisah and Etzkowitz (2008) suggest that some level of external intervention is required to promote fruitful interaction between government, academia and industry actors and broker and grow knowledge networks that span the institutional spheres. Todeva (2013) subsequently highlighted that triple helix networks require new forms of community governance and dedicated mechanisms for coordinating trilateral innovation activities and that illustrated the importance and need for intermediaries to build and manage a triple helix network.

Based on the need for external intervention in coordinating and managing triple helix networks, the remainder of this section will provide an overview of innovation intermediation and explore how it may be leveraged to facilitate the development of a triple helix consensus space within a niche innovation network.

4.4.1 Overview of innovation intermediation

Intermediation is the process by which an actor brokers a relational tie between two (or more) other actors which would not have formed otherwise. In the past decade, there has been increasing recognition of the value of intermediation – particularly in the fields of innovation and sustainability transitions (Kivimaa *et al.*, 2019). Intermediation research initially focussed on innovation management and brokering relationships between a handful of firms (Bessant and Rush 1995). More recently, the role and value of innovation intermediation has expanded in scope whereby different forms of innovation intermediaries have been studied in relation to connecting different innovation system components (Klerkx and Leeuwis 2009), enhancing the diffusion of innovations and eco-innovations (Kanda *et al.*, 2018), managing networks, performing industrial symbiosis (Chertow and Ehrenfeld 2012) and contributing to sustainability transitions (Kivimaa 2014).

Research into the role of innovation intermediation in governing sustainability transitions has only recently began to gain traction (Hodson and Marvin 2009; Moss

2009). Howells (2006, p.720) defined an innovation intermediary as any "organization[s] or bod[ies] that act as agent[s] or broker[s] in any aspect of the innovation process between two or more parties". Johnson (2009) highlighted the role of innovation intermediaries as a mechanism for bridging institutional gaps and therefore accelerating the formation of triple helix networks. The activities of innovation intermediaries include the likes of acting as neutral mediator for contract management between collaborating organisations, identifying the potential for and facilitating the formation of new innovation collaborations, pulling in external resources such as funding and advice to further support the innovations that arise from such collaborations and network building through to accreditation and evaluation of results (Kivimaa 2014; Kivimaa *et al.,* 2019; Klerkx and Leeuwis 2009; Todeva 2013).

Innovation intermediation targeted at specific sustainability transitions has been shown to offer significant benefits. Gliedt et al. (2018) suggested that 'sustainability-oriented innovation intermediaries' help encourage green economic development by linking green initiatives between local, regional and state levels. Hodson et al. (2013) and Kivimaa (2014) demonstrated that the presence of innovation intermediaries serves as a catalyst to speed up the rate of change from incumbent to reconfigured sustainable socio-technical systems. This was in part due to their ability to link knowledge and resource flow gaps between actors and initiatives and even between the niche and regime levels (Fischer and Newig 2016; Kivimaa 2014; White and Stirling 2013).

Although innovation intermediaries appear beneficial for stimulating knowledge and resource flow across innovation networks – the question remains as to the how current forms of innovation intermediary may fair in: (i) promoting increased polycentric governance between triple helix actors within a niche innovation network, and (ii) managing the broader niche in line with the wider inter-niche, niche regime and inter-regime circular economy transition dynamics.

By adopting the visualisation of a triple helix system within a protected space, Figure 4.5 (Point 1) demonstrates one of the main limitations of traditional forms of innovation intermediaries, is that they tend sit in the interstitial space between two of the three triple helix actors. Such intermediaries include university spin out offices or a government agencies (Etzkowitz *et al.*, 2000). Caniëls and Romijn (2008, p.615) argue that “close interaction between [niche] actors is essential because important tacit, informal and uncodified elements in new knowledge can only be absorbed and shared by means of intensive - indeed direct - communication and learning by doing”. Yet, by existing in the space between two out of the three triple helix institutions, Kivimaa (2014) suggests such intermediaries are restricted in their ability to fully understand or influence the wider innovation network dynamics to foster regime change.

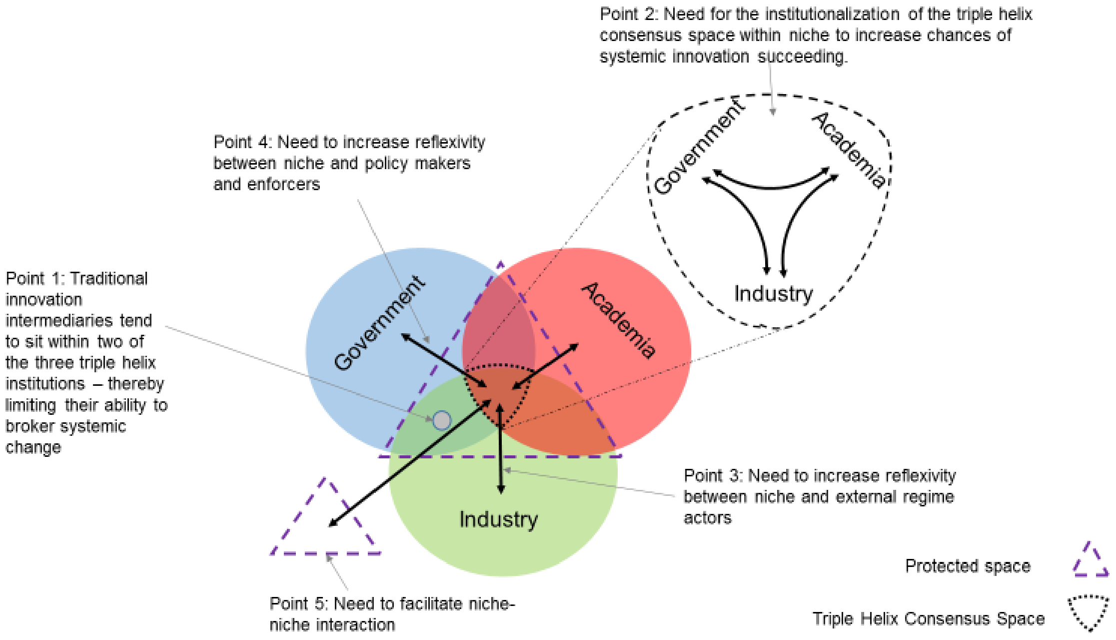


Figure 4.5: The need to adapt the approach to niche management to encourage the formation of a triple helix consensus space within the protected space and thus increase the chances of systemic innovation occurring.

In light of the current limitations of traditional innovation intermediaries, several studies have explored the need for system level intermediaries to support the transition from intra to inter-organizational networks of innovation (Klerkx and Leeuwis 2009; van Lente *et al.*, 2003; Todeva 2013). As outlined in a study by Kivimaa (2014), a systemic intermediary supports innovation at the higher system level by articulating demand, developing strategy, identifying, aligning and mobilising actors, building consensus, managing complex and long term innovation projects and creating an environment for learning by doing and using. Kivimaa, 2014 (p.1379) concludes that the “existence of system intermediaries is likely to be crucial to achieving regime destabilisation” and that systemic intermediaries (particularly operating in the niche) are the “most crucial forms of intermediary actors in transitions” (Kivimaa *et al.*, 2019).

In an attempt to synthesis the research into transition intermediaries, Kivimaa et al. (2018) introduced the notion of an ecology of intermediaries to facilitate a societal transition and identified five main types of transition intermediaries: (i) Systemic; (ii) Regime-based; (iii) Niche (or grassroots); (iv) Process; and (v) User. The different classes of intermediaries are defined by their context/level of action, emergence (origins), goals, normative positions (position to niche and neutrality/interest). Such a classification has merit as it helps policy makers assess the current landscape and ecology of intermediaries involved in a specific transition and identify gaps in the ecology which need filled.

When assessing what type of intermediary would be able to strategically manage an inner-loop protected space in-line with a broader circular economy transition – it appears that the characteristics of a systemic intermediary best suits. For a triple helix consensus space to form within a protected space, the triple helix actors need to progress from *intra* to *inter*-organizational transformation. In other words, triple helix actors have to evolve from simply assuming a role of the other triple helix actor as a secondary activity to a closer form of trilateral cooperation (Cai 2015; Etzkowitz 2008). Metcalfe (2010) argues that due to the continued institutional isolation of each of the university-industry-government helices, the design and provision of efficient legal intermediation practices and organizations should be of paramount importance. Tuunainen (2002) also states that triple helix-based system intermediation is essential to transcend the long-standing and pervasively practiced institutional separateness and resistance to innovate and transform among the helices.

To realise trilateral cooperation, this thesis argues that it is necessary for the niche manager to play a system level brokering role between all three triple helix stakeholders within the niche. To achieve this the triple helix niche manager would be best placed to exist within the institutional overlap of all three triple helix institutions (Figure 4.5).

The niche manager must be able to nurture a protected space niche innovation network. This requires being able to build a social network, increase shared learning and raise expectations. Such nurturing would be most effectively achieved through brokering the growth of trilateral relationships (and hence a consensus space) between triple helix niche actors (Figure 4.5 Point 2). This aligns with Kivimaa et al. (2018) description of a systemic intermediary which is intermediating on a system level between multiple actors and interests and which pursues given goals on a system level with the ambition to disrupt the existing system.

However, unlike an outsider to the niche (which Kivimaa et al. (2018) defines as a characteristic of a systemic intermediary) – an inner-loop niche network manager should hold the normative stance of ensuring the niche succeeds (akin to Kivimaa et al. (2018) definition of a niche intermediary) and as such the niche manager such should be co-governed and managed by the triple helix actors within niche network rather an external body.

In addition to nurturing the niche network, the inner-loop niche innovation network manager must also be able to empower the niche by aligning its local ‘stretch and transform’ and ‘fit and conform’ activities with wider regime dynamics and ensuring effective knowledge transfer between the niche and the relevant public-sector stakeholders responsible for enforcing and drafting policy relating to the niche (Figure 4.5 Points 3, 4 and 5).

The niche manager must therefore be able to simultaneously perform the role of niche intermediary through nurturing a triple helix consensus space within a protected space, as well as acting as a system intermediary through acting as a broker between the niche and the broader circular economy dynamics. As such, it is therefore evident that a new typology of intermediary is required. The following section will outline the characteristics of a such an intermediary.

4.4.2 Defining a triple helix-based niche manager

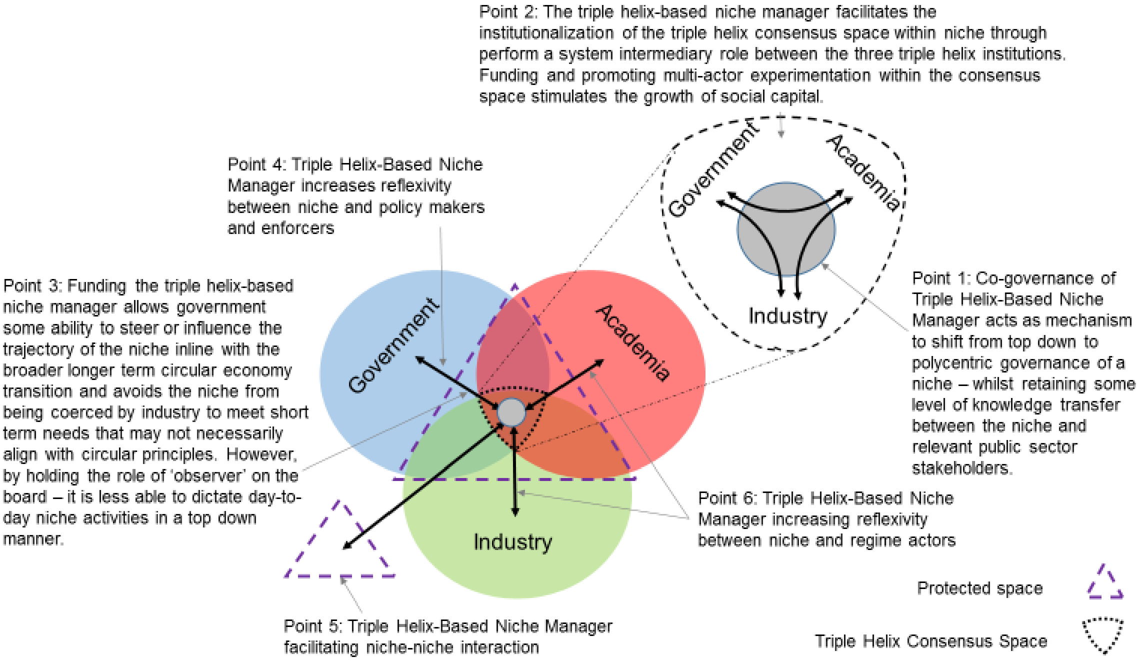
In recognition of the need for a new form of strategic niche manager within an inner-loop niche innovation network, this thesis proposes the theoretical concept of a triple helix-based niche manager as a new format of innovation intermediary. The characteristics of a triple helix-based niche manager are outlined in Table 4.1. The characteristics described are drawn on the core characteristics of an intermediary as outlined by Kivimaa et al. (2018). The concept of a triple helix-niche manager is graphically represented in Figure 4.6.

Table 4.1: Characteristics of a triple helix-based niche manager

Aspects	Description
Intention	To nurture and empower inner-loop niche innovation networks in line with circular economy principles
Level of action	A triple helix-based niche manager would be nested within a niche innovation network. However, it would also act as a broker between the niche and the wider circular economy transition actors and initiatives.
Funding	It should be funded by the public-sector. This allows government some ability to steer or influence the trajectory of the niche inline with the broader longer term circular economy transition and avoids the niche from being co-erced by industry to meet short term needs that may not necessarily align with circular principles.
Governance	It should be governed by a regularly revolving governance board made up of a range of public-sector (regulators), academia (knowledge producers) and industry (knowledge users) network stakeholders. Public-sector stakeholders should be assigned the role of observer on the board rather than active board members. This ensure knowledge is transferred between the niche and public-sector stakeholders, but also prevents government falling into the trap of top down governance as per traditional forms of SNM.
Entities brokered	Public-sector Stakeholders, Industrial actors (both niche and regime), Universities, Other innovation intermediaries
Process performed	To accelerate sustainable transformation by enhancing cooperation and collaboration amongst triple helix actors within the protected space network
Roles or functions	Articulating demand, developing strategy, identifying, aligning and mobilising actors, building triple helix consensus, managing complex and long term innovation projects and creating an environment for learning by doing and using.

A triple helix-based niche manager would have the remit to nurture and empower inner-loop niche innovation networks in line with the broader circular economy transition. In order to nurture the niche through promoting the growth of a triple helix consensus space, the niche manager should adopt a polycentric governance model in which it is co-governed by an equal mixture of niche network actors from each triple helix institution (Figure 4.6 Point 1). Through such a co-governance model, a triple helix-based niche manager may act as a vehicle for increased knowledge transfer and coordination between the triple helix institutions and would thus foster shared expectations and learning necessary for niche expansion (Figure 4.6 Point 2).

Public-sector stakeholders should be assigned the role of observer on the board rather than active board members. This would ensure knowledge is transferred between the niche and public-sector stakeholders, but also prevents government falling into the trap of top-down governance as per traditional forms of SNM. By promoting co-governance of the niche manager by the niche actors themselves, the niche network manager may become more responsive to the immediate needs of the network and thus undertake nurturing and empowering activities more effectively than what the traditional network manager would do (Figure 4.6 Point 3).



Point 2: The triple helix-based niche manager facilitates the institutionalization of the triple helix consensus space within niche through perform a system intermediary role between the three triple helix institutions. Funding and promoting multi-actor experimentation within the consensus space stimulates the growth of social capital.

Point 4: Triple Helix-Based Niche Manager increases reflexivity between niche and policy makers and enforcers

Point 3: Funding the triple helix-based niche manager allows government some ability to steer or influence the trajectory of the niche inline with the broader longer term circular economy transition and avoids the niche from being coerced by industry to meet short term needs that may not necessarily align with circular principles. However, by holding the role of 'observer' on the board – it is less able to dictate day-to-day niche activities in a top down manner.

Point 1: Co-governance of Triple Helix-Based Niche Manager acts as mechanism to shift from top down to polycentric governance of a niche – whilst retaining some level of knowledge transfer between the niche and relevant public sector stakeholders.

Point 6: Triple Helix-Based Niche Manager increasing reflexivity between niche and regime actors

Point 5: Triple Helix-Based Niche Manager facilitating niche-niche interaction

Figure 4.6: The role of a triple helix-based niche manager in nurturing a niche innovation network through brokering a triple helix consensus space and empowering it through increasing reflexivity between niche actors and policy makers and enforcers as well between the niche actors and incumbent regime actors

A triple helix-based niche manager should be majority funded by the public purse. This allows government some ability to steer or influence the trajectory of the niche in line with the broader longer-term circular economy transition yet avoids the niche from being coerced by industry to meet short term needs that may not necessarily align with circular principles (Figure 4.6 Point 3).

A triple helix-based niche manager would assume a wide range of roles and functions including articulating the demands of the niche, developing niche strategy in line with the wider circular economy transition dynamics, identifying, aligning and mobilising the relevant internal and external actors to expand the niche, building and maintaining a health triple helix consensus space within the niche (Figure 4.6 Point 4,5,6).

At the niche level, it should also hold the role of managing complex and long-term innovation projects and creating an environment for learning by doing and using. This may be achieved by co-funding and coordinating multiple multi-stakeholder niche experiments to stimulate the growth of social capital and raise expectations within and out with the niche. It should play the key intermediary role between government and public-sector stakeholders (knowledge regulators), industry (both niche and regime actors), academia (knowledge producers) and other innovation intermediaries (resource providers and knowledge brokers) (Figure 4.5 Point 2).

Several examples of triple helix-based intermediaries exist in practice in the UK (Scottish Innovation Centres (Reid 2016), the UK Catapult Centres (Kerry and Danson 2016)); in Europe (Sweden's Competency Centres (Stern *et al.*, 2013), Climate-KIC (Climate KIC, 2018), Germany's Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung (Fraunhofer-Society) (Reich-Graefe 2016); and in Australia (Cooperative Research Centres) (Miles 2015)). Yet the intermediation of triple helix trilateral networks within specific technological niches, particularly in relation to a circular economy transition, remains significantly understudied (Metcalfe 2010; Suvinen *et al.,* 2010).

Although the proposition of a triple helix-based niche manager compared to a traditional niche manager offers theoretical advantages, there is no evidence to suggest such benefits would be realized in practice. In particular, a question remains around how versatile such an intermediary may be with regards to simultaneously nurturing and empowering different types of 'inner-loop' niche networks (remanufacturing and industrial biotechnology, for example), and niche networks at different stages of maturation (embryonic or fully developed – as discussed in Lopolito et al*.* (2011)). As such, to assess how they perform in practice, this thesis conducted in-depth case studies of two triple helix-based niche managers managing national inner-loop innovation networks in Scotland. The following chapter provides the background and context to the case studies.

Chapter 5: Background to research

To assess the effectiveness of triple helix-based niche managers in practice, this thesis undertook two case studies. The case studies measured and compared the ability of the Scottish Institute for Remanufacturing (SIR) and the Industrial Biotechnology Innovation Centre (IBioIC) to strategically manage their respective national innovation networks. This chapter therefore provides the context, background and rationale for selecting SIR and IBioIC as case studies. It is divided into three sections. The first section provides the context of the Scottish circular economy transition. The second section provides an overview of the case studies of two triple helix-based niche managers undertaken in this thesis and explains how they are embedded within the wider Scottish circular economy transition. The final section outlines the aims and objectives of the thesis.

5.1 The Scottish circular economy experiment via embedded case studies

The aim of this thesis is to assess the ability of a triple helix-based niche manager to nurture and empower different circular economy inner-loop niche innovation networks. Scotland was selected as the geographic region for this study as it has been widely promoted as an exemplar of governance in the transition to a circular economy (Ellen MacArthur Foundation and Scottish Enterprise 2014). In 2017, Scotland was the recipient of the World Economic Forum Circular Economy Award and was identified as the European Union’s Circular Economy Hotspot 2018. Building on its reputation as a leading circular economy nation, the Scottish Government received a £17 million circular economy grant from the European Regional Development Fund to stimulate circular economy innovation in Scotland (Ellen MacArthur Foundation and Scottish Enterprise 2014).

Two Scottish triple helix-based niche managers were identified for the purpose of comparative analysis: the Industrial Biotechnology Innovation Centre (IBioIC) and the

Scottish Institute for Remanufacturing (SIR). IBioIC and SIR were selected for empirical case study for the following five reasons.

Firstly, industrial biotechnology is a strategic inner-loop activity with regards to biological nutrient flows within the economy and remanufacturing is a strategic inner-loop with regards to technical nutrient flows (Braungart *et al.,* 2007). As such, a comparison allows for greater understanding of the challenges of stimulating both biological and technical 'inner-loop' innovation. Secondly, both IBioIC and SIR were publicly funded through the Scottish Funding Council and were established with the explicit mandate to manage the entire national niche network in line with the national circular economy strategy rather than support an individual experiment (Scottish Government 2016). Thirdly, both IBioIC and SIR meet the criteria of a triple helix-based niche manager as outlined in Section 4.4.2. Fourthly, both intermediaries, established in January 2015, were nested within the same regional innovation system and so the external macro pressures influencing the performance of the intermediary are more likely to be similar than for intermediaries operating in differing innovation systems and regions. Finally, the study had unique access to data from all network member actors for both networks.

5.2 The evolution of a triple helix-based approach to innovation in Scotland

This section provides a contextual background to the emergence of IBioIC and SIR as triple helix-based niche managers within the Scottish innovation system. Using model developed in Cai (2015)[7] of the four stages of triple helix institutionalisation, this section maps how the notion of the 'triple helix' approach to innovation developed within Scotland and how this notion became progressively institutionalised.

As such the section explains the progression from a recognised need to increased triple helix interaction to attempts to institutionalise the triple helix approach across the

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[7] The four stages of triple helix institutionalization include: Stage I: realization of needs, Stage II: intra-organizational transformation, Stage III: inter-organizational interactions and Stage IV: institutionalization of the Triple Helix concept. These are detailed in the remainder of Section 5.2.

innovation system and how this development coincided with the need to align the innovation system with the national circular economy strategy.

5.2.1 Recognized need for increased interaction between Knowledge and Innovation Spaces

Since the 1950s, Scotland's manufacturing industries have experienced a slow decline, and with them the Scottish Economy. By the early 1990's, it was recognized that with respect to business birth rate and innovation, Scotland was performing lower than the UK average. At the same time globalization and liberalization of free trade meant that Scotland could no longer rely on low wages and government grants to attract inward investment. According to Botham and Downes (1999), if Scotland was to create and sustain a high-income economy, it would have to foster new sources of competitive advantage.

Scotland has a strong heritage of being a world leader in the generation of advanced scientific knowledge, particularly in life sciences, mainly through its higher education institutes. However it performs poorly with regards to commercially exploiting this knowledge and encouraging high levels of business expenditure on research and development (Roper *et al*., 2007; Rosiello *et al*., 2015; Levie *et al*., 2013). In 2005, only 1% of the total research income of UK HEIs came from industry, commerce and public corporations and only 0.59% of GDP comes from research and development expenditure by business in Scotland (Rosiello *et al.*, 2015). Connecting the knowledge space, consisting mainly of Scottish higher education institutes, and the innovation space, made up predominantly by industry, has therefore been a key priority for the Scottish Government for the past decade or so (Scottish Government 2016).

A clear demonstration of the political will to bridge the gap between Scotland's universities and industry was the 'Single Knowledge Exchange Office Working Group' established between 2011-12 (Universities Scotland 2011). The remit of which was to enhance the harmonisation of systems and approaches to establishing linkages between academia and industry across Scotland. Following the establishment of this group, the Innovation Scotland strategy was launched through the partnership of the Scottish Funding Council and Scottish and Highlands and Islands Enterprises. The aim of the strategy was to increase the efficiency, effectiveness, clarity, and sustainability of the support for innovation and entrepreneurship between universities and business in Scotland. This strategy has led to a more prominent role for Interface (a business-university innovation match-making organisation) as well as a national policy forum.

Biotechnology has been targeted as a priority sector by Scottish Enterprise for promoting the formation of reciprocal industry-academia-government relationships since the late 1990's due to the existence of a manufacturing and chemicals sector and biotechnology/life sciences research base and the potential to export to a growing global market (Ecotec 2005; Leibovitz 2004; Rosiello *et al.*, 2015). Although a wide range of events and initiatives have contributed to the fostering a triple helix culture within Scotland's broader innovation system. This section therefore outlines four initiatives that appeared, according to the literature, to have a significant impact on the regulative and normative formation of this culture. These include the: (i) Industry Cluster Approach; (ii) Intermediate Technology Institutes; (iii) Industry Leadership Groups; and (iv) Innovation Centres.

5.2.2 Intra and Inter-organizational triple helix interactions increase

The Scottish Government has funded a number of initiatives to promote inter-organizational transformation in the biotechnology and manufacturing sectors in Scotland. In 1993, Scottish Enterprise, the main economic development agency in Scotland, established a vanguard pilot cluster approach to "increase the business birth rate, generate innovation and attract knowledge-based inward investment." (Botham and Downes 1999). Firstly, the Monitor Group was commissioned to identify the most important clusters in Scotland. Four pilot clusters were then selected for strategic development including biotechnology, food and drink, semiconductors and oil and gas. The cluster approach put greater emphasis on nurturing and empowering networks as a form of 'cluster governance' and it was seen as critical that the private sector was involved in both setting the vision and implementation (Botham and Downes 1999).

Although the cluster strategy realized nominal growth in the biotechnology sector, it has not had the impact initially expected due to the Scottish innovation system remaining locked into the top-down linear policy approach inherited from the UK model in which Scottish Enterprise acts as the main coordinating mechanism for the cluster leading to supply push rather than demand led innovation. Although it is yet to produce the outcomes expected, the cluster approach has proven to be a useful exercise in understanding the complexities of encouraging inter-organizational relationships between the triple helix actors and indicated the ambitions of the Scottish Government to move away from the outdated linear model of innovation.

To extract more commercial value out of Scotland's world leading research base, increase the number of new high technology firms and increase the level of business expenditure on research and development, Scottish Enterprise launched one the most ambitious innovation policy experiments in Europe and established the Intermediate Technology Initiative (ITI) from 2003-2013 (Brown *et al.,* 2015). The initiative had an initial budget of £450 million. The objective of the ITI was to identify emerging global market opportunities in the key sectors of techmedia, information and communication technology and life sciences – of which biotechnology was a main strand. An institute was established for each sector to operationalize the initiative. The model was heavily reliant on the institutes being proficient in advanced technological foresighting.

Regrettably the ITIs proved to be largely unsuccessful due to the continued reliance on an outdated linear intellectual property (IP) structure in which an institute identified areas for research and development through foresighting, funded universities to undertake the research and development, and then subsequently owned and licensed the IP to ensure full exploitation of the platform technology. This resulted in poor buy-in from academia who wanted to retain control over the IP and low levels of engagement with industry and venture capital due to the feeling of lack of security of IP ownership. Moreover, the platform technologies developed by the ITI were not seen to be market ready and therefore required further investment by the IP licensee and for many of the Scottish based SMEs the technology was too advanced for their requirements leading to poor buy in from local industry (Brown *et al.,* 2015). The ITI program resulted in only five new technology-based firms, rather than the goal of 75, which only generated £600,000 in IP licensing. Although not successful, the ITI offered a valuable lesson to all stakeholders involved in the process on the need for fostering a thriving triple helix system through matching the knowledge generation more closely with market and industry demand (Brown *et al.*, 2015). Moreover, it did not reduce the appetite to institutionalise a triple helix innovation system.

To streamline sector support, alongside the cluster approach, Scottish Enterprise established 15 industry leadership groups (ILG). The aim of an ILG is to provide strategic leadership and form a unified vision for the sector. Each ILG is governed using a triple helix approach whereby all three triple helix actors are involved in the governance of the groups. Each ILG is made up of circa 15 members, of which approximately 80% are active in the private sector and/or academia. Although the Industry Leadership Groups have acted as a useful voice and catalyst for change in the sector, for example supporting the launch of the Scottish Industrial Biotechnology Group, they are regarded as perhaps more of a passive form of triple helix collaboration. Moreover, ILG’s have a wider remit than just innovation and are not able to focus entirely on the promotion of innovation within the sector. However, as the preceding section outlines, they have played an important role for cognitively instilling a triple helix culture within the industrial biotechnology sector but not so much in the manufacturing sector.

In addition to the ILGs, and to encourage demand-led growth from within priority sectors, Scottish Enterprise undertook a policy scoping exercise of 150 leading innovation polices from around the world (Roper *et al.*, 2007). This was combined with a survey in 2012 with members from the ILGs which highlighted considerable interest in establishing innovation centres which target Scotland’s research strengths that were not entirely reflected in the areas covered by UK wide innovation initiatives such as the Innovate UK Catapult Innovation Centres.

Eight national Innovation Centres were established in 2014 as a result of this exercise. The £175m Innovation Centres were loosely based on the format of the Swedish Competency Centres, discussed in Roper et al. (2007) in which a centre is expected to be supported by a consortium (minimum 5-8) local firms and projects between academia and industry are co-funded by the Innovation Centre. The innovation centres therefore, in part, address the concerns raised that the Scottish Executive has focussed too much on commercialising academic research rather than increasing the involvement of SMEs - which make up the bulk of Scotland’s private sector (Lyall

2005). The main objective of the innovation centres is to capture scientific knowledge at the experimental/proof of concept stage and support it through to demonstration of a system prototype.

The Innovation Centres adopted the same triple helix governance structure to the ILGs. Although initially funded by Government, the Innovation Centres are assumed to be governed by industry and in part academia. Government only holds an observational role on the board of governance and unlike the ITI, does not retain ownership over IP. This ensures the services offered by the Innovation Centres can evolve alongside the needs of the sector more effectively than traditional top down governance support. The selection of each Innovation Centre was done through a competitive application process in which industry and academia were expected to submit a joint-bid which demonstrated a plan and the need for enhanced collaboration and knowledge exchange between the three triple helix actors in their respective sector. This involved a significant amount of discussion between individuals from all three actors and input from the ILGs and hence the subsequent forming of a shared consensus – albeit between industry leaders.

5.2.3 Evidence of institutionalisation of the triple helix in the biotechnology and remanufacturing value chains

Significant advances in gene editing technology from 2007 onwards combined with the growing strength of Scotland’s chemicals sector and life sciences research base led to the collective agreement between industry, academia and government that there was a significant opportunity for Scotland to capitalize on their strengths to grow an industrial biotechnology sector. This need to capture the value was further accelerated through the release of the UK Industrial Biotechnology Strategy in 2009.

Chemical Sciences Scotland, the ILG responsible for the Chemicals sector, proposed the establishment of the Scottish Industrial Biotechnology Development Group (SIBDG) to play the role of ILG for the fledgling industrial biotechnology sector. The collaboration between Chemical Sciences Scotland and the SIBDG over the period of 2012-2013 led to the launch of the National Plan for Industrial Biotechnology alongside. The launch of this plan highlighted the strong drive by government, industry and academia to develop the sector. It created a weak form of protected space and common objective with which further cross party discussions and collaborations could take place.

In recognition of the limited capacity of the ILGs to play a more active role within the industrial biotechnology protected space, the National Plan for Industrial Biotechnology called for the formation of a niche manager that replicated the triple helix governance approach practiced by the ILGs which would be situated within the sector as opposed to at policy level. The need for such a sector level intermediary coincided with the launch of the Innovation Centre policy and due to the level of consensus formed through the ILGs and SIBDG the Industrial Biotechnology Innovation Centre (IBioIC) was formed. Similar to the governance structure of the ILGs, all three triple helix actors sat on the governance board (Table 5.1). The formation of IBioIC combined with an £10m funding pot laid the foundations for a more active protected space. The aim of IBioIC was to facilitate the growth of Scotland's industrial biotechnology sector from 43 companies turning over €225 million/year to 200 companies turning over €1,075million/year by 2030. The scale of this ambition represents the level of optimism in the triple helix approach being employed by IBioIC. The transferral of the triple helix concept from the ILGs at policy level to IBioIC which is nested within and is co-governed by niche innovation network actors, suggests some form of triple helix institutionalisation.

At the same time the innovation centres were being launched (and IBioIC was being set up), there was an increased recognition that there was a missed opportunity to align the innovation centres with the national Circular Economy strategy – therefore the Scottish Institute for Remanufacturing was established using a similar governance approach to the innovation centres. SIR was provided with £1 million funding to build and manage a national remanufacturing innovation network, support increased academia-industry collaborative innovation through funded collaborative research projects and raise awareness of the potential for remanufacturing in Scotland. Both IBioIC and SIR were provided space within Strathclyde University – however their staff were not university employees.

Although there were many similarities between the IBioIC and SIR models as niche network managers, there was a notable difference in scale of the resources available to both organisations which needed to be accounted when comparing the ability of each intermediary to impact their respective niche innovation networks. At the time of the study, IBioIC was provided with £10 million funding from the Scottish Funding Council and had eight permanent staff members whereas SIR was only provided £1 million funding and had two permanent members of staff.

The triple helix governance structure between IBioIC and SIR also slightly differed. IBioIC had a three governance boards: (i) an overall governance board; (ii) a commercial advisory board; and (iii) a scientific advisory board (Table 5.1). The commercial advisory board recommended collaborative research projects and commercial opportunities for the niche technologies whereas the scientific advisory board gave input on the current scientific developments, challenges and opportunities. This was to ensure that an equal weighting between the ideas and expectations of both universities and industry were considered.

SIR, on the other hand, only had a steering board and an operational board. The steering board was comprised of a mixture of leading academics, industry representatives and public-sector stakeholders. The operational board was comprised of the program director of SIR and leading academics who voted on which collaborative research projects should be funded and supported by SIR.

Due to IBioIC receiving much higher levels of funding compared to SIR (£10 million versus £1 million) IBioIC was able to provide physical laboratory facilities with which to test and scale up innovations. They were also able to employ a team of 12 full time staff with over 100 years combined experience in industrial biotechnology innovation and commercialisation and run an annual international conference for 400 delegates. Whereas SIR was restricted to funding collaborative research projects (without supplying lab space or equipment) and hosting a conference for the local niche network.

Table 5.1: Overview of the governance model for IBioIC and SIR

			Number of Representatives on the board			
		Purpose of Board	**Industry**	**Academia**	**Public-sector Stakeholders**	**Total**
IBioIC	Governance Board	• Ensure IBioIC is on track to meet milestones set by funding body • Aligns IBioIC with national IB roadmap and Making Things Last (Circular Economy) Strategy	6	3	3	12
	Commercial Advisory Board	• Advises IBioIC on the emerging commercial opportunities for IB technology and the viability of proposed collaborative research projects	7	2	2	11
	Scientific Advisory board	• Advises IBioIC on the emerging scientific development for IB technology and the fundamental scientific research which is required.	4	6	0	10
SIR	Steering Board	• Ensure SIR is on track to meet milestones set by funding body • Provides expert input on priority areas/sector for SIR • Aligns SIR with Scottish Manufacturing Strategy and Making Things Last (Circular Economy) Strategy	4	4	2	8
	Operational Board	• Performs day to day management of SIR including attending events, selecting and monitoring and reporting on funded collaborative research projects.	0	3	1	4

5.3 Research Aim and Objectives

Transition to circular economy involves systemic changes to the economy in which deeply embedded path dependencies and lock-ins in the socio-technical regimes that underpin the traditional linear ‘make, use, dispose’ economic model are disrupted. Thus, in the transition process, major shifts would be expected to occur in technological trajectories as a result of innovation, and also in market trajectories as a result of changing socio-economic trends. These trajectories would also be expected to align in a systemic framework to ensure that the use of resources across the economic spectrum increasingly leads to a circular economy (Webster 2015).

The argument made in Chapters 2 and 3 is that transition to circular economy is best approached through the identification and prioritization of inner-loop activities such as reuse, repair and remanufacturing and the subsequent strategic management of inner-loop niche innovation networks with a system of governance that would help enhance the disruption of socio-technical regimes associated with the linear model of economic activities.

Section 3.5 outlined that the application of SNM to inner-loop niche innovation networks, while providing the necessary condition for niche innovation, lacks the consensus, network reflexivity and social capital base with which to disrupt incumbent socio-technical regimes and provide mechanisms to impact social functions, and activities in wealth creation and organised knowledge production, thus paving the way for a circular economy transition. SNM is essentially a top-down governance system which invokes network tension for lack of reflexivity. This would make it restrictive in terms of its contribution to enhancing innovation and possibilities for accelerating the diffusion of inner-loop activities.

The task of SNM is likely to increase in complexity as the circular economy transition requires protected spaces with much wider network boundaries to promote the cross sectoral uptake of disruptive circular economy enabling platform technologies such as industrial biotechnology and the blockchain.

As such, Chapter 4 outlined that the problem of SNM governance within circular economy-oriented niche innovation networks is likely to be mitigated when SNM is applied in the context of the triple helix system, as this would enhance consensus, network reflexivity and social capital base between the triple helix actors. The issue of triple helix-leveraged transition to circular economy, however, raises questions about how the triple helix approach can be operationalised within the niche. The notion of a triple helix-based niche manager was proposed as a new form of SNM manager with the mandate to stimulate the formation of a triple helix consensus space and ultimately lay the networks capacity to generate and scale inner-loop-oriented innovation in-line with a broader circular economy transition. However, the concept of a triple helix-based niche manager has not been empirically evaluated in practice.

This thesis therefore addresses such a knowledge gap by undertaking a detailed empirical case study of two triple helix niche managers (IBioIC and SIR) operating as niche managers within two separate circular economy-oriented protected spaces. The following chapter outlines the methodology employed to achieve the thesis aim and objectives.

Chapter 6: Methodology[8]

This chapter describes the methodology used to assess the ability of triple helix-based niche managers to strategically manage 'inner loop' niche innovation networks in-line with a broader circular economy transition. Chapter 2 established why the need to strategically manage technological innovation to accelerate the transition to a circular economy is a topic that requires consideration. Chapters 3 and 4 established the theoretical concept of a triple helix-based niche manager through the combination of strategic niche management, the triple helix approach to innovation and system intermediation. This chapter outlines the methodology used to collect and analyse the data used to achieve the aim and objectives of this thesis. The overall aim of the thesis is to uncover:

> *To what extent a triple helix-based niche manager can perform key nurturing and empowering activities within a circular economy-oriented inner loop niche innovation network.*

To achieve this aim, two main objectives were developed:

Objective 1: Empirically measure, through the combination of a complete social network analyses and qualitative research methods, the impact a triple helix-based niche manager may have on a circular economy-oriented niche innovation network with regards to the following niche nurturing activities: (i) building of the social network; (ii) raising shared expectations; and (iii) facilitating shared learning.

Objective 2: Empirically measure, through the combination of a complete social network analyses and qualitative research methods, the impact a triple helix-based niche manager may have on a circular economy-oriented niche innovation network with regards to the following niche empowering activities: (i) supporting niche

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[8] A summary of this chapter is published in: Barrie *et al.*, (2019).

innovations to compete against incumbent technologies; and (ii) altering selection environments in favour of the niche innovation.

Figure 6.1 provides a summary of the methodological process employed to achieve the aim and objectives. A mixed methods approach was adopted to offer both qualitative and quantitative analysis. As such, the methodology can be broken into two sections. Firstly, a complete social network analysis of the industrial biotechnology and remanufacturing networks were undertaken. This allowed the measurement of the impact of IBioIC and SIR on the formation of six different relational attribute ties between all network actors. As such, the impact of IBioIC and SIR on the overall network structure, triple helix interactions and their respective levels of centrality within the networks could be measured. The second part of the methodology involved collecting different types of data to explain and build on the findings from the complete social network analysis. Methods included three different network member surveys and focus groups with the business development staff from IBioIC and SIR.

The methodological chapter is divided into two sections. Section 6.1 outlines how the complete social network analysis was performed on the industrial biotechnology and remanufacturing innovation networks. Section 6.2 details the additional qualitative approaches used to support and develop the findings from the social network analysis.

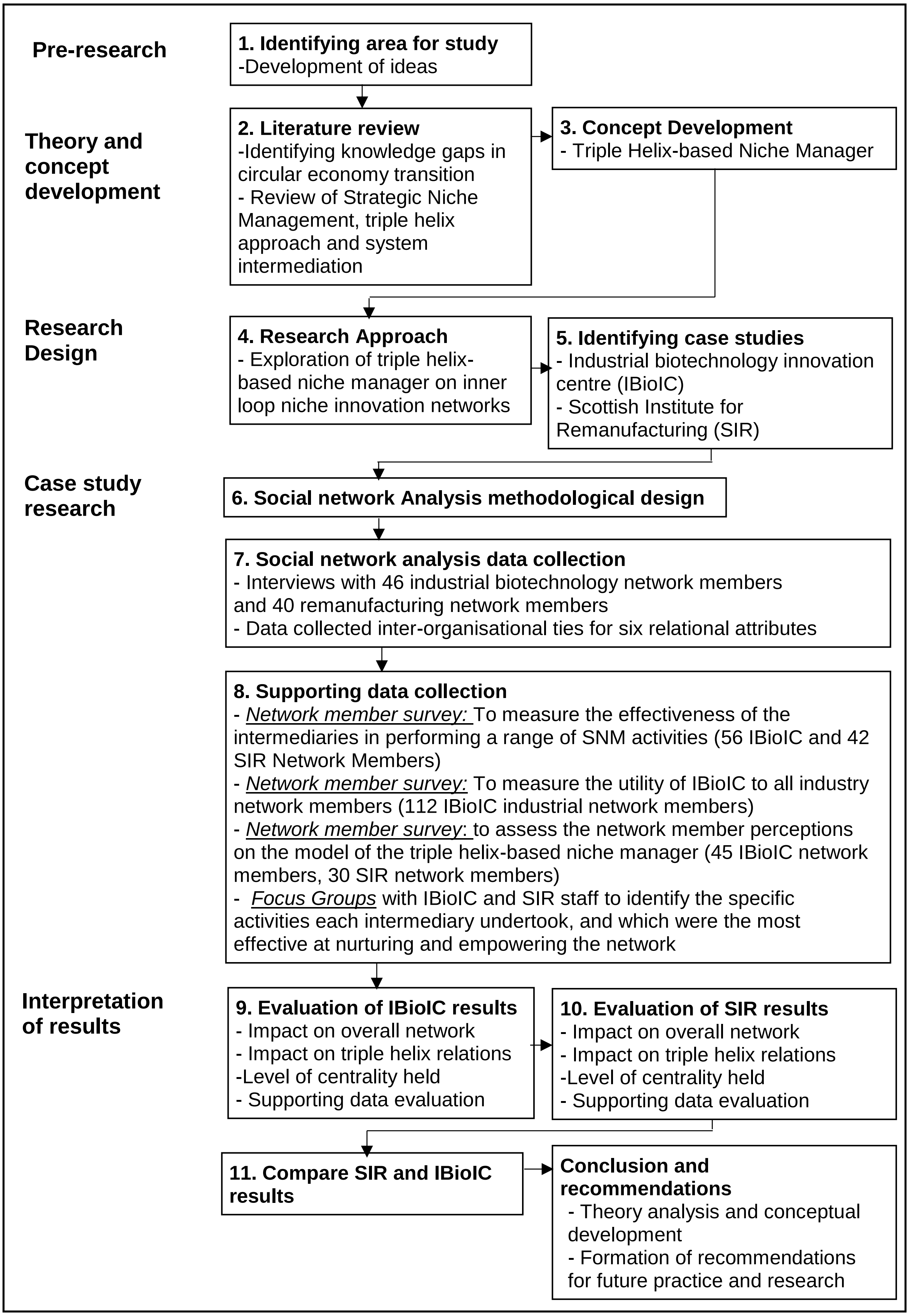

Figure 6.1 Diagram of the methodological process carried out

6.1 Complete social network analysis methodological approach

A complete social network analysis was undertaken on both the industrial biotechnology and remanufacturing niche networks in order to empirically measure the impact of each triple helix-based niche manager with regards to nurturing and empowering the networks. The following section offers an overview of social network analysis, the rationale for adopting it within this thesis and the methodology developed to address Objectives 1 and 2.

6.1.1 Overview of social network analysis

Social networks are increasingly being recognized as being important for innovation (Powell *et al.,* 1996; Powell *et al.*, 1999; Gay and Dousset 2005). A recent policy brief by the Organization for Economic Co-operation and Development highlighted that the occurrence of innovation relies upon how connected the innovation network is and how efficiently knowledge circulates through the network (OECD 2008). The report contends that there is need to better understand how to implement policies to foster such networks. Van der Valk et al. (2011) highlighted that the structure, strength of relationships and nature of networks influence the diffusion of knowledge, which, according to Gay and Dousset (2005), in its turn influences the innovation output of an economy or sector. The study of networks is therefore necessary in the context of innovation governance.

A social network is comprised of a set of actors with a set of relations between them (Wasserman and Faust 1994). Social networks can therefore be studied with regards to their relational form, or structure, or their relational content, referred to as the 'social world of the network' (Crossley 2010). Social network analysis (SNA) is a set of mathematical, graphical and theoretical tools for modelling networks. There is a growing body of literature on the use of SNA for the assessment and quantification of relational structures (Butts 2008). Although it has not been directly applied to the investigation of the evolutionary dynamics of triple helix systems, SNA has been applied across a wide range of research domains ranging from sociology, anthropology, economics, physics and innovation (Powell *et al.,* 1996; Freeman 2004).

There are many specific advantages to applying SNA as a tool to study innovation networks in comparison to standard quantitative methods such as patent counts. This is because the foundational structures of innovation systems are networks of knowledge generators, regulators and users (Leydesdorff and Etzkowitz 1998) and SNA is therefore a powerful tool for exploring the processes and structures that lead to the creation and spread of knowledge that supports innovation, rather than just the network outputs such as jobs, revenue or patents created. Wasserman and Faust (1994) also argue that SNA offers a methodological approach to test theories and study the relevant structural properties at all levels of the network from individuals and dyadic relationships to subgroups and groups.

SNA also offers a visual conceptual framework with which to identify and asses the connections between a heterogeneous set of organizations. This is particularly relevant for the study of triple helix systems due to the complexity of relationships between a number of heterogeneous actors operating under different institutional norms, practices and cultures (Nakwa *et al.,* 2012). The study by van der Valk et al. (2011) on the use of SNA for innovation studies highlighted that inter-organizational networks of collaboration is an important theme that is studied using SNA methods. Additionally, SNA offers a way to combine micro-level 'firm-centric' data to understand the broader meso-level inter-organizational dynamics, which is particularly useful for assessing niche level SNM.

6.1.2 Rationale for adopting complete social network analysis

A complete social network analysis was undertaken to allow for the study of the structure and composition of the entire niche innovation networks of IBioIC and SIR. The following sections provide an overview of why a complete social network analysis was undertaken and the methodological processes involved.

Network performance has received little attention within the topic of collaborative networks for innovation (van der Valk *et al.*, 2011). The majority of studies focus on an individual actor or 'egocentric' level as opposed to at the network level and there is a significant absence of literature on the innovative performance of networks (van der Valk *et al.,* 2011). Studies which make the network the unit of analysis tend to offer a purely quantitative and structural network level analysis of innovation networks as seen in Hermans et al. (2013) and Caniëls and Romijn (2008). Such studies also tend to display a dominant focus on industry-industry interactions as opposed to the broader triple helix interactions between public-sector, academia and industry, which Ranga and Etzkowitz (2013) argues is essential for systemic innovation to succeed.

The benefits of using SNA as a tool to study the effectiveness of SNM activities have been highlighted in a handful of studies. Caniëls and Romijn (2008) argued that SNA can open a 'black box', allowing for more systemic analysis of the niche dynamics. Lopolito et al*.* (2011) applied SNA to the study of SNM for the purpose of identifying and tracking the development phases of a niche; and Morone et al*.* (2015) investigated the multi-relational aspects of a niche network. However, these studies remain limited with regards to explaining how SNM was practically operationalized as well as measuring the impact of intermediaries on the nurturing and empowering of inner-loop niche innovation networks.

This study explores the leveraging effect of the application of the triple helix approach and system intermediation on SNM as a governance framework for transition to circular economy in industrially developed economies. The first objective of the study is therefore to evaluate the role of a triple helix-based niche manager in nurturing a circular economy-oriented protected space network. Nurturing cultivates the innovation network within the protected space and is achieved through developing social capital by fostering shared expectations, promoting shared learning and building the actor network (Schot and Geels, 2008). As such, SNM nurturing is based around the notion of nurturing the entire niche network as opposed to the individual niche stakeholders. It is therefore necessary to assess the impact of the triple helix-based niche manager on the entire niche network. One such analytical tool to achieve that is complete social network analysis.

A complete social network analysis maps the network structure in its entirety. The goal of which is to build a detailed reconstruction of the entire social network on a given population and is therefore referred to as the ‘gold standard’ of network analysis (Butts 2008). Complete social network analysis also allows the boundary of the network to become clearly identifiable (Butts 2008).

Complete SNA offers many theoretical benefits regarding the assessment of the role of triple helix-based niche managers in niche innovation networks. The entire niche network structure can be mapped and empirically analysed to measure key structural properties that facilitate knowledge diffusion and innovative activity including network cohesion, the presence of cohesive subgroups and centralization. It also allows for the identification of where the triple helix-based niche managers are structurally located within the network, how influential they are relative to other network actors, the extent to which they bridge structural holes between cohesive subgroups, and their level of centrality relative to other network actors. In addition, the level of engagement and knowledge transfer between different triple helix actors and institutions can be assessed. Complete SNA thereby offers the ability to map and assess the structure and composition of the entire niche network rather than at an individual project level, as advocated by Mourik and Raven (2006).

The SNA-based studies of Nakwa *et al.,* (2012) and Nakwa and Zawdie (2013) demonstrate the empirical value this type of methodology brings to the field of triple helix systems. Heidenreich *et al.*, (2016) also highlights that although the importance of network managers for network performance is widely recognized in research and management practice, not much has been done to empirically investigate and validate such a proposition.

A complete social network analysis was therefore undertaken to investigate the impact of the triple helix-based niche managers (IBioIC and SIR) on the (i) structural properties of the network; and (ii) the level of triple helix interaction within the two circular economy-oriented protected space networks. In addition, the complete social network analysis allowed for the level of power and influence each intermediary held within the network to be measured via egocentric analysis. Through such analysis, the role each triple helix-based niche manager played in the nurturing and empowerment of each niche network could be explored.

The embedded case study, which examines two separate protected space networks embedded within the same regional innovation system, fills a gap in the SNM literature. This is because most empirical studies have been criticized for over-reliance on descriptive methods and for being too concentrated on specific case studies

(Caniëls and Romijn 2008). Undertaking complete SNA for two circular economy-oriented protected space networks greatly strengthens the ability to evaluate the hypotheses proposed in Section 5.3, as outlined in van der Valk et al. (2011). Undertaking a comparative assessment of case studies also helps overcome the a common limitation of SNA whereby it is difficult to determine what an ‘optimal’ network property value is without comparing it to networks with similar properties (van der Valk *et al.,* 2011). Moreover, assessing niche innovation networks from both the biological and technical domains of the circular economy allows for a comparison between the differing challenges associated with managing different niches.

6.1.3 Complete social network analysis methodology

The complete social network analysis process followed four methodological steps adapted from Mckether et al. (2009) which are outlined in Figure 6.2. The following section will provide a detailed description of each step.

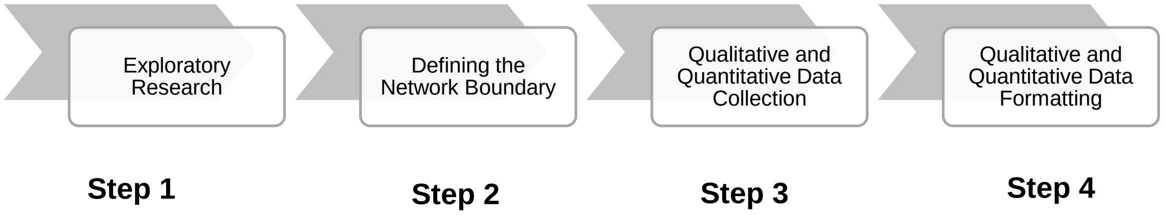

Figure 6.2: Outline of the four methodological steps employed for data collection and formatting to allow for a complete social network analysis

6.1.3.1 Step 1: Exploratory Research

Exploratory research was undertaken in order to build a comprehensive understanding of the context surrounding the emergence of both the remanufacturing (SIR) and industrial biotechnology (IBioIC) niche innovation networks (as recommended in Yin (2014)).

Five meetings were held with key individuals in Scotland who held positions in government, higher education institutes and the private sector and who were active members of each network, as identified by IBioIC and SIR staff. Stakeholders responsible for the broader circular economy transition in Scotland were also solicited for their experiential knowledge. Furthermore, observations and informal discussions were undertaken through attending key events and workshops such as IBioIC and SIR’s annual conferences, national circular economy events and bio-economy workshops. This was done in parallel with a review of the relevant literature. The results of this exercise are outlined in Chapter 2.

The aim of the stakeholder meetings was to explore the general attitude of the network actors towards the triple helix approach of policy and governance in Scotland and the need to explore the phenomenon in more depth. The exploratory meetings highlighted the emergence of the recent triple helix approach for protected spaces as a new phenomenon in Scotland which has been adopted as a conscious policy effort to drive economic growth and transition to a circular economy. However, a lack of best practice knowledge for such a policy approach was also highlighted. The exploratory process also allowed for the estimation of the: (i) projected size of protected space networks; (ii) timeline for network inception and formation; (iii) heterogeneity of the networks; (iv) details of all projects and events; and (v) projected growth and goals of the networks.

The exploratory approach highlighted the need for further study into both the internal structure and wider impact of the triple helix policy approach in both the industrial biotechnology and remanufacturing networks. A clear knowledge gap was evident within public-sector stakeholders on how to operationalize such an approach, particularly with respect to aligning it with broader societal transitions such as the circular economy transition and the existing innovation system. The findings of the exploratory research were used in the design of the methodology for the complete social network analysis.

6.1.3.2 Step 2: Defining the niche innovation network boundary

To ensure all relevant network actors were included in the analysis, a roster of active network organizations was provided by SIR and IBioIC. Rosters are the most common type of instrument for mapping interpersonal networks. They are easy to use, and they significantly reduce the risk of false negatives due to respondents forgetting organizations. The paper by Butts (2008) states that rosters should generally be preferred over name generating techniques.

The roster included the names of individuals from each organization who were best placed to identify inter-organizational relations within the niche network. The industrial biotechnology network was comprised 64 network members (Public-sector Stakeholders n=5, Academia n=16, Industry n=36, Innovation Intermediaries[9] n=7). The remanufacturing network was comprised 42 network members (Public-sector Stakeholders n=6, Academia n=6, Industry n=35, Innovation Intermediaries n=6).

A snowball method, as applied in Lopolito et al. (2011), was subsequently employed to develop an open-ended sociometric chain and identify any other individuals from other organizations in the network. This was done by asking each SNA survey respondent to suggest 3-5 organizations and individuals who they felt played a key outward facing innovation role in their organizations and would therefore be useful to be included in the SNA. This method also helped identify when the network had been fully mapped with regards to a complete social network analysis when respondents continually referred the same individuals. In addition – respondents were given the option to add organizations to the roster that were outside the network but were of strategic importance to their innovation potential.

6.1.3.3 Step 3: Data collection for complete social network analysis

By collecting data on a mixture of different forms of relational ties, a fine-grained understanding of the impact of IBioIC and SIR on the three key nurturing activities could be obtained. A total of 6 inter-organisational attributes were selected to be collected for this study. This was decided for two main reason. Firstly, due to the moderate size of the rosters for IBioIC and SIR, each respondent was required to recall the inter-organisational relationships their organisation had with all other network member organisations. Therefore, by asking them to repeat this process for each relational attribute there was a risk of recall fatigue if too many relational attributes were selected, in which the respondent would begin to forget or incorrectly identify relations or become impatient with the process and decline to give a response.

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[9] Innovation intermediaries may influence, but cannot fully control, the design or use of the innovation outcomes, which sets them apart from other actors that are more aptly described as suppliers and users of new products or services (Stewart and Sampsa 2008).

In contrast, by selecting too few relational attributes, the nuances in the ability of SIR and IBioIC to broker different forms of relational attributes would be lost.

As such six relational attributes were selected which encompassed a mixture of interaction, knowledge and resource transfer which are outlined in Table 6.1. Frequency of contact was collected to serve as a general indicator of how frequently network members were interacting with one another. Contact, in this sense, was described to the survey respondents as the instance of any direct communication (email, letter, phone call or face-to-face) between the two organisations on the topics of industrial biotechnology or remanufacturing innovation depending on the respective network which the survey respondent was part of. Frequency of contact is one of the most common relational attributes used in inter-organisation SNA (Borgatti and LI 2009; Kolleck 2013). However, as a relational attribute it is limited as it does not identify whether such contact resulted in action (such as collaborative activities or knowledge or resource transfer) or remained a ‘talking-shop’. For instance, the frequency of contact between two organisations may be high since they both attend the same events or share the same office space, however, this does not explicitly mean that they are collaborating or innovating together. Furthermore, it does not allow for an assessment of how intimate inter-organisational relations were, nor the extent of inter-organisation trust, and as such the extent to which social capital (or a triple helix consensus space) was developing within the niche. Therefore, in addition to frequency of contact, an additional five relational attributes were collected: (i) total knowledge transfer (a combination of tacit and explicit knowledge); (ii) collaborative research projects; (iii) technology transfer; (iv) cash transfer; and (v) intellectual property (IP) transfer.

Total knowledge transfer was identified to be when both tacit and explicit knowledge inter-organisational transfer occurred on the topics of either industrial biotechnology or remanufacturing. For this study, explicit knowledge was defined as knowledge which can be easily expressed and recorded as words, numbers, codes, mathematical and scientific formulae. Whereas tacit knowledge was defined as knowledge that is embedded in the human mind through experience and jobs and which is very difficult to extract and codify. Rather than analysing tacit and knowledge transfer separately, they were combined to indicate ‘total knowledge transfer’ for ease of analysis.

Table 6.1: Relational attribute ties collected in network member survey

Relational Attribute	**Rationale for assessing relational attribute**	**Reference**
Frequency of Contact	Initial indicator of strategic importance of other organization and subsequent strength of other relations. If any organization identified as 2 or above it is selected to assessment for all other relations.	(Borgatti and LI 2009) (Kolleck 2013)
Total Knowledge (tacit + explicit knowledge)	For this study, explicit knowledge was defined as knowledge which can be easily expressed and recorded as words, numbers, codes, mathematical and scientific formulae. Whereas tacit knowledge was defined as knowledge that is embedded in the human mind through experience and jobs and which is very difficult to extract and codify. Rather than analysing tacit and knowledge transfer separately, they were combined to indicate 'total knowledge transfer'	(Borgatti and LI 2009) (van Egeraat and Curran 2014)
Collaborative Research Projects	Presence of collaborative research project suggests direct joint innovation effort. Also allows quantification of impact of triple helix intermediary on level of collaborative projects in the network. Active collaboration is seen as critical to the success of the niche (Morone *et al*., 2015). Through collaborative research projects, different types of actors learn how to work together. By learning to work together, organizations can learn about specific technologies and the market and increase their absorptive capacity for new knowledge. In addition, successful collaboration is self-reinforcing in that it stimulates further collaboration which can ultimately lead to niche wide advances (Powell *et al*., 1996).	(Takahashi *et al.,* 2018) (Morone *et al*., 2015) (Powell *et al*., 1996).
Technology Transfer	Indicates a high level of trust between two actors as well as increasing allocation of resources to the success of the niche.	(Borgatti and LI 2009) (Ferraro and Iovanella 2017)
Cash Transfer	Indicates a high level of trust between two actors as well as increasing allocation of resources to the success of the niche.	(Borgatti and LI 2009)
IP Transfer	Indicates a high level of trust between two actors as well as increasing allocation of resources to the success of the niche.	(Borgatti and LI 2009)

The presence of collaborative research projects was selected to be collected since the existence of experimentation within the niche is crucial for stimulating high quality knowledge transfer between niche actors as well as raising expectations both within and external to the niche (Raven 2005). The presence of inter-organisational collaborative research projects also indicates growing trust between niche network actors. Bradach and Eccles (1989, p.104) claimed that trust is a form of expectation. If trust is present, it lessens the fear that an organisation with which you partner with will not act in an opportunistic or selfish way. Therefore, when there is mutual trust between two parties, they are much more willing to collaborate and commit resources to a shared endeavour without the fear that the other organisation will take advantage of the situation. Although the presence of collaborative research projects indicates a growing sense of trust and consensus within the network, it does not explicitly result in an output which can progress the niche from a technological niche to a market niche – nor destabilise the incumbent regime. Secondly, a collaborative research project does not necessarily require a very high level of trust nor commitment between the participating parties.

It was therefore necessary to also measure the extent to which resource transfer occurred between the niche actors. Evidence of increased resource transfer between the triple helix niche actors also infers the strengthening of a triple helix consensus space within the niche. The three resources, related to innovation activity, were technological, cash and intellectual property (IP) transfer. Measuring different types of resource transfer offers the ability to quantify the extent to which external resources were transferred into and around the niche. By including the resource transfer relational attributes of technology, cash and IP transfer and collaborative research projects, this paper has sought to build on the study by Morone et al*.* (2015) which only assessed interaction and knowledge relational ties.

Inter-organization relational data were collected via interviews with individual representatives from each organization in the IBioIC network between September 2016 and March 2017 and via online surveys with individual from representatives from each organization in the SIR network between June 2017 and December 2017. The interviewees were individually identified by IBioIC and SIR staff as being responsible for managing inter-organizational innovation relationships within the network. Each interviewee was provided with a description of the research and a consent form to sign (See Appendix I). A total of 47 out of a total of 64 network members were interviewed from the industrial biotechnology network. This included four Scottish public-sector stakeholder, 12 academia, 27 industry and four innovation intermediary network member organisations. Out of the 17 organisations not interviewed, a total of 10 organisations were identified by IBioIC as 'fringe' actors to the network, in other words played very little role in the network, three responded that they were not active in the network enough to warrant an interview and five had exited the network or gone into liquidation between the drafting of the raster and the end of the interview period. As such, only a total of 3 (or 5% of the total network) active members were not interviewed. A total of 38 out of a total of 53 network members were surveyed from the remanufacturing network. This included three Scottish public-sector stakeholder, four academia, 27 industry and four innovation intermediary network member organisations. Of the 15 organisations not interviewed, seven were identified by SIR business development staff as ‘fringe’ actors and two had exited the network or gone into liquidation. As such, only six (or 11% of the original network) active members were not interviewed. Each organizational representative was asked to identify the existence of the six relational ties between their respective organization and all other organizations in the network as outlined in Table 6.2. Table 6.2 provides an overview of the questions asked to respondents, their response options and the nurturing activities that the relational ties impact. The adjacency matrix templates that IBioIC and SIR network members were asked to complete are located in Appendix III.

Table 6.2: Questions each network organisation representative was asked in order to identify and value the existence of 9 different relational ties their organization held with every other network member organization

#	**Questions asked to each organization regarding their relationships with each network member organizations**	**Response Options**
1	How frequently do you have contact (on the topic of biotechnology/remanufacturing)? (Email, phone, letter, face-to-face)	None, None but in future, Once a quarter, Once a month
2	Were all of your inter-organisational relations formed through IBioIC and SIR?	No, Partially, Yes
3	Were all of your inter-organisational relations strengthened through IBioIC and SIR?	No, Low, Medium, High, Very High
4	Do you currently participate in collaborative biotechnology/remanufacturing research projects together?	Yes/No
5	What level of tacit knowledge (related to biotechnology/remanufacturing) do they transfer to your organization?	Poor, Moderate, High
6	What level of explicit knowledge (related to biotechnology/remanufacturing) do they transfer to your organization?	Poor, Moderate, High
7	Has there been industrial biotechnology/remanufacturing technology transfer between your organizations in the past 2 years?	None, From you to them, From them to you, Both ways
8	Has there been biotechnology/remanufacturing intellectual property transfer between your organizations in the past 2 years?	None, From you to them, From them to you, Both ways
9	Has there been biotechnology/remanufacturing cash transfer between your organizations in the past 2 years?	None, From you to them, From them to you, Both ways

Notes:

1. For this study, explicit knowledge was defined as knowledge which can be easily expressed and recorded as words, numbers, codes, mathematical and scientific formulae. Whereas tacit knowledge was defined as knowledge that is embedded in the human mind through experience and jobs and which is very difficult to extract and codify.
2. Respondents were asked to rate the strategic importance of knowledge transfer between all other network members - as such, although it does not explicitly state which type of knowledge, it does identify how valuable this knowledge transfer, and subsequent learning, was to the continued success of the organisation
3. Relational attribute data for relational attributes 2 and 3 were collected solely as a means to measure the impact of IBioIC and SIR on relational attributes 1,4-9.
4. Total knowledge transfer was included as an additional attribute in the analysis. Total knowledge transfer is a multiplex relational attribute formed through the combination of values from tacit and explicit knowledge transfer relational attributes using the UCINET 6.1 multiplex function.

To measure the existence and strength of the various relational ties between two organizations, each respondent was asked to fill in an actor-relation incidence matrix which listed a roster of network actors in the first column and the different types of relations they held with them in the following columns. To avoid recall error, only staff identified by IBioIC and SIR as having detailed knowledge of their respective organization relations with other network members, were selected to be interviewed. Several individuals were interviewed from large organizations to cross-check the actor-relation matrix and add in any missing data. This was particularly the case for universities where knowledge of external relations from other departments was low.

Initially, respondents were asked to rate the frequency of inter-organizational contact for each organization on the roster. If the frequency of contact was identified as none or none but in future, then it was assumed there was no pre-existing relations between the two organizations. As such, respondents only had to identify and rate the level of different types of relations that existed for organisation where they had a frequency of contact once a quarter or above (Questions 2-9 in Table 6.2). This was a pragmatic step to reduce the need for each respondent to fill in an entire 42x42 (for SIR) or 64x64 (for IBioIC) matrix and therefore risk recall fatigue. In addition to identifying inter-organizational relational ties, respondents were also asked whether such ties were created or significantly strengthened through the brokering activities of SIR and IBioIC. This allowed for the ability to measure the impact of SIR and IBioIC on each relational tie type. Analysis of the social network data was conducted using the social network analysis software UCINET 6.1 (Borgatti *et al.,* 2002).

Prior to data analysis, UCINET 6.1 required the creation of a relational data set in the format of adjacency matrices (built in Microsoft Excel). An adjacency matrix is a square, two-dimensional actor-actor matrix. An adjacency matrix was created for each relational attribute. The adjacency matrices were then uploaded to UCINET 6.1 and converted into dual-file format, which allowed for a wide range of quantitative network analysis indicators to be calculated, such as network density and the measure of betweenness centrality of the individual actors in the network. In addition, the data could also be visually represented as sociograms (network diagrams) via the software NetDraw.

6.1.4 Framework for comparing the impact of each intermediary with respect to nurturing and empowering their respective niche networks

The complete network analysis of the industrial biotechnology and remanufacturing networks allowed for a comparative impact analysis framework to be developed. The framework assesses the impact of each triple helix-based niche manager on three different network aspects. These were the (i) overall network structure; (ii) inter-relations between triple helix groups; and (iii) the network centrality of the intermediary as described in Table 6.3. How the impact of IBioIC and SIR on each network aspect was measured is outlined in the following three sections. See Appendix II for a full description of the social network analysis formulae.

6.1.4.1 Measuring impact of triple helix-based niche manager on network structure characteristics

Three aspects of the overall network structures for SIR and IBioIC were evaluated using network structural aspects as previously used by van der Valk et al*.* (2011) for measuring the innovation potential of different innovation networks. These were the level of network cohesion, the presence of cohesive subgroups and the degree of centralization. The rationale for selecting these network evaluation criteria to assess the ability for SIR and IBioIC to perform key nurturing and empowering activities is outlined below. As per in van der Valk et al*.* (2011), each network characteristic was assessed via one or several proxy indicators which are common SNA measurements. Table 6.3 outlines which SNA measurements were used as a proxy for each network characteristic and Appendix II outlines the equations used to calculated each SNA measurement.

What is evident from Table 6.3, is that the complete SNA offered more value as an assessment tool for IBioIC and SIRs ability to nurture their respective networks compared to assessing their ability to empower them. Hence, additional qualitative data was collected via network member surveys and focus groups to compliment the SNA findings – the methodology of which is outlined in Section 6.2.

Network Cohesion

Network cohesion describes the extent to which network actors are related to one another. Increased network cohesion enables the build-up of social capital (Coleman 1988). Social capital has been shown to increase the likelihood of shared learning and expectations and therefore the innovative performance of individual network actors (Kilpatrick *et al.,* 1999). Yet, too high a level of cohesion can lead to 'over-embeddedness' which restricts new information from entering the network thereby reducing the chances of novel combinations of knowledge and the networks ability to adapt to exogenous change (Coleman 1988). An increase in network cohesion is a strong indicator of building networks and the potential for shared learning to occur.

The aspects of networks structure (cohesion, cohesive subgroups and centralization) cannot be measured directly using social network analysis techniques (van der Valk *et al.,* 2011). However, they can be inferred from the measurement of proxy structural characteristics of networks which are outlined in Table 6.3 and calculated using UCINET 6.1 software. Regarding the overall network structure, the level of network cohesion was evaluated through the measurement of the following three SNA measurements:

1. **Total number of ties in the network:** A count of the total number of undirected relational ties between all possible dyadic sets of organisations. An undirected tie is a relational tie which has no direction assigned to it.
2. **Network density:** The total number of ties divided by the total number of possible ties
3. **Average path length:** The average length of all paths between all nodes in the network. As the path length increases, the 'distances' between the network actors becomes longer

Presence of Cohesive Subgroups

The presence of cohesive subgroups identifies the extent to which the network is comprised of separate cohesive subgroups. As the presence of cohesive subgroups increases, local knowledge flow and shared learning increases. Yet, there is a risk of the cohesive subgroups becoming highly 'cliquish' whereby local knowledge lock-in occurs if subgroups are not sufficiently inter-connected. This is particularly dangerous for niche networks which are reliant on influencing wider incumbent regimes through knowledge and resource exchange.

A balance is therefore required between the presence of subgroups and the connectedness between them. Burt (2000) argues that most efficient network architecture is likely in the small world typology. Small world networks are networks in which cohesive subgroups are sufficiently interconnected to simultaneously ensure effective knowledge exchange at the local level, whilst preventing knowledge lock-ins.

As in van der Valk et al*.* (2011) and Hanneman and Riddle (2005), the increase or decrease in the presence of cohesive sub-groups was calculated by comparing the measurement of clustering coefficient value with the overall network density. This was done for both before and after the introduction of IBioIC and SIR to the network. The clustering coefficient of a network actor is a measurement of how complete a neighbourhood of a network actor is. This can be scaled up to the clustering coefficient for the entire network which is the average clustering coefficient over all nodes in the network.

An increase in the overall network clustering coefficient value does not necessarily indicate an increase in the presence of cohesive subgroups. For instance, the overall network density may also have increased at the same rate and therefore the entire network has become more clustered as opposed to particular subgroups. Therefore, as recommended by UCINET 6.1 and Hanneman and Riddle (2005), the presence of cohesive subgroups can be inferred through comparing the delta increase in overall network density to the relative increase in clustering coefficient for each actors neighbourhood. If an actors clustering coefficient increases more relative to the overall network density, then the presence of cohesive subgroups increases. As such, the average network clustering coefficient was calculated for the network. The relative change in clustering coefficient to change in network density was calculated using the following equation:

$$\text{Presence of cohesive subgroups } = \frac{(\text{Average Network Clustering Coefficient} - \text{Density})}{\text{Average Network Clustering Coefficient}}$$

Formula 6.1: Average network clustering coefficient

The identification of the extent to which the presence of cohesive subgroups have formed within the networks provides a useful metric to ask questions such as: has the introduction of the triple helix-based niche manger led to the formation of tightly closed cliques thereby increasing the chances of knowledge transfer or the risk of creating knowledge lock-in? or has their introduction contributed to the building of a small world network typology whereby knowledge may flow efficiently between different cohesive subgroups?

Network Centralisation

A high level of centralisation offers an indication of the emergence of hubs with above averagely connected central nodes. Networks with a high level of centralisation tend to be more robust and less influenced by the removal or addition of a network member (Borgatti *et al.,* 2006). A clear sense of leadership and shared expectations within the network is also prevalent in highly centralised networks (Freeman 1978) which has been shown to be important for innovation (van der Valk *et al.,* 2011). Yet, highly centralised networks are reliant on the actions of the actors at the centre of these hubs. As such, the exiting of these actors, such as intermediaries, can have profound and potentially disruptive effects on the structure of the network.

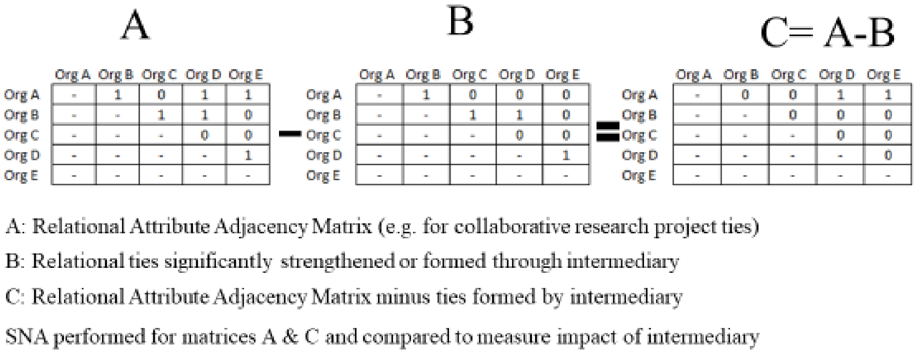
The extent to which the network has become more or less centralised is a useful measurement for assessing the impact of the triple helix-based niche manager on the network structure as well as the extent to which expectations are shared across the network. The network centralization was inferred from the measurement of the centralization index as per van der Valk et al*.* (2011). According to Hanneman and Riddle (2005), the centralisation index provides an overall insight into the inequality of centrality of individual actors in the network. A high centralisation index means there are a handful of highly connected and powerful actors which sit at the centre of the network.

Table 6.3: Outline of structural aspects measured for the six relational attributes presented in Table 6.1 (expanded from van der Valk et al. *(2011))*

					Meaning of high value of measures	**Relevance for nurturing activities**			**Relevance for empowering activities**	
Structural Aspects		**SNA Measurement (See for further explanation)**	**Calculation**	**Range of Values**		**Building Networks**	**Promoting shared expectations**	**Shared Learning**	**innovations to compete against incumbent technologies**	**altering selection environments in favour of niche**
Overall network structure	Network Cohesion	Number of Ties	The total number of ties	>0	The network is highly connected	✓✓	X	✓✓	X	X
		Density	The total number of present ties divided by the total number of possible ties	0 to 1	The network is densely connected.					
		Average Path Length	The average length of all paths between all nodes in the network	>0	The distances between the entities are long					
	Presence of Cohesive Subgroups	Δ Density / Δ Clustering Coefficient (%)	The ratio between the change in network density and the change in clustering coefficient (the weighted mean of the clustering coefficients of all actors)	0 to 1	The network comprises of different clusters. To evaluate the level of clustering, the clustering coefficient must be compared to the overall network density.	✓✓	✓	✓✓	X	X
	Degree of Centralization	Centralization Index	The degree of inequality or variance in the network as a percentage of that of a perfect star network of the same size	0 to 100%	There are clear hubs among a large number of more limitedly connected others.	✓	✓✓	✓✓	X	X
Triple helix interaction		Group density	Group Density function, which calculates the sum of ties between and within triple helix groups and the density of ties.	0 to 1 for density of ties	The triple helix groups are highly connected to each other and other network members	✓✓	✓✓	✓✓	✓✓	X
Niche-Regime Interaction		Group density	Group Density function, which calculates the sum of ties between and within triple helix groups and the density of ties.	0 to 1 for density of ties	The niche and regime actors are highly connected to each other and other network members	✓✓	✓	✓✓	✓✓	X
Intermediary centrality		Degree	The number of relational ties incident on each network actor	>0	The actor is highly connected	✓✓	✓	✓✓	X	X
		Closeness	The average length of the shortest path between the actor and all other actors	>0	The actor is close to many other actors in the network	✓✓	✓	✓✓	X	X
		Betweenness	The number of times an actor acts as a bridge along the shortest path between two other actors	>0	The actor holds a high level of control over knowledge and resource exchange between other network actors	✓✓	✓	✓✓	X	X
		Effective Size	The number of alters that ego has, minus the average number of ties that each alter has to other alters. Effective size is actors network size minus redundancy in actor's network.	1 to N (total number of ties)	The higher the effective size, the higher, the social capital – the more different regions of the network an actor has ties with, the greater the potential information and control benefits	✓✓	✓	✓✓	X	X

X	Not applicable
✓	Cannot be directly linked to impacting nurturing or empowering activities – but suggests possible indirect effect
✓✓	Can be directly linked to impacting nurturing or empowering activities.

The impact of IBioIC and SIR on each SNA measurement (and hence structural aspect) was determined by firstly calculating the value of measurement (Table 6.3) for all six relational ties (Table 6.1). The calculations were then re-run excluding all ties created by IBioIC and SIR brokering activities. The results of both sets of calculations (IBioIC and SIR included in the network versus IBioIC and SIR excluded from the network) were compared. This process involved three main steps as described below (and outlined in Figure 6.3).



A

	Org A	Org B	Org C	Org D	Org E
Org A	-	1	0	1	1
Org B	-	-	1	1	0
Org C	-	-	-	0	0
Org D	-	-	-	-	1
Org E	-	-	-	-	-

B

	Org A	Org B	Org C	Org D	Org E
Org A	-	1	0	0	0
Org B	-	-	1	1	0
Org C	-	-	-	0	0
Org D	-	-	-	-	1
Org E	-	-	-	-	-

C= A-B

	Org A	Org B	Org C	Org D	Org E
Org A	-	0	0	1	1
Org B	-	-	0	0	0
Org C	-	-	-	0	0
Org D	-	-	-	-	0
Org E	-	-	-	-	-

A: Relational Attribute Adjacency Matrix (e.g. for collaborative research project ties)

B: Relational ties significantly strengthened or formed through intermediary

C: Relational Attribute Adjacency Matrix minus ties formed by intermediary

SNA performed for matrices A & C and compared to measure impact of intermediary

Figure 6.3: An example of measuring the impact of IBioIC and SIR on the network characteristics.

Step 1: Create an intermediary impact adjacency matrix

An adjacency matrix was created to record any direct ties to and from IBioIC and SIR and all ties where IBioIC and SIR had been identified as being directly responsible for forming or significantly strengthening between two organisations (Matrix B Figure 6.3). Matrix B was created from the responses to Questions 2 and 3 outlined in Table 6.2.

Step 2: Create relational attribute adjacency matrices that do not include ties formed through IBioIC and SIR

The ties in the intermediary impact adjacency Matrix B were then subtracted from each relational attribute adjacency Matrix A (Figure 6.3) using the UCINET 6.1 matrix subtraction function. The resulting adjacency Matrix C (Figure 6.3) produced for each relational attribute represented the relational ties formed out with the brokerage activities of IBioIC and SIR.

Step 3: Measure the difference between relational attribute adjacency matrices that include and exclude ties formed through IBioIC and SIR

The SNA measurements (Table 6.3) were then calculated using UCINET 6.1 for each set of relational attribute adjacency matrices (including and excluding ties formed by

IBioIC and SIR). The results were then compared, and the percentage differences were calculated as a means of quantifying the change in structural characteristics.

6.1.4.2 Measuring the impact of IBioIC and SIR on the level of inter-triple helix and niche-regime relations

In addition to the impact each triple helix-based niche manager had on the overall network structure, it is also useful to understand their impact on stimulating the formation of a triple helix consensus space within the niche. SNA is a powerful tool for achieving this as the increase or decrease in relational ties between the triple helix groups can be empirically measured. Furthermore, the ability for the triple helix-based niche managers to nurture different forms of relational attributes (such as knowledge transfer, collaborative research projects or technology transfer as outlined in Table 6.1) can also be assessed. Finally, by identifying any increase in high trust based relational ties (or lack thereof) between the triple helix groups also indicates the change in potential for shared expectations to emerge which in turn influences collaborative activity.

The number of new triple helix relational ties for the six relational attributes outlined in Table 6.1 were calculated within and between each triple helix group using the UCINET 6.1 Group Density function, which calculates the sum of ties between the pre-defined triple helix groups and the density of ties (see Table 6.3). Results of the analysis were visualised via sociograms built in NetDraw. The triple helix groups were identified as: public-sector stakeholders; universities; industry and innovation intermediaries.

A critical function of SNM is to enable the niche to alter the evolutionary trajectory of existing incumbent regimes (Hegger *et al*., 2007). By measuring the impact each triple helix-based niche manager had on the formation of different types of relational ties between niche and regime actors, it is possible to assess the extent to which they were able to empower the niche by connecting it with regime actors who would traditionally be external to the niche, but necessary participants if the niche were to expand.

To achieve this, industry actors were categorized into regime and niche actors, as identified by IBioIC and SIR business development staff; and the density between the two groups was calculated. Actors were identified as regime actors if their main value generation was obtained through incumbent regime value chains or their innovation was likely to reinforce the status quo. Whereas a niche industry actor was identified if the organisation was pursuing innovation which was likely to alter the configuration of the niche to increase its chances of aligning with a circular trajectory. The impact of IBioIC and SIR on niche regime interaction was subsequently calculated using the UCINET 6.1 Group Density Function (see Table 6.3).

As per the structural properties of the network, the interaction between triple helix groups was evaluated separately for each relational or multiplex relational attributes. Thus, the level of triple helix interaction for each relational attribute could be compared. The impact of the triple helix-based niche manager on the density of relational ties between the triple helix actors was then calculated, as previously outlined in Section 6.1.4.1. Results of the analysis were visualised using NetDraw.

6.1.4.3 Measuring centrality of IBioIC and SIR in their respective networks

Actor network centrality is widely used as an SNA technique to investigate how central an individual actor is within the network and hence how much power and influence they hold over knowledge and resource flow throughout the network (Borgatti and LI 2009; Borgatti and Lopez-Kidwell 2014; Freeman 1978). Network actor centrality can be measured in several different forms to assess particular aspects of the actor such as their ability to direct and control knowledge and resource transfer through the network as well as determining which actors enter the network. Four common measures of centrality to assess the overall power and influence held by intermediaries within the network are outlined in Pilar Latorre et al. (2017) and Carolan (2014). These are the actors' degree, closeness, betweenness centrality and the effective network size bridged.

Degree centrality: The number of relational ties incident on each network actor. A high degree centrality means that the actor is highly connected compared to other network members.

Closeness centrality: The average length of the shortest path between the actor and all other actors. A high level of closeness means that the actor is structurally close to other network actors and therefore more likely to trust each other and share knowledge and resources.

Betweenness centrality: The number of times an actor acts as a bridge along the shortest path between two other actors. A high betweenness infers that the actor holds a high level of control over knowledge and resource exchange between other network actors

Effective Network Size: The effective network size calculates how effectively each network actor bridges structural holes between other actors in the network. It does this by calculating the proportion of redundant ties in an actors' network relative to the total number of ties that network holds with the other actors. As an example, if Actor A has a relational tie with Actor B and Actor C, and Actors B and C do not have a direct tie then Actor A is bridging a structural hole and as such its ties with Actors B and C are non-redundant. However, if Actors B and C do have a direct tie with each other then Actor A's ties are redundant. The lower the number of redundant ties, the higher the effective size of an actors' network. A high effective size increases the level of social capital that an actor can draw from in the network and increases the level of power and control an actor holds over the flow of information and resources throughout between unconnected areas or cliques in the network (Burt 1992).

The value of calculating each centrality measure for IBioIC and SIR with regards to understanding their ability to nurture and empower their networks is outlined in Table 6.3. Each centrality measure was calculated using built-in UCINET 6.1 algorithms (as outlined in Appendix II). The centrality measures were then ranked compared to all other network member centrality values to allow for a comparison of the level of centrality of IBioIC and SIR compared to all other network members.

6.2 Supporting data for social network analysis

SNA provides a unique insight into the structural aspects of a niche innovation network; however, it is limited in terms of explaining why such a structure has emerged. Additional qualitative data was therefore collected from niche network members which was used to shed light on the reasons behind the impact of IBioIC and SIR on the network structures. This section outlines the rationale for collecting additional qualitative data, how the data was collected and how it was analysed.

6.2.1 Rationale for adopting mixed methods approach

Quantitatively mapping the structure of a network by collecting and analysing numerical actor-actor relation data allows researchers to empirically examine key network properties such as the cohesiveness, centralization and existence of cliques or ‘structural holes’ as well as identify the boundary of the network. Such properties act as indicators of how efficiently resources, such as knowledge, flows through different network types. Quantitative network mapping also allows for analysis of structural properties of individual network actors, like for instance, their level of brokerage or isolation. Yet, quantitative analysis of the network via the SNA method is limited in its ability to offer insight into the relational content of the network. By simplifying the relations between actors into numerical data, this approach neglects the equally important questions surrounding “the construction, reproduction, variability and dynamics of complex social ties” (Edwards 2010, p.10). In addition, network maps derived from quantitative methods are limited to producing ‘snap shots’ in time of the network structure, whereas in reality social networks are dynamic and constantly evolving structures (Mønsted 1995, p.206).

In a critique of SNA, Butts (2008) argued that even though it is a powerful tool for understanding social processes, it is incorrect to believe that all social scientific questions can be solved solely using network data. Rather, effective conclusions drawn from SNA should be triangulated with data collected on network member attributes, any contextual variables specific to that network as well as social processes (Butts 2008). In addition, Edwards (2010) suggested that by numerically mapping the existence, or lack of, social relations, quantitative analysis techniques are limited in their ability to capture and present ties that are latent, very weak or emerging, which, in dynamic networks are often important in inciting change. It is therefore evident that gaining a deeper understanding of both the relational form and content of the inner-loop niche innovation networks requires a mixed methods approach incorporating both quantitative and qualitative analysis is required.

There are a number of benefits to mixing quantitative and qualitative approaches when undertaking SNA. Edwards (2010) notes that both techniques complement each other with quantitative analysis providing an 'outsiders view' of the network i.e. the structure that cannot be observed by any one actor in the network, whereas qualitative analysis provides an 'insider's view' i.e. the content and process of the network. This is based on the notion that social networks consist of both structure and process at the same time and therefore "evade simple categorization as either quantitative or qualitative phenomena*"* (Edwards 2010, p.10).

Crossley (2010) refers to the mixed approach as a division of labour approach and posits that qualitative analysis is necessary to uncover the social content of the network, as quantitative approaches 'over simplify' the social world of the network. The qualitative approach also helps to enhance understanding of the context of the network which cannot be assessed through numerical methods, such as how and why it formed, the motivations of each actor in participating in the network, the dynamics of relations or why certain actors have a high degree of centralization and brokerage. Although a mixed quantitative and qualitative approach to social network analysis is a more laborious task, as it tends to produce 'messy results', Lievrouw et al*.* (1987) argue that it provides a much deeper understanding of the network and perhaps reflects the actual 'messiness' of most social networks.

Regarding the study of innovation in social networks, Kolleck (2013) demonstrated the benefits of adopting a mixed methods approach to investigating why and how social innovations emerge. The study highlighted that although quantitative SNA allowed for the identification of network boundaries and structure, what is important for a better understanding of the opportunities and barriers to innovation is qualitative analysis through the combination of egocentric network mapping and semi-structured interviews. This helped reveal the 'causes, motivations, ideas, or perceptions', in other words the social fabric that is embedded within the structure.

One must be cautious when using SNA to draw conclusions about a network. Successful network analysis is equally dependent on the researcher’s knowledge of the phenomenon being studied - that is to say, the researcher must be able to determine where non-network data should be utilized to solve questions related to SNA methodology or analysis (Butts 2008). Qualitative data were therefore collected for both industrial biotechnology and remanufacturing networks to help build a deeper contextual understanding and fill the knowledge area not addressed through the quantitative SNA. This study therefore adopted the mixed methods approach by complementing the complete social network analysis with a combination of semi-structured interviews, surveys and focus groups with network members.

6.2.2 Qualitative data collection methods

The following sections offer a detailed overview of the mixed quantitative and qualitative approaches used to achieve Objectives 1 and 2 as outlined in Table 6.4.

Table 6.4: Overview of qualitative methods adopted to assess the role of IBioIC and SIR in nurturing and empowering the niche networks

			Relevance to nurturing Activities			**Relevance to Empowering**	
Compositional Aspects	**Purpose**	**Respondents**	**Building Networks**	**Promoting shared expectations**	**Shared Learning**	**Supporting niche innovations to compete against incumbent technologies**	**Altering selection environments in favour of the niche innovation**
Network member survey A	Measure the effectiveness of the intermediaries in performing a range of SNM activities	Network members (Both)	✓✓	✓✓	✓✓	X	✓
Network Member Survey B	To measure the utility of IBioIC to all industry network members	Industry network members (IBioIC)	✓✓	X	✓	✓✓	X
Semi-structured interview	To assess the network member perceptions on the model of the triple helix-based niche manager	Network members (IBioIC)	✓✓	✓	X	X	X
Network Member Online Survey	To assess the network member perceptions on the model of the triple helix-based niche manager	Network members (SIR)	✓	✓✓	X	X	X
Focus Group	To identify the specific activities each intermediary undertook, and which were the most effective at nurturing and empowering the network	IBioIC and SIR business development staff (Both)	✓✓	✓✓	✓✓	✓✓	✓✓

X	Not applicable
✓	Cannot be directly linked to impacting nurturing or empowering activities – but suggests possible indirect effect
✓✓	Can be directly linked to impacting nurturing or empowering activities.

6.2.2.1 Network member surveys

Two IBioIC network member surveys and one SIR network member survey were conducted in order to understand and compare how effective IBioIC and SIR were in undertaking a wide range of nurturing and empowering activities at the niche level and what benefits have accrued in the network since the introduction of IBioIC and SIR as network managers.

IBioIC Network Member Surveys

The first survey (A) was conducted by the author in January 2016. The aim of the first survey was to measure the effectiveness of IBioIC with regards to undertaking activities critical to nurturing the niche innovation network. All 64 organizations in the Scottish industrial biotechnology network, at the time, were approached for the survey resulting in a total 56 responses from network member individuals from Scottish public-sector stakeholders (9), academia (20) and industry (27), representing 40 active network member organizations.

The survey adopted the system intermediary framework introduced by Kivimaa (2014) to evaluate 22 potential nurturing activities of intermediaries – whereby nurturing is achieved through successful articulation of expectations and visions, promoting learning processes and building social networks (Table 6.5). Respondents were asked to rank the quality of activity undertaken by IBioIC into five categories: Very High (5), High (4), Moderate (3), Low (2), Very Low (1) and None (0). Five categories were selected to provide a wide enough spread of responses whilst retaining an odd number of responses as recommended by (Yin 2014).

The survey was predominantly targeted at assessing IBioIC’s ability to perform the key nurturing activities. However, it was also useful for assessing how effective IBioIC was able to empower the niche through altering the selection environment in in favour of the niche innovation as it assessed the roles of ‘influencing policy’ and ‘managing financial resources through finding potential funding and funding activities’.

Table 6.5: A list of the 22 nurturing activities of an intermediary that IBioIC was assessed against with regards to nurturing the industrial biotechnology protected space (adapted from Kivimaa 2014)

Articulation of expectations and visions	**Learning processes and exploration at multiple dimensions**	**Building of social networks**
• Articulation of needs, expectations and requirements • Strategy Development • Acceleration of the application and commercialisation of new technologies • Advancement of sustainability aims • Influencing policy • Accreditation and standard setting	• Knowledge gathering, processing, generation and combination • Technology assessment and evaluations • Prototyping and piloting • Investments in new businesses • Communication and dissemination of knowledge • Education and training • Provision of advice and support • Creating conditions for learning by doing and using • (long term) project design, management and evaluation	• Creation and facilitation of new networks • Gatekeeping and brokering • Configuring and aligning interests • Managing financial resources – finding potential funding and funding activities • Identification and management of human resource needs • Arbitration based on trust and neutrality • Creating new jobs

Note:

1. The quality of service by IBioIC for each activity was ranked by respondents into five categories: Very High (5), High (4), Moderate (3), Low (2), Very Low (1) and None (0).
2. The roles highlighted in grey were not included in the SIR network member survey

In addition to the first survey, the authors were provided full access to the raw dataset from a survey (B) conducted by IBioIC in July 2017 with 121 network member individuals representing 116 industry organizations in the Scottish industrial biotechnology network[10]. The survey asked each respondent to identify the extent to which they agreed with the statements outlined in Table 6.6. The survey also asked the companies to identify whether IBioIC activities had contributed to nine different economic gains on the business Table 6.6.

This survey was particularly valuable for evaluating IBioIC's ability to build the social network of the niche as well as supporting niche innovations to compete against incumbent technologies by identifying the business activities that IBioIC contributed to, in particular IP development, additional products or services, sales increased, and international market share gained.

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[10] Note: the number of organizations in the network grew from 60 to 116 organizations in the interim period between the Survey A conducted in January 2016 and Survey B conducted by IBioIC in July 2017.

Table 6.6: Survey data collected in IBioIC industry member survey in July 2017.

Survey respondents asked to what extent they agree with the following statements:

1. IBioIC has made a positive impact to the Industrial Biotechnology industry over the past 3 years
2. Your company has directly benefited from the activities undertaken by IBioIC
3. The current format of IBioIC meets your company needs
4. There is a continued need for IBioIC to exist
5. IBioIC activities contributed to the following economic gains
    a. Creation of Business-to-Academic strategic relationships
    b. Creation of Business-to-Business strategic relationships
    c. Product/service improvement
    d. IP Development
    e. Additional Products or Services
    f. Growth in jobs
    g. Sales increased
    h. International market share gained
    i. Additional or Other

Notes:

1. The survey was designed and conducted by IBioIC.
2. For statements 1-4, survey respondents were provided with the following response options: Strongly Disagree, Disagree, Neither Disagree nor Agree, Agree, Strongly Disagree.
3. For statement 5, survey respondents were provided with the following response options: Disagree, Agree.

SIR Network Member Survey

The SIR network member survey was a replica from the IBioIC survey (A) and was conducted by the author in May 2017. All 42 organizations in the Scottish remanufacturing network, at the time, were approached for the survey resulting in a total 32 responses from network member individuals representing 32 active network member organizations from Scottish public-sector stakeholders (8), academia (3) and industry (23).

The SIR network member survey evaluated 15 potential nurturing activities of intermediaries rather than the 22 evaluated in the IBioIC survey (A) (Table 6.7). This was based on feedback from IBioIC interviewees that asking them to rank 22 roles was tiring, time consuming and repetitive which would likely lead to lower quality results. When asked which roles should be removed, IBioIC respondents identified a total of 8 roles[11]. The additional role of 'Raising awareness of the circular economy' was added upon request from SIR staff to help them understand how effectively they were promoting circular economy opportunities.

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[11] The eight roles removed from the SIR survey (that were in the IBioIC survey A) are highlighted in grey in Table 6.5.

The survey was predominantly targeted at assessing SIR's ability to perform the key nurturing activities. However, it was also useful for assessing how effectively SIR was able to empower the niche through altering the selection environment in favour of niche innovations as it assessed the roles of 'influencing policy' and 'managing financial resources through finding potential funding and funding activities'.

Table 6.7: A list of the 15 nurturing activities of an intermediary that SIR was assessed against with regards to nurturing the remanufacturing protected space (adapted from Kivimaa 2014))

Articulation of expectations and visions	**Learning processes and exploration at multiple dimensions**	**Building of social networks**
• Articulation of needs, expectations and requirements • Strategy Development • Acceleration of the application and commercialisation of new technologies • Advancement of sustainability aims • Influencing policy • Raising awareness of the circular economy	• Knowledge gathering, processing, generation and combination • Technology assessment and evaluations • Communication and dissemination of knowledge • Education and training • Provision of advice and support • Creating conditions for learning by doing and using	• Creation and facilitation of new networks • Configuring and aligning interests • Managing financial resources – finding potential funding and funding activities

Note: 1. Activities highlighted in grey are additional to the roles IBioIC survey A.

6.2.2.2 Semi-structured interviews with network members

To evaluate the effectiveness of the triple helix governance model employed by IBioIC in further depth, semi-structured interviews were conducted between September 2016 and January 2017. The interviews covered representatives from 45 organizations actively participating in the Scottish industrial biotechnology network (11 universities, 27 industry actors, 7 public-sector stakeholders) out of a total of 60 organizations. The respondents were asked to respond to the following questions:

(i) How effective was IBioIC with regards to building consensus within the network and whether the triple helix governance structure promoted self-governance of the industrial biotechnology protected space;
(ii) How effective was IBioIC with regards to stimulating of knowledge exchange between the organisational network actors and policy makers.

Due to time constraints, it was not possible to conduct individual interviews with each SIR network member. Therefore, an online survey was conducted with representatives from 30 active network organizations. The survey respondents were asked the following:

(i) To what extent is the presence of SIR required to build consensus between industry, academia and government around a future vision for re-use, re-distribution, repair, re-conditioning or remanufacturing in Scotland?

(ii) Does SIR act as an effective broker between the public-sector, industry and universities with regards to re-use?

The semi-structured interviews were predominantly targeted at assessing IBioIC and SIRs ability build a triple helix consensus space within the niche. It was also valuable in assessing the extent to which IBioIC and SIR were able empower the niche by enhancing knowledge flow between niche actors and policy makers thereby increasing the chance of altering selection environments in favour of the niche innovation. The phrasing of the questions to the SIR network members who took the survey were adjusted to aid clarity on what the research was asking. This was based on experience of having to explain the meaning behind the questions during the IBioIC interviews. As SIR network members were answering the questions remotely via an online survey form – it was important that the wording of the questions was revised to increase their ability to understand the meaning behind the questions.

6.2.2.3 Focus groups with IBioIC and SIR staff

To complement the findings of the surveys and semi-structured interviews, focus groups were undertaken in March 2017 with IBioIC and SIR core business development staff who were responsible for managing activities and partnerships in the network. This included 8 staff members from IBioIC and 3 staff members from SIR. The aim of each focus group was to identify and discuss specific inward and outward facing activities IBioIC and SIR had undertaken to nurture and empower the protected space network. The focus group was constructed as follows:

- **Step A:** The focus group was asked to list all the activities either IBioIC or SIR had undertaken to nurture and empower the network and subsequently classify them as either inward or outward looking to the niche, or both.

- **Step B:** The focus group was then asked to identify and rank the most influential activities from the full list of activities (identified in Step A). The activities were ranked with regards to their impact on each of the following nurturing functions: (i) building networks; (ii) stimulating both first order (accumulation of facts and data) and second order learning (enabling changes in frames and assumptions); and (iii) articulating expectations.

- **Step C:** The focus group were asked to perform the same task in Step B for ‘stretch and transform’ and ‘fit and conform’ empowerment functions.

This chapter outlined the methodology developed to assess the ability of IBioIC and SIR to nurture and empower their respective inner-loop niche innovation networks. It outlined the benefits of assessing the impact of the triple helix-based niche managers on the niche network structure using a complete SNA; in terms of the overall network, relations between triple helix groups and their network centrality. However, it also identified that such analysis can be further strengthened through additional qualitative research methods. It therefore outlined the range of qualitative methods employed to support the SNA including network member surveys and interviews as well as focus groups with the triple helix-based niche network managers. Following the overview of the research approach to this thesis, the next two chapters are dedicated to presenting the results and analyses from the case studies of IBioIC and SIR respectively.

Chapter 7: Case Study of the role of the Industrial Biotechnology Innovation Centre as a triple helix-based niche manager[12]

This chapter presents the results and analysis from the industrial biotechnology niche network case study. An initial overview of the importance of industrial biotechnology is provided before presenting the results from the complete social network analysis which includes the impact of IBioIC on the overarching network structure, triple helix interactions and the level of power and centrality IBioIC held within the network. Secondly, the results from the qualitative methods are presented which includes the network member surveys, semi-structured interviews and focus group. Finally, the results are discussed in relation to the ability for IBioIC to nurture and empower the niche network.

7.1 Background to industrial biotechnology in the context of the circular economy

As outlined in Figure 2.3, a circular economy is considered to consist of two main nutrient flows; (i) biological; and (ii) technical. Much of the organic waste produced globally is used in low value applications such as fertiliser, animal feed and energy or it is simply dumped to landfill or the environment (WWF 2009). As such, there is significant potential to valorise such organic waste by shortening the return loop between the organic waste and the end user. Due to recent technological developments in genomics and biotechnology, there is now the opportunity to valorise organic waste through biorefining which retains the embodied ‘value’ of the organic waste. The report on urban biocycles by Ellen MacArthur Foundation (2017), identified biorefining as the inner most loop of the biological cycle in the butterfly diagram.

Biorefining follows a similar process to the refinement of crude oil (Kamm *et al.*, 2005). Crude oil enters a refinery and is converted into a wide range of different products (petrol, diesel, kerosene etc). The same process occurs in biorefining. Waste organic

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[12] A summary of this chapter is published in: Barrie et al. (2019).

matter enters the biorefinery and is subsequently converted, using a suite of industrial biotechnologies which use enzymes and micro-organisms, into high value products in sectors ranging from chemicals, food and feed, detergents, paper and pulp, textiles and liquid fuels (World Economic Forum 2017).

Industrial biotechnology is a key enabler of the biorefining process. It is not one technology but a broad suite of cross disciplinary technologies including, but not limited to, genomics, bio-retrosynthesis, molecular biology, feedstock processing, synthetic biology and bio-informatics. The industrial biotechnology process retains the embedded value of organics waste initially created from the energy, resources and labour used to grow it. The conversion of organic matter into higher value products has been used for thousands of years. Take for example the fermentation of grains for beer. However, the difference with industrial biotechnology is that the enzymes and micro-organisms can be engineered in the lab and be pre-programmed to break down organic waste in specific ways thereby creating a multitude of products from virtually any organic feedstock. As such the scaling of industrial biotechnology is predicted to become a cornerstone technology in the transition to a bio-economy (an economy where economic assets are derived from renewable biological feedstocks rather than non-renewable feedstocks) (World Economic Forum 2017; Zabaniotou 2018). Industrial biotechnology is therefore potentially disruptive to many incumbent linear regimes – particularly the chemicals, fuels and plastic industries which are predominantly based on fossil fuels.

Although industrial biotechnology offers significant potential with regards to valorising organic waste, there are many challenges to be overcome before the potential for the technology can be fully realised. This is because the development of industrial biotechnologies requires the application of multiple disciplines ranging from microbiology, molecular genetics, process technology and biochemistry. The development of biotechnologies is dependent on the generation of scientific and technical knowledge (Powell *et al.,* 1996). As such it requires a high level of collaboration and coordination between academic researchers and industrial actors (both process experts and renewable feedstock producers). Furthermore, due to current legislation on the handling and processing of organic waste being inherently linear in nature and thereby restrictive to the use of industrial biotechnological processes on different organic waste streams, there is the need for alignment between government and industry actors (Philp and Winickoff 2017).

The development of industrial biotechnology is predicated on the academic researchers and industrial actors through experimentation, as well as some form of government support and regulation, therefore it is evident that some form of SNM is required. In recognition of this need, the Scottish Government funded the Industrial Biotechnology Innovation Centre, a triple helix-based niche manager, in the beginning of 2014 to manage the national industrial biotechnology innovation network.

The remainder of this chapter presents the results, analysis and discussion of the role IBioIC played in nurturing and empowering the niche innovation network over the period of two years between 2014 and 2016 as described in the methodology in Chapter 6.

7.2 Complete social network data analysis

This section presents the results obtained from the complete social network analysis. This includes the whole network analysis (impact of nurturing on the structure of the network and on triple helix interactions) and the egocentric analysis (centrality of IBioIC relative to all other network members).

7.2.1 Industrial biotechnology network composition excluding relational ties and network actors created and added by IBioIC

The IBioIC network structure at the time of the study was comprised of a mixture of industry actors, universities, public-sector stakeholders and innovation intermediaries (outlined in Table 7.1). Just over half of the network (56%) was made up of industry actors (39% regime actors and 17% niche actors). Nearly a third (30%) of the network was made up of universities (15 of which were Scottish and 4 were based in England). The remainder of the network was made up of public-sector stakeholders and innovation intermediaries. Figure 7.1 also demonstrates the broad spread of expertise in the network with regards to different parts of the supply chain and different sectors.

Table 7.1: Composition of the industrial biotechnology network

Triple Helix Group	**Total number of organizations in industrial biotechnology network**	**% Proportion of network**
Industry	36	56%
Regime	*25*	39%
Niche	*11*	17%
Universities	19	30%
Public-sector Stakeholders	5	8%
Innovation Intermediaries	4	6%

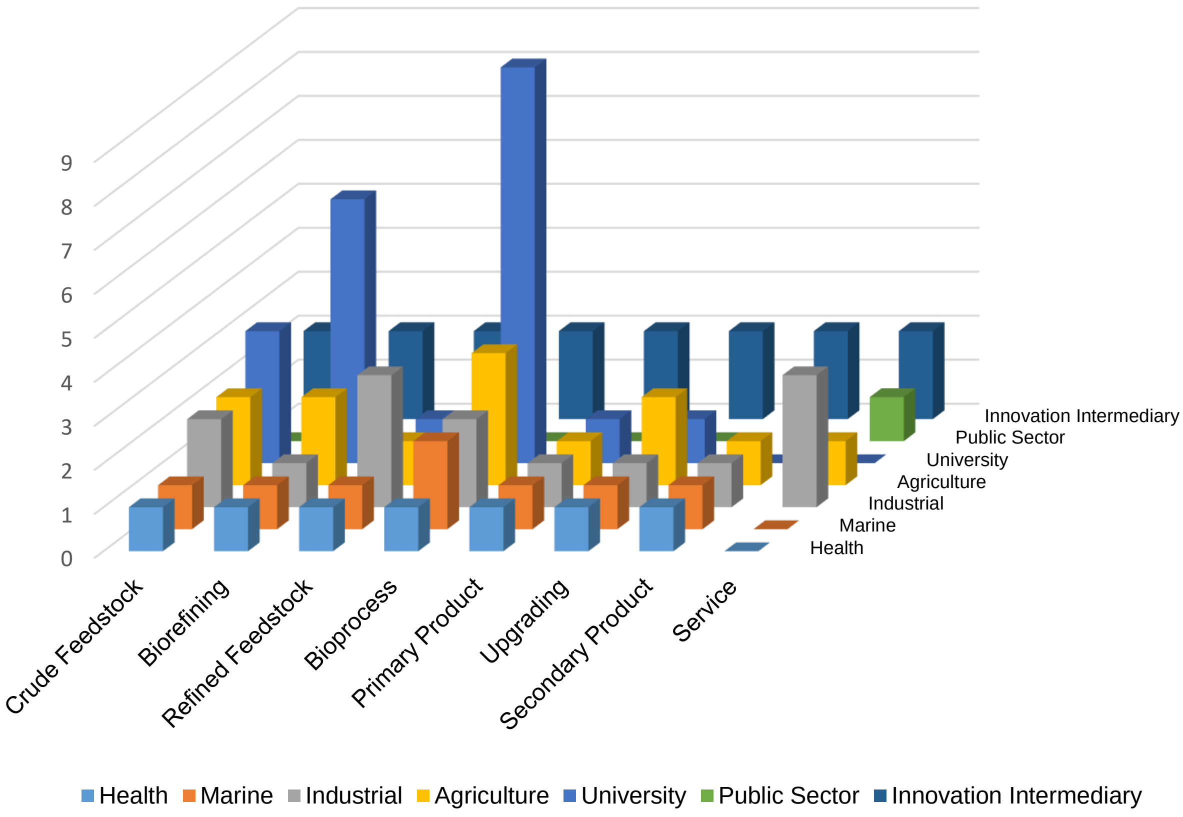

Figure 7.1: The composition of the industrial biotechnology network at the time of the analysis with regards to the different sectors on the y axis and the expertise held in each step in the industrial biotechnology value chain on the x-axis.

Note: The figure demonstrates that the network was broad and covered value chain phase for each sector. There was some clustering with regards to expertise in biorefining, refined feedstocks and bioprocessing – particularly for marine, industrial and agricultural industry actors and universities

7.2.2 Impact of IBioIC on overall network structural characteristics

Table 7.2 outlines the impact IBioIC had on the industrial biotechnology network with regards to cohesion, presence of cohesive subgroups and centralisation. The impact was measured as a percentage change in the respective proxy indicator (density, number of ties etc.) for each relational attribute due to the presence of IBioIC, as outlined in Section 6.1.3. The results from the network analysis performed in UCINET 6.1 and the associated impacts of IBioIC are included in Appendix IV. The formula used to calculate the value of each structural aspect can be found in Appendix II.

7.2.2.1 Impact of IBioIC on network cohesion

The results in Table 7.3 indicate that, overall, IBioIC increased the level of network cohesion for all six relational attributes. The relational attribute of frequency of contact demonstrated the highest final density value of 0.315. However, as the type of relational tie becomes more complex and requires more trust between organisations, the density of the network drops significantly. For example, the density of relational ties dropped to 0.046 for technology transfer and 0.032 for IP transfer.

The relational attribute that increased the most, with regards to the number of ties, was the existence of frequent contact between actors, in which IBioIC increased the number of frequent contact ties from 976 to 1270 ties. Such an increase suggests IBioIC was effective at deepening the network through building additional ties between actors who were previously disconnected. This can be seen in Figures 7.2 and 7.3, where the increase in number of ties across the network, particularly for actors on the edges of the network, is evident.

When the percentage increase in the number of ties is considered, the stronger forms of ties, such as collaborative research projects, cash transfer and IP transfer increased by 63%, 72% and 113% respectively, compared to the 30% increase in ties for frequent contact. This suggests that IBioIC demonstrated the greatest impact with regards to brokering relational ties which are dependent on trust, and perhaps only likely to form through a neutral broker. Carpenter et al. (2012) found that an increase in such trust-based ties can foster an environment of reciprocity and cooperation throughout the network, whilst constraining the network actors through strong norms and shared expectations. Michelfelder and Kratzer (2013) also found that such ties are necessary for complex knowledge to be transferred and exploited via technological development and experimentation. This is particularly important with regards to the formation of a triple helix consensus space within a protected space (Ranga and Etzkowitz 2013).

Table 7.2: An outline of the increase/decrease in the industrial biotechnology structural network values for each relational attribute with respect to the impact of IBioIC

	Cohesion								**Cohesive Subgroups**				**Centralisation**		
	Density		**Number of Ties**			**Path Length**			**Clustering Coefficient**				**Centralisation Index**		
	With	**Without**	**With**	**Without**	**% Change**	**With**	**Without**	**% Change**	**With**	**Without**	**%Change**	(CC-D)/CC **Difference**	**With**	**Without**	**% Change**
Frequency of Contact	0.315	0.242	1270	976	**30%**	1.7	1.9	**-12%**	0.483	0.394	**23%**	**-3.8%**	0.6907	0.3072	**125%**
Total Knowledge Transfer	0.11	0.067	442	270	**64%**	2.2	2.6	**-18%**	0.341	0.18	**89%**	**5.0%**	0.4112	0.1767	**133%**
Collaborative Research Projects	0.106	0.065	426	262	**63%**	2.2	2.5	**-14%**	0.318	0.144	**121%**	**11.8%**	0.3661	0.1787	**105%**
Technology Transfer	0.046	0.03	186	120	**55%**	2.7	3.5	**-30%**	0.024	0.000	**N/A**	**N/A**	0.1654	0.1659	**0%**
Cash Transfer	0.084	0.049	340	198	**72%**	2.3	2.9	**-26%**	0.244	0.12	**103%**	**6.4%**	0.4864	0.1951	**149%**
IP Transfer	0.032	0.015	128	60	**113%**	5.5	7.6	**-38%**	0.152	0.036	**322%**	**20.6%**	0.1639	0.0502	**226%**

Notes:

1. The number under the column ‘With’ is the relational attribute value including the ties formed by IBioIC. The number under the column ‘Without’ is the relational attribute value without the presence of IBioIC.
2. For Path Length: A negative number indicates that the average path length has reduced between network members
3. For Centralization Index: A positive number indicates a % increase in value due to the presence of IBioIC. The % value was calculated by taking the ratio between the centralisation index value including any ties directly formed through IBioIC and the centralisation index value not including any ties formed directly through IBioIC and then converting the ratio to a % change.
4. Only frequency of contact identified as being once every quarter or more were included in the analysis
5. Ratio between Density and Clustering Coefficient: The increase or decrease in presence of cohesive sub-groups was calculated by examining the ratio of the clustering coefficient value with the density values for both before and after the introduction of IBioIC to the network. The formulae recommended in UCINET 6.1 of (Clustering Coefficient-Density)/Clustering Coefficient was used to estimate the level of clustering relative to density for the network with relational ties formed by IBioIC included and without them included. The results of which were then compared to assess the difference.
6. The clustering coefficient for technology transfer without IBioIC was 0 due to there being no triadic ties (ties between three network members). The global clustering coefficient is based on triplets of nodes. A triplet consists of three connected nodes. A triangle therefore includes three closed triplets, one centred on each of the nodes (n.b. this means the three triplets in a triangle come from overlapping selections of nodes). The global clustering coefficient is the number of closed triplets (or 3 x triangles) over the total number of triplets (both open and closed).

The introduction of IBioIC into the network also led to the reduction of average path length between actors for all relational attributes. Path length reduction is most evidenced for the increased trust relational attributes such as technology, cash and IP transfer, in which the average path length within the network reduced by 30%, 26% and 38% respectively. The reduced path length is perhaps most visible for IP transfer (see Figure 7.3) whereby previously disconnected clusters of IP transfer became much more interconnected. The reduction in average path length helps increase network cohesion by making it easier for knowledge and resources to be shared between any two network actors (Wang and Hua 2013).

7.2.2.2 Impact of IBioIC on presence of cohesive subgroups

The increase or decrease in the presence of cohesive sub-groups was calculated by comparing the ratios of clustering coefficient values with network density values for both before and after the introduction of IBioIC to the network (as recommended in Borgatti and Lopez-Kidwell (2014)). If the percentage increase of this ratio is larger for the network that includes IBioIC ties, IBioIC increased the presence of cohesive subgroups. Conversely, if the value is lower, IBioIC decreased the presence of cohesive subgroups. Although IBioIC increased the network density and clustering coefficient for every relational attribute, the impact it had on the presence of cohesive subgroups varied. For example, the presence of cohesive subgroups for frequent contact marginally reduced by 3.8%, whereas the presence of cohesive subgroups for more trust based relational attributes such as total knowledge transfer, collaborative research projects and IP transfer increased by 5%, 11.8% and 20.6% respectively.

The clustering coefficient for technology transfer marginally increased from 0.000 (there were no triadic ties present) to 0.024 due to the presence of IBioIC. The value is an order of magnitude less than the clustering coefficients calculated for all other relational ties suggesting that there was very little technology transfer clustering. Although the calculation for the presence of cohesive subgroups could not be completed due to the clustering coefficient for technology transfer without IBioIC formed ties being 0, it can be assumed that IBioIC increased the presence of cohesive subgroups (even though the value is -91.7%). This is due to the inspection of Figure 7.3 were several triadic ties appear to have formed due to IBioIC.

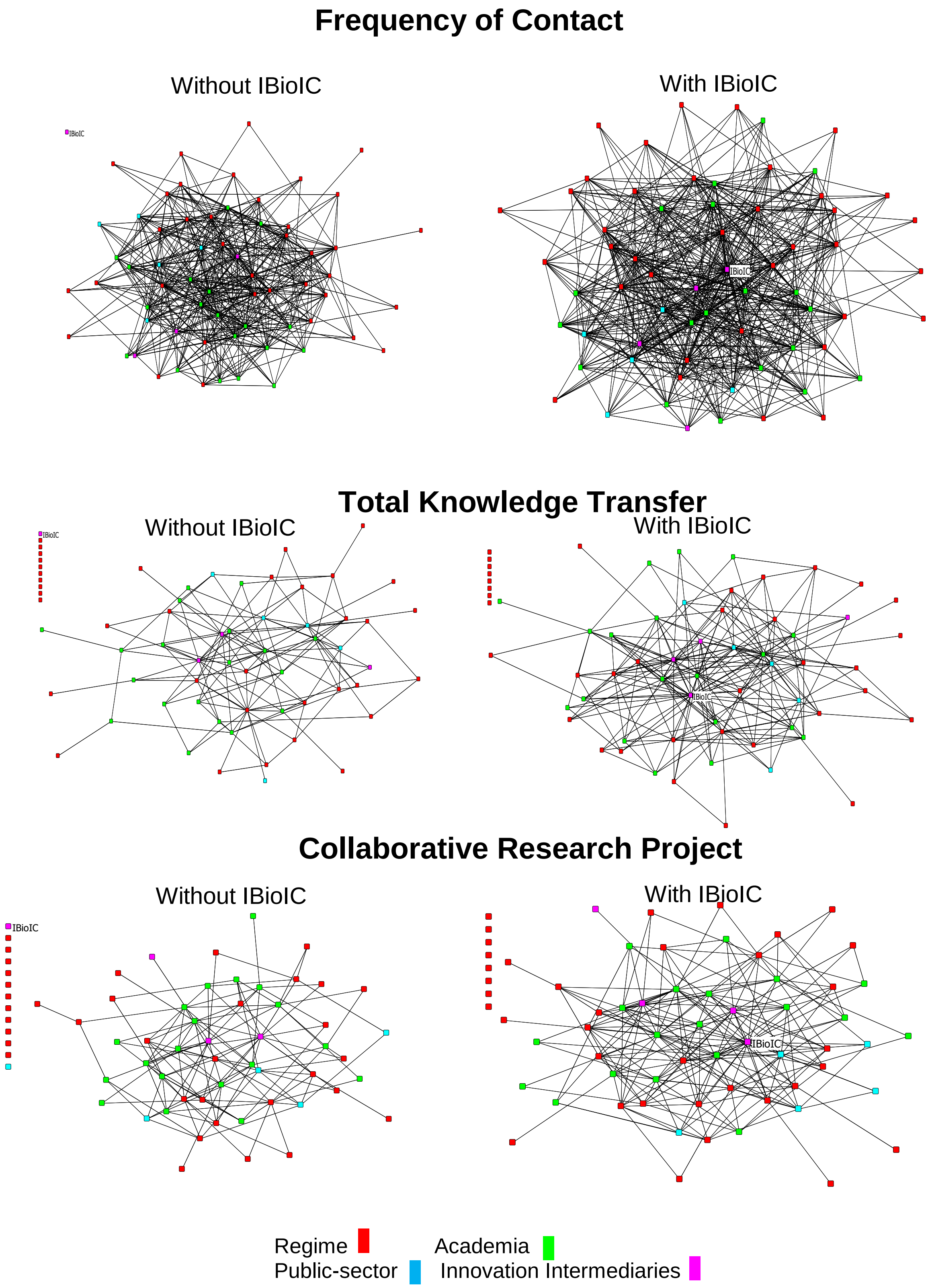

Figure 7.2: Sociogram diagrams demonstrating the change in the number of relational ties in the industrial biotechnology network with and without IBioIC for frequency of contact, total knowledge transfer and collaborative research projects.

Notes: 1. The sociograms were produced using the software NetDraw by Borgatti (2002). 2. Larger versions of these images can be found in Appendix IV

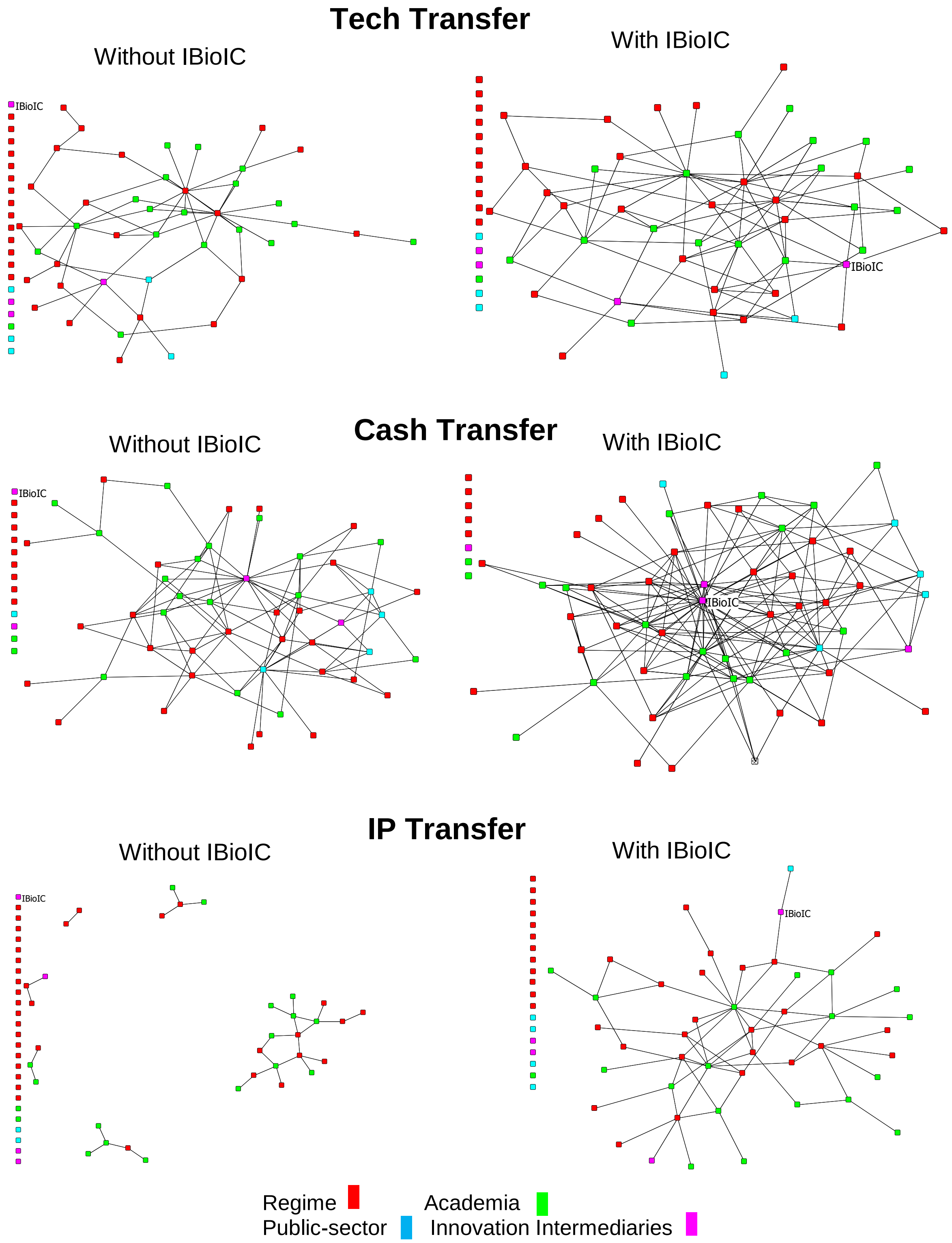

Figure 7.3: Sociogram diagrams demonstrating the change in the number of relational ties in the industrial biotechnology network with and without IBioIC for technology, cash and IP transfer.

Notes: 1. The sociograms were produced using the software NetDraw by Borgatti (2002). 2. Larger versions of these images can be found in Appendix IV

The results therefore suggest that IBioIC was able to increase the frequency of contact between network members by up to 30% without the formation of cohesive subgroups and hence the risk of knowledge lock in. Yet, IBioIC was simultaneously able to increase the presence of cohesive subgroups for relational attributes which require high levels of trust and coordination such as knowledge transfer, collaborative research projects and IP transfer. This suggests that IBioIC was able to increase clustering for relational attributes where a strong sense of trust is needed but reduce clustering for lest trust-based ties thereby increasing the likelihood of knowledge transferring between clusters – and perhaps the emergence of small world network structure. Small world networks are thought to be the most conducive network structure for innovation to occur (Burt 2001). As such, IBioIC was able to enhance the level network cohesion without significantly increasing the risk of over-embeddedness and hence knowledge lock-in.

7.2.2.3 Impact of IBioIC on network centralisation

The centralisation index increased for all relational attributes except for technology transfer which remained the same. An increase in network centralisation indicates that the immediate network or 'neighbourhood' of each network actor became more connected. The increase in centralisation index was particularly high for cash transfer ties (149%) and IP transfer ties (226%). An increase of frequency of contact centralization index of 125% suggests that IBioIC was an effective mechanism for enhancing both the depth and width of the niche network by increasing the connectedness between existing actors as well as bringing in new actors.

By increasing the centralization for increasingly trust based relational attributes, such as IP or cash transfer, IBioIC's activities have not only increased the long term robustness of the network but have also created the foundations for shared expectations between network actors to emerge, which is critical for the success of the niche. The sociograms indicating IP transfer ties formed through IBioIC and without IBioIC outlined in Figure 7.3 offers a clear demonstration of increased centralisation with regards to IP transfer. Initially, IP transfer was only between distinct cohesive subgroups, however the brokering activities of IBioIC was successful in bridging structural holes between such cohesive subgroups and hence encouraging IP transfer to occur across the entire span of the network. As well as inter-connecting existing cohesive subgroups, IBioIC was also able to increase the number of network actors involved in IP by 21%.

The results of the SNA suggest that IBioIC had an overall positive effect on the network cohesion, presence of cohesive subgroups and centralisation. As such, IBioIC increased the chances of collaborative innovation and experimentation to occur which is critical for the success of the niche.

7.2.3 Impact of IBioIC on triple helix interaction

In addition to the impact of IBioIC on the overall structural characteristics of the network, IBioIC's impact on the formation of relational ties between and within triple helix groups was also assessed (academia, government, universities and innovation intermediaries). Figure 7.4 graphically illustrates the relational ties, for each relational attribute, formed between the triple helix groups due to the brokering role of IBioIC. Each black line represents a new relational tie formed. It is evident, from Figure 7.4, that IBioIC not only brokered a large number of relational ties between the triple helix groups – particularly between academia and industry, but also brokered ties within each group.

Table 7.3 outlines the empirical impact of IBioIC on triple helix relations for the six types of relational ties. Academia-industry relational ties experienced the highest increase in terms of the number of relational ties on average compared to academia-government and industry-government relations. The frequency of contact relational ties increased between academia-industry by 21% and by 17% between academia-public-sector, whereas frequency of contact relational ties between industry-public-sector was lower at 5%. Frequency of contact relational ties also increased within each group. Industry-to-industry and public-sector-public-sector contact increased by 21% and 33% respectively.

IBioIC was particularly effective at increasing shared learning among the triple helix groups. Total knowledge exchange relational ties increased by 69% between academia and industry; by 63% between academia and public-sector; and by 13%

between industry and government. The fact that knowledge exchange ties increased between industry, universities and public-sector stakeholders triple helix groups offers a glimpse of the strength of the triple helix governance model of IBioIC with regards to encouraging the formation of a triple helix consensus space[13].

The greatest increase in relational ties occurred between academia-industry, industry-industry and between other innovation intermediaries and industry or academia. IBioIC was most successful at brokering total knowledge exchange, collaborative research projects, and technology, cash, and IP transfer ties between academia and industry.

The presence of IBioIC also had a noticeable impact on the level of resource transfer ties (cash infusion, technology, intellectual property) between universities and industry. The level of IP transfer ties between academia and industry saw a particularly high increase of 60%. The total percentage increase in collaborative research project relational ties was even higher than the frequency of contact between academia and industry, thus demonstrating that IBioIC has played a critical role not only on the frequency of interaction within the network, but also on brokering increasingly trust based ties, which are generally likely to increase the chances of shared learning.

The results also highlight that IBioIC was able to increase the total number of relational ties between itself (as an innovation intermediary) and the other triple helix groups. This is particularly the case for frequent contact, total knowledge transfer, collaborative research projects and technology and cash transfer. This may be due to the niche-level brokering role IBioIC held which allowed it to successfully broker relations with a wide range of different type of network actor.

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[13] Ranga and Etzkowitz (2013, p.20) define the consensus space as "the set of activities that bring together the Triple Helix system components to brainstorm, discuss and evaluate proposals for advancement towards a knowledge-based regime. Through cross-fertilizing diverse perspectives, ideas may be generated, and results may be achieved that actors are not likely to have accomplished individually".

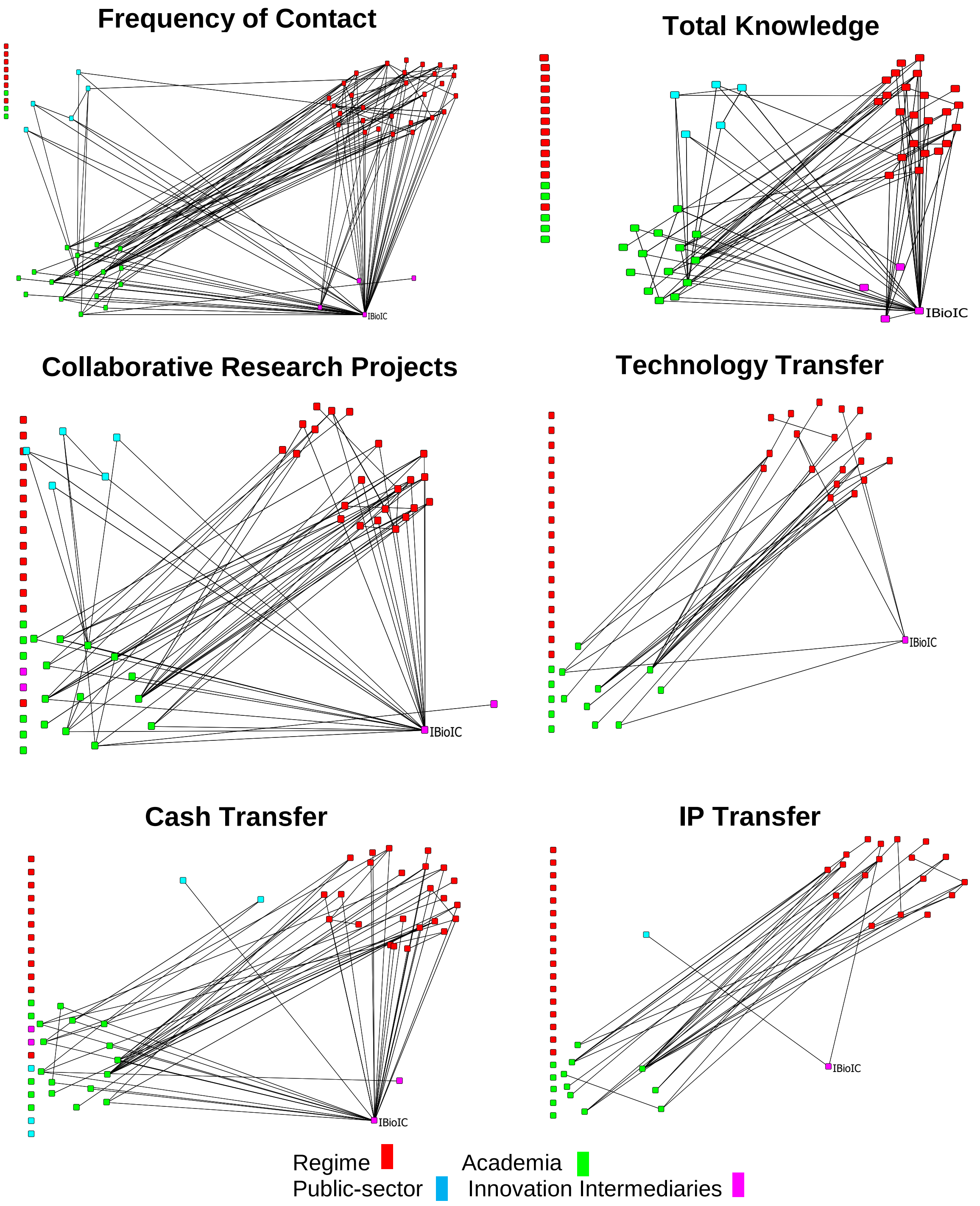


Figure 7.4: Sociograms displaying the triple helix relational ties formed in the industrial biotechnology network through IBioIC.

Notes: 1. The sociograms were produced using the software NetDraw by Borgatti (2002). 2. Larger versions of these images can be found in Appendix IV. *3. Each line represents the formation of a new relational tie between two organizations due to the presence of IBioIC.*

Table 7.3: A measurement of the increase/decrease the number of ties between and amongst triple helix groups for each relational attribute due to the presence of IBioIC

		With IBioIC Ties				**Without IBioIC Ties**				**Difference (With – Without)**				**% Difference (With-Without / Without)**			
		Industry	**University**	**Public-sector**	**Innovation Intermediaries**	**Industry**	**University**	**Public-sector**	**Innovation Intermediaries**	**Industry**	**University**	**Public-sector**	**Innovation Intermediaries**	**Industry**	**University**	**Public-sector**	**Innovation Intermediaries**
Frequency of Contact	Industry	284				234				50				21			
	University	212	128			175	118			37	10			21	8		
	Public-sector	42	34	16		40	29	12		2	5	4		5	17	33	
	Innovation Intermediaries	62/27	52/33	15/10	8/2	21	32	8	2	41/6	20/1	7/2	6/0	195/29	63/2	88/25	300/0
Total Knowledge Transfer	Industry	60				44				16				36			
	University	61	50			36	42			25	8			69	19		
	Public-sector	18	13	10		16	8	6		2	5	4		13	63	67	
	Innovation Intermediaries	27/13	32/20	8/3	4/2	7	19	2	2	20/6	13/1	6/1	2/0	286/86	68/5	300/50	100/0
Collab. Research Projects	Industry	50				32				18				56			
	University	75	56			43	48			32	8			74	17		
	Public-sector	12	10	10		12	5	6		0	5	4		0	100	67	
	Innovation Intermediaries	23/11	29/18	5/0	2/0	11	17	0	0	12/0	12/1	5/0	2/0	109/0	71/0	N/A	N/A
Tech Transfer	Industry	24				16				8				50			
	University	64	4			41	4			23	0			56	0		
	Public-sector	3	1	0		3	1	0		0	0	0		0	0	N/A	
	Innovation Intermediaries	7/3	4/2	0/0	0/0	3	2	0	0	4/0	2/0	0/0	0/0	133/0	100/0	0/0	0/0
Cash Transfer	Industry	38				28				10				36			
	University	59	20			33	16			26	4			79	400		
	Public-sector	18	7	2		18	5	2		0	2	0		0	40	0	
	Innovation Intermediaries	30/8	22/10	4/3	0/0	8	9	3	0	22/0	13/1	1/0	0/0	275/0	144/11	33/0	0
IP Transfer	Industry	22				12				10				83			
	University	43	14			17	12			26	2			153	17		
	Public-sector	0	0	0		0	0	0		0	0	0		N/A	N/A	N/A	
	Innovation Intermediaries	2/1	0/0	1/0	0/0	1	0	0	0	1/0	0/0	1/0	0/0	100/0	0	N/A	0%

Notes:

1. The numbers under the column ‘With’ is number of ties between each triple helix group including the ties formed by IBioIC. The number under the column ‘Without’ number of ties between each triple helix group excluding the ties formed by IBioIC.
2. The numbers under the Difference heading are the total increase or decrease in triple helix relational ties due to the presence of IBioIC. A positive number indicates and increase in ties. A negative number indicates a decrease in ties.
3. The number before the / for innovation intermediaries is the difference including ties to IBioIC, the numbers to the right of the / are the ties not including IBioIC as an innovation intermediary

IBioIC was not as effective at brokering relational ties between the triple helix groups and the other innovation intermediaries. However, it was still able to increase the total number of ties, particularly for intermediary-industry and intermediary-public-sector relations which experienced an 86% and 50% rise in total knowledge transfer ties respectively. Additionally, IBioIC was able to build direct frequent contact and knowledge transfer ties with all other innovation intermediaries in the network thereby acting as a central knowledge transfer hub for innovation intermediaries and allowing an increased level of coordination between the other intermediaries. By increasing the number of knowledge and cash transfer ties from innovation intermediaries and industry and academia, it is evident that the structure of IBioIC enabled it to attract external resources into the niche to help it grow and expand. The ability for IBioIC to broker such relational ties highlights the importance of niche level manager like IBioIC to coordinate the niche at the network level. It should be noted that, although the percentage increase in ties was relatively high, the total number of new ties between other innovation intermediaries and industry or academia and was far lower than the new ties formed directly with IBioIC. However, this may be attributed to there being proportionally far fewer intermediary organisations relative to the other triple helix groups.

Although lower on average, compared to academia-industry-innovation intermediary relational ties, an increase in academia-public-sector, industry-public-sector and innovation intermediary-public-sector relational ties was still observed to occur particularly for frequent contact, knowledge exchange and collaborative research projects. Mourik and Raven (2006) identified that the public-sector can play a critical enabling role for experiments (collaborative research projects) to scale. Therefore, the involvement of public-sector agencies is seen as a particular success for the IBioIC model. Furthermore, including the public-sector agencies in experiments allowed for direct learning by the public-sector on the opportunities and challenges of implementing such a technology. Such learning is therefore more likely to translate in to more appropriate SNM policy and public-sector support services.

7.2.4 Impact of IBioIC on niche-regime interaction

A critical task of SNM to enable the niche to alter the evolutionary trajectory of existing incumbent regimes through building relations between niche and regime actors (Hegger *et al.*, 2007). The results demonstrated that IBioIC was largely successful at brokering all types of relational attribute ties between the niche actors with regime and academia and also directly with IBioIC as an innovation intermediary. For example, niche-regime and niche-academia knowledge transfer ties increased by 71% and 250% respectively (Table 7.4). IBioIC was also successful in connecting other innovation intermediaries with niche actors whereby frequent contact and knowledge transfer ties increased by 86% and 200% respectively. Although the number of relational ties between niche actors and the public-sector did not increase for any relational attribute it did increase between regime and public-sector actors for frequent contact and knowledge transfer ties.

Figure 7.5 visually represents the inter and inner-triple helix group ties directly formed through the presence of IBioIC whereby niche and regime actors are split into two distinct groups. The figures graphically demonstrate how IBioIC was able to build relational ties between niche actors and other groups for all relational attributes (including other innovation intermediaries) thereby raising the chances of shared expectations to emerge upon which a triple helix consensus space can form.

Table 7.4: Triple helix relational ties in the industrial biotechnology network created by IBioIC - including niche and regime ties

		With					Without					Difference (With-Without)					% Difference (With-Without / Without)				
		Regime	Niche	University	Public-sector	Innovation Intermediaries	Regime	Niche	University	Public-sector	Innovation Intermediaries	Regime	Niche	University	Public-sector	Innovation	Regime	Niche	University	Public-sector	Innovation Intermediaries
Frequency of Contact	Regime	126					122					4					3				
	Niche	58	42				46	20				12	22				26	110			
	University	138	74	128			125	50	118			13	24	10			10	48	8		
	Public-sector	17	25	34	16		15	25	29	12		2	0	5	4		13	0	17	33	
	Innovation Intermediaries	39/14	23/13	52/33	15/10	8/2	14	7	32	8	2	25/0	16/6	20/1	7/2	6/0	179/0	229/86	63/3	88/25	300
Knowledge Transfer	Regime	24					24					0					0				
	Niche	12	12				7	6				5	6				71	100			
	University	40	21	50			30	6	42			10	15	8			33	250	19		
	Public-sector	7	11	13	10		5	11	8	6		2	0	5	4		40	0	63	67	
	Innovation Intermediaries	11/4	16/9	32/20	8/3	4/2	4	3	19	2	2	7/0	13/6	13/1	6/1	2/0	17/0	433/200	68/5	300/50	100/0
Collab. Research Projects	Regime	16					16					0					0				
	Niche	9	16				5	6				4	10				80	167			
	University	43	32	56			32	11	48			11	21	8			34	191	17		
	Public-sector	4	8	10	10		4	8	5	6		0	0	5	4		0	0	100	67	
	Innovation Intermediaries	11/6	12/5	29/18	5/0	2/0	6	5	17	0	0	5/0	7/0	12/1	5/0	2/0	83/0	140/0	71/6	N/A	N/A
Tech Transfer	Regime	2					2					0					0				
	Niche	7	8				4	6				3	2				75	33			
	University	44	20	4			35	6	4			9	14	0			26	233	0		
	Public-sector	0	3	1	0		0	3	1	0		0	0	0	0		N/A	0	0	N/A	
	Innovation Intermediaries	1/1	6/2	4/2	0/0	0/0	1	2	2	0	0	0/0	4/0	2/0	0/0	0/0	0/0	200/0	100/0	N/A	0
Cash Transfer	Regime	20					18					2					11				
	Niche	6	6				4	2				2	4				50	200			
	University	35	24	20			24	9	16			11	15	4			46	167	25		
	Public-sector	5	13	7	2		5	13	5	2		0	0	2	0		0	0	40	0	
	Innovation Intermediaries	15/3	15/5	22/10	4/3	0/0	3	5	9	3	0	12/0	10/0	13/1	1/0	0/0	400/0	200/0	144/11	33/0	0
IP Transfer	Regime	6					6					0					0				
	Niche	4	8				1	4				3	4				300	100			
	University	22	21	14			13	4	12			9	17	2			69	425	17		
	Public-sector	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
	Innovation Intermediaries	1/0	1/1	0/0	1/0	0/0	0	1	0	0	0	1/0	0/0	0/0	1/0	0/0	N/A	0/0	N/A	N/A	N/A

Notes:

1. The numbers under the column ‘With’ is number of ties between each triple helix group (including niche and regime actor groups and the ties formed by IBioIC). The number under the column ‘Without’ number of ties between each triple helix group excluding the ties formed by IBioIC.
2. The numbers under the Difference heading are the total increase or decrease in triple helix relational ties due to the presence of IBioIC. A positive number indicates and increase in ties. A negative number indicates a decrease in ties.
3. The number before the / for innovation intermediaries is the difference including ties to IBioIC, the numbers to the right of the / are the ties not including IBioIC as an innovation intermediary

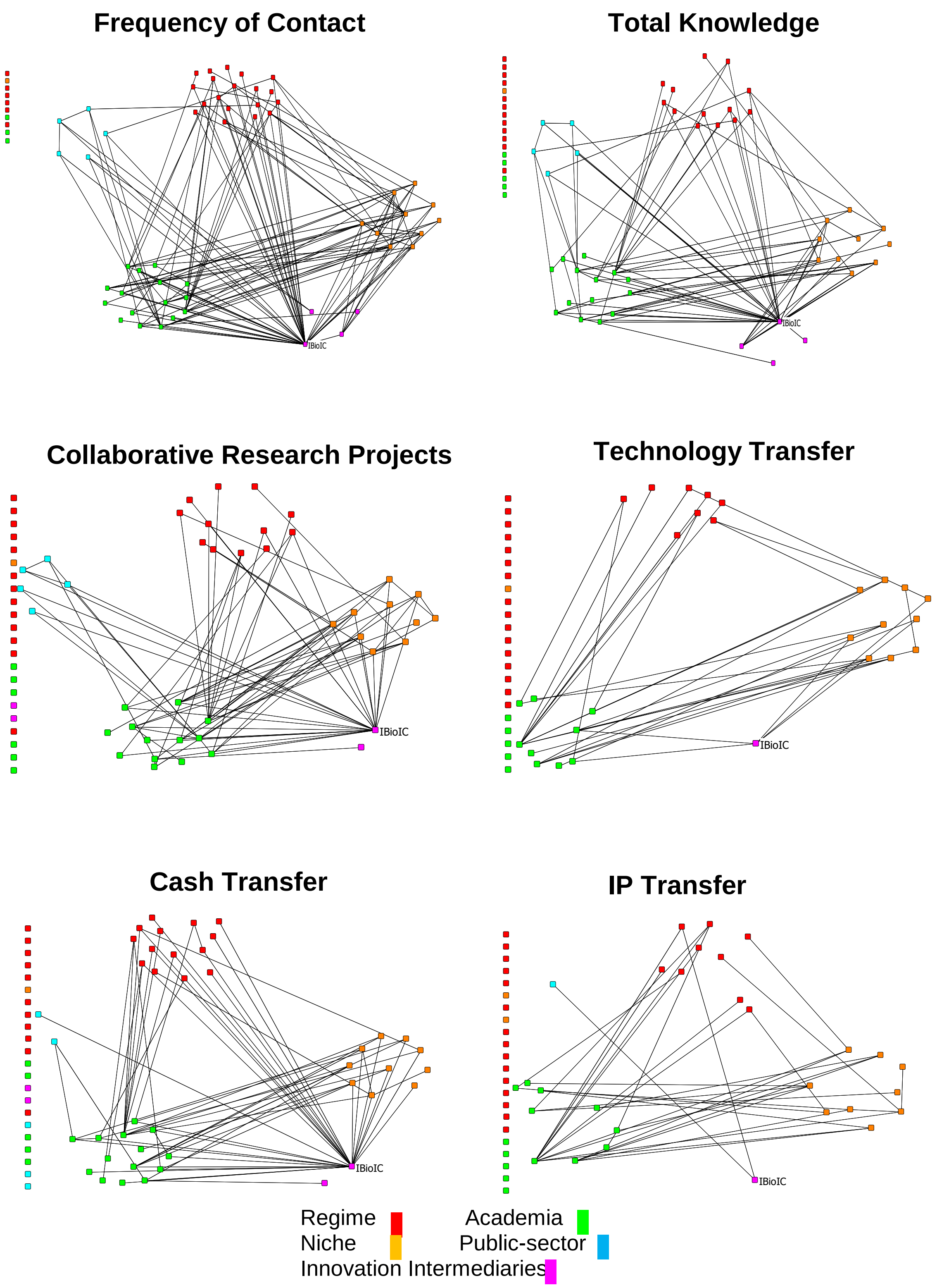


Figure 7.5: Sociograms displaying the niche-regime relational ties formed in the industrial biotechnology network through IBioIC.

Notes: 1. The sociograms were produced using the software NetDraw by Borgatti (2002). 2. Larger versions of these images can be found in Appendix IV. 3. Each line represents the formation of a new relational tie between two organizations due to the presence of IBioIC.

7.2.5 Centrality of IBioIC in the network

In addition to measuring the impact IBioIC had on the overall structure of the network and the relations between triple helix groups, an egocentric analysis of IBioIC was undertaken. Egocentric analysis measures the centrality of a network actor relative all other network actors. Actors with high centrality tend to hold significant influence and power within the network with regards to directing knowledge and transfer flow as well as who enters and exits the network (Freeman 1978). NetDraw was used to produce a network diagram to offer a visual representation of where IBioIC was structurally located in the network relative to other network players.

Table 7.5 provides the empirical results of the egocentric analysis with regards to IBioIC's degree of centrality for each relational attribute. It ranks IBioIC relative to the degree of centrality of every other network member. Overall, IBioIC ranked highest among all network members for all centrality indicators of all relational attributes apart from technology and IP transfer. This is to be expected as, although IBioIC helped broker IP and technology transfer ties, they do not directly participate in these actions.

The number of direct ties IBioIC held for all relational attributes was, on average, 5 times higher than the average network actor and up to 7 times for cash infusions. However, the number of direct ties alone does not fully describe the degree of influence IBioIC held within the network. For that, the centrality measures of closeness, betweenness and the effective size of IBioIC's network were measured (see Table 6.3 for full description).

IBioIC demonstrated lower closeness and higher betweenness values relative to all other actors for nearly all relational attributes. This suggests that in addition to having the shortest path length on average to all other network actors, thereby aiding knowledge transfer and acquisition, IBioIC was also able to exert a high level of control over knowledge and resource exchange between other network actors. One reason for IBioIC obtaining high closeness and betweenness scores may be due to the fact that it was able to develop a large 'effective size' of network. As actor A's effective network size approaches the total number of ties it shares with other actors, the redundancy in its network reduces to zero. No redundancy means that any actor that

Actor A is connected to is not directly connected to any other actor and as such, Actor A has maximised its capacity for bridging structural holes between all other actors. The results in Table 7.5 demonstrate that IBioIC had an effective network size of up to four times the network average for frequency of contact, total knowledge, collaborative research projects and cash transfer. Moreover, the effective size was close to IBioIC's total network size. For example, the effective size for total knowledge transfer was 26 compared to a total network size of 32. Thereby suggesting that only 6 out of the 32 actors held direct ties with each other and therefore IBioIC was bridging structural holes between the remaining 26 network actors. IBioIC was particularly effective at bridging structural holes for cash transfer whereby it had an effective network size of 33 relative to the total network size of 35. The effective size of IBioIC's technology and IP transfer networks were much smaller than the other relational attributes, at 6 and 2 respectively.

In contrast to the other relational attributes, IBioIC held a low level of centrality for technology and IP transfer relational attributes. This is logical, as IBioIC did not actively get involved in the transfer of technology and IP transfer even though they performed the role of neutral broker in the discussion around technology and IP transfer in many of these occasions. How IP and technology is transferred within and out with the niche will ultimately dictate the trajectory of the niche and as such the results highlight a limitation of the triple helix-based niche manager model with regards to steering a niche in-line with a broader circular economy transition. Although IBioIC held a high level of influence over which experiments took place within the niche, it was not able to control the output of those experiments. In the case of this network, the control over IP and tech transfer was in the hands of a small handful of universities and regime actors.

Figure 7.6 provides sociograms of the level of centrality IBioIC held for each relational attribute. The size of the actor node is scaled relative its betweenness score. What is evident is that IBioIC held a higher level of 'betweenness' than any other network actor for all the relational attributes apart from technology and IP transfer. This suggests that IBioIC held considerable power and influence over the flow of knowledge and resources throughout the network, which means it could effectively play the role of a gate keeper to the network.

Table 7.5: Results from egocentric analysis of IBioIC with regards to its level of centrality for each relational attribute within the industrial biotechnology network compared to all 64 other network actors.

	Frequency of Contact				**Total Knowledge Transfer**				**Collab Research Projects**			
Structural Characteristic	IBioIC	Network Average	Network Median	Rank (out of 64)	IBioIC	Network Average	Network Median	Rank (out of 64)	IBioIC	Network Average	Network Median	Rank (out of 64)
Degree	62	20	20	1	32	7	6	1	29	7	6	1
Closeness	64	107	106	1	118	179	161	1	123	182	163	1
Betweenness	403	22	10.3	1	326.50	28	6.2	1	282	30	6.7	1
Effective Size	43	10	9	1	26	5	4	1	23	5	4	1

	Tech Transfer				**Cash Infusion**				**IP**			
	IBioIC	Network Average	Network Median	Rank (out of 64)	IBioIC	Network Average	Network Median	Rank (out of 64)	IBioIC	Network Average	Network Median	Rank (out of 64)
Degree	6	3	2	8	35	5	4.5	1	2.00	2.00	1.00	20
Closeness	236	297.00	252.00	14	116	183.00	162	1	316.00	359.00	315.00	33
Betweenness	60	30.00	5.3	10	716.00	30.00	7.90	1	43.00	36.00	0.00	20
Effective Size	6	3	2	8	33	4	3	1	2	2	0	20

Note: See Table 6.3 for a full description of centrality measures

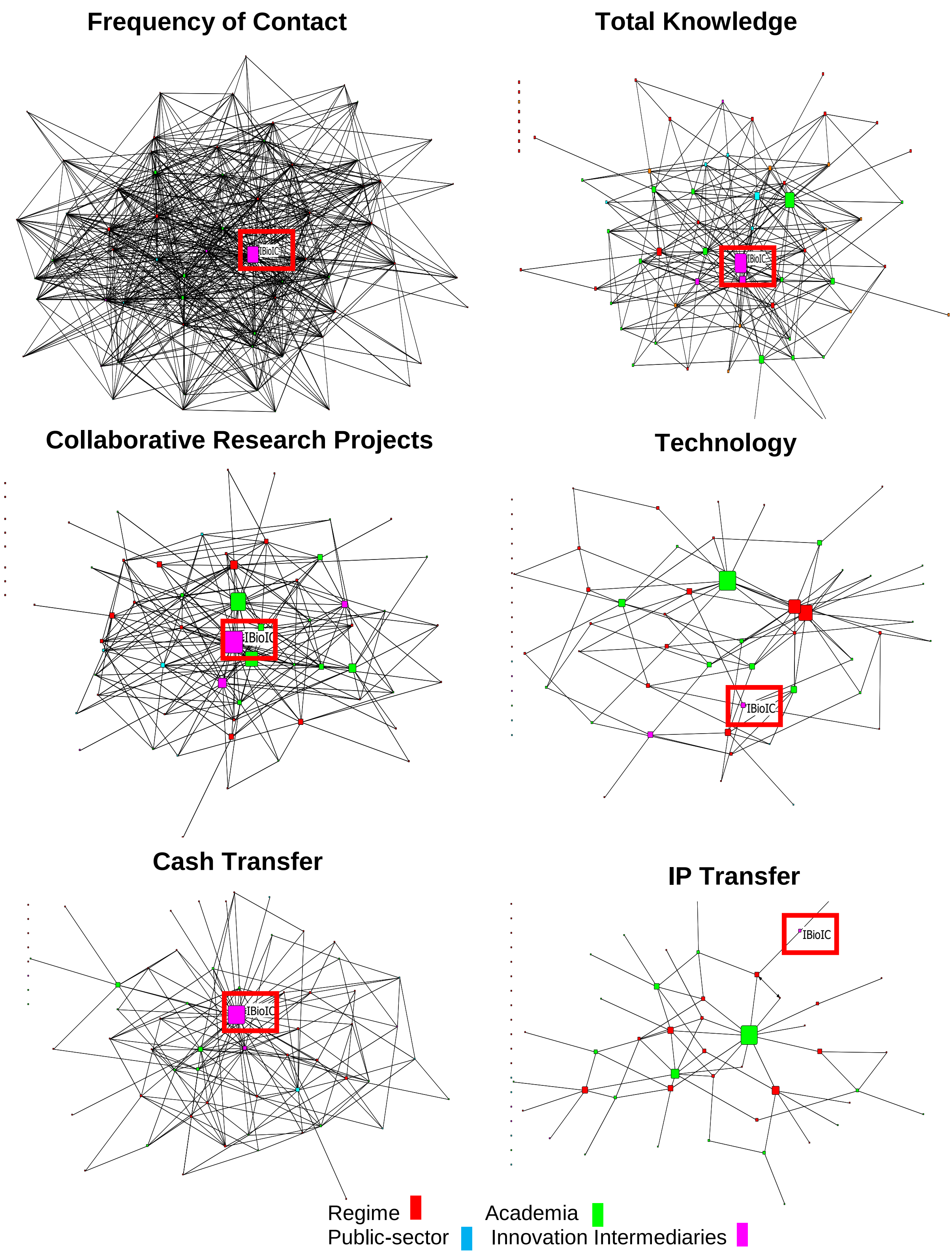


Figure 7.6: Network diagrams demonstrating the structural centrality of IBioIC in the industrial biotechnology network for all six relational attributes

Notes: 1. The sociograms were produced using the software NetDraw by Borgatti (2002). 2. Larger versions of these images can be found in Appendix IV. 3. Each line represents a connection between two organizations. 4. The size of the actor node is scaled by the value of betweenness of the actor compare to all other network member. IBioIC is surrounded by a red box.

7.3 Qualitative data analysis

This section outlines the results and analysis from: (i) the two network member surveys; (ii) the semi-structured interviews with network member organizations; and (iii) the focus group involving IBioIC staff responsible for network development.

7.3.1 Network member perceptions of the utility of IBioIC as a niche manager

The results of the network member survey outlined in Table 7.6 demonstrate that IBioIC ranked highly with regards to its ability to nurture the network. IBioIC achieved, on average, a high approval rating of 73% for all 22 activities combined. Approval was very high from industry in which nine of the 22 activities were ranked above the 80% approval rate. Conversely, public-sector stakeholders held the lowest approval ratings with 13 roles receiving approval ratings below 70% with two activities – the advancement of sustainability aims and investments in new business receiving a moderate value-added score of 57% and 55% respectively. Overall, IBioIC appears to have successfully undertaken a wide range of nurturing activities which support: (i) the articulation of expectations and visions; (ii) learning processes and exploration at multiple dimensions; and (iii) building of social networks.

IBioIC's ability to promote multi-level knowledge flow between the Scottish Government or other public-sector agencies and the protected space network ranked very highly among all three triple helix groups. In particular, IBioIC's ability to articulate sector needs, expectations, requirements and strategy as well as accelerate the application and commercialisation of new technologies received an approval rating of above 76%.

IBioIC scored an average of 73% approval for influencing policy, although approval was lower on average from public-sector respondents. The activities that were believed to offer very high added-value, receiving an average of 84% and 80% respectively was IBioIC's ability to create and facilitate new networks and communicate and disseminate knowledge within the protected space.

Table 7.6: Results from IBioIC network member survey A undertaken in February 2016 outlining the network members' opinions on the effectiveness of IBioIC in undertaking 22 nurturing activities undertaken by a triple helix-based niche manager

Rank	Niche Manager Activities	SME	Non SME	Academia	Public-sector Stakeholder	Average Score (out of 5)	Average Score (%)
		n=19	**n=8**	**n=20**	**n=9**		
1	Creation and facilitation of new networks	4.24	4.38	4.10	4.13	**4.21**	**84**
2	Communication and dissemination of knowledge	4.10	4.14	3.90	3.86	**4.00**	**80**
3	Knowledge gathering, processing, generation and combination	4.00	4.14	3.79	3.88	**3.95**	**79**
4	Articulation of sector needs, expectations and requirements	3.75	4.00	3.85	4.00	**3.90**	**78**
5	Sector strategy development	4.10	4.00	3.80	3.50	**3.85**	**77**
6	Education and training	3.65	4.57	3.79	3.43	**3.86**	**77**
7	Acceleration of the application and commercialisation of new technologies	3.83	3.86	3.70	3.75	**3.79**	**76**
8	Configuring and aligning interests	3.84	4.00	3.85	3.43	**3.78**	**76**
9	Influencing policy	3.89	3.71	3.72	3.38	**3.68**	**74**
10	Creating conditions for learning by doing and using	4.00	4.00	3.83	3.00	**3.71**	**74**
11	Provision of advice and support	4.00	3.71	3.56	3.57	**3.71**	**74**
12	Technology assessment and evaluation	3.65	3.67	3.47	3.57	**3.59**	**72**
13	Finding potential funding and funding activities	3.83	3.67	3.55	3.43	**3.62**	**72**
14	Prototyping and piloting	3.47	3.67	3.35	3.43	**3.48**	**70**
15	Arbitration based on neutrality and trust	3.15	3.40	3.93	3.33	**3.46**	**69**
16	(Long-term) project design, management and evaluation	3.67	3.50	3.67	3.00	**3.46**	**69**
17	Identification and management of human resource needs (skills)	3.47	3.17	3.61	3.57	**3.45**	**69**
18	Gatekeeping and brokering	3.54	3.50	3.42	3.14	**3.40**	**68**
19	Creating new jobs	3.22	3.71	3.50	3.14	**3.39**	**68**
20	Accreditation and standard setting	3.13	3.57	3.35	3.00	**3.26**	**65**
21	Advancement of sustainability aims	3.32	3.38	3.53	2.86	**3.27**	**65**
22	Investments in new businesses	2.87	3.00	3.32	2.75	**2.98**	**60**
	Average Score	**3.67**	**3.76**	**3.66**	**3.42**		
	Average Score (%)	**73**	**75**	**73**	**68**		

Notes:

1. Level of service into five categories: Very High (5)(81%-100%), High (4)(61%-80%), Moderate (3)(41%-60%), Low (2)(21%-40%), Very Low (1)(1%-20%) and None (0)(0%).
2. Average score in % is produced by dividing the average score by 5.

The results of the industry member survey conducted in July 2017 by IBioIC staff, when the network had grown from 60 to 116 active members, can be seen in Table 7.7. The results demonstrate that 88% of respondents agreed that IBioIC had a positive impact on the industrial biotechnology industry, with 40% strongly agreeing. A total of 91% of respondents agreed that their company directly benefited from IBioIC activities and 85% agreed that IBioIC successfully met the needs of their companies.

Finally, 99% of respondents agreed there was a need for IBioIC to exist, with 61% strongly agreeing. One respondent noted that: “In first year of membership I am impressed by the level of interaction and scope of IBioIC network” and a second commented that “IBioIC is an excellent model for generating close cooperation between SME's that could otherwise be isolated from academia”.

Table 7.7: Results of the IBioIC network member survey B, assessing the impact of IBioIC on the network and respective organizations of the respondents

Statement	**Organization**	**Strongly Disagree (%)**	**Disagree (%)**	**Neither Agree nor Disagree (%)**	**Agree (%)**	**Strongly Agree (%)**
IBioIC has made a positive impact to the Industrial Biotechnology industry over the past 3 years	Total (n=121)	1.7	0.0	9.9	47.9	40.5
	Micro & SME (n=84)	0.0	0.0	9.5	41.7	48.8
	Large (n=32)	6.3	0.0	9.4	62.5	21.9
Your company has directly benefited from the activities undertaken by IBioIC	Total (n=121)	0.0	4.1	12.4	52.1	31.4
	Micro & SME (n=84)	0.0	3.6	9.5	50.0	36.9
	Large (n=32)	6.3	6.3	15.6	59.4	18.8
The current format of IBioIC meets your company needs	Total (n=117)	0.0	6.0	8.5	63.2	22.2
	Micro & SME (n=84)	0.0	7.1	8.3	57.1	26.2
	Large (n=30)	0.0	0.0	10.0	80.0	10.0
There is a continued need for IBioIC to exist	Total (n=121)	0.0	0.8	0.0	38.0	61.2
	Micro & SME (n=84)	0.0	1.2	0.0	35.7	63.1
	Large (n=32)	0.0	0.0	0.0	37.5	62.5

Note: Out of a total of 181 responses, only network members (n=121) were included for analysis, any organization that identified as not a member was not included (n=60).

It is evident from the results in Table 7.7 that IBioIC is valued marginally more so by SME and micro organizations in comparison to large organizations. A total of 49% of SME and micro organizations strongly agreed that IBioIC had a more positive impact on the industry compared to 22% for large organizations. Similarly, 37% of SME and micro companies strongly agreed that they had benefitted from IBioIC activities, compared to 19% for large organizations. Nonetheless, 63% of both SME (and micro) and large organizations strongly agreed on the need for IBioIC to continue its activities.

Respondents were also asked whether their interactions with IBioIC contributed to a range of economic benefits to their company, as outlined in Figure 7.7. The survey results showed that the most influential activity of IBioIC with regards to the economic benefits for both SMEs (and micro) and large organizations were facilitating the creation of industry-to-academia and industry-to-industry strategic relationships, with 65% of the respondents benefiting from the former and 44% from the latter. However, SMEs and micro organisations appeared to accrue more benefits when translating such relationships into hard economic outputs, such as growth of jobs, sales and market share. Overall, the results of the industry network member survey demonstrate a collective agreement within industry on the strategic importance of IBioIC for managing the inner-loop niche innovation network.

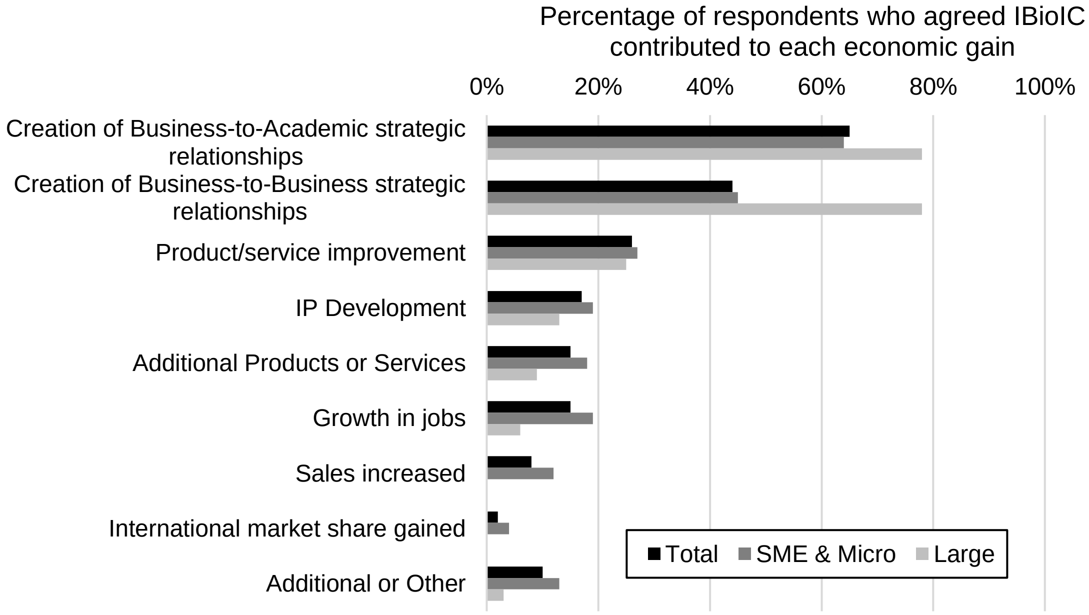


Figure 7.7: Industry network member opinions from the IBioIC network member survey B on the economic benefits created through IBioIC Activities

Notes:

1. Out of 181 total responses, only network members (n=121) were included for analysis, any organization that identified as not a member was not included (n=60). There were 84 SME and Micro organizations and 32 large organizations.
2. Additional/Other benefits suggested by respondents were: (i) raising status and profile of industrial biotechnology in Scotland; (ii) new technology identification; and (iii) raising awareness of opportunities

7.3.2 Network member perceptions of the governance structure of IBioIC

The results of the semi-structured interviews with 40 active network members closely align with the findings from both network member surveys. A total of 72.5% of the interviewees strongly believed that IBioIC, as a niche manager, played a key role in managing and fostering network level consensus and promoted self-governance. Only 7.5% did not believe this was the case. However, it was generally felt that due to the heterogeneous nature of the network combined with multiple technological paths and sectors, the network is unlikely to achieve full consensus around a specific vision. Therefore, rather than trying to achieve total consensus, the role of the IBioIC should involve the delicate task of balancing and representing the immediate needs of different actors in the niche network with the long term vision as outlined in the Scottish Industrial Biotechnology Roadmap (Life Sciences Scotland 2014).

Similarly, 70% of interviewees strongly believed that the triple helix governance structure embedded within IBioIC was very effective for enabling self-governance capacity within the network and for enhancing knowledge flow to policy makers with many stating that the goal of the network cannot be achieved without it. A further 22% believed it to be effective. One respondent from a leading university in the network stated that "the network cannot do without IBioIC. They do very well at balancing the needs between industry, academia and the public-sector". One of the most prominent industrial members commented that "[IBioIC is a] force for good through building the foundations of network. They are critical and an important piece of the puzzle". A general sentiment of the interviewees was that SMEs and micro organizations do not have sufficient resources to challenge and inform government. IBioIC, on the other hand, acted as an amplifier for the collective voices of all the SMEs, both to traditional 'regime' actors and to public-sector stakeholders. The results from the network member surveys indicate that IBioIC boasted a significantly high approval rating from individual network members from across the spheres of government, academia and industry with regards to performing key SNM nurturing activities, such as building networks, articulating expectations and visions and stimulating learning.

7.3.3 Identifying the nurturing and empowerment activities undertaken by IBioIC on the niche innovation network

During the focus group, the IBioIC business development staff responsible for managing the network identified 28 nurturing and empowering activities undertaken by IBioIC between January 2014 and March 2017. The activities were wide ranging in their nature and were largely balanced between inward facing to the protected space network and outward facing towards wider niche and circular economy activities as is evidenced in Table 7.8. Seven of the roles were identified by the focus group to play a dual inward and outward facing role, which brought the niche and regime actors together, such as hosting the European Forum for Industrial Biotechnology or the annual National Industrial Biotechnology Conference.

Table 7.8: Results from IBioIC focus group exploring the inward and outward facing activities undertaken by IBioIC in which the most effective activities were identified and ranked according to their impact on the nurturing and empowerment objectives of the protected niche innovation network

		Nurturing Roles				**Empowering Roles**	
	IBioIC Activities	**Building Networks**	**Stimulating Learning (1st Order)**	**Stimulating Learning (2nd Order)**	**Articulating Expectations**	**Fit and Conform**	**Stretch and Transform**
Inward Facing	Technical Support	11	1	6	12	-	-
	One to One Consultations	8	3	-	6	-	-
	Regular Board meetings	14	8	-	5	-	-
	PhD Sponsorships	3	6	-	-	-	-
	Introductions	5	-	-	-	-	-
	Rapid Bio-processing Facilities	-	7	-	-	-	7
	Rotating Board	13	-	-	-	-	-
	HND Course	-	-	-	13	-	-
	Funding Masters Students	-	-	-	14	-	-
Both Inward and Outward	IBioIC Conference	1	4	1	1	-	2
	Project Group formations/Focus Groups	6	2	3	15	-	10
	Winning and Hosting European Forum for Industrial Biotechnology	16	-	7	3	-	-
	Showcased Events	7	-	5	-	-	-
	Case studies	-	9		10	-	-
	Media releases	-	10	12	9	-	-
	Newsletters	-	-	13	11	-	-
Outward Facing	Network Integrator Role	4	-	4	-	-	4
	International Partnerships	9	-	2	-	-	1
	Influencing IB Roadmap	-	-	-	4	-	-
	Informing Policy/Public-sector	-	-	9	2	-	9
	BioPilots UK	15	-	-	7	-	6
	Biobased Industry	12	-	8	8	-	8
	Consortium (EU Level)	10	-	10	-	-	5
	Public Outreach	-	11	-	-	-	-
	Influencing public funding	-	-	-	-	-	11
	Scottish Industrial Biotech Development Group	-	-	11	-	-	13
	Supporting 'stretch and transform' initiatives	-	-	-	-	-	12

Notes:

1. Fit and Conform activities column is blank as focus group believed that all of their activities were tailored towards stretch and transform empowerment.
2. The focus group was allowed to select up to 15 activities per nurturing and empowering function – however, in some cases a total of 15 were not selected.
3. The focus group ranked the selected activities from 1-15

IBioIC identified a wide range of activities that they believed contributed to the objectives of nurturing the network. Their services ranged from interaction with individual network members such as one-to-one consultations, introductions, and the setting up and coordinating of individual research groups to funding collaborative research projects between industry and academia. Outward facing activities were also identified by IBioIC to have an impact on the nurturing of the network. Building partnerships with foreign universities and industry was viewed by the focus groups as being very important for raising expectations within the protected space network.

The annual conference, which hosts up to 400 individual network members from government, academia and industry, was ranked the most influential activity for nurturing the network and the second most influential activity with regards to empowering the network. This is in-line with the claim by Caniëls and Romijn (2006) that a key activity of the niche network manager is to organize public conferences and meetings at regular interval. The conference was viewed by the focus groups as being particularly effective in creating a space for high levels of second order learning to take place between triple helix groups. Expectations were also raised through the attendance of and presentations from global industry leaders and senior policy makers.

All members of the focus group agreed that IBioIC’s empowerment activities were oriented towards encouraging a ‘stretch and transform’ trajectory for the niche as opposed to the ‘fit and conform’ path, and so did not rank activities relating to the ‘fit and conform function’ (Table 7.8). Both inward and outward facing activities were identified as contributing to ‘stretch and transform’ empowerment. This demonstrates the normative position of IBioIC as a niche network manager which is mandated to disrupt the status quo.

The most valued outward facing activities included becoming members of pan-European consortiums and initiatives striving towards a transition to a bio-economy. IBioIC also played a central role in the formation of Bio-pilots UK which is an alliance with other industrial biotechnology intermediaries located across the UK with the aim of supporting the coordination between similar protected space networks in differing geographical areas. In addition, IBioIC played an important role in shaping the Scottish

Industrial Biotechnology Roadmap (Chemical Sciences Scotland 2015) as well as ensuring that industrial biotechnology sat at the heart of the national circular economy strategy. The focus groups believed that becoming members of such initiatives helped to connect the niche actors to wider niche developments as well as providing a voice for the niche to influence global niche developments.

IBioIC was also instrumental with regards to informing public-sector agencies on the funding requirements of the network and in directing external circular economy-oriented public funding into the network. An example being IBioIC's successful bid in 2017 for £1 million from the Scottish Circular Economy Investment Fund to be invested in the niche network. More recently, in July 2018, IBioIC were awarded an additional £10 million to continue to their activities. IBioIC also played a key role as a broker in 'stretch and transform' initiatives such as the Algal Solutions For Local Energy Economy (ASLEE) project which aims to eradicate the reliance of rural manufacturing companies on fossil fuels through the novel application of industrial biotechnology and algae growing technology.

A unique empowerment activity discussed within the IBioIC focus group was the introduction of the 'network integrator role'. This is a dedicated 'stretch and transform' role held by IBioIC which was funded by Scottish Enterprise (Scotland's largest public-sector enterprise agency). The network integrator role was initially proposed by Scottish Enterprise. The aim of this role is to introduce external actors to the protected space network who are likely to play a crucial role in the transition from a technological to market niche. In the case of the industrial biotechnology protected space network, such actors range from producers to handlers of organic material such as the agricultural, food and waste haulage sectors. The transfer of the network integrator role from Scottish Enterprise to IBioIC is evidence of the recognition by Scotland's largest public-sector enterprise agency that IBioIC, a triple helix-based niche manager which is deeply nested within the network, is likely to be a more effective network integrator than itself. It also demonstrates how IBioIC can be used as a mechanism by public-sector agencies to devolve governance to the members of protected space network.

7.4 Evaluating the effectiveness of IBioIC in nurturing and empowering a niche innovation network

This thesis hypothesised that the effectiveness of niche innovation networks for creating the conditions for the emergence of a circular economy transition would largely depend on the manner in which strategic niche management is operationalized within the niche network. In particular, the extent to which the active participation of the triple helix players is facilitated to promote knowledge generation, use and regulation in-line with circular economy principles is critical. The results of the IBioIC case study supports the hypotheses of this thesis by demonstrating that the introduction of a triple helix-based niche manager had a significant positive effect in terms of nurturing the niche by building social networks, facilitating shared learning and promoting shared expectations. Moreover, through connecting the individual niche innovators with wider niche and circular economy activities and attracting additional external funding and resources to the niche, IBioIC was able to contribute and build the level of empowerment within the niche. The remainder of this section discusses the ability of IBioIC to nurture and empower of the network.

7.4.1 Ability of IBioIC to nurture the niche network: building social networks

Unlike traditional SNM managers, the triple helix-based niche manager in this study was uniquely tasked with the management of the niche at the national level rather than the individual experiment level and was co-governed by representatives from public-sector stakeholders, universities and industry network members. In the space of two years, IBioIC was responsible for increasing the network size for collaborative research projects from 51 to 59 active members which included a mixture of local SMEs, international firms, universities and public-sector stakeholders. However, it did not have such a big impact on increasing frequency of contact with new actors where the network size for frequently interacting actors only increased from 53 to 56. This may be due to IBioIC inheriting an already well-connected network. Importantly, IBioIC was able to widen and expand the number of actors participating in more intimate trust-based relationships necessary for systemic innovation such as cash and IP transfer, where the number of active actors increased from 52 to 58 and 34 to 45 active actors respectively.

The social network analysis and network member survey presented clear evidence of network building by IBioIC. In the period between January 2014 and March 2017, IBioIC was able increase the number of both weak and strong ties between and within the individual triple helix institutions. The number of knowledge transfer ties increased by 64% and the number of cash and IP transfer ties increased by 72% and 113% respectively. In addition to increasing triple helix interactions, the intermediary was able to increase collaborative research project ties between niche and regime actors by 80%, thereby extending the network out-with the immediate niche and increasing the chances of the niche experiments growing into a market niche and eventually disrupting the current regime configuration.

The industrial network member survey, completed approximately a year after the SNA data was collected, demonstrated more than a doubling in the network size from 60 to 116 active industrial organisations. The results also demonstrated that IBioIC contributed to the creation of business-business and business-university strategic relationships by 65% and 44% respectively. This demonstrates that IBioIC has been effective as both expanding the network out with the initial niche network and has been able to broker a high number of strategic relational ties between different actors which are necessary to allow shared learning to occur.

By adopting the role of a neutral actor between the triple helix institutions, through the co-governance of all three, IBioIC was able to increase the degree of network centralization between them. A clear sense of leadership and shared expectations within the network tends to be also prevalent in centralised networks, and has been shown to be important for innovation (van der Valk *et al*., 2011).

7.4.2 Ability of IBioIC to nurture the niche network: facilitating shared learning

The success of high scientific technological innovation, such as industrial biotechnology, is dependent on the effective generation, transfer and use of knowledge and resources amongst universities and research institutes and industry (Etzkowitz 2003). The results of the network analysis demonstrated that the introduction of triple helix-based niche manager into a niche network can increase the level of knowledge and learning exchange within and between all of the triple helix groups.

Knowledge transfer ties between universities and industry increased by 69% due to the presence of the intermediary. Technology and IP transfer ties between the universities and industry increased by 56% and 153% respectively. Asides from brokering knowledge exchange between organizations, IBioIC was also regarded by the network players as an important source of knowledge and was identified in the egocentric analysis as the highest knowledge transferring network actor. The results of the member survey (Figure 7.7) demonstrated that IBioIC contributed directly to an increase in economic benefits such as in product/service improvement, IP development and additional products or services for 26%, 17% and 15% of the respondents respectively. By contributing the increase in such economic benefits, IBioIC has directly contributed to the increase in, and application of, learning within the network.

As outlined in Section 3.5.4, collaborative research projects (or experiments) play an important role in stimulating high quality learning. Moreover, Hoogma et al. (2002) found that the relationship between the quality of learning within experiments is dependent upon the actors involved. By increasing the number of regime and public-sector actors who were traditionally external to the niche participating in the niche experiments, IBioIC increased the chances of the niche innovations scaling and being absorbed by the regime.

In addition to stimulating knowledge exchange across the network, IBioIC increased the network cohesion and centralisation for all relational attributes, whilst maintaining a similar level of network clustering. By doing this, IBioIC helped lay the important foundations for both tacit and explicit forms of knowledge to be shared more efficiently throughout the network.

Due to the governance structure of the intermediary, in which public-sector stakeholders were members of the governing board, knowledge transfer between the public-sector stakeholders, academia and industry actors was observed to increase. In addition to the increase in knowledge transfer to academia and industry, the number of knowledge transfer ties amongst public-sector stakeholders increased by 67%. Such an increase in high quality knowledge transfer, both to and amongst public-sector stakeholders, would be expected to increase reflexivity in the policy making process and help balance the need for both top-down and polycentric governance of the niche. As such, it also helped lay the foundations for improved introduction and withdrawal of appropriate public-sector support, which is a critical objective of SNM.

7.4.3 Ability of IBioIC to nurture the niche network: promoting shared expectations

Dedicated intermediating work is needed for expectations to develop within a niche (Raven *et al.*, 2008). This is due to the niche network being comprised of a heterogeneous group of stakeholders holding different social interests and perspectives. As such, policy actors are likely to have different expectation profiles compared to a technology developer and the industrial regime actors' expectations may contrast with those of the niche innovators. The work by Raven et al. (2008) found that aligning expectations was challenging for specific local projects for this reason. It is therefore logical to argue that upon scaling up the role of niche manager from the project to niche level, the task of promoting and aligning shared expectations is likely to become too challenging for any one organization to attain.

Due to the heterogeneous nature of the network, in which different technologies and processes are under development, the task of promoting shared expectations is challenging for any one organization to attain. Yet, due to the highly central position of IBioIC within the network, with regards to the structural holes bridged and the level of knowledge and resources flowing through it, IBioIC appeared to hold a position with which it could significantly control and influence the shared expectations originating from *within* the network.

It is argued, from the results of this case study, that the role of a niche manager is more likely to involve creating the conditions within the network for shared expectations to emerge and evolve organically over time (see Figure 4.3). In particular, Schot and Geels (2008) suggest that expectations are substantiated by on-going collaborative projects. Successful projects confirm initial expectations and new actors are more likely to invest or participate in niche activities thereby strengthening the alignment of expectations (Hermans *et al.*, 2013). The results of the complete social network analysis suggest that IBioIC contributed to the establishment of these conditions by brokering strong relational ties between the triple helix niche actors thereby increasing collaborative research project ties by up to 63%. Perhaps, more importantly, IBioIC was able to bridge structural holes between distant parts of the network and between triple helix institutions. This in turn, increased the network centrality. Increased network centrality, and connectivity, increases the likelihood for expectations to be shared and discussed.

By increasing the number of collaborative and trust based ties (such as collaborative research projects, technology transfer and IP transfer) between the triple helix institutions, as well as bridging structural holes within the network, IBioIC helped build the foundations in the network for what Ranga and Etzkowitz (2013, p.20) call a ‘triple helix consensus space’. Ranga and Etzkowitz (2013) argue that it is only when consensus space emerges that expectations between the triple helix institutions can begin to develop and align.

Coleman (1988) argues that it is in this institutional overlap (a consensus space) where social capital emerges and grows. The efficiency of activities within the network increases with the increase of social capital, which encourages the level of cooperative behaviour required for innovation within networks (Nahapiet and Ghoshal 2017). Increased social capital also enables the emergence of shared expectations and visions and consequently an increase in capacity for self-governance within protected space networks (Cai 2015; Ranga and Etzkowitz, 2013). In adition, building social capital between triple helix institutions is likely to increase the build-up of recombinant knowledge required for successful innovation (Lungeanu and Contractor 2015).

An important finding of this paper is that, although the intermediary held a somewhat constrained mandate to prioritise academia-industry relations within the network, it was able to increase collaborative research ties between regime and niche industry actors by 80%. This increase in niche-regime interactions is not simply an increase in frequency of contact, but also an increase in knowledge and resource flows. The latter, in particular, is suggestive of the emergence of shared expectations between niche and regime actors, and of the increasing likelihood of niche innovations being adopted by regime actors. These findings agree with the study by Kivimaa (2014) which argues that the presence of system intermediaries is crucial for triggering regime destabilisation. They also agree with Elzen et al. (2012) which determined that niche-regime hybrid actors, such as innovation intermediaries are critical to technological, network and institutional niche-regime anchoring.

The rather rigid triple helix structure of IBioIC appears to have prevented it from incorporating civil society and third sector actors into the network (otherwise known as the quadruple helix) (Carayannis and Campbell 2010). This is a crucial omission considering the significance of civil society as integral component in the choice environment for a circular economy-oriented innovation trajectory. SNM researchers have identified that technology users have a critical and active role to play in ensuring the niche innovations are more widely adopted (Weber and Rohracher 2012). Furthermore, the lack of considerations towards the social dimension within circular economy initiatives has been identified as a key barrier to progress (Broto *et al.*, 2012; Geng *et al.*, 2012; Murray *et al.*, 2017). Therefore, further investigation needs to be done with regards to exploring how civil society may be incorporated into the development of a niche.

7.4.4 Ability of IBioIC to empower the overall niche network

Many of the nurturing activities undertaken by IBioIC also contributed to the empowerment of the niche. These activities included hosting an annual international conference, increasing the connectivity between the niche network and global niche activities and building collaborative research projects between niche innovators and regime actors. However, IBioIC was also able to undertake dedicated empowerment activities including becoming a member of a pan-European consortium which exposed the niche innovators to a much wider support network as well as informing public-sector stakeholders and policy makers as to the immediate and long term needs of the network.

Although the benefit IBioIC delivered to all three triple helix actors was widely acknowledged within the network, IBioIC appears to have provided particular value to small-scale niche innovators through increasing IP development, jobs, sales and international market share. These findings highlight the important role of a triple helix-based niche manager in empowering the networks ability to scale up inner-loop innovations and disrupt the more established linear value chains, which is crucial for transitioning to a circular economy.

The focus group identified and ranked the inward and outward facing activities of IBioIC with regards to nurturing and empowering the protected space network. The results suggested that strategically managing a protected niche innovation network requires a combination of both inward and outward facing activities and that the triple helix governance model of IBioIC strengthened its ability to successfully perform both. As IBioIC was deeply nested within the protected space network and was co-governed by its network members, it was able to perform nurturing activities which required intimate knowledge of the network, such as one-to-one consultation and focus groups, which a public-sector body would likely be unable to perform effectively.

Yet, IBioIC also performed broader empowering activities such as influencing the wider circular economy national strategy and attracting external funding due to the close ties with public-sector bodies who sat as observers on the governance board. The empowering effects of such activities were made evident in the results of the complete social network analysis where the number of knowledge transfer and collaborative research project ties between niche and regime actors increased by 71% and 80% respectively. Such collaborative projects help to build trust between the niche and regime actors and accelerate knowledge transfer between the two. More importantly, they increase the alignment of the niche innovations with the needs of the regime thus increasing the chances of widespread adoption. The collaborative research projects brokered by IBioIC spanned multiple regimes including energy, chemicals and materials thereby facilitating niche-multi regime interaction. As outlined in Figure 3.3, niche-multi regime interaction is necessary to ensure a more cohesive transition and increases the potential disruptive impact of the niche technology.

This chapter assessed the ability for a triple helix-based niche manager to nurture and empower a ‘biological based’ inner loop niche innovation network in-line with the broader circular economy transition. The following chapter assess the ability of a triple helix-based niche manager to perform the task for a key ‘technical’ based inner loop innovation network – that of remanufacturing.

Chapter 8: Case Study of the role of the Scottish Institute for Remanufacturing as a triple helix-based niche manager

This chapter covers the case study of the impact of the Scottish Institute of Remanufacturing on the Scottish Remanufacturing Network. First, it introduces the concept of remanufacturing as an industrial process and discusses why it is a critical inner-loop activity for realising a circular economy transition. It then presents the analysis of the results and discusses the implications of the results with regards to the role of triple helix-based niche managers in nurturing and empowering inner-loop niche innovation networks.

8.1 Background to remanufacturing in the context of the circular economy

The process of remanufacturing products is perceived by many institutions and researchers as being key to enabling a circular economy transition (Lieder and Rashid 2016). At end-of-life, the majority of technical products (products which cannot be returned to the earth safely) are discarded to landfill, or at best, recycled for scrap. This means that valuable materials such as rare earth metals are simply thrown away. In addition, all value added by the energy and labour used to build the product is lost. This system of ‘make, use, dispose’ was developed in a time of abundant resources and cheap labour and energy costs, subsequently there was very little perceived need to recapture and retain that value for as long as possible. Exceptions to the rule did evolve however for items with very high residual value such as aerospace components, whereby it made economic sense to retain the value of the product for as long as possible due to the extremely high costs of manufacturing it. Nonetheless, the vast majority of common technical items such as cars, white goods and electronics were simply designed to be discarded or recycled.

However, in the past decade the global economy has suffered a global financial crash, stagnating growth and productivity and increasingly rising and volatile commodity prices. This toxic mix of landscape pressures has forced the manufacturing industry to explore the viability of retaining the value of the products for as long as possible to decouple their reliance on volatile and increasing prices of materials and to remain competitive by decoupling their material throughput from profit. The process of remanufacturing has therefore been increasingly discussed as a viable way to achieve such a decoupling. The American National Standard for remanufacturing, developed by the Remanufacturing Industries Council (2017, p.1) defined remanufacturing as:

> ‘A comprehensive and rigorous industrial process by which a previously sold or leased product or part is returned through a controlled, reproducible and sustainable process to a “like-new” or “better-than-new” condition in performance level and quality for form, fit and function’.

By taking an old product and remanufacturing it to like new (or better), the process of remanufacturing offers many environmental, economic and social benefits. Firstly, by re-using existing materials, who’s extraction, transport, refining, production had have resulted in toxic emissions to air and water to produce, remanufacturing can significantly reduce a products ecological footprint. Alexopoulos and Packianather (2017) found that remanufacturing automotive components can result in up to 88% of materials saved versus using a new product. This material saving resulted in a 53% drop in CO^2 emissions and 56 % lower energy required than making a new product.

The potential retention of materials in a product for as long as possible led the Ellen MacArthur Foundation to identify remanufacturing as a critical inner-loop within the circular economy butterfly diagram (Figure 8.1). Although remanufacturing is identified as a single loop in the butterfly diagram – the reality is that the remanufacturing process allows manufacturing firms to more easily encompass the other inner-loops of re-use, repair, refurbishment and recycling to maximise the material efficiency when providing a product to a user which is of sufficient quality. For example, when a product is remanufactured, the entire product is disassembled into component parts which are then cleaned and individually inspected. Parts which can be reused are reused, parts which need repaired are repaired, parts which need cleaned or refurbished are cleaned or refurbished and any part that cannot be fixed will be recycled and replaced with a new or refurbished component from another product. Furthermore, if technology has progressed since the original manufacture of the product, there is the opportunity to integrate the new technology during the remanufacturing process to help prevent obsolescence of the product. It is due to the potential for maximising a products lifetime through integrating reuse, repair, refurbishment and recycling that remanufacturing is seen as a critical circular economy activity.

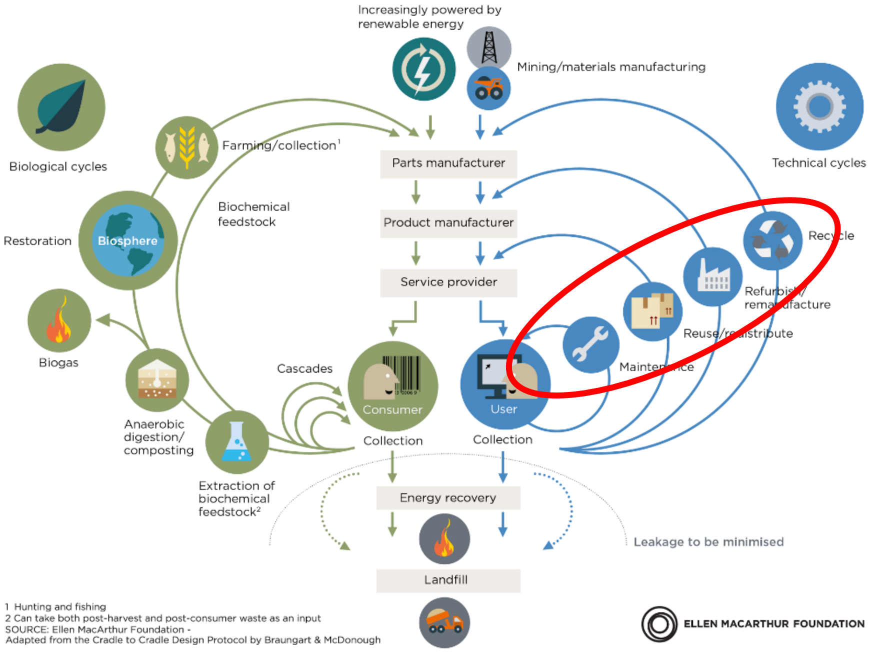


Figure 8.1: The butterfly diagram representing the inner loops of the circular economy, highlighting in red the remanufacturing processes which encompass all inner-loop cascades to maximise material efficiency

In economic terms, all the savings produced from re-capturing the value of existing materials translates into cheaper products. The cheaper production price, combined with new forms of business models designed to easily recapture the product at end of life such as servitization (charging for a service the product provides rather than the product itself), translates into large savings for both the users and manufacturers of the product. In some cases of remanufacturing, businesses have experienced the reduction in price of between 35-40% compared to the original product price whilst achieving a profit margin of 20% (Alexopoulos and Packianather 2017).

Other economic benefits include the need for the creation of a range of high skilled jobs to disassemble, clean, inspect, repair and re-assemble the products. At the national level, remanufacturing helps to safeguard and retain valuable materials such as rare earth metals, with which many countries are reliant on another country to supply. Many renewable technologies such as wind turbines and solar panels are reliant on the use of these highly expensive and rare resources and as such it is critical that such materials are retained in the economic system to allow the transition to a renewable energy economy over the long term.

Although there appears to be many benefits to the scale up of remanufacturing – it remains undervalued within the economy and predominantly exists within specific market niches. This is due to numerous technical, economic and legal barriers which impede it’s scale up. Firstly, the manufacturing value chain has evolved as a highly efficient linear system, whereby an original equipment manufacturer (OEM) buys from a material supplier, the manufacturer buys from an OEM, the retailer buys from the manufacturer and then the user buys from the retailer and then discards the product to landfill, or at the best, recycles it. Therefore, for the manufacturer to re-collect the core (or product) they need to design an entirely new business model such as product leasing to incentivize the customer to return the product. They also need to track the product throughout its lifetime and the value chain to know when to expect its return. They then need to implement an entirely new reverse logistics process to get the core back to their site. They must develop and install new technology (IoT, additive manufacturing, inspection equipment) and train a new labour force with which to disassemble, inspect, clean and re-assembly the product and then develop a secondary sales channel to sell the remanufactured product. In addition to all of this, it is likely they would need to completely re-design their product so that, rather than being designed to break after a set period forcing the user to buy a new one, it should be designed to last as long as possible to extract as much rent from the user as possible. It should also be re-designed to be as easy as possible to disassemble, inspect, clean and re-assemble.

Matsumoto et al. (2016) identified that products that have the highest potential for remanufacturing show the following characteristics: (1) stable product technology, (2) stable process technology, and (3) a physical lifetime of critical subparts that is substantially longer than the actual life-time of the product itself. As such, the second barrier to being able to remanufacture a wide range of products is the rate of change of technologies which leave many products and parts obsolete before the time for them to be remanufactured arrives.

It is therefore evident that if remanufacturing is to become mainstream – several barriers must be overcome. These barriers are not insurmountable. Renault successfully operate their remanufacturing plant in Choisy-le-Roi (France) where they remanufacture thousands of automobile parts such as gearboxes and injection pumps. This has resulted in the use of 80% less energy, 88% less water, 92% less chemical products and 70% less water in production (Ellen MacArthur Foundation 2018a). Nonetheless, it has taken Renault more than 50 years to develop such a plant.

For remanufacturing to be common place amongst a wide range of high-volume low value technical products (such as white good and electronics) a range of new technologies needs to be adopted and there needs to be collaboration and coordination throughout the entire value chain. A recent study by the European Remanufacturing Network found that industry-academia collaboration is particularly critical to the success of remanufacturing. It is therefore evident that if remanufacturing is to scale from a niche to become a dominant regime practice, it needs some level of protected space available to allow for experimentation of new supply chains and business models which would accelerate the adoption of the practice (European Remanufacturing Network 2019).

Collaborative experimentation, particularly between academia and industry is valuable to generate and share learning and align expectations. This case study therefore assesses the impact that the Scottish Institute for Remanufacturing, a triple helix-based niche manager, had in nurturing and empowering a national remanufacturing niche innovation network in Scotland. This was done via complete social network analysis and analysis of supporting qualitative data – the methodology of which is outlined in Sections 6.1 and 6.2. The remainder of this chapter presents the results and discussion of this analysis.

8.2 Complete social network data analysis

This section covers the results obtained from the complete social network analysis of the remanufacturing network. It includes both the whole network analysis (impact of nurturing on the structure of the network and on triple helix interactions) and the egocentric analysis (centrality of SIR relative to all other network members).

8.2.1 Remanufacturing network composition excluding ties and actors created and added by SIR

The SIR network structure at the time of the study was comprised of a mixture of industry actors, universities, public-sector stakeholders and innovation intermediaries. Two thirds of the network (66%) was made up of industry actors (55% regime actors and 11% niche actors). One tenth (11%) of the network was made up of universities (all of which were Scottish) (Table 8.1). The remainder of the network was made up of public-sector stakeholders and innovation intermediaries.

Table 8.1: Composition of the remanufacturing network

Triple Helix Group	**Total number of organizations in the remanufacturing network**	**Proportion of Network**
Industry	35	66%
Regime	29	55%
Niche	6	11%
Universities	6	11%
Public-sector Stakeholders	6	11%
Innovation Intermediaries	6	11%

Note: Regime and Niche actors were identified by the SIR business development team.

The network organisations spanned more than 8 sectors including automotive, information and communication technologies (ICT), energy, textiles, aerospace, construction and logistics. For each sector, there was generally expertise from at least one organisation for each phase in the remanufacturing supply chain. Particularly for automotive, ICT, energy, textiles and aerospace (Figure 8.2).

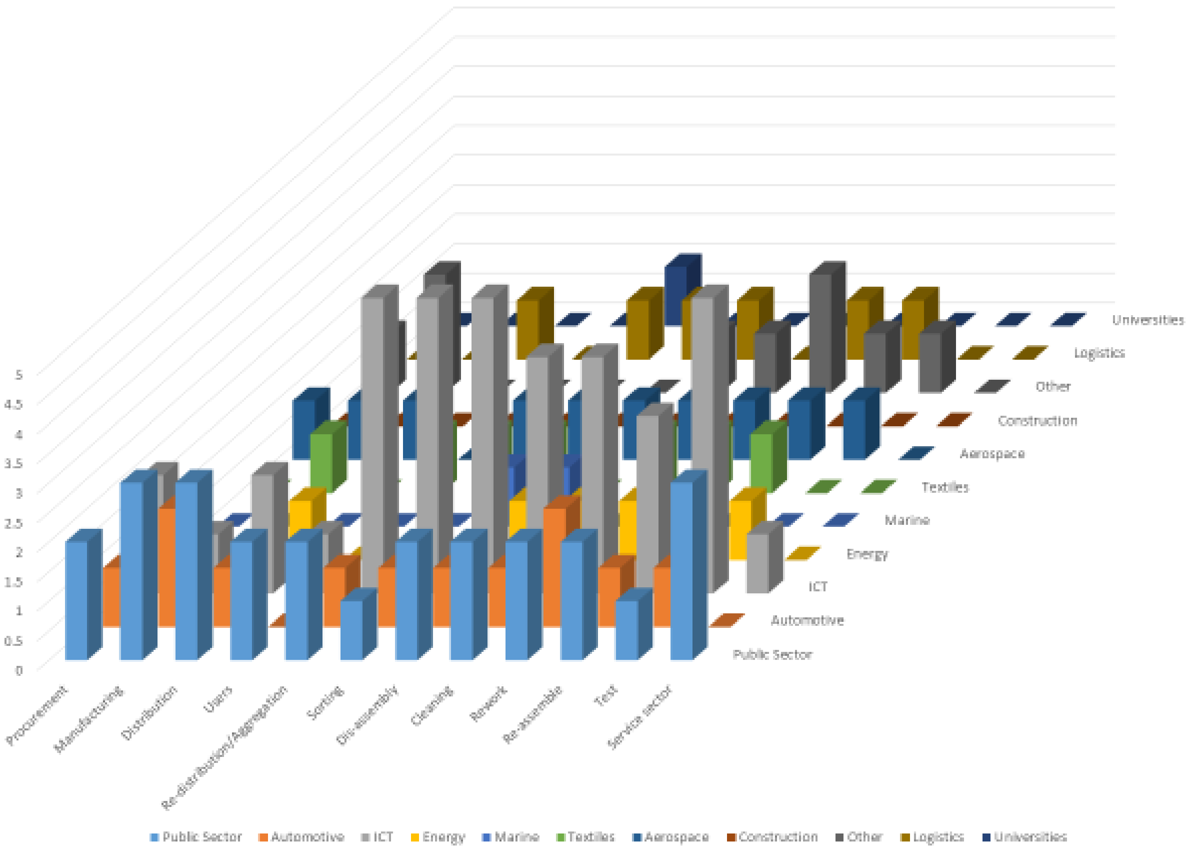


Figure 8.2: This figure outlines the composition of the remanufacturing network at the time of the analysis with regards to the different sectors on the y axis and the expertise held in each step in the remanufacturing value chain.

Note: Figure 8.2 demonstrates that the network was broad and covered many value chain phases for multiple sectors ranging from automotive, ICT, energy, textiles, aerospace, construction and logistics. There was some clustering with regards to expertise in manufacturing, sorting, disassembly, cleaning and re-work – particularly for automotive, ICT and energy.

8.2.2 Impact of SIR on the overall network structural characteristics

The impact SIR had on the network cohesion, presence of cohesive subgroups and centralisation is outlined in Table 8.2. The impact was measured as a percentage change in the respective proxy indicator for each relational attribute to the presence of SIR, as outlined in Section 3.1.2.

8.2.2.1 Impact of SIR on network cohesion

The results in Table 8.2 indicate that SIR increased the level of cohesion for all types of relational ties. The network density increased for all relational attributes due to the brokering services undertaken by SIR. The frequency of contact relational attribute demonstrated the highest density value of 0.156. However, as observed in the IBioIC case study, when the type of relational tie requires a deeper level of trust between actors, the density of ties drops. For example, the density of relational ties dropped from a density of 0.156 for frequent contact relational ties to 0.051 for technology transfer and 0.025 for IP transfer.

Frequent contact ties between organizations experienced the biggest increase in the total number of ties relative to the other relational attributes. SIR increased the number of frequent contact ties from 260 to 430, an increase of 65%. A large increase in the number of frequent contact ties, as observed from the results, indicates SIR was effective at connecting actors who were members of the same social network but had not necessarily had the opportunity to directly and frequently interact with one another. By brokering new relational ties between organisations, SIR greatly increased the potential for the formation of weak ties which support knowledge exchange between two previously unconnected parts of the network. Michelfelder and Kratzer (2013) found that weak ties are required within innovation networks for fostering idea generation and introducing innovation opportunities.

The relational attributes that experienced the highest increase in relational ties was total knowledge transfer, collaborative research projects and IP transfer which increased by 154%, 179%, 127% respectively. This is significantly higher than the increase in the less intimate form of relational ties such as the frequency of contact which only increased by 42%. This suggests that, as with IBioIC, SIR was more effective at brokering intimate and trust bound relational ties necessary for innovation. More intimate ties such as collaborative research projects help to encourage the build-up of trust, reciprocity and cooperation between network actors (Carpenter *et al*., 2012). Additionally, such ties help reinforce the convergence of norms and expectations of the niche. Michelfelder and Kratzer (2013) argue that it is only through such strong intimate ties that efficient transfer and exploitation of complex knowledge can occur. This is particularly important with regards to the formation of a triple helix consensus space within a protected space where traditionally there exists barriers to effective knowledge transfer between triple helix institutions due to differences in culture and normative values.

In addition to the impact of SIR on the network density and the number of ties, this case study also measured the change in average path length between two network actors. The results in Table 8.2 demonstrate that the path length reduced for all relation attributes apart from cash transfer which increased slightly. The total knowledge relational attribute saw the biggest drop in average path length of 41%, second was frequency of interaction which dropped by 21%. The more intimate relationships such as collaborative research projects and IP transfer also reduced by 19% and 8% respectively. The increase in path length for cash infusions is likely due to SIR doubling the number of new entrants to the network who are participating directly in cash transfers – as such this serves to raise the average path length even if the total number of ties and actors increased.

8.2.2.1 Impact of SIR on the presence of cohesive subgroups

The increase or decrease in the presence of cohesive sub-groups was calculated by comparing the ratios of clustering coefficient values with network density values for both before and after the introduction of SIR to the network. If the percentage increase of this ratio is larger for the network which includes ties formed through SIR, then SIR has increased the presence of cohesive subgroups. Conversely, if the value is lower, then SIR had decreased the presence of cohesive subgroups.

The clustering coefficient for IP increased from 0.000 (no triadic ties) to 0.143 due to the presence of SIR. The calculation for presence of cohesive subgroups could not be completed due to the clustering coefficient value for IP transfer without SIR being 0. However, it can be stated that SIR increased the presence of cohesive subgroups since, upon inspection of Figures 8.3 and 8.4, it is evident that several triadic ties were formed due to SIR.

As seen with IBioIC, SIR was able to increase the network density and clustering coefficient for every relational attribute, yet the impact it had on the presence of cohesive subgroups varied. For example, the presence of cohesive subgroups for frequent contact and cash transfer reduced by 13.3% and 7.7% respectively, whereas it increased for knowledge transfer and collaborative research projects by 4.9% and 9.9% respectively. The reason for this difference may be that SIR was the broker for more than 30 collaborative research projects whereby they ensured a diverse spread of network participants in the projects. In turn, this served to reduce the cliquishness and concentration of cash transfer between a handful of organisations which would have naturally formed if SIR had not been in control of participant selection in the projects.

The results suggest that SIR was able to increase frequent contact ties by up to 65% whilst reducing the level of cohesive subgroups for this relational attribute and hence the risk of knowledge lock in. Yet, SIR was simultaneously able to increase the presence of cohesive subgroups for relational attributes which require high levels of trust and coordination such as high-quality knowledge transfer, collaborative research projects and IP transfer. This suggests that, as with IBioIC, SIR was able to increase clustering for relational attributes where a strong sense of trust is needed but reduce clustering for less trust-based ties. This increases the likelihood of knowledge transferring between clusters crossing structural holes in the network thereby laying the foundations for a small world network structure as argued by Burt (2001).

8.2.2.1 Impact of SIR on network centralisation

The centralisation index for all relational attributes increased in the remanufacturing network or remained unchanged. If a network's centralisation increases, each network actor's immediate neighbourhood becomes more connected. The increase in centralisation index was particularly high for relational ties which do not require a high level of trust such as frequent contact (159%), total knowledge transfer (359%). Such an increase of frequent contact centralization index suggests that SIR was able to increase the diversity of each actor's immediate network and increase the chances of knowledge from one side of the network reaching the other side.

SIR was equally as successful regarding increasing the level of centralization for more intimate trust bound relations such as collaborative research projects (89%) and IP transfer (176%). This increases the chances of the development of multi-stakeholder collaboration and wider niche alignment which is essential for the circular economy transition as discussed in Section 3.4.

Table 8.2: An outline of the increase/decrease in the remanufacturing structural network values for each relational attribute with respect to the impact of SIR showing the significant positive impact of SIR on almost all measures of centrality.

	Cohesio								**Cohesive Subgroups**				**Centralisatio**		
	Density		**Number of Ties**			**Path Length**			**Clustering Coefficient**				**Centralisation Index**		
	With	**Without**	**With**	**Without**	**% Change**	**With**	**Without**	**% Change**	**With**	**Without**	**% Change**	**(CC-D)/CC Difference**	**With**	**Without**	**% Change**
Frequency of Contact	0.156	0.094	430	260	**65%**	1.9	2.4	**-21%**	0.309	0.253	**22%**	**-13.3%**	0.6772	0.2617	**159%**
Total Knowledge Transfer	0.065	0.025	178	70	**154%**	2.3	3.9	**-41%**	0.479	0.135	**255%**	**4.9%**	0.6124	0.1335	**359%**
Collaborative Res. Projects	0.057	0.02	156	56	**179%**	2.5	3.1	**-19%**	0.51	0.095	**437%**	**9.9%**	0.2204	0.1188	**86%**
Technology Transfer	0.051	0.03	140	82	**71%**	2.7	2.9	**-7%**	0.322	0.189	**70%**	**0.0%**	0.1471	0.1489	**-1%**
Cash Transfer	0.036	0.023	100	64	**56%**	3.1	2.9	**7%**	0.111	0.093	**19%**	**-7.7%**	0.1621	0.1357	**19%**
IP Transfer	0.025	0.011	68	30	**127%**	3.4	3.7	**-8%**	0.143	0	**N/A**	**N/A**	0.1342	0.0486	**176%**

Notes:

1. The number under the column ‘With’ is the relational attribute value including the ties formed by SIR. The number under the column ‘Without’ is the relational attribute value without the presence of SIR.
2. For Path Length: A negative number indicates that the average path length has reduced between network members
3. For Centralization Index: A positive number indicates a % increase in value due to the presence of SIR. The % value was calculated by taking the ratio between the centralisation index value including any ties directly formed through SIR and the centralisation index value not including any ties formed directly through SIR and then converting the ratio to a % change.
4. Only frequency of contact identified as being once every quarter or more were included in the analysis
5. Ratio between Density and Clustering Coefficient: The increase or decrease in presence of cohesive sub-groups was calculated by examining the ratio of the clustering coefficient value with the density values for both before and after the introduction of SIR to the network. The formulae recommended in UCINET 6.1 of (Clustering Coefficient-Density)/Clustering Coefficient was used to estimate the level of clustering relative to density for the network with relational ties formed by SIR included and without them included. The results of which were then compared to assess the difference.
6. The clustering coefficient for technology transfer without SIR was 0 due to there being no triadic ties (ties between three network members). The global clustering coefficient is based on triplets of nodes. A triplet consists of three connected nodes. A triangle therefore includes three closed triplets, one centred on each of the nodes (n.b. this means the three triplets in a triangle come from overlapping selections of nodes). The global clustering coefficient is the number of closed triplets (or 3 x triangles) over the total number of triplets (both open and closed)

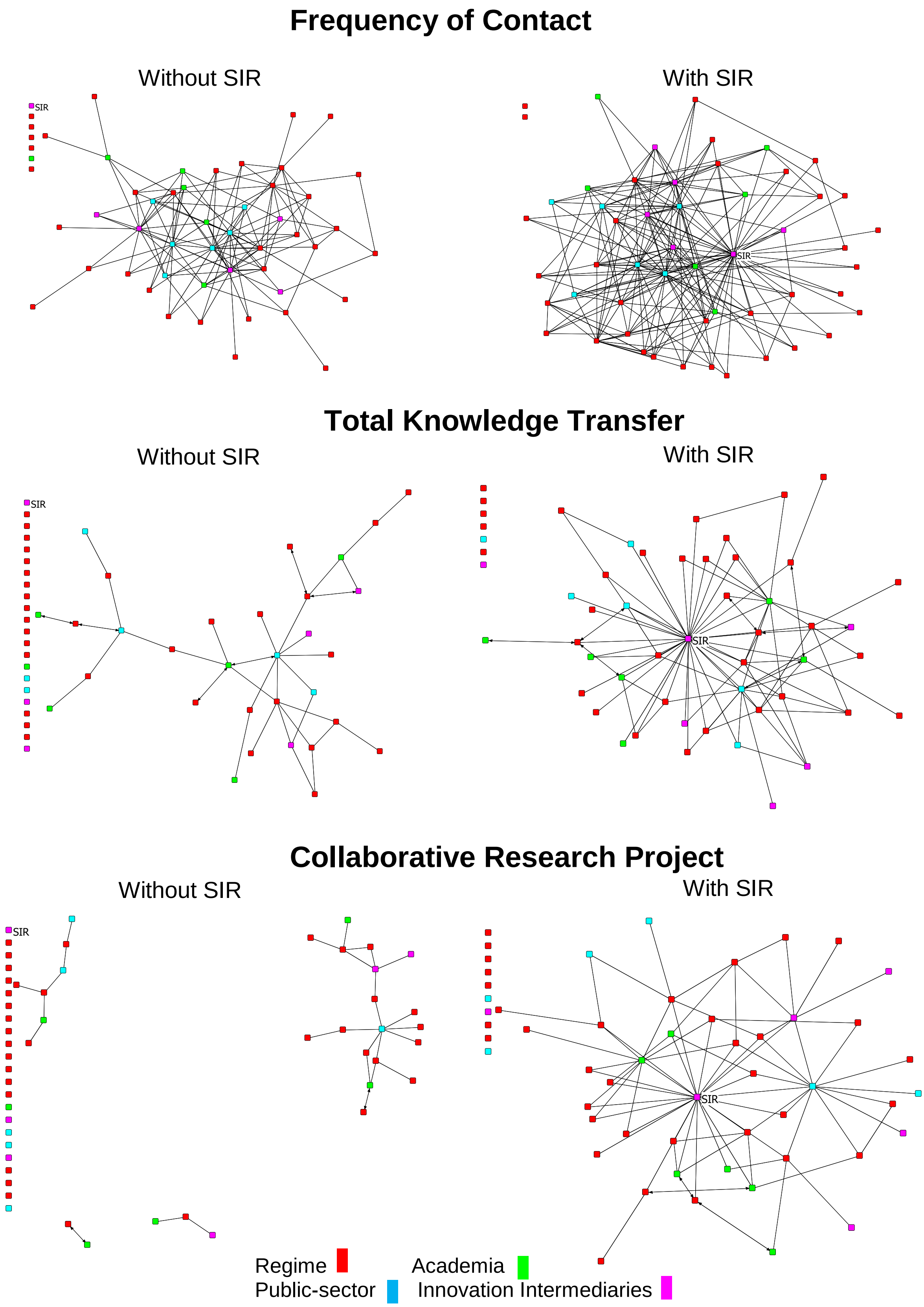


Figure 8.3: Sociogram diagrams of the remanufacturing network demonstrating the change in the number of relational ties with and without SIR for frequency of contact, total knowledge transfer and collaborative research projects

Notes: 1. The sociograms were produced using the software NetDraw by Borgatti (2002). 2. Larger versions of these images can be found in Appendix IV.

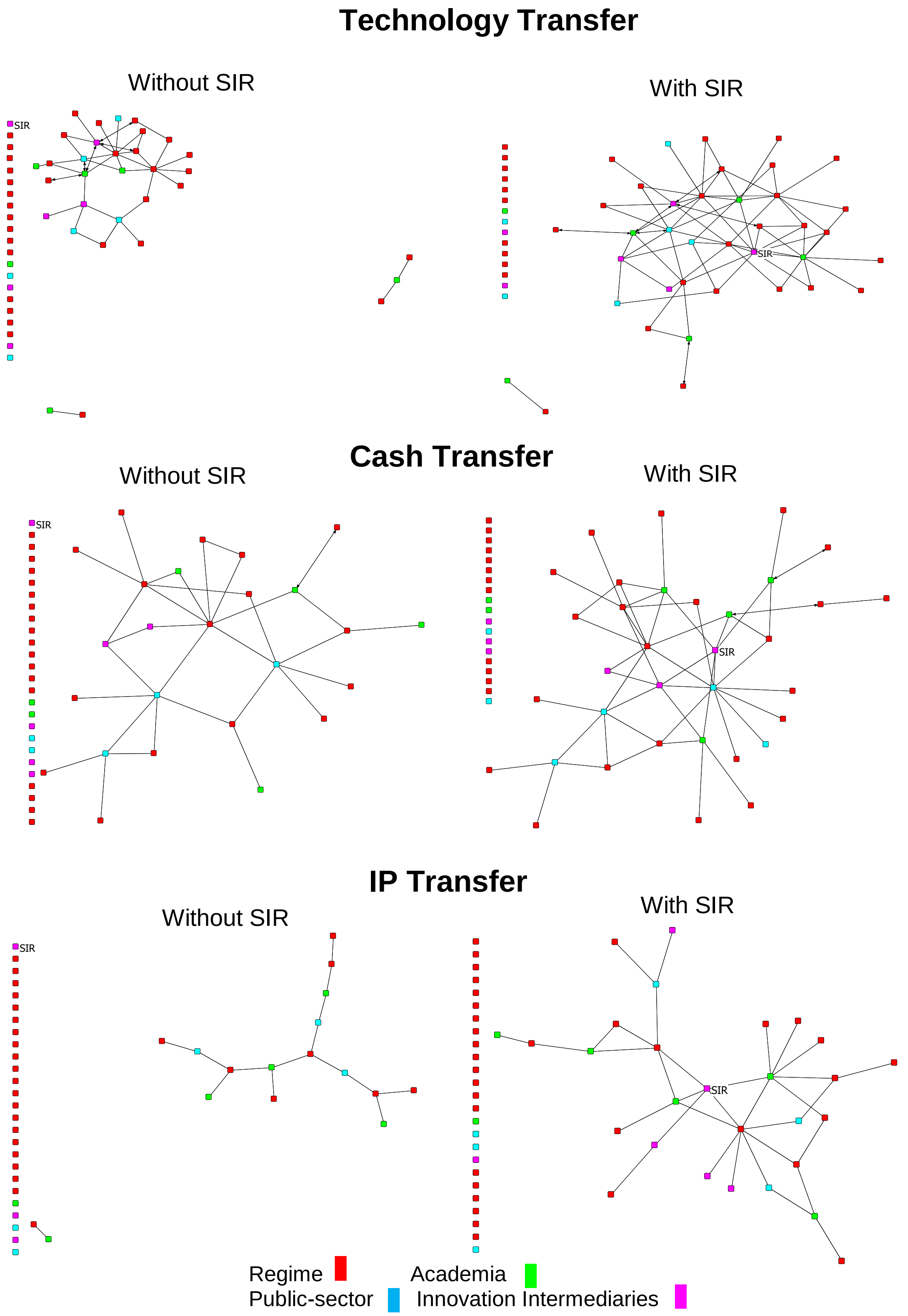


Figure 8.4: Sociogram diagrams of the remanufacturing network demonstrating the change in the number of relational ties with and without SIR for technology, cash and IP transfer

Notes: 1. The sociograms were produced using the software NetDraw by Borgatti (2002). 2. Larger versions of these images can be found in Appendix IV.

8.2.3 Impact of SIR on triple helix interactions

As discussed in the IBioIC case study, the impact SIR had on the level of interaction between and within four distinct triple helix groups (academia, government, universities and innovation intermediaries) was measured. Table 8.3 and Figure 8.5 outline the impact of SIR on triple helix relations for the six types of relational ties.

It is evident that SIR excelled with regards to building all forms of relations between the universities and industry. The lower trust level relational attribute of frequency of contact increased between academia-industry by 94% and the higher trust level relational attributes of collaborative research projects and IP transfer increased by 175% and 114% respectively. Although SIR was mandated to focus on university-industry relations, SIR was also able to broker the formation of industry-industry relational ties, whereby the number of collaborative research project ties increased by 80%. An increase in academia-industry and industry-industry ties help increase the chances of successful knowledge exploitation for circular innovation.

SIR was less successful at increasing relational ties between universities lowering the chances of diverse knowledge recombination and coordinated knowledge generation necessary for systemic innovation. This may be due to the significant difference in research topic and projects each university department was undertaking along with the network members' perceived limited need for knowledge transfer compared to the industrial biotechnology network (where the need for knowledge exchange was perceived as much more urgent).

SIR increased the relational ties between industry and public-sector stakeholders. Total knowledge exchange increased by 30% thus supporting the notion that a triple helix-based niche manager supports knowledge exchange and reflexivity between niche actors and the public-sector. However, SIR was unable to increase relational ties between universities and public-sector stakeholders.

SIR was particularly successful with regards to building triple helix relational ties for collaborative research projects. Academia-industry frequency of contact relational ties increased by 94% whereas academia-industry collaborative research project ties increased by 175%. This suggests that SIR was instrumental in the formation of cross-institutional trust based relational ties, necessary for a balanced triple helix system to form.

As with IBioIC, a greater increase in interactions was observed between academia and industry than between academia and public-sector or industry and public-sector. However, in opposition to IBioIC, the incidence of knowledge exchange increased much more between industry and public-sector than between academia and public-sector, suggesting an impending challenge for SIR in brokering stronger academia-public-sector relations.

The results highlighted the key role SIR played as a network integrator through brokering relational ties between the other intermediaries and the other network actors. By doing so, SIR was not only able to broaden the network, but also integrate the niche into the wider innovation ecosystem thereby potentially unlocking more resources and buy-in from incumbent regimes.

The frequency of contact between other innovation intermediaries and industry, universities and government stakeholders increased by 25%, 25% and 33%, respectively. An important observation is that SIR was able to increase frequent contact between the innovation intermediaries themselves by 50%. This is important to help re-align the existing support infrastructure in the wider innovation system to be better aligned with the needs of the niche.

As a niche manager, SIR was able to form a significantly higher number of relational ties with the other triple helix groups compared the other innovation intermediaries. For example, SIR was able to form 25 direct knowledge transfer ties with industry relative to the other innovation intermediaries' who managed a combined total of two. The same can been seen for collaborative research projects whereby SIR was able to form 19 direct knowledge transfer ties with industry relative to the other innovation intermediaries' who managed a combined total value of one. A similar difference can be seen for academia, public-sector and other intermediary ties.

SIR was also able to increase innovation intermediary-industry collaboration in collaborative research projects by 25%. SIR was also successful at increasing the connectivity between public-sector stakeholders and the innovation intermediaries. For example, the frequent contact and total knowledge transfer ties between other intermediaries (including SIR) and public-sector stakeholders increased by 75% and 300% respectively. The results demonstrate the need for such a niche manager to be present within the niche to coordinate and broker ties between all the triple helix institutions rather than relying on more traditional forms of intermediation which remain limited in their ability to integrate such a broad network.

Figure 8.5 compliments the observations from Table 8.3. Each black line represents a new frequent contact relational tie formed due to the brokering activities of SIR. The sociogram highlights the ability for SIR to sit in the institutional overlap between all four triple helix groups and as such broker the formation of many ties between and within each group.

Table 8.3: A measurement of the percentage increase/decrease the number of ties between and amongst triple helix groups in the remanufacturing network for each relational attribute due to the presence of SIR.

		With				Without				Difference (With-Without)				% Difference (With-Without)/Without			
		Industry	University	Public-sector	Innovation Intermediaries	Industry	University	Public-sector	Innovation Intermediaries	Industry	University	Public-sector	Innovation Intermediaries	Industry	University	Public-sector	Innovation Intermediaries
Frequency of Contact	Industry	62				52				10				19			
	University	33	0			17	0			16	0			94	0		
	Public-sector	43	7	20		33	7	18		10	0	0		30	0	11	
	Innovation Intermediaries	47/20	15/10	21/16	16/6	16	8	12	4	31/4	7/2	9/4	12/2	194/25	88/25	75/33	300/50
Total Knowledge Transfer	Industry	24				16				8				50			
	University	19	0			9	0			10	0			111	0		
	Public-sector	13	1	2		10	1	2		3	0	0		30	0	0	
	Innovation Intermediaries	28/5	6/1	8/3	2/0	3	1	2	0	25/2	5/0	6/1	2/0	833/67	500/0	300/50	N/A/0
Collab. Research Projects	Industry	18				10				8				80			
	University	22	0			8	0			14	0			175	0		
	Public-sector	13	0	2		10	0	0		3	0	2		30	0	N/A	
	Innovation Intermediaries	23/5	5/0	3/2	4/2	4	0	0	2	19/1	5/0	3/2	2/0	475/25	N/A/0	N/A	100/0
Tech Transfer	Industry	30				24				6				25			
	University	20	0			9	0			11	0			122	0		
	Public-sector	10	2	0		8	2	0		2	0	0		25	0	0	
	Innovation Intermediaries	15/7	4/2	3/3	2/2	5	2	2	2	10/2	2/0	1/1	0/0	200/40	100/0	50/50	0/0
Cash Transfer	Industry	18				14				4				29			
	University	13	0			7	0			6	0			86	0		
	Public-sector	14	0	4		13	0	2		1	0	2		8	0	100	
	Innovation Intermediaries	2/2	5/1	3/2	4/2	2	0	1	2	0/0	5/1	2/1	2/0	0/0	N/A	200/100	1/0
IP Transfer	Industry	8				4				4				100			
	University	15	0			7	0			8	0			114	0		
	Public-sector	5	1	0		5	1	0		0	0	0		0	0	0	
	Innovation Intermediaries	5/3	2/0	1/1	2/0	0	0	0	0	5/3	2/0	1/1	2/0	N/A	N/A/0	N/A	N/A/0

Notes:

1. The numbers under the column ‘With’ is number of ties between each triple helix group including the ties formed by SIR. The number under the column ‘Without’ number of ties between each triple helix group excluding the ties formed by SIR.
2. The numbers under the Difference heading are the total increase or decrease in triple helix relational ties due to the presence of SIR. A positive number indicates and increase in ties. A negative number indicates a decrease in ties. The number before the / is the difference including ties to SIR, the numbers to the right of the / are the ties not including IBioIC as an innovation intermediary

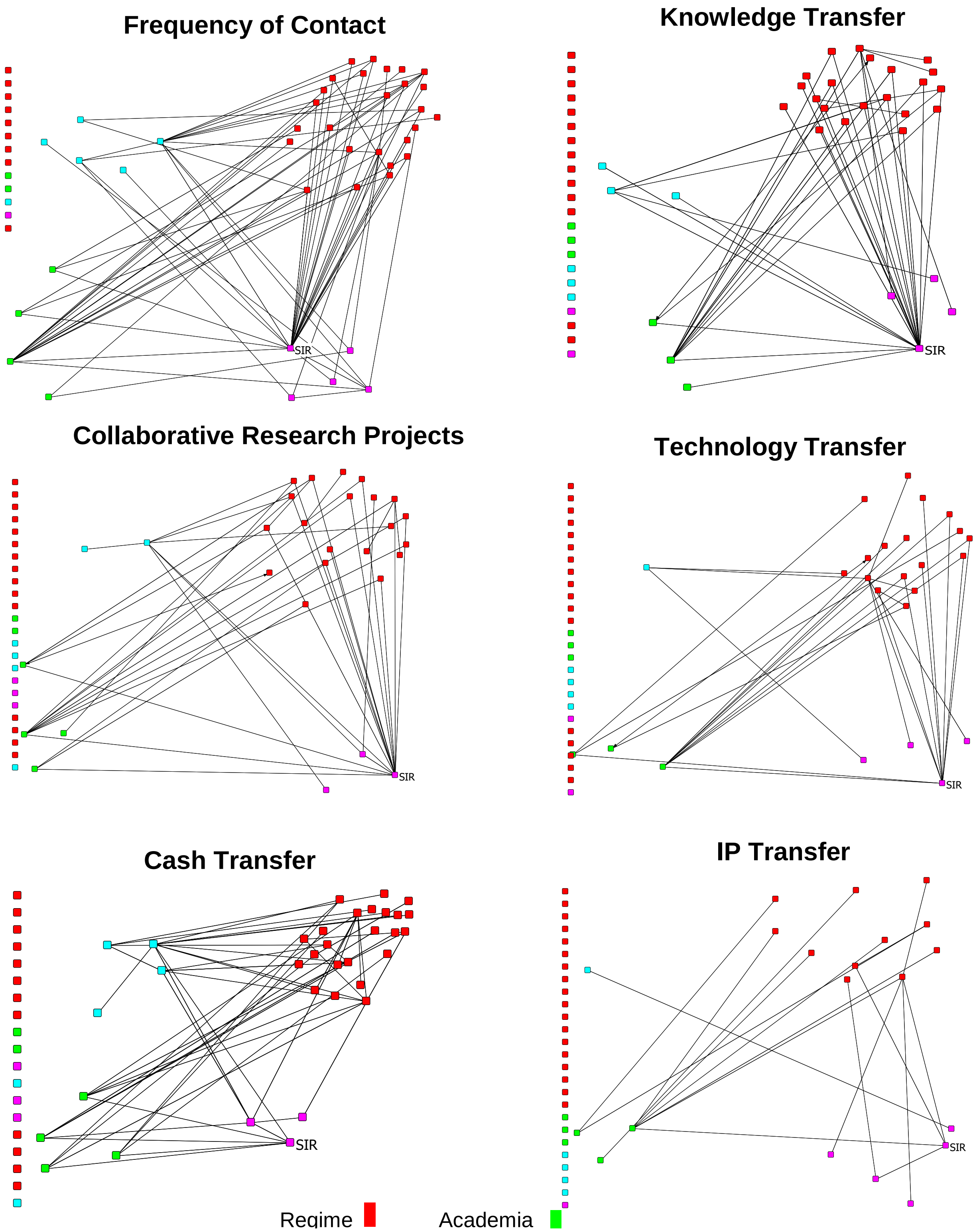


Figure 8.5: Sociograms displaying the triple helix relational ties formed in the remanufacturing network through SIR.

Note: Each line represents the formation of a new relational tie between two organizations due to the presence of SIR. The sociograms were produced using the software NetDraw by Borgatti (2002). 2. Larger versions of these images can be found in Appendix IV

8.2.4 Impact of SIR on niche regime interaction

A critical task of SNM is to enable the niche to alter the evolutionary trajectory of existing incumbent regimes (Hegger *et al.,* 2007). The results in Table 8.4 demonstrate that SIR increased the number of niche-regime ties for frequent contact, total knowledge transfer, collaborative research projects and technology transfer relational attributes. This is evidence of SIR helping anchor the niche to the regime which is necessary for the niche to expand (Elzen *et al.*, 2012). In contrast to IBioIC, overall SIR was more effective at increasing the total relational ties between regime actors and universities, public-sector stakeholders and other innovation intermediaries relative to connecting them to niche actors. For example, SIR increased the total number of collaborative research projects between regime actors and universities by 12 ties compared to only two new ties for niche actors. SIR also brokered nine technology transfer ties between regime actors and universities relative to only two new ties for niche actors.

As mentioned above, SIR was much more effective than other innovation intermediaries with regards to forming relational ties with both niche and regime actors. For example, it created 16 collaborative research project ties with regime actors and 3 ties with niche actors compared to the combined total of other intermediaries being 1 and 0 respectively.

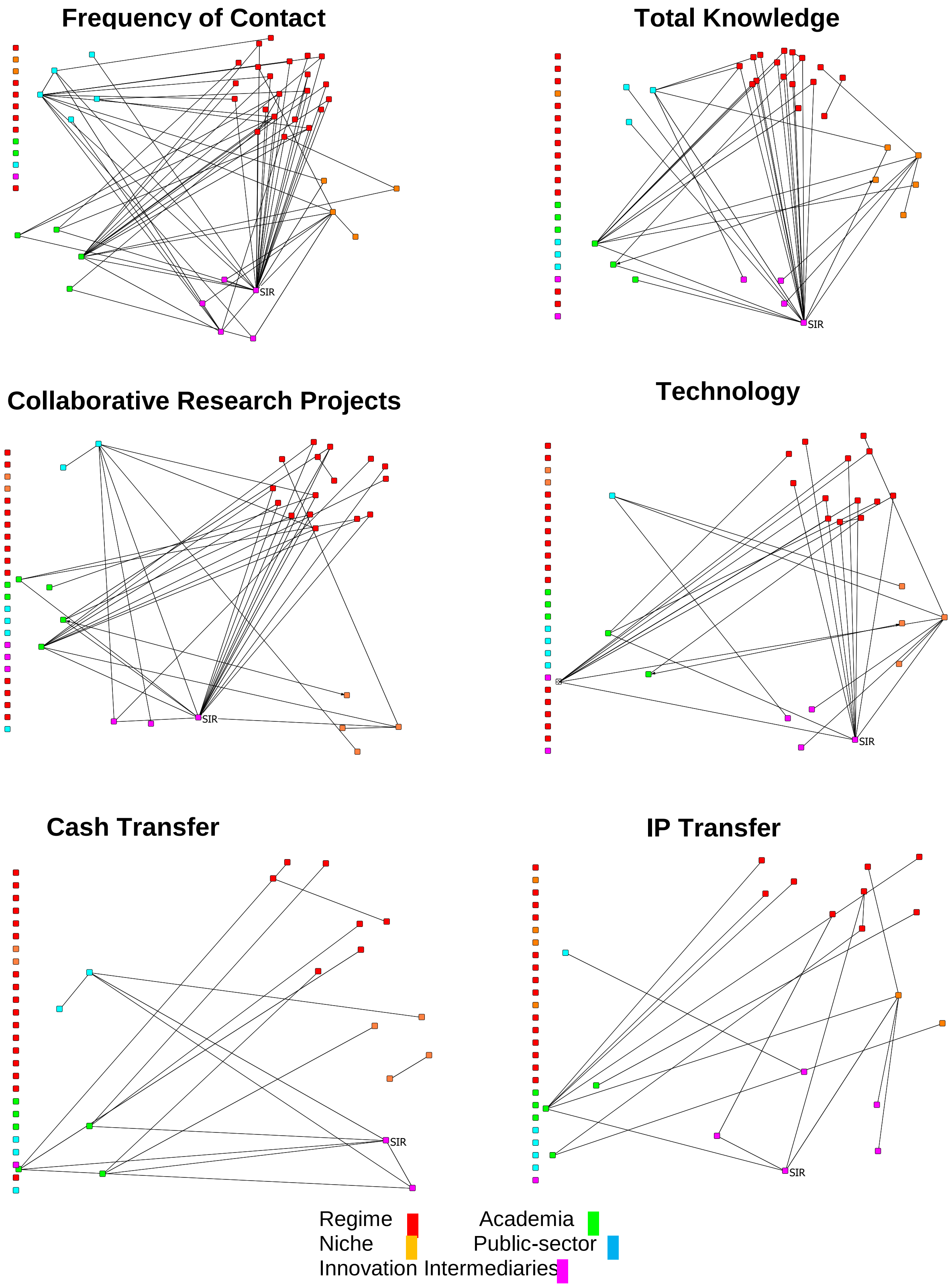
Figure 8.6 visually represents the ties directly formed through the presence of SIR. It clearly demonstrates that strong ties were formed between universities and regime and niche actors rather than directly between niche and regime actors. Secondly, it demonstrates how regime actors dominate the collaborative research project ties compared to niche actors. Finally, the sociograms in Figure 8.6 demonstrate the increased number of direct ties from SIR to niche and regime actors relative to the other innovation intermediaries (for instance with collaborative research projects) demonstrating the critical importance of SIR in fostering collaborative innovation within the niche network.

Table 8.4: Triple helix relational ties formed in the remanufacturing network through the introduction of SIR to the network – differentiating between niche and regime actors.

		With					Without					Difference With-Without					% Difference (With-Without)/Without				
		Regime	Niche	University	Public-sector	Innovation Intermediaries	Regime	Niche	University	Public-sector	Innovation Intermediaries	Regime	Niche	University	Public-sector	Innovation Intermediaries	Regime	Niche	University	Public-sector	Innovation Intermediaries
Frequency of Contact	Regime	52					48					4					8				
	Niche	4	2				2	0				2	2				100	N/A			
	University	28	5	0			14	3	0			14	2	0			100	67	0		
	Public-sector	34	9	7	20		26	7	7	18		8	2	0	2		31	0	0	0	
	Innovation Intermediaries	35/13	12/7	15/10	21/16	16/6	12	4	8	12	4	23/1	8/3	7/2	9/4	12/2	192/8	200/75	88/25	75/33	300/50
Knowledge Transfer	Regime	16					12					4					33				
	Niche	3	2				2	0				1	2				50	N/A			
	University	13	6	0			6	3	0			7	3	0			117	100	0		
	Public-sector	8	5	1	2		6	4	1	2		2	1	0	0		33	25	0	0	
	Innovation Intermediaries	20/2	8/3	6/1	8/3	2/0	2	1	1	2	0	18/0	7/2	5/0	6/1	2/0	900/0	700/200	500/0	300/50	N/A/0
Collab. Research Projects	Regime	12					8					4					50				
	Niche	2	2				1	0				1	2				100	N/A			
	University	19	3	0			7	1	0			12	2	0			171	200	0		
	Public-sector	8	5	0	2		6	4	0	0		2	1	0	2		33	25	0	N/A	
	Innovation Intermediaries	19/4	4/1	5/0	3/2	4/2	3	1	0	0	2	16/1	3/0	5/0	3/2	2/0	533/33	300/0	N/A/0	N/A/N/A	1000
Tech Transfer	Regime	24					22					2					9				
	Niche	2	2				1	0				1	2				100	N/A			
	University	17	3	0			8	1	0			9	2	0			113	200	0		
	Public-sector	6	4	2	0		6	2	2	0		0	2	0	0		0	100	0	0	
	Innovation Intermediaries	10/3	5/4	4/2	3/3	2/2	3	2	2	2	2	7/0	3/2	2/0	1/1	0/0	233/0	150/100	100/0	50/50	0/0
Cash Transfer	Regime	16					14					2					14				
	Niche	0	2				0	0				0	2				0	N/A			
	University	11	2	0			6	1	0			5	1	0			83	100	0		
	Public-sector	9	5	0	4		9	4	0	2		0	1	0	2		0	25	0	100	
	Innovation Intermediaries	2/2	0/0	5/1	3/2	4/2	2	0	0	1	2	0/0	0/0	5/1	2/1	2/0	0/0	0/0	N/A	200/100	100
IP Transfer	Regime	6					4					2					50				
	Niche	1	0				0	0				1	0				N/A	0			
	University	11	4	0			5	2	0			6	2	0			120	100	0		
	Public-sector	2	3	1	0		2	3	1	0		0	0	0	0		0	0	0	0	
	Innovation Intermediaries	2/1	3/2	2/0	1/1	2/0	0	0	0	0	0	2/1	3/2	2/0	1/1	2/0	N/A	N/A	N/A/0	N/A	N/A

Note:

1. The numbers under the column ‘With’ is number of ties between each triple helix group (including niche and regime actor groups and the ties formed by SIR). The number under the column ‘Without’ number of ties between each triple helix group excluding the ties formed by SIR.
2. The numbers under the Difference heading are the total increase or decrease in triple helix relational ties due to the presence of SIR. A positive number indicates and increase in ties. A negative number indicates a decrease in ties.
3. The number before the / for innovation intermediaries is the difference including ties to SIR, the numbers to the right of the / are the ties not including SIR as an innovation intermediary


Frequency of Contact

Total Knowledge

Collaborative Research Projects

Technology

Cash Transfer

IP Transfer

Figure 8.6: Sociograms displaying the niche-regime relational ties formed in the remanufacturing network through SIR.

Notes: 1. The sociograms were produced using the software NetDraw by Borgatti (2002). 2. Larger versions of these images can be found in Appendix IV. 3. Each line represents the formation of a new relational tie between two organizations due to the presence of SIR.

8.2.5 Centrality of SIR in the network

This case study completed an analysis of SIRs immediate network. This was based on the direct relational tie data gathered during the complete social network analysis data collection process. The aim of the egocentric network analysis was to empirically assess the size and composition of SIR's immediate network relative to all other network members and well as understand how centrally located SIR is in the network structure for each relational attribute.

The results of the analysis provide an insight into the level of power and influence SIR held over knowledge and resource flows as well as who entered and exited the network. NetDraw software was used to produce sociograms to offer a visual representation the location and structural centrality of SIR within the network relative to other network actors. The results of which are outlined in Figure 8.7. Table 8.5 displays the results of the egocentric analysis with regards to SIR's degree, closeness, betweenness and effective network size. As in the IBioIC case study, the table ranks the level of centrality held by SIR relative to every other network member.

Overall, SIR was ranked number one for all centrality indicators of all relational attributes apart from cash infusion and IP transfer. SIR maintained, on average, 5 times higher number of frequent contact ties than all other network actors and up to 7 times the number of collaborative research project ties. An actors' degree centrality only paints part of the picture however and does not explain SIRs ability to control or influence network flows nor bridge structural gaps across the network. As such the additional centrality measures of closeness and betweenness were measured as well as the effective network size (see Section 6.1.4.3 for full description).

SIR had far lower closeness and higher betweenness centrality values relative to all other actors for nearly all relational attributes apart from IP transfer. A low level of closeness centrality combined with a high level of betweenness implies that, not only did SIR have the shortest path length on average to all other network actors thereby aiding knowledge transfer and acquisition, but it also had the ability to monitor and control the flow of knowledge resources throughout the network – particularly between previously disconnected parts of the network.

The results in Table 8.5 demonstrate that SIR had an effective network size of between 5 and 10 times the network average for all relational attributes. The total knowledge transfer effective size for SIR was 32 compared to the network average of 2. Moreover, as observed for IBioIC, the effective size was close to SIR's total network size. For example, the total network size for knowledge transfer was 34. Thereby suggesting that only 2 out of the 34 actors held direct ties with each other and therefore SIR was bridging structural holes between the remaining 32 network actors. The effective size of SIR's technology, cash and IP transfer networks were much smaller than the other relational attributes, at 9, 5 and 4 respectively. Unlike IBioIC, SIR was the most central actor in the network for technology transfer ties and ranked in the top four most central actors for IP transfer. Yet, although SIR held high centrality in the more trust-based relational attributes, several other actors also held high levels of betweenness (see technology, cash and IP transfer sociograms in Figure 8.7) suggesting that SIR did not hold as much control and influence of these relational attributes compared to the likes of frequency of contact and knowledge transfer. The reasons for such differences between SIR and IBioIC centralities for increasingly trust based relational attributes are discussed in Sections 9.1.6 and 9.2.

Figure 8.6 presents sociograms for all the relational attributes. The size of each actor node is based on their 'betweenness' value. Therefore, the bigger the actor node the higher their betweenness is. The results of the centrality analysis visually demonstrate that SIR held a far higher degree of 'betweenness' than any other network actor. They also show that SIR was located in highly central locations with each relational attribute network. Such high betweenness suggests that SIR retained a certain level of influence over knowledge and resource transfer throughout the network. Maintaining some level of influence within the niche would better allow SIR to exercise its normative beliefs and steer the niche in a circular economy trajectory.

Table 8.5: Results from egocentric analysis of SIR with regards to its level of centrality in the remanufacturing network for each relational attribute compared to all 53 other network actors.

	Frequency of Contact				**Total Knowledge Transfer**				**Collab Res. Projects**			
Structural Characteristic	**SIR**	**Network Average**	**Network Median**	**Rank (out of 48)**	**SIR**	**Network Average**	**Network Median**	**Rank (out of 48)**	**SIR**	**Network Average**	**Network Median**	**Rank (out of 48)**
Degree	42	8	6	1	34	3.4	2	1	25	3	2	1
Closeness	66	108	106	1	91	153	133	1	109	174	160	1
Betweenness	535	22	2.7	1	749.00	25	0	1	555	25	0	1
Effective Size	36	5	3	1	32	2	1	1	23	2	1	1
	Tech Transfer				**Cash Infusion**				**IP Transfer**			
Degree	10	2.6	2	1	6	2	1	1	5.00	1.28	1.00	3
Closeness	186	262.00	229.00	1	204	281.00	248	1	283.00	387.90	354.00	1
Betweenness	156	20.40	0	1	119.00	22.00	0.00	1	144.00	17.00	0.00	3
Effective Size	9	2	1	1	5	1	0	3	4	1	0.00	4

Note: See Table 6.3 for a full definition for each type of centrality measure

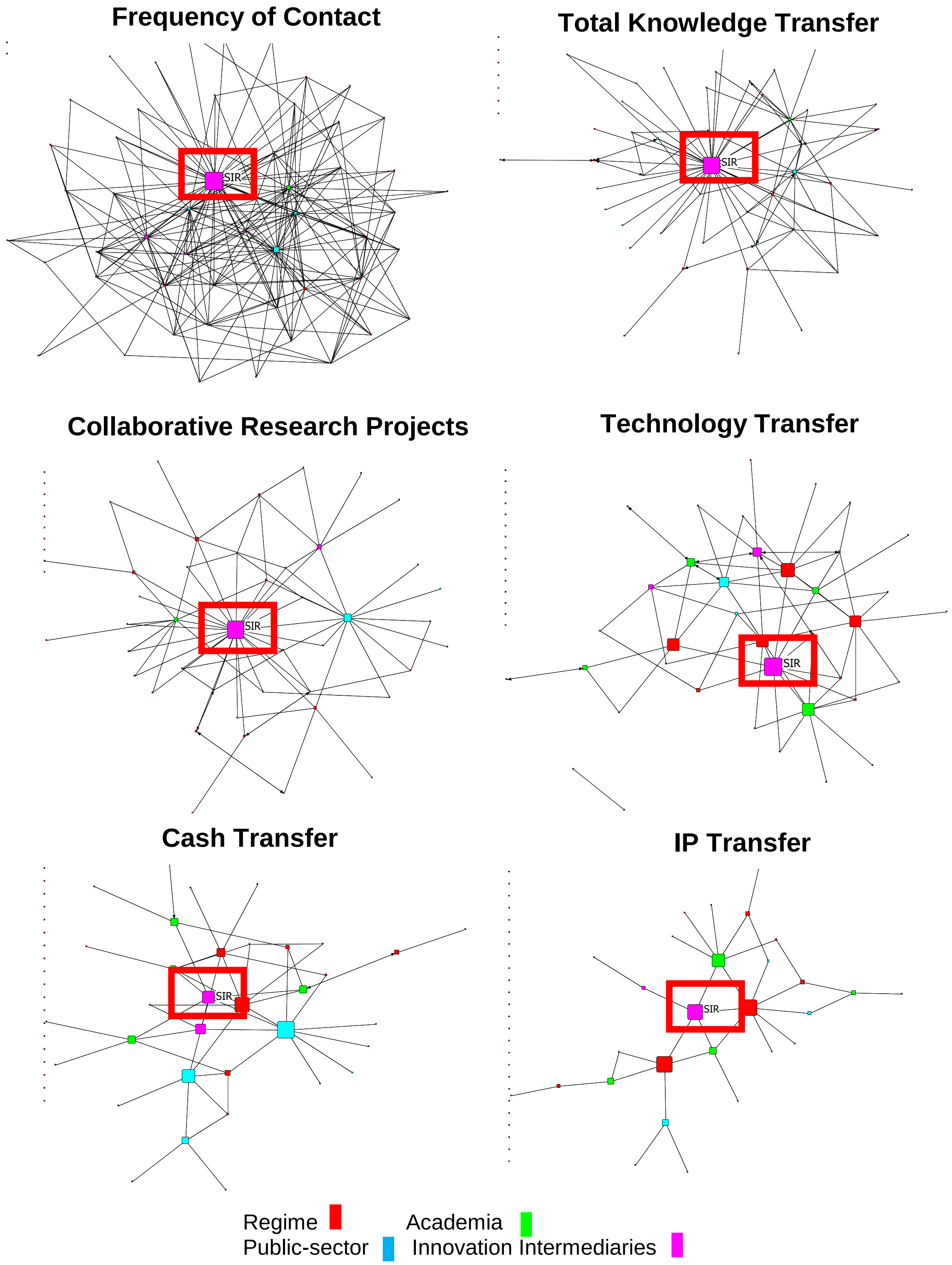


Figure 8.7: Network diagram of the remanufacturing network demonstrating the level of structural centrality held by SIR for all six relational attributes.

Notes: 1. The sociograms were produced using the software NetDraw by Borgatti (2002). 2. Larger versions of these images can be found in Appendix IV. 3. The size of the actor node is scaled by the value of betweenness of the actor compare to all other network member. SIR is the largest node located in the centre of the network and it is surrounded by a red box.

8.3 Qualitative data analysis

This section outlines the analysis of the data collected via the network member surveys and focus groups to strengthen and deepen the findings from the complete SNA in Section 8.2.

8.3.1 Network member perceptions of the utility of SIR as a niche manager

The following section outlines the results of the network member survey to measure the value each network member attributed to the 15 niche nurturing activities undertaken by SIR. Overall, the results demonstrated that SIR added value for all the nurturing activities outlined in Table 8.6. The top three activities where SIR provided the most value, as perceived by the network members, was technology assessment and evaluation, raising awareness of the circular economy and creation and facilitation of a remanufacturing network which scored 59%, 57% and 57% respectively. The activity with the lowest value added was the articulation of sector needs, expectations and requirements which provided a moderate level of value and achieved an average value of 34%. It was however more valued by academia than industry or public-sector agencies. SIR appeared to offer the most added value overall to academia, where the value added was believed to be high, achieving an overall added value score of 59%, relative to the 47% average from the other triple helix groups. Additionally, 12 of the 15 activities were ranked as adding high value or above by academia network actors.

Conversely, public-sector stakeholders, SMEs and industry only moderately valued SIR activities with an average score of 45% overall. However, they did rank the top 5 roles in Table 8.6 highly, particularly technology assessment and evaluation, raising awareness of the circular economy and the creation and facilitation of a remanufacturing network. The remaining 9 roles were only moderately valued by SMEs, industry and public-sector stakeholders.

Overall, SIR appears to have moderate success with regards to undertaking the 15 nurturing activities which support: (i) the articulation of expectations and visions; (ii) learning processes and exploration at multiple dimensions; and (iii) building of social networks. SIR has offered particular value to academia network members. However, they appeared to offer high-value to all triple helix groups for activities 1-5 outlined in Table 8.6.

Table 8.6: Results from SIR network member survey undertaken in February 2017 outlining triple helix actor opinion on the effectiveness of SIR in undertaking 15 nurturing activities undertaken by a triple helix-based niche manager

Rank	Niche Manager Activities	SME (n=16) (out of 5)	Non SME (n=8) (out of 5)	Academia (n=3) (out of 5)	Public-sector (out of 5)	Average Score (out of 5)	Average Score (%)
1	Technology assessment and evaluation	2.9	2.9	3.3	3.0	3.0	59
2	Raising awareness of the circular economy	2.9	2.6	3.7	2.8	2.9	57
3	Creation and facilitation of a remanufacturing network	2.9	2.6	3.7	2.8	2.9	57
4	Acceleration of the application and commercialisation of new technologies	2.6	2.6	2.7	2.6	2.6	53
5	Communication and dissemination of knowledge	2.5	2.4	3.3	2.8	2.6	52
6	Configuring and aligning interests	2.5	2.5	2.7	2.5	2.5	50
7	Advancement of sustainability aims	2.0	2.3	3.5	2.4	2.3	45
8	Knowledge gathering, processing, generation and combination	2.0	2.3	3.5	2.4	2.3	45
9	Creating conditions for learning by doing and using	2.3	2.1	2.7	2.0	2.2	45
10	Finding potential funding and funding activities	2.3	2.1	2.0	2.0	2.2	44
11	Provision of advice and support	2.1	2.1	2.0	2.3	2.1	42
12	Influencing policy	2.1	1.9	2.0	2.4	2.1	41
13	Education and training	1.8	2.5	2.7	1.7	2.1	41
14	Sector strategy development	1.6	1.9	2.7	1.0	1.7	35
15	Articulation of sector needs, expectations and requirements	1.6	1.6	2.7	1.3	1.7	34
	Average Score:	2.3	2.3	2.9	2.3	2.3	
	Average Score (%):	45	46	57	45	47	

Notes:

1. Level of service into five categories: Very High (5)(81%-100%), High (4)(61%-80%), Moderate (3)(41%-60%), Low (2)(21%-40%), Very Low (1)(1%-20%) and None (0)(0%).
2. Average score in % is produced by dividing the average score by 5.

8.3.2 Network member perceptions of the governance structure of SIR

The following section outlines the results of the network member survey to measure the value each network member attributed to SIR’s ability to broker triple helix interaction and the necessity of the presence of SIR in the network to build consensus between the triple helix actors. A total of 30 network organizations responded to the survey from a total of 42.

When asked the question "to what extent SIR acted as an effective broker between the public-sector, industry and universities with regards to re-use?" all the respondents attributed some level of value to the triple helix brokering service offered by SIR (Figure 8.8). A total of 73% of respondents found SIR to be an effective triple helix broker. A further 40% believed SIR was very effective and 10% extremely effective. All public-sector stakeholder respondents valued such a brokering service as very effective or extremely effective suggesting SIR was a valuable broker between the public-sector and niche actors.

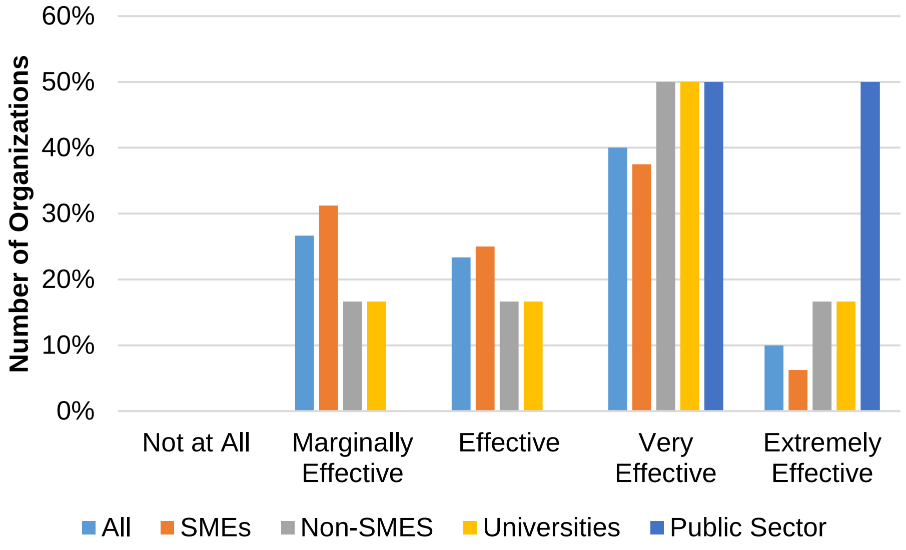


Figure 8.8: Remanufacturing network member responses to the questions: To what extent has SIR acted as an effective broker between public-sector, industry and universities with regards to remanufacturing?(n=30)

When asked the question "to what extent is the presence of SIR required to build consensus between industry, academia and government around a future vision for re-use, re-distribution, repair, re-conditioning or remanufacturing in Scotland?", all the respondents believed presence of SIR was, at least, required a little to help achieve consensus (Figure 8.9). A total of 73% of respondents believed such a broker is required and nearly half believed it was essential. All public-sector respondents believed the presence of SIR to achieve niche consensus was essential. Thus SIR held a high level of legitimacy as a niche network manager. Human and Provan (2019) outlines that legitimacy in an innovation network is essential for attracting external actors and resources and hence its expansion. It is important to note that the public-sector stakeholder respondents where not the direct funders of SIR and so did not have any 'skin in the game'.

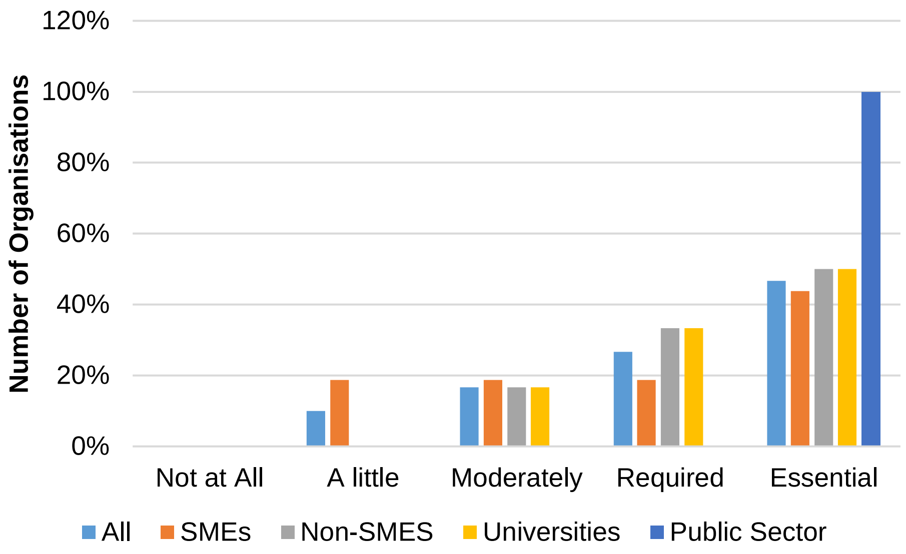


Figure 8.9: Remanufacturing network member responses to the question: To what extent is the presence of SIR required to build consensus between industry, academia and government around a future vision for re-use, re-distribution, repair, re-conditioning or remanufacturing in Scotland? (n=30)

8.3.3 Identifying the nurturing and empowerment activities undertaken by SIR on the niche innovation network

During the focus group, the SIR business development staff responsible for managing the network identified 26 nurturing and empowering activities undertaken by SIR between January 2014 and March 2018 (Table 8.7). The services SIR offered ranged from inward facing activities such as interaction with individual niche network members such as network member workshops, events and lectures, one-to-one consultations and focussed working groups to outward facing activities such as external referrals and hosting the Re-made award at the National Manufacturing Awards.

Eleven of the 26 roles were identified by the focus group to play a dual inward and outward facing roles which brought the niche and external actors together. These activities included funding joint collaborative research projects and attending a wide range of events that were not specific to remanufacturing to raise awareness on the topic to external actors. SIR appeared to value the inward and both inward and outward facing roles over specifically outward facing roles.

Table 8.7: Results from SIR focus group exploring the inward and outward facing activities undertaken by SIR in which the most effective activities were identified and ranked according to their impact on the nurturing and empowerment objectives of the protected space

		Nurturing Roles				**Empowering Roles**	
	SIR Activities	**Building Networks**	**Stimulating Learning (1st Order)**	**Stimulating Learning (2st Order)**	**Expectations**	**Fit and Conform**	**Stretch and Transform**
Inward	SIR Workshops, events, lectures	7	3	2	5	5	5
	One to One Consultations	-	2	4	4	7	7
	Focused Working Groups	8	-	3	7	8	8
	Newsletters	-	6	-	8	-	-
	Regular Board meetings	-	10	-	-	-	-
	Research Projects	-	-	10	-	12	12
Both	Funding Collaborative KE Projects	1	-	1	-	1	1
	Attending External Events	3	4	-	1	2	2
	Building Partner relationships	2	-	-	3	4	4
	Participating in Partner Events	4	5	-	2	3	3
	SIR Conference	5	1	7	6	6	6
	Introductions	-	7	6	10	-	-
	Case studies	-	8	9	9	9	9
	One stop information source	-	9	8	11	-	-
	Academic Outreach	6	12	5	14	11	11
	Reports and Publications	-	-	-	-	-	-
	Media releases	12	-	-	13	-	-
Outward	Referrals	9	-	-	-	-	-
	Referrals to other services	-	-	-	-	10	10
	International Partnerships	11	-	-	-	-	-
	Informing Policy/Public-sector	-	-	-	12	-	-
	Re-made award	10	13	-	15	-	-
	Public Outreach	-	-	-	-	-	-
	Influencing Manufacturing Policy…	-	-	-	-	-	-

Notes:

1. Fit and Conform and Stretch and Transform activities columns are identical as the focus group believed the roles played an identical role for both.
2. The focus group was permitted to select up to 15 activities per nurturing and empowering function – however, in some cases a total of 15 were not selected.
3. The focus group ranked the selected activities from 1-15

The most valued roles for building the network were identified to be a combination of funding collaborative research projects, building partner relations and maintaining a presence at external events to the niche through attendance and presentations. With regards to stimulating 1st order learning, SIR identified the annual SIR conference, one-to-one consultations and hosting workshops, events and lectures as the most valuable activities. Yet, for stimulating 2nd order learning, collaborative research projects, focussed working groups and hosting workshops events and lectures were identified as most valuable. With regards to stimulating shared expectations of remanufacturing both within and outside the niche, the roles of attending external events, building partner relationships and participating in partner events were identified as most valuable.

The SIR focus group believed that 12 of their activities equally contributed to both ‘fit and conform’ and ‘stretch and transform’ empowerment. The funding of collaborative research projects, maintaining a presence at external events and participating in wider partner events existing out with the niche were believed to be the most valuable empowering activities. However, SIR also believed they played a critical network integrator role by maintaining close relations and forming partnerships with public-sector organizations existing out with the network. The fact that SIR identified both ‘fit and conform’ and ‘stretch and transform’ activities suggests an important normative difference to IBioIC with regards to their role as a niche network manager. This is explored in further depth in Chapter 9:.

8.4 Evaluating the effectiveness of SIR in nurturing and empowering a niche innovation network

This thesis outlined the hypotheses that a triple helix-based niche manager would be an effective niche network manager for circular economy-oriented niche innovation networks. In particular, Section 4.4 outlined that by sitting in the institutional overlap between all three triple helix groups, a triple helix intermediary would better provide nurturing and empowering services to the niche compared to traditional niche managers or innovation intermediaries.

The results of the SIR case study support the hypotheses of this thesis by demonstrating that the introduction of SIR into the Scottish remanufacturing network, as a triple helix-based niche manager, had a significant positive effect in terms of the level of niche nurturing by building social networks, facilitating shared learning and promoting shared expectations. Moreover, SIR played a critical brokerage role between the niche and wider niche and circular economy activities and as such, helped to empower the niche with regards to its ability to align with and in some case challenge the incumbent linear manufacturing sector. The remainder of this section discusses the findings in more depth.

8.4.1 Ability of SIR to nurture the niche network: building social networks

SIR was established under the mandate to manage the remanufacturing niche at the national level rather than the individual at the experiment level, which a traditional SNM manager would undertake. This difference in focus towards the wider niche rather than the individual experiment has resulted in SIR playing a key role in the expansion and interconnectedness of the existing niche network. As such, the network members identified that the third most value-added role that SIR played was in the creation and facilitation of the remanufacturing network.

In the space of two years, SIR was responsible for increasing the network size in terms of organisations participating in knowledge transfer from 31 to 45 and collaborative research projects from 29 to 43 members which included a mixture of local SMEs, international firms, universities and public-sector stakeholders. Importantly, SIR was able to widen and expand the number of actors participating in more intimate trust-based relationships necessary for systemic innovation such as technology transfer, where the number of active actors increased from 17 to 28 actors.

SIR was also able to increase the number of traditional manufacturers to the network, who would be considered regime actors. As such, SIR increased the level of collaborative research projects between niche and regime actors by 100% which is believed to be critical to the long term success of the niche as a whole (Smith and Raven 2012). It was, however, more successful at connecting regime and niche actors with universities whereby collaborative research project ties increased by 171% and 200% respectively.

The complete social network analysis powerfully demonstrated the impacts of SIR on the building of the network. Overall, the number of high frequency communication ties increased by 65% and knowledge transfer ties increased by 154%. Perhaps more importantly, the number of more trust-based and intimate relational ties such as collaborative research projects and IP transfer increased by 179% and 127% respectively.

As a niche manager, co-governed by representatives from the triple helix groups, SIR was able to broker a very high number of structural holes existing between the three institutions. As such, the brokering services of SIR led to higher levels of collaboration between the triple helix groups, for example knowledge transfer between industry and public-sector stakeholders increased by 30% and collaborative research project ties increased between academia and industry by 175%. The results of the network member survey agreed with the SNA results and showed that 73% of survey respondents believed SIR to be an effective broker between the three triple helix institutions and 40% believed SIR to be very effective.

Asides from increasing the size of the network and the total number of relational ties, SIR was also able to build a more stable and robust network structure that is better able to cope with the potential impacts of powerful actors leaving or entering the network. For instance, although the level of connectivity increased within the network, the presence of cohesive subgroups remained relatively the same thereby preventing the formation of strong cliques leading to knowledge lock-in and thus prevention of knowledge transfer to other parts of the network easily. Furthermore, the overall level of network centralisation increased. As discussed in Section 6.1.4.1, an increase in centralisation creates a more robust network both to endogenous and exogenous shock. It also increases the chances that network members are working towards a shared outcome. However, due to the exceptionally high level of centrality held by SIR, there is the risk of network fragmentation if the funding for SIR were to be suddenly removed.

8.4.2 Ability of SIR to nurture the niche network: facilitating shared learning

The wide spread diffusion of remanufacturing processes requires the implementation of new product design approaches, business models and reverse logistics supply chains as well as the uptake and development of a suite of new technologies ranging from real time product condition monitoring and tracking to component cleaning, inspection and remanufacturing technologies. As such, the transition from remanufacturing as a niche to mainstream economic activity dependent on effective and efficient generation, transfer and use of knowledge and resources amongst universities (knowledge producers), industry (knowledge users) and the public-sector (knowledge regulators) (Etzkowitz 2003). Both the network analysis and qualitative analysis demonstrated that SIR, as a system level broker between the triple helix institutions, was able to increase the level of knowledge exchange within and between the triple helix groups.

Out of the 15 intermediary nurturing roles performed by SIR, the role of communication and dissemination of knowledge was identified by network members as the fourth most valuable service offered. This aligned with the results from the SIR focus group, whereby the group identified a range of activities they undertook to stimulate both first and second order collaborative learning including an annual conference, one-to-one expert consultations and hosting workshops, events and lectures, identifying as well as funding collaborative research projects and focussed working groups.

The results from the network member survey and the SIR focus group aligned with the empirical results from the complete social network analysis whereby SIR was responsible for an increase of knowledge transfer of 154% across the entire network. More crucially, knowledge transfer between the triple helix institutions increased. For instance, knowledge transfer between academia and industry increased by 111%, public-sector and other intermediaries (including SIR) increased by 300% and public-sector and industry increased by 30%.

By holding the role of network manager of the whole network, SIR was crucially able to broker knowledge transfer between public-sector and the rest of the niche network. It is therefore argued that SIR helped lay the foundations for better coordination and enforcement of niche-oriented policy and hence the introduction and withdrawal of appropriate public-sector support, which is a critical objective of SNM.

Second order learning was particularly enhanced through the increase in collaborative research project ties by 179%. As a network actor, SIR was identified to be the most central node for knowledge exchange. By holding such a high level of centrality, SIR was also able to maintain a high level of control and influence over the direction and type of knowledge exchange throughout the network, as identified in the focus group. As such, SIR was able to significantly raise awareness and learning throughout the network of Scotland’s wider circular economy transition.

As discussed in the section above, SIR was able to increase the overall density and centralisation of the network without the formation of overly connected cliques. The brokerage undertaken by SIR therefore helped construct a network structure which is less susceptible to knowledge lock from structural gaps and enhances the chances for knowledge exchange across different parts of the network.

8.4.3 Ability of SIR to nurture the niche network: promoting shared expectations

It is important for the development of the niche that credible expectations of the potential success of the technologies are driving the niche. If expectations are too low, the niche innovations will struggle to emerge from the niche as they will attract little buy-in and resources from the regime actors. However, if expectations are too high, innovations will struggle to meet such high standards. As such, confidence and political support for the niche drops quickly and the niche eventually withers and dies. Therefore, the development and communication of sensible expectations is a critical role of the niche manager.

Establishing realistic expectations within the niche network is challenging for the remanufacturing niche network. Unlike traditional niches discussed in the SNM literature, which are based around a single technology, remanufacturing encompasses a broad range of technologies and stakeholders from several different value chains ranging from automotive, aerospace and textiles to ICT and electronics. Therefore, it may not necessarily be realistic for SIR to try to articulate global shared expectations on the topic of remanufacturing – particularly as one actor – rather create the conditions for effective knowledge exchange and collaboration to occur between actors with which expectations to emerge and evolve naturally over time.

The network member survey results highlighted that, out of all the intermediary roles SIR played, its ability to articulate sector needs, expectations and requirements was ranked the lowest value-adding activity. This finding is at odds with the results from the IBioIC network member survey where IBioIC's ability to articulate sector needs and expectations was very high. One hypothesis is that awareness within the manufacturing industry of the circular economy and remanufacturing appeared to be low relative to the industrial biotechnology sector where knowledge of the core technology was high and expectations had already been clearly set by the National Industrial Biotechnology Roadmap (Life Sciences Scotland 2014). A second hypothesis is that the industrial biotechnology sector is much more dependent on a shared vision of the future in which industrial biotechnology is a mainstream technology used for biorefining and displaces the current dominant fossil fuel regime. Whereas remanufacturing, in some senses, has existed for half a century within the regime and actors do not necessarily require a united front to destabilize the niche, rather it is dependent on the actions of individual manufacturers.

Although SIR was identified as offering moderate value with regards to building shared expectations, the egocentric analysis highlighted the highly central position it held within the network. Being the most central actor in a network comprised of actors from a range of different traditionally disconnected value chains and sectors, SIR was able to broker an order of magnitude higher number of structural holes relative to any other network actor and as such, stimulate knowledge and resource exchange to occur between previously disconnected areas of the network. In particular, SIR increased the number of collaborative research projects, IP, cash and technology transfer ties between triple helix institutions significantly. By increasing such ties, SIR increased the likelihood of the emergence of a triple helix consensus space within the network (as discussed in Section 4.1). A consensus space, where institutional overlap can occur, encourages the build-up of social capital and hence the efficiency of collaborative activities and build-up of recombinant knowledge necessary for successful systemic innovation (Lungeanu and Contractor 2015).

This high centrality and level of brokerage suggests that although SIR was not able to successfully individually articulate sector needs, expectations and requirements, it was effective in laying the structural foundations within the network for dialogue around shared expectations to emerge.

Furthermore, the network member survey results suggest that the network members believed SIR’s ability to communicate and disseminate knowledge throughout the network as well as configuring and aligning the interests of the network as some of the most valuable roles. This suggests that perhaps the remanufacturing network was at a very early stage in its development compared to the industrial biotechnology network and as such, before shared expectations could be articulated, the network required an increased awareness around the topic of circular economy and remanufacturing, increased knowledge sharing and collaboration and experimentation with which to build enough social capital for shared expectations to emerge. One could also argue that the physical existence of SIR was in of itself an effective tool to help raise expectations by demonstrating the public-sectors confidence in the topic.

SIR undertook a range of specific activities and events targeted at raising expectations for the potential of remanufacturing. SIR was influential in the revision of the Scottish Manufacturing Action plan, in which remanufacturing was identified as a promising area for growth within the Scottish economy and the Government’s priority area for stimulating innovation. They also maintained a public presence at external events, built partner relationships funded a national remanufacturing award.

An important finding of this case study, as with the IBioIC case study, was SIR’s ability to strengthen collaborative ties between regime actors and the rest of the network. By increasing innovation collaboration between these two groups, the likelihood of regime adoption and scaling of such innovations is more likely to occur. By demonstrating regime support and interest in remanufacturing, SIR was able to increase awareness around the legitimacy of remanufacturing and as such, raise expectations throughout the wider network.

8.4.4 Ability of SIR to empower the overall niche network

The SIR focus group identified a wide range of outward facing activities performed by SIR which directly contributed to the empowerment the protected space network. The results suggested that such a wide range of activities could be performed due to the governance structure and broad mandate of SIR.

SIR initiated, funded and publicised collaborative research projects and raised awareness of remanufacturing out with the niche network at high profile external events. Perhaps more importantly, SIR acted as a knowledge conduit from the niche network to the wider innovation system in Scotland and internationally. Figure 8.10 demonstrates how SIR acted as a gateway broker between the niche network and the wider Scottish innovation system as well as international initiatives and networks. For example, they received referrals from other innovation system actors such as the Scottish Manufacturing Action Service (SMAS) who recommended industrial organisations who would benefit from participating in the network. Another example was their partnership with Zero Waste Scotland who provided referrals for actors who would not traditionally have fit the remit for participating in the network – but who offered potential for cross-pollination of ideas and knowledge, for example reverse logistics companies who are looking for new ways to grow their business. SIR was also influential in the drafting of the national manufacturing strategy ensuring that remanufacturing was identified as a priority with the strategy. They were also able to attract external funding to the network due to the close ties with public-sector bodies who sat as observers on the governance board.

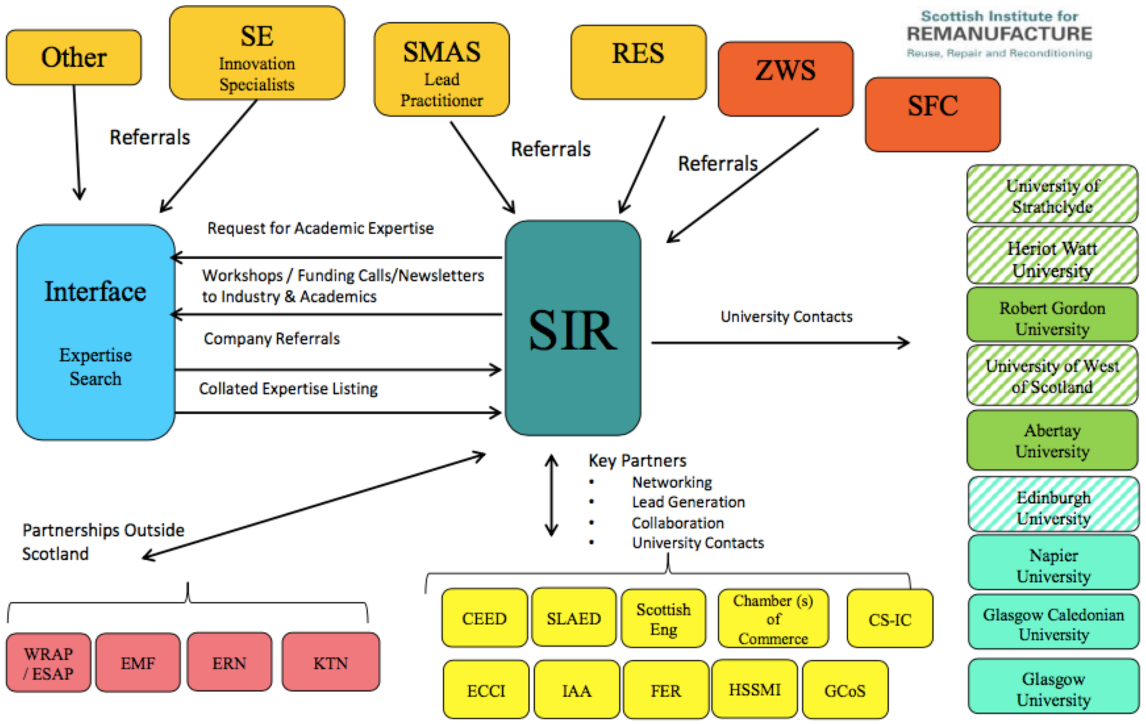


Figure 8.10: SIR acting as gateway for niche innovators to the wider Scottish innovation system and international networks (Source: SIR (2018))

SIR also connected niche actors with international networks and programmes such as the Innovate UK Knowledge Transfer Network (KTN) which provides a wide range of sector specific innovation support or the Ellen MacArthur Foundation which connects global businesses with niche innovators. Perhaps the most important outward facing role where SIR connected the network actors with global niche developments was being an ambassador for the niche network organisations as a member of the European Remanufacturing Network which lobbies the European Commission on easing existing barriers to undertaking remanufacturing activities in Europe. These are all examples of outward facing roles which are ideally suited to a triple helix-based niche manager which is nested within and co-governed by the network actors and therefore capable of connecting internal niche dynamics with external opportunities.

The empowering effects of such activities were made evident in the results of the complete social network analysis which demonstrated where SIR was able to connect network actors with traditionally external innovation intermediaries. These intermediaries provided additional expertise and resources as well as helped expand the niche innovations out with the niche by connecting the niche innovators with into their wider networks. In addition, SIR increased the number of collaborative research project ties with regime actors spanning multiple regimes thereby increasing the chances of the output from the niche aligning with the needs of the regime thus increasing the chances of widespread adoption. This also helped facilitate increased niche-multi regime interaction which was outlined as important for a systemic circular economy transition.

Although SIR was able to integrate the network members into the wider innovation system as well as global niche networks, the uptake in remanufacturing processes and technologies remains constrained due to the existing policy and business environment. For example, in the EU, there are currently unresolved legal issues surrounding producer compliance, particularly around the use of Extended Producer Responsibility (EPR) to encourage producers to collect their products post use and increase the number of repaired or refurbished components within new products added to the market. However, remanufacturing third parties are wary of being classed as a ‘producer’ as they would become economically responsible for collecting and recycling any remanufactured product they put on the market. In addition, there are particular complications surrounding whether remanufacturing of a product by an organisation which is not the original equipment manufacturer (OEM) breaches intellectual property and therefore there is the risk of legal action brought by the OEM (Maitre-Ekern and Dalhammar 2016). Such barriers to scaling remanufacturing activities likely lies outwith the capacity of a triple helix-based niche manager responsibilities.

Chapter 9: Comparing results from SIR and IBioIC case studies

Chapter 7 and Chapter 8 comprised of individual case studies of IBioIC and SIR respectively. However, to build a deeper understanding of the ability of a triple helix-based niche manager to strategically manage different types of inner-loop niche innovation networks, a comparison of the two case studies is required. This chapter therefore compares the results of the case study results for both IBioIC and SIR. As such, it explores the similarities and differences in their abilities to nurture and empower two very different niche innovation networks.

9.1 Nurturing circular economy niche protected spaces

The case studies of IBioIC and SIR assessed their ability to achieve three key nurturing outputs: (i) building networks; (ii) increasing shared learning; and (iii) facilitating shared expectations. To assess each intermediary's respective impact on the three nurturing outputs, their impact on key structural aspects of the niche networks which influence the nurturing outputs was assessed. The following section compares and contrasts the ability for IBioIC and SIR to enhance the structural aspects of the niche networks and hence their ability to nurture their respective niche innovation network.

9.1.1 Industrial biotechnology and remanufacturing niche network composition and maturity levels

Before comparing IBioIC and SIR's impact on the networks, it is useful to understand the differences in the composition and maturity level of the niche networks they were tasked to manage. Table 9.1 outlines the composition of each network with respect to the percentage of actors within each triple helix group. Both networks were of similar size and composition with regards to the numbers of triple helix actors at the time of the study. The industrial biotechnology network consisted of 36 companies spanning 4 sectors, and the remanufacturing network had 35 companies across 7 sectors.

IBioIC had a higher proportion of universities (30%) and niche actors (17%) participating in the network compared to the SIR network where universities and niche actors each made up 11% each. SIR had a much higher proportion of regime actors (55%) in the network relative to the IBioIC network (39%). As such, the IBioIC network was more evenly distributed in terms of niche-regime and university-industry-public-sector participation and that the SIR network was heavily comprised of regime actors. An additional observation is that both networks did not contain any civil society and third sector groups such as charities, advocacy groups or community groups.

Table 9.1: Initial niche network structural characteristics of the industrial biotechnology and remanufacturing networks

	Industrial biotechnology network		*Remanufacturing network*	
Relational Attributes	**Total number of organizations**	**% Proportion of network**	**Total number of organizations**	**% Proportion of network**
Industry	36	56%	35	66%
Regime	*25*	*39%*	*29*	*55%*
Niche	*11*	*17%*	*6*	*11%*
Universities	19	30%	6	11%
Public-sector Stakeholders	5	8%	6	11%
Innovation Intermediaries	4	6%	6	11%

Although the composition of the two networks appears similar in terms of number and diversity of actors, Figure 9.1 demonstrates that the IBioIC network was much more active for the likes of collaborative research projects, technology and cash transfer ties compared to the SIR network. The relational ties in Figure 9.1 are ties that were formed independent of the brokering activities of IBioIC or SIR.

Figure 9.1 also highlights that the industrial biotechnology and remanufacturing networks were in different maturity phases when IBioIC and SIR were established. Lopolito et al. (2011) identified that the maturity of a niche can be partitioned into four phases: (i) absent; (ii) embryonic; (iii) proto-niche; and (iv) fully developed.

Based on the four maturity phases outlined by Lopolito et al. (2011), the industrial biotechnology network could be identified as a ‘proto-niche’ in which there was high willingness amongst actors involved in the network as evidenced by existence of a shared vision through the Scottish Industrial Biotechnology Roadmap which was produced through collaboration between industry and public-sector agencies. Furthermore, willingness was also demonstrated through the number of pre-existing collaborative research projects occurring across the network and the existence of a handful of powerful actors such as large pharmaceutical companies which have the resources to progress the niche to a ‘Full’ state. However, knowledge transfer across the network was identified to be poor and there was little evidence of a converging or dominant design and as such IBioIC was formed to bridge the knowledge transfer gap and accelerate such a convergence.

The fragmented SIR network on the other hand, as evidenced in Figure 9.1, would more likely fit the description of sitting between an absent and embryonic state. There was no articulated vision within the niche, there was little to low knowledge transfer and low levels of collaboration. SIR was therefore established principally to help raise basic awareness and expectations around the potential for remanufacturing and develop the network into a proto-niche through funding industry-university collaborative research projects and to bring in powerful external actor who could inject resources and build legitimacy around the niche technology options.

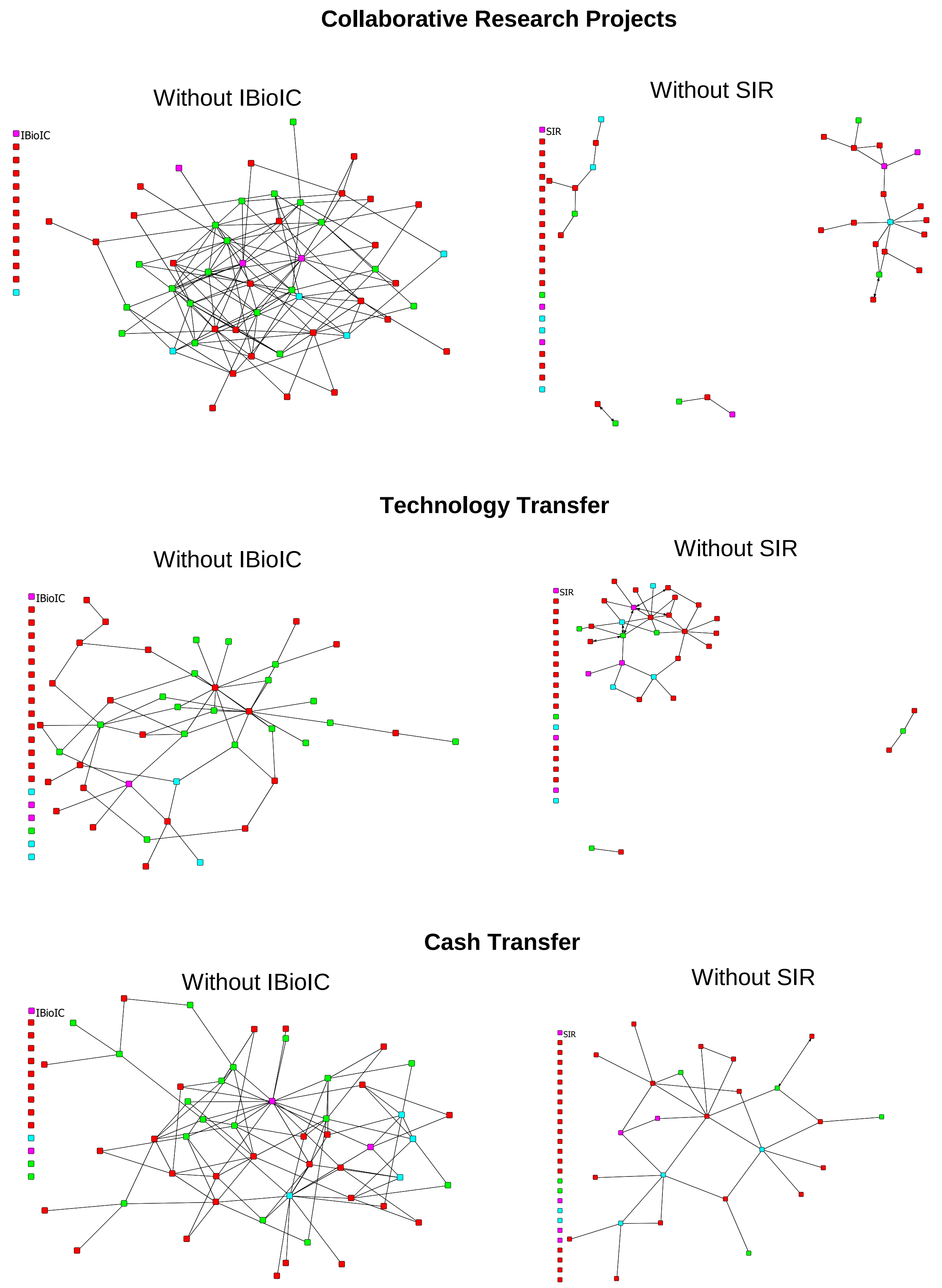


Figure 9.1: A comparison of the differences in interconnectedness and maturity of the remanufacturing and industrial biotechnology networks (excluding any ties formed or actors added by IBioIC and SIR)

9.1.2 Ability of IBioIC and SIR to broaden the networks

In light of the different maturity phases and network compositions, this section looks at how IBioIC and SIR were able to build the niche networks. In the case of this thesis, building niche networks has been divided into two categories: (i) increasing the breadth of the network, i.e. bringing in new actors in the network; and (ii) increasing the depth of the network, i.e. increasing the level of connectivity across the network. This section explores how effective IBioIC and SIR were at increasing the breadth of the network.

Table 9.2 compares the number of actors IBioIC and SIR added to the network for each relational attribute. Although SIR and IBioIC inherited the niche innovation networks in different stages of development, both intermediaries were able to increase the size their respective networks for all relational attributes. However, SIR was more successful than IBioIC at increasing the absolute number of network members. This is likely due to the IBioIC network already being relatively well developed. In other words, the actors that should be in the IBioIC network are likely already in it. SIR was particularly effective at attracting external actors to participate in knowledge transfer, undertake collaborative research projects and transfer IP which are critical to progressing an embryonic niche towards a proto-niche maturity.

Table 9.2: A comparison of the number of new network actors brokered into the industrial biotechnology and remanufacturing networks due to IBioIC and SIR for each relational attribute

	Number of Network Actors				**% Difference**	
Relational Attribute	**Without IBioIC**	**With IBioIC**	**Without SIR**	**With Sir**	**IBioIC % Difference**	**SIR % Difference**
Frequency of Contact	63	64	47	51	2%	8%
Knowledge transfer	53	56	31	45	6%	31%
Collaborative Research Projects	51	59	29	43	16%	33%
Technology Transfer	43	47	31	38	9%	18%
Cash Transfer	52	58	29	34	12%	15%
IP Transfer	34	45	17	28	32%	39%

9.1.3 Impact of IBioIC and SIR on the structural aspects of the networks

In addition to broadening the network, both SIR and IBioIC increased the total number of ties and network density for each relational attribute thereby increasing the depth of the network (Table 9.3). It is evident from Table 9.3 that SIR was more effective than IBioIC with respect to percentage increase of ties. For example, SIR increased total knowledge transfer ties and collaborative research projects by 154% and 179% whereas IBioIC increased them by 64% and 63% respectively. This is likely due to the low initial density of the network compared to the industrial biotechnology network. Conversely, IBioIC was more effective at increasing the absolute total number ties. For example, SIR increased total knowledge transfer ties and collaborative research projects by 108 and 100 whereas IBioIC increased them by 172 and 164 respectively.

Figure 9.3 offers a visual representation of the difference in the total number of ties produced by IBioIC compared to SIR for all relational attributes. It is particularly evident for high trust based relational ties where IBioIC brokered 30 more IP transfer and 106 more cash transfer ties than SIR. This difference may be due to the edge IBioIC had over SIR in terms of higher budget allocation to stimulate such an increase. It may also reflect the fact that the existing culture of the industrial biotechnology network was more open to knowledge exploration through increasing relational ties.

In-line with the increased density and number of ties, the presence of both intermediaries induced a path length reduction for all relational attributes. Although IBioIC brokered far more relational ties than SIR in absolute terms, SIR was able to reduce the average path length between all network actors for the weaker ties with respect to frequency of contact, knowledge transfer and collaborative research projects due to the initially fragmented condition of the network. IBioIC was more effective at reducing the path length for the stronger ties regarding technology, cash and IP transfer. This suggests that due to the increased maturity of the industrial biotechnology network and its embedded culture of collaboration, the network was more open to trust-based collaboration compared to the remanufacturing network. As such, SIR would likely require more time to nurture such a culture within the network and would require more funding than IBioIC to help overcome this cultural difference.

Table 9.3: Changes in structural network values for each relational attribute with respect to the impact of IBioIC and SIR - showing the significant positive impact of intermediaries on almost all measures of centrality.

Relational Attributes	**Δ *Network Density***		**Δ *Total Number of Ties* (Without→With) *(%Δ)***		**Δ *Path Length (%)***		**Δ(CC-D)/CC**		**Δ *Centralisation Index (%)***	
	(Without→With)	(Without→With)	(Without→With)	(Without→With)						
Frequency of Contact	0.242→0.315	0.094 →0.156	976→1270(30)	260→430(65)	-12%	-21%	-3.8%	-13%	125%	159%
Total Knowledge Transfer	0.067→0.11	0.025→0.065	270→442(64)	70→178 (154)	-18%	-41%	5.0%	5%	133%	359%
Collaborative Research Projects	0.065→0.106	0.020→0.057	262→426(63)	56→156 (179)	-14%	-19%	11.8%	10%	105%	86%
Technology Transfer	0.030→0.046	0.030→0.051	120→186(55)	82→140 (71)	-30%	-7%	N/A	0%	0%	-1%
Cash Transfer	0.049→0.084	0.023→0.036	198→340(72)	64→100 (56)	-26%	7%	6.4%	-8%	149%	19%
IP Transfer	0.015→0.032	0.011→0.025	60→128(113)	30→68 (127)	-38%	-8%	20.6%	N/A	226%	176%
	IB	**Reman**	**IB**	**Reman**	**IB**	**Reman**	**IB**	**Reman**	**IB**	**Reman**

Notes:

1. IB = Industrial biotechnology network; Reman = Remanufacturing network
2. The number under the column ‘With’ is the relational attribute value including the ties formed by IBioIC/SIR. The number under the column ‘Without’ is the relational attribute value without the presence of IBioIC/SIR.
3. For Path Length: A negative number indicates that the average path length has reduced between network members
4. For Centralization Index: A positive number indicates a % increase in value due to the presence of IBioIC/SIR. The % value was calculated by taking the ratio between the centralisation index value including any ties directly formed through IBioIC/SIR and the centralisation index value not including any ties formed directly through IBioIC/SIR and then converting the ratio to a % change.
5. Only frequency of contact identified as being once every quarter or more were included in the analysis
6. Ratio between Density and Clustering Coefficient: The increase or decrease in presence of cohesive sub-groups was calculated by examining the ratio of the clustering coefficient value with the density values for both before and after the introduction of IBioIC/SIR to the network. The formulae recommended in UCINET 6.1 of (Clustering Coefficient-Density)/Clustering Coefficient was used to estimate the level of clustering relative to density for the network with relational ties formed by IBioIC/SIR included and without them included. The results of which were then compared to assess the difference.

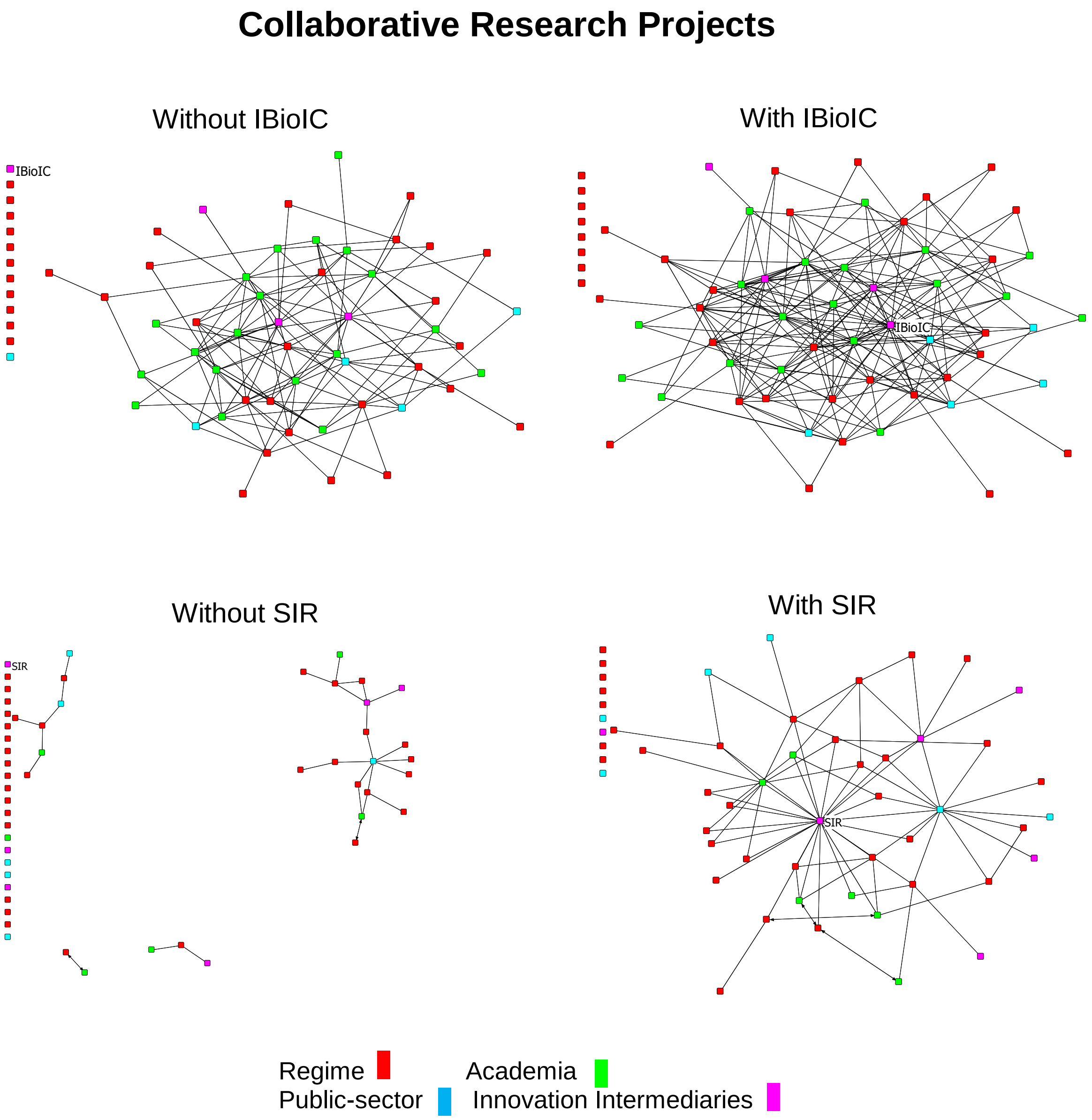


Figure 9.2: Sociograms demonstrating the change in number of collaborative research project ties of the industrial biotechnology and remanufacturing networks due to the introduction of IBioIC and SIR

The ratio between the change in network density and the change in clustering coefficient was calculated to determine if each intermediary increased the presence of cohesive subgroups in the network compared to the level prior to the introduction of the intermediary. The results suggest that although the density increased for both intermediaries for all relational attributes, the increase in density varied significantly from 30% to 179% and the level of clustering experienced a much lower increase or decrease of between -13 and 20.6%. This suggests that both intermediaries were able to avoid the formation of overly connected cliques and the associated danger of knowledge lock-in whilst increasing the overall connectedness of the network

The introduction of the intermediaries to both networks led to an increase in network centralization for all relational attributes, apart from technology transfer, which did not experience a change in centralization. For example, knowledge transfer centralization increased by 133% for IBioIC and 359% for SIR. The ‘collaborative research projects’ centralization index increased by 105% for IBioIC and 86% for SIR. A visual representation of the increase in network centralisation for collaborative research projects with and without IBioIC and SIR is evident in Figure 9.2.

The high increase in centralization is in part due to the exceptional level of connectedness of the intermediaries (see results of egocentric analysis in Section 9.1.6). High centrality may not necessarily be a bad thing for both networks, which are yet to fully mature, as it allows for the intermediaries to shape and manage how the niche evolves. Such a high centrality is also needed for networks with relatively low density which are vulnerable to the risk of fragmenting, as in the case of the SIR network.

An increase in centrality is generally associated with increased level of patenting and collaborative partnerships within a network (Powell and Grodal 2009). Unlike the other relational attributes, the level of clustering and centralization of IP significantly increased for SIR and IBioIC. This may be due to the dominance of a core group of universities. The impact of universities on IP transfer is discussed in more depth in the following section.

9.1.4 Ability of IBioIC and SIR to facilitate triple helix interaction

The hypothesis of this thesis is that a triple helix-based niche manager may be an effective mechanism for enhancing collaboration and coordination between the triple helix actors within the niche. With increased level of collaboration and knowledge transfer between the triple helix groups, there is an increased chance of a triple helix consensus space forming within the niche which Ranga and Etzkowitz (2013) speculate is necessary for the success of systemic innovation. The formation of a such a consensus space, where ideas can be shared and acted upon, would also facilitate the progression of a niche along the maturity levels.

Table 9.4 outlines the change in the number of ties between triple helix groups due to the introduction of IBioIC and SIR. The results demonstrate that both intermediaries experienced relative success with regards to increasing relational ties both within and between all triple helix groups. They were particularly effective at increasing both frequent interactions and more trust based relational attributes between industry-industry and academia-industry. Both intermediaries were particularly successful at integrating other innovation intermediaries into the network from the wider innovation system. Integrating the existing network into the wider innovation system is critical to the expansion of the niche as it increases the chances of external resources being invested into the niche and increases the legitimacy of the niche to external actors.

Although IBioIC and SIR appeared to be effective system brokers, particularly between universities and industry, there were observable differences between the effectiveness of the two. Table 9.4 shows the additional number of ties IBioIC brokered compared to SIR. Based on these results, it is evident that IBioIC was able to broker more ties between universities and all other triple helix groups more effectively than SIR. It also brokered more industry-industry ties for all relational attributes than SIR did. Yet, SIR brokered more public-sector-industry relational ties than IBioIC.

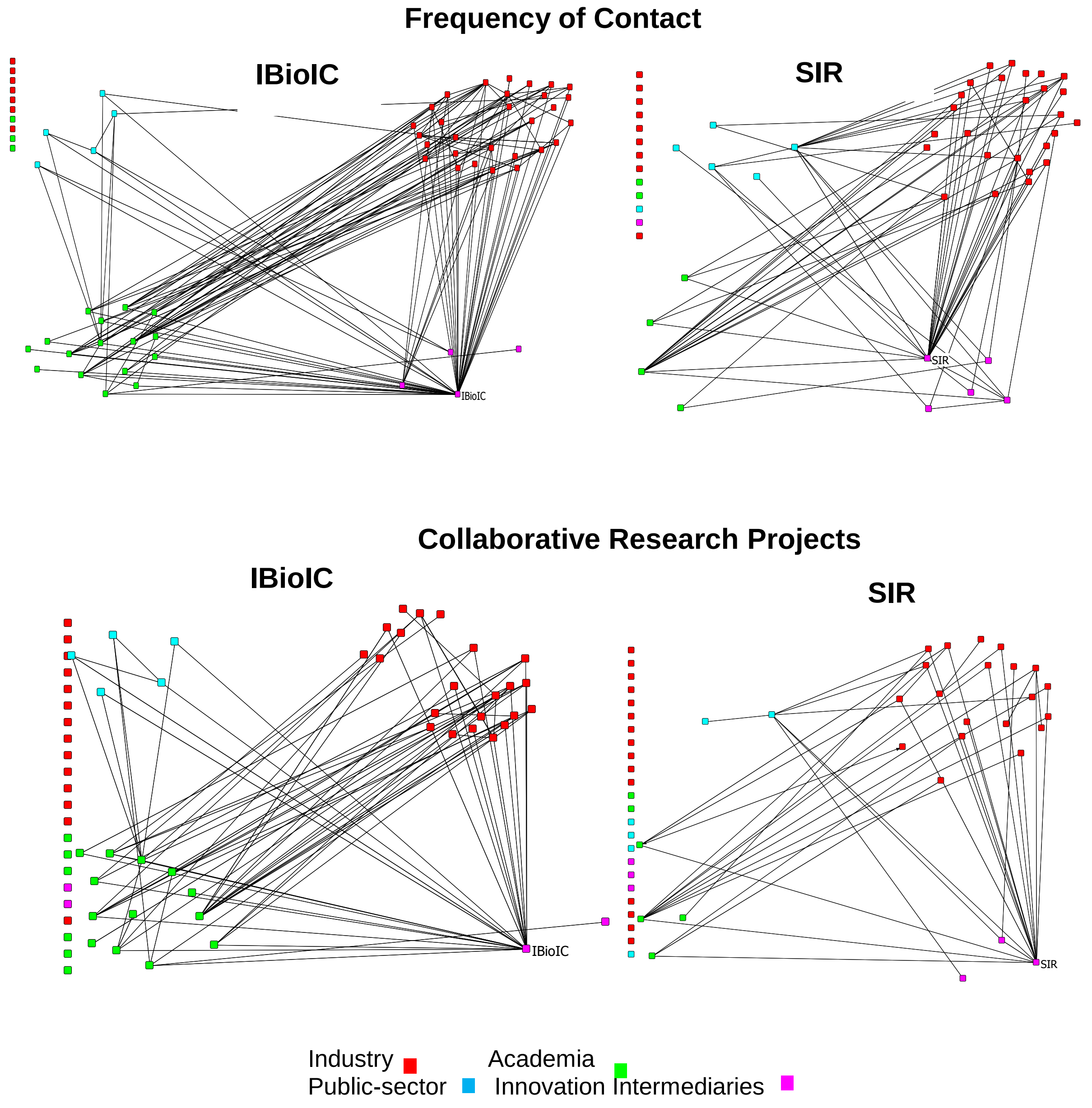
SIR was not effective with regards to connecting universities to other universities or universities to public-sector stakeholders for all types of relational tie. In contrast, IBioIC was able to increase such ties for all relational attributes, where public-sector-university and university-university collaborative research ties increased by 5 and 8 respectively.

Table 9.4: Change in the number of ties between triple helix groups due to the introduction of IBioIC and SIR to their respective niche networks

	Industrial Biotechnology Network				**Remanufacturing Network**				**Difference**			
	I	A	G	Int.	I	A	G	Int.	I	A	G	Int.
	Frequency of Contact											
I	50				10				40			
A	37	10			16	0			21	10		
G	2	5	4		10	0	0		-8	5	4	
Int.	41	20	7	6	31	7	9	12	10	13	-2	-6
	Total Knowledge											
I	16				8				8			
A	25	8			10	0			15	8		
G	2	5	4		3	0	0		-1	5	4	
Int.	20	13	6	2	25	5	6	2	-5	8	0	0
	Collaborative Research Projects											
I	18				8				10			
A	32	8			14	0			18	8		
G	0	5	4		3	0	2		-3	5	2	
Int.	12	12	5	2	19	5	3	2	-7	7	2	0
	Tech Transfer											
I	8				6				2			
A	23	0			11	0			12	0		
G	0	0	0		2	0	0		-2	0	0	
Int.	4	2	0	0	10	2	1	0	-6	0	-1	0
	Cash Infusion											
I	10				4				6			
A	26	4			6	0			20	4		
G	0	2	0		1	0	2		-1	2	-2	
Int.	22	13	1	0	0	5	2	2	22	8	-1	-2
	IP Transfer											
I	10				4				6			
A	26	2			8	0			18	2		
G	0	0	0		0	0	0		0	0	0	
Int.	1	0	1	0	5	2	1	2	-4	-2	0	-2

Notes: 1. Positive number (Green) = IBioIC created more ties, Negative number = SIR created more ties. 2. Key: I = Industry, A=Academia, G=Public-sector Stakeholders and Int.=Innovation Intermediaries

The intermediaries brokered very few ties between the public sector stakeholders and other triple helix groups with regards to stronger ties such as technology, cash and IP transfer. This is not necessarily a limitation as the intermediaries were established and funded by the government to remove the need for such direct ties to be present – thereby limiting the need for direct government or public-sector intervention. Despite the differences in performance, both intermediaries played a critical brokering role between the triple helix network actors for all relational ties – this is evident in Figure 9.3.



Frequency of Contact

Collaborative Research Projects

Figure 9.3: Sociograms displaying the triple helix relational ties formed through IBioIC and SIR in their respective networks.

Notes: 1. The sociograms were produced using the software NetDraw by Borgatti (2002). 2. Each line represents the formation of a new relational tie between two organizations due to the presence of IBioIC.

9.1.5 Ability for IBioIC and SIR to facilitate niche-regime Interaction

Table 9.5 compares the total number of relational ties created by IBioIC and SIR. IBioIC stimulated much higher niche-regime and niche-universities relational tie formation compared to SIR. This is in part due to there being more niche actors in the IBioIC network (11 niche actors compared to 6 in the SIR network). The difference may not be wholly attributed to there being more niche actors in the industrial biotechnology network. For example, IBioIC brokered 10 more frequent contact niche-regime and 20 more niche-niche ties compared to SIR.

In contrast, SIR was more effective at building triple helix ties with regime actors for knowledge transfer and collaborative research projects. Overall, however, both SIR and IBioIC successfully increased the number of frequent interactions, knowledge transfer and collaborative research projects between innovation intermediaries and niche and regime actors.

Both SIR and IBioIC formed significantly higher levels of triple helix ties than any other innovation intermediary as evidenced in Figure 9.4. This suggests how important the network actors perceive SIR and IBioIC to be with regards to innovation brokering through the initiatives they take to form such relational ties with them.

Table 9.5: Comparison of the number of ties created by IBioIC and SIR in their respective networks

		Industrial Biotechnology Network					**Remanufacturing Network**					**Difference**				
		Regime	Niche	University	Public-sector	Innovation Intermediaries	Regime	Niche	University	Public-sector	Innovation Intermediaries	Regime	Niche	University	Public-sector	Innovation Intermediaries
Frequency of Contact	Regime	4					4					0				
	Niche	12	22				2	2				10	20			
	University	13	24	10			14	2	0			-1	22	10		
	Public-sector	2	0	5	4		8	2	0	2		-6	-2	5	2	
	Innovation Intermediaries	25	16	20	7	6	23	8	7	9	12	2	8	13	-2	-6
Knowledge Transfer	Regime	0					4					-4				
	Niche	5	6				1	2				4	4			
	University	10	15	8			7	3	0			3	12	8		
	Public-sector	2	0	5	4		2	1	0	0		0	-1	5	4	
	Innovation Intermediaries	7	13	13	6	2	18	7	5	6	2	-11	6	8	0	0
Collab. Research Projects	Regime	0					4					-4				
	Niche	4	10				1	2				3	8			
	University	11	21	8			12	2	0			-1	19	8		
	Public-sector	0	0	5	4		2	1	0	2		-2	-1	5	2	
	Innovation Intermediaries	5	7	12	5	2	16	3	5	3	2	-11	4	7	2	0
Tech Transfer	Regime	0					2					-2				
	Niche	3	2				1	2				2	0			
	University	9	14	0			9	2	0			0	12	0		
	Public-sector	0	0	0	0		0	2	0	0		0	-2	0	0	
	Innovation Intermediaries	0	4	2	0	0	7	3	2	1	0	-7	1	0	-1	0
Cash Transfer	Regime	2					2					0				
	Niche	2	4				0	2				2	2			
	University	11	15	4			5	1	0			6	14	4		
	Public-sector	0	0	2	0		0	1	0	2		0	-1	2	-2	
	Innovation Intermediaries	12	10	13	1	0	0	0	5	2	2	12	10	8	-1	-2
IP Transfer	Regime	0					2					-2				
	Niche	3	4				1	0				2	4			
	University	9	17	2			6	2	0			3	15	2		
	Public-sector	0	0	0	0		0	0	0	0		0	0	0	0	
	Innovation Intermediaries	1	0	0	1	0	2	3	2	1	2	-1	-3	-2	0	-2

Notes: 1. Positive number (Green) = IBioIC created more ties, Negative number = SIR created more ties.

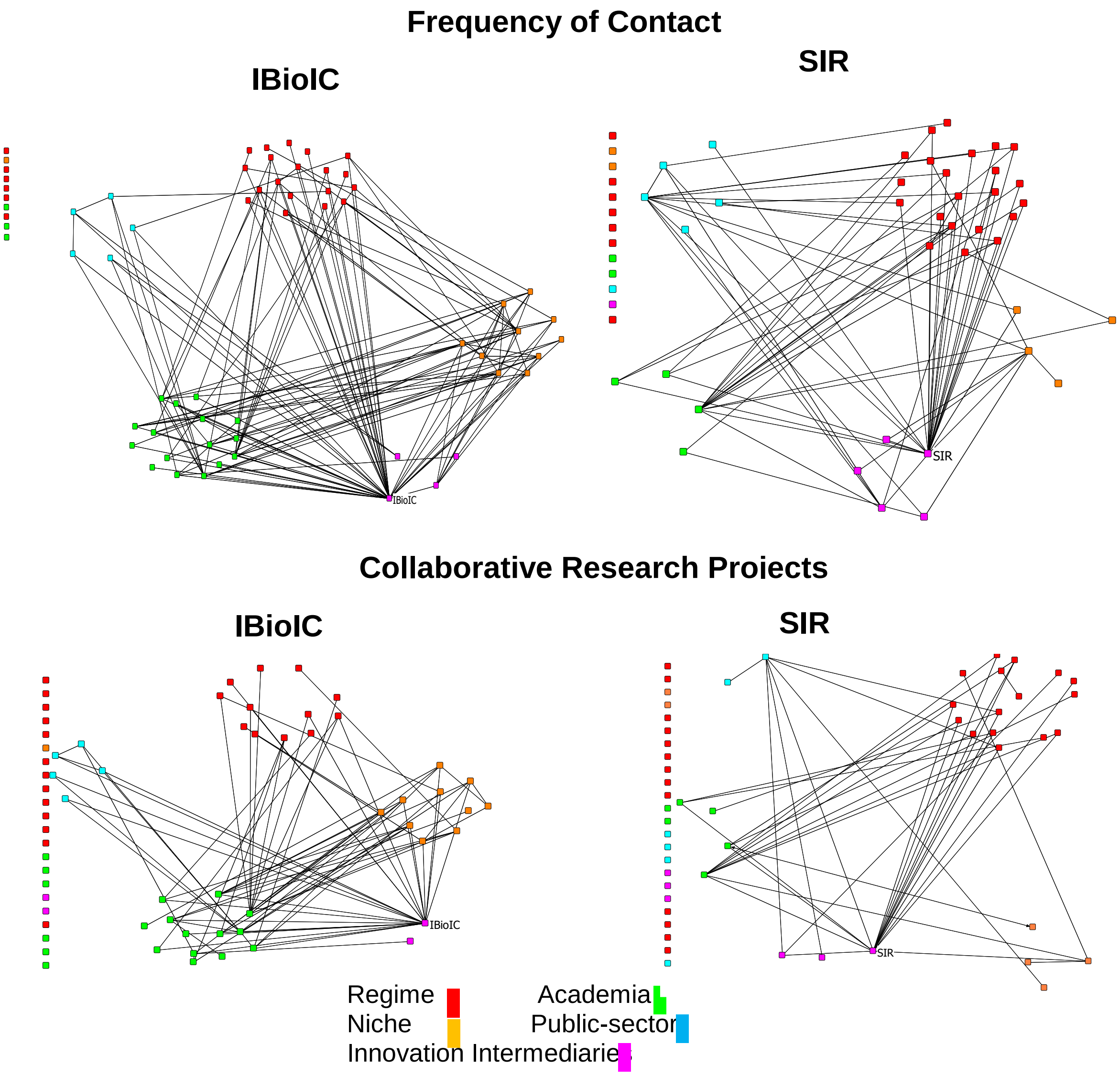


Figure 9.4: Sociograms displaying the niche-regime relational ties formed through IBioIC and SIR. Each line represents the formation of a new relational tie between two organizations due to the presence of IBioIC and SIR.

Note: The sociograms were produced using the software NetDraw by Borgatti (2002).

9.1.6 Measuring the centrality of IBioIC and SIR

In addition to the impact of IBioIC and SIR on the structural characteristics of their networks, a comparison of their level of individual centrality (influence and power) within the network was also undertaken. Table 9.6 outlines the results of the egocentric analysis which measures the level of centrality each intermediary held within their respective networks with regards to all six relational attributes assessed. It allows for comparison of differences in the measures' centrality between SIR and IBioIC and how they ranked in the network with respect to each relational attribute relative to their peers.

Table 9.6: Results from egocentric analysis of IBioIC and SIR with regards to their level of centrality in their respective networks for each relational attribute compared to all other network actors.

	IBioIC			**SIR**		
Centrality Measure	IBioIC	Network Average	Rank (out of 64)	SIR	Network Average	Rank (out of 42)
Frequency of Contact						
Degree	62	20	1	42	8	1
Closeness	64	107	1	66	108	1
Betweenness	403	22	1	535	22	1
Effective Size	43	10	1	36	5	1
Total Knowledge Flow						
Degree	32	7	1	34	3	1
Closeness	118	179	1	91	153	1
Betweenness	327	28	1	749	25	1
Effective Size	26	5	1	32	2	1
Collaborative Research Projects						
Degree	29	7	1	25	3	1
Closeness	123	182	1	109	174	1
Betweenness	282	30	1	555	25	1
Effective Size	23	5	1	23	2	1
Technology Transfer						
Degree	6	3	8	10	3	1
Closeness	236	297	14	186	262	1
Betweenness	60	30	10	156	20	1
Effective Size	6	3	8	9	2	1
Cash Infusion						
Degree	35	5	1	6	2	1
Closeness	116	183	1	204	281	1
Betweenness	716	30	1	119	22	1
Effective Size	33	4	1	5	1	3
IP Transfer						
Degree	2	2	20	5	1	3
Closeness	316	359	33	283	388	1
Betweenness	43	36	20	144	17	3
Effective Size	2	2	20	4	1	4

Both SIR and IBioIC were by far the most central actors for the likes of frequent contact, total knowledge flow and collaborative research projects. As can be seen in Table 9.6, the degree of centrality of both intermediaries (i.e. the number of direct ties) was approximately four times higher than the average network member, meaning they were well connected.

Both SIR and IBioIC held much lower closeness scores and much higher betweenness scores than the average network member. This suggests that in addition to having the shortest path length on average relative to all other network actors, thereby aiding knowledge transfer and acquisition, IBioIC and SIR were able to exert a high level of control over knowledge and resource exchange between other network actors.

One reason for IBioIC and SIR obtaining such a level of centrality value may be attributed to their governance structure and their mandate to manage the entire niche network. As such, they were able to develop high effective size networks and bridge a higher number of structural holes between the triple helix groups compared to any other actor in the network. An interesting point to note is that, within the space of two years, IBioIC managed to achieve such high centrality in a relatively established 'proto-niche' network with a number of pre-existing powerful actors which is visually represented in Figure 9.5.

For the relational attributes which require a deeper level of trust and commitment between actors, such as technology and IP transfer, the intermediaries' centrality reduced somewhat. This was particularly the case for IBioIC. Although SIR ranked top in relation to technology and cash transfer, it's centrality dropped to the third most central actor for IP transfer, behind two regime actors. Nonetheless, SIR was still able to retain a very high level of centrality for such relational attributes, whereas the centrality of IBioIC diminished significantly for technology and IP transfer. One possible explanation for this difference is that IP transfer was much more prevalent in the industrial biotechnology network compared to the remanufacturing network and that IBioIC would therefore need to broker a far higher number of IP ties to reach a similar level of centrality to SIR. As such, being in an embryonic niche, SIR held more power and influence over the formation of IP and on the trajectory of the niche. IBioIC did however retain the highest centrality ranking for cash transfer. This may be due to the fact that there was no other agency or intermediary specialised in brokering or stimulating cash transfer within the industrial biotechnology sector in Scotland at that time.

The high degrees of intermediary centrality are reflective of the risk of impending network collapse should SIR or IBioIC cease to exist. This threat is most noticeable for the remanufacturing network due to its ‘embryonic’ nature and where the culture of open innovation has not taken root as in the case of the industrial biotechnology network.

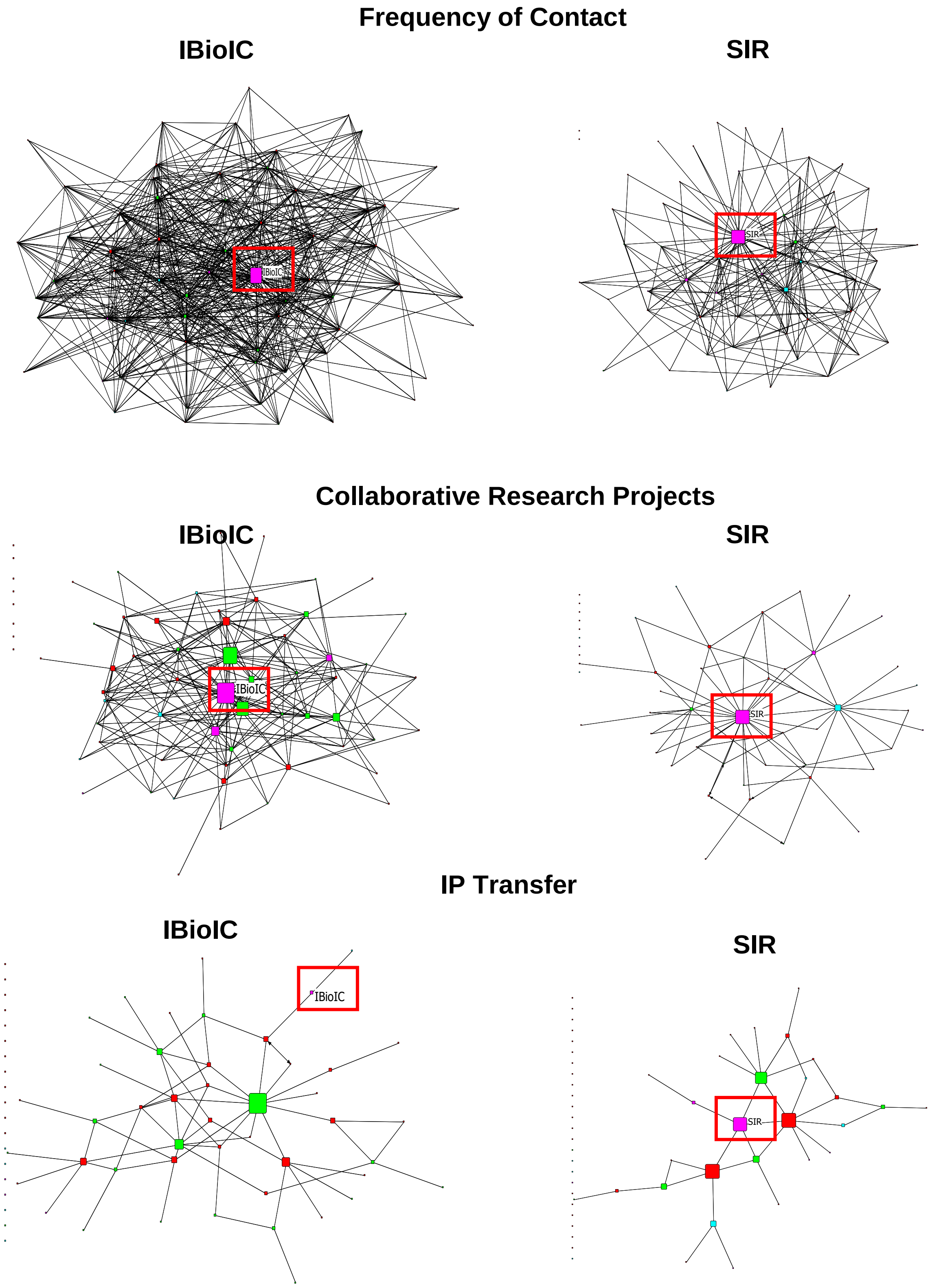


Figure 9.5: Sociograms demonstrating centrality of IBioIC and SIR for all relational attributes.

Notes: 1. The size of the node is relative to the betweenness value of all other network actors. 2. *IBioIC and SIR are surrounded by a red box.*

9.1.7 Comparison of IBioIC and SIR niche manager roles and activities

This section offers a comparison between the roles assumed and activities undertaken by IBioIC and SIR to achieve the structural changes and individual network centrality outlined in the previous section. The activities undertaken by both intermediaries are outlined in Table 9.7. Any activity highlighted in grey indicates the same activity was undertaken by both intermediaries.

It is evident from Table 9.7 that there are similarities and differences between SIR and IBioIC in the nurturing and empowering activities that undertook. With regards to inward facing roles, both intermediaries recognised the value of undertaking one-to-one consultations with network members to identify specific brokering support they could provide. They also valued regular board meetings to ensure knowledge was shared among the board members.

Due to the lack of basic awareness around the potential for remanufacturing, the most valued inward facing activity was awareness raising through educational workshops, events and lectures. In addition, SIR established and coordinated formal working groups bringing in a broad spectrum of stakeholders to discuss and develop specific areas of interest within the network such as the remanufacturing of ICT equipment.

Awareness of the potential of industrial biotechnology as a technology category was higher in the IBioIC network than that of remanufacturing in the SIR network; and therefore IBioIC believed the activity of providing technical support and prototyping facilities to the network members as being most valuable. Due to its additional funding support compared to SIR, IBioIC was also able to fund 30 PhD studentships with industry network members and an HND course. This was believed to be a critical inward facing role as it helped to build a local workforce with the aim to help expand the niche and increase relational ties and knowledge flow between academia and industry.

Both intermediaries also identified a range of activities they perceived to be simultaneously inward and outward facing. The hosting of an annual multi-disciplinary conference was one such inward and outward facing role valued by both IBioIC and

SIR. Both intermediaries' conferences combined presentations from government, academia and industry actors. In addition, they included presentations from representatives of world leading companies working within remanufacturing and industrial biotechnology arenas thereby connecting the niche network actors to external global events as well as raising expectations. Publicly available case studies of collaborative research projects were also seen as a useful tool for sharing knowledge across the network as well as raising expectations and increasing the legitimacy of the niche to external actors.

With regards to externally facing activities, both intermediaries identified securing international partnerships as being critical for helping the network to gain legitimacy and to attract new members to the network. Informing and influencing public policy was also seen by both as being a necessary role. Finally, public outreach was believed to be essential for garnering public support and public acceptance for the niche, as this was recognised to be crucial for putting pressure to bear on policy.

The results from the network member surveys, outlined in Table 9.8, highlight that overall, SIR and IBioIC were highly valued actors within the network and were able to perform a wide range of brokering roles which were identified by van der Valk et al. (2011) as being necessary for innovation to occur across networks. However, the industrial biotechnology network members on average ranked the roles assumed by IBioIC as offering higher value than their remanufacturing counterparts for the roles assumed by SIR. For example, with respect to the creation and facilitation of the network, the score for IBioIC was 87% compared to 57% for SIR.

The most highly valued service provided by SIR was technology assessment and evaluation. This may be due to low awareness across the network with regards to the potential of remanufacturing technologies and processes. As such, network members required support from SIR to assess the technological landscape. In the IBioIC network, this was ranked as one of the lowest value-adding roles – which is due in part to the fact that many of the network members were technology developers who had a relatively clear view of the technological landscape.

Table 9.7: A comparison of the inward and outward facing roles undertaken by IBioIC and SIR as identified in the focus groups

	IBioIC	**SIR**
Inward Facing	Technical Support	SIR Workshops, events, lectures
	One to One Consultations	**One to One Consultations**
	Regular Board meetings	Focused Working Groups
	PhD Sponsorships	Newsletters
	Introductions	**Regular Board meetings**
	Rapid Bio-processing and Flex Bio Facilities	Research Projects
	Rotating Board	
	HND Course	
	Funding Masters Students	
Both Inward and Outward	**IBioIC Conference**	Funding Collaborative KE Projects
	Project Group formations/Focus Groups	Attending External Events
	Hosting European Forum for IB	Building Partner relationships
	Showcased Events	Participating in Partner Events
	Case studies	**SIR Conference**
	Media releases	Introductions
	Newsletters	**Case studies**
		One stop information source
		Academic Outreach
		Reports and Publications
		Media releases
Outward Facing	Network Integrator Role	Referrals to other services
	International Partnerships	**International Partnerships**
	Influencing IB Roadmap	**Informing Policy/Public-sector**
	Informing Policy/Public-sector	Re-made award
	BioPilots UK	**Public Outreach**
	Bio-Pilots and Biobased Industry Consortium (EU Level)	**Influencing Manufacturing Policy**
	Public Outreach	
	Influencing public funding	

Note: The inward, both inward and outward and outward facing activities highlighted in **bold** and grey are activities that both intermediaries undertook and valued

A second contrast in the results was the ranking of the ability of IBioIC and SIR to articulate sector needs, expectations and requirements. This role was ranked 4th for IBioIC (with a 78% approval rating) and 15th for SIR (with a 34% approval rating). This is likely due to the differences in the maturity stage of the networks. For instance, as described in Section 5.2, biotechnology in Scotland has a long history of collaboration and coordination in terms of technology development. As such, many organisations were familiar with other network actors and their associated technologies or services; and the industrial biotechnology network had already formed some level of cohesion prior to IBioIC entering the network. In addition, although industrial biotechnology encompasses a wide suite of technologies, the network vision was clearly defined through the industrial biotechnology roadmap which was to replace fossil fuel-based plastics, fuels and chemicals with bio-based alternatives.

The remanufacturing network in Scotland was highly fragmented and consisted of a handful of mainly one-to-one relational ties between individual regime actors and university departments - particularly for the more trust-based relational attributes. This is partly due to the historical ‘linear’ nature of the manufacturing industry whereby an organisation deals with immediate value chain partners but not necessarily actors at the end of value chains or in completely different value chains or sectors. As such, the culture of open-innovation in the SIR network was not as strong as it was in the industrial biotechnology network. Furthermore, the adoption of remanufacturing does not necessarily threaten to disrupt any regime – rather it promises to re-configure and optimise existing value chains. As such, the vision and needs for the network are not directly apparent. The role of IBioIC to articulate sector needs, expectations and requirements is therefore likely to be an easier task compared to SIR’s role. Such results demonstrate the increased effort and resources required by a triple helix-based niche manager to articulate needs and expectations in an embryonic and highly fragmented niche.

The results from the network member surveys and semi-structured interviews highlighted that both IBioIC and SIR were considered by the network members as highly effective brokering mechanisms between triple helix institutions and polycentric governance mechanisms with which to steer the niche. Both were seen by the majority of the network as essential for the healthy functioning of the network. A total of 73% of respondents believed SIR was required and nearly half believed it was essential. For IBioIC, 99% of respondents agreed there was a need for IBioIC to exist, with 61% strongly agreeing. One IBioIC network member stated that “the network cannot do without IBioIC. They do very well at balancing the needs between industry, academia and the public-sector”.

Table 9.8: A comparison of how the remanufacturing and industrial biotechnology network members valued innovation brokering roles performed by SIR and IBioIC

Rank	**IBioIC Activities**	**Average Score (%)**	**Rank**	**SIR Activities**	**Average Score (%)**
1	Creation and facilitation of new networks	84	1	Technology assessment and evaluation	59
2	Communication and dissemination of knowledge	80	2	Raising awareness of the circular economy	57
3	Knowledge gathering, processing, generation and combination	79	3	Creation and facilitation of a remanufacturing network	57
4	Articulation of sector needs, expectations and requirements	78	4	Acceleration of the application and commercialisation of new technologies	53
5	Sector strategy development	77	5	Communication and dissemination of knowledge	52
6	Education and training	77	6	Configuring and aligning interests	50
7	Acceleration of the application and commercialisation of new technologies	76	7	Advancement of sustainability aims	45
8	Configuring and aligning interests	76	8	Knowledge gathering, processing, generation and combination	45
9	Influencing policy	74	9	Creating conditions for learning by doing and using	45
10	Creating conditions for learning by doing and using	74	10	Finding potential funding and funding activities	44
11	Provision of advice and support	74	11	Provision of advice and support	42
12	Technology assessment and evaluation	72	12	Influencing policy	41
13	Finding potential funding and funding activities	72	13	Education and training	41
14	Prototyping and piloting	70	14	Sector strategy development	35
15	Arbitration based on neutrality and trust	69	15	Articulation of sector needs, expectations and requirements	34
16	(Long-term) project design, management and evaluation	69			
17	Identification and management of human resource needs (skills)	69			
18	Gatekeeping and brokering	68			
19	Creating new jobs	68			
20	Accreditation and standard setting	65			
21	Advancement of sustainability aims	65			
22	Investments in new businesses	60			

Notes:

1. Level of service into five categories: Very High (5)(81%-100%), High (4)(61%-80%), Moderate (3)(41%-60%), Low (2)(21%-40%), Very Low (1)(1%-20%) and None (0)(0%).
2. Average score in % is produced by dividing the average score by 5.

9.2 Ability of IBioIC and SIR to nurture the niche network: building social networks

The remanufacturing and industrial biotechnology networks were selected for comparison due to the differences in niche technology and maturity. The differences in niche technology were largely based around the extent to which the niches are ‘stretching and transforming’ existing regimes or ‘fitting and conforming’ with existing regimes. It is argued in this thesis that the industrial biotechnology niche is on a trajectory to stretch and transform the existing fossil fuel driven chemicals, fuels and plastic regimes. This is because industrial biotechnology entirely replaces the feedstock entering the plastic, fuels and chemicals value chains from fossil fuels to organic material derived from the agricultural and food and drink sectors. As such, there is a significant threat to the petrochemical industries of reducing demand for petrochemicals to make plastics, fuels and chemicals. Secondly, the products produced from industrial biotechnology may also be re-used or recycled into different markets compared to oil-based fuels, chemicals and plastics, thereby disrupting the end of the values chains for these products.

In contrast, remanufacturing aligns more with the ‘fit and conform’ ethos. This is because the scale-up of remanufacturing does not necessarily threaten the overhaul of entire value chains; rather it offers to extend the lifetime of existing products and hence increase the profits of existing regime actors within the value chain. Remanufacturing can therefore be viewed as an extension of existing value chains. In order to successfully remanufacture a product, however, the manufacturer has to be able to track the product through the value chain and get the product back to their plant by adjusting their business models and introducing reverse logistics processes; to re-design the product to be easily disassembled; to install equipment; and to train staff to disassemble, inspect, clean, refurbish and repair components and re-assemble the products. The process of remanufacturing therefore requires a significant level of collaboration and coordination across the entire value chain. It also requires a high level of knowledge and resource exchange between actors in the value chain, such as OEMs, manufacturers, retailers and recyclers, universities who are developing the disassembling, inspection and cleaning technologies, and public-sector stakeholders responsible for waste and product re-use legislation.

With regards to niche maturity, the case of the industrial biotechnology network demonstrated the characteristics associated with a proto-niche whereby several powerful actors were present and active in the network. There was universal willingness to develop the niche; and knowledge transfer has been demonstrated through a wide range of collaborative research projects being undertaken. Furthermore, a joint industry-public-sector Scottish Industrial Biotechnology roadmap was published which set an ambitious vision for the network.

The level of connectivity in the industrial biotechnology network was also high relative to the remanufacturing network, particularly for higher trust-based relational attributes such as technology or IP transfer. This can be attributed to the open-innovation based culture in the biotechnology field observed in a number of studies (Gay and Dousset 2005; Powell *et al.*, 1999; Powell, *et al.,* 1996). This culture exists due to the rapid technological development of deep knowledge-based technologies such as genomics technology. Partnership and collaboration with several network members is therefore essential for individual firms to keep abreast of developments and to ensure that their own technology does not become obsolete.

Secondly, compared to the remanufacturing niche network, the industrial biotechnology niche network hosts a number of universities and university spin-out niche innovators (SME’s). This is because industrial biotechnologies, by their very nature, arise from university laboratories and research institutes without necessarily being developed for a specific industrial application. Joining the niche network would increase the chances of partnering with industrial actors who can exploit such a technology. The rate of technological development within industrial biotechnology means that these niche innovators are forced to build large networks of collaboration in order to exploit potential opportunities and ensure that their technologies do not become obsolete (Powell *et al.*, 1999). This would allow the industrial biotechnology niche network to develop a culture of open innovation through multi-stakeholder collaboration and knowledge transfer.

In contrast, it was found that the perceived urgency for action in the remanufacturing niche network was lower than in the industrial biotechnology niche. As such, the remanufacturing niche network studied in this thesis could be described as an embryonic niche. This lack of urgency is due to the reduced perceived threat that such technological innovation would challenge their fundamental business model. Secondly, although remanufacturing has existed for a long time in niches of very high value low volume products, such as in aerospace, the notion of undertaking the remanufacturing of high volume medium value goods, such as vehicles, electronics and white goods, only became popular due to the rise of the circular economy narrative. As such, there is little awareness in traditional manufacturing value chains on the potential benefits of shifting towards a remanufacturing model. Therefore, participation in niche innovation networks, such as the one studied in this thesis, appears to have been low relative to industrial biotechnology due to lack of awareness and lack of open-innovation culture.

Considering these differences, it is understandable that a high level of collaboration developed organically in the industrial biotechnology network without the brokering support of IBioIC, whereas the level of collaboration that occurred naturally in the remanufacturing network was minimal. Thus, the challenge for SIR was starting the network from scratch with building a network, whereas for IBioIC, it was one of prospecting new opportunities for collaboration that had not already naturally occurred.

Despite the differences in the networks, both networks were observed to have shown increases in terms of number of actors, level of cohesion and degree of centralization largely due to the respective role of IBioIC and SIR in facilitating knowledge and resource transfer. For actors in the industrial biotechnology network, the most valuable role IBioIC played was the creation and facilitation of the niche networks. The feeling among players towards the intermediary role of SIR in the creation and facilitation of the remanufacturing niche network was not, however, as strong. In the space of two years, IBioIC was able to increase the niche network size from 60 to 116 active industrial organisations; and SIR was responsible for increasing the collaborative research project network size from 29 to 43 active members. Importantly, though, SIR was able to grow the number of actors participating in more intimate trust-based relationships such as technology transfer, which increased from 17 to 28 actors.

Both IBioIC and SIR were successful at increasing network participation from innovation intermediaries existing in the wider Scottish innovation system thereby attracting external resources to their respective niches whilst also connecting their niche networks to the wider innovation ecosystem. Furthermore, increasing the level of regime participation within the niche is crucial for anchoring the niche technologies to the regime and increasing likelihood of adoption (Elzen *et al.*, 2012). The findings here agree with that of Elzen et al. (2012) and Smink et al. (2015) that boundary spanning actors or intermediaries between niche and regime are crucial for niche anchoring to occur.

Such an increase in network breadth and depth only serves to increase knowledge transfer, thereby laying the foundations for the stability of the network structure in the future. As discussed in Section 6.1.3, an increase in network centralisation also creates a more robust network both to endogenous and exogenous shock and increases the chances that network members are working towards a shared outcome. In addition, although the density and level of connectivity increased within both networks, the presence of cohesive subgroups remained relatively stable. This had the effect of reducing the likelihood for the formation of closed cliques and knowledge lock-ins that would constrain the process of knowledge transfer to other parts of the network.

IBioIC and SIR also held high levels of centrality within their respective networks, and this afforded them unique influence on the direction of knowledge and resource exchange as well as on the selection of actors entering the network. The fact that both developed high centrality in the space of two years, suggests that there is a real need for such a niche level brokering role and that there is natural willingness from the network actors to make use of such a service. By assuming the role of a highly central, but importantly neutral, actor between the triple helix institutions, 73% of SIR survey respondents believed that SIR was an effective broker between the three triple helix institutions. On the other hand, 73% of the interviewees from the industrial biotechnology network strongly believed that, as a niche manager, IBioIC played a key role in managing and fostering triple helix network level consensus and promoting self-governance.

A high level of centrality for intermediaries, however, poses the potential risk of network becoming overly dependent on the brokering services of the intermediaries. It also means that a funding cut to the intermediaries could significantly retard niche growth. This is particularly the case for the remanufacturing network which is largely a policy induced network currently in an embryonic phase.

An important point to note is that civil society groups such as environmental groups and charities were not incorporated into the niche network. The inclusion of civil society and end users into niche experiments is argued to be crucial to the success of the niche (Arnkil *et al.*, 2010). The lack of inclusion of civil society groups may be due to the normative aspect of the triple helix approach which assumes that government and public-sector stakeholders act as representatives of civil society and also the normative difference between the notion of sustainability (benefiting environment, economy and society - triple-bottom-line perspective) and the circular economy which prioritises the economic systems and gaining environmental benefits while only implicitly including social aspects (Geissdoerfer *et al.*, 2017). This normative perspective appears to be present within the triple helix-based niche managers studied in this thesis.

9.3 Ability of IBioIC and SIR to nurture the niche network: increasing shared learning

The wide spread adoption of remanufacturing and industrial biotechnology requires the implementation of new product design approaches, business models and reverse logistics as well as the development and exploitation of a suite of new technologies such as bio-retrosynthesis, bioinformatics, fermentation and molecular biology for industrial biotechnology to component product tracking, disassembly, cleaning, inspection and refurbishing technologies for remanufacturing. As such, the transition from remanufacturing and industrial biotechnology as a niche to mainstream economic activity is dependent on effective and efficient generation, transfer and use of knowledge and resources across the major triple helix actors, including universities (the knowledge producers), industry (the knowledge users) and the public-sector (the knowledge regulators) (Etzkowitz 2003).

The data collected in the two case studies showed that both intermediaries were able to increase knowledge and resource transfer ties within and amongst the triple helix groups. Knowledge transfer ties between universities and industry increased by 69% for IBioIC and 111% for SIR. The intermediaries were particularly effective at stimulating knowledge, technology and IP exchange between academia and industry actors. This is particularly important for the industrial biotechnology network in which the creation of new biotechnologies and biotechnology processes is dependent on basic scientific research performed by research centres and universities.

Due to the triple helix-based governance structure of IBioIC and SIR, knowledge transfer between the public-sector stakeholders and the wider network was observed to increase. In the context of public sector-innovation intermediary relations, the number of knowledge transfer ties increased by 300% for both IBioIC and SIR. Such an increase in high quality knowledge transfer both to and amongst public-sector stakeholders enhances the scope for reflexivity in the policy making process and for balancing the top-down and polycentric governance need of the niche. It also helps lay the foundations for improved introduction and withdrawal of appropriate public-sector support, which is a critical objective of SNM. The results therefore suggest a triple helix-based niche manager can play the role of policy entrepreneur connecting policy makers and enforcers with niche actors (Gliedt *et al.*, 2018).

Due to the high level of network centrality that SIR and IBioIC held with regards to knowledge exchange, and their position interfacing industry and university, they were able to select and fund collaborative projects that produced learning outputs which were in-line with the national circular economy target sectors. Active collaboration through research projects is critical for the success of the niche as collaborative research projects stimulate the production of high quality learning (Morone *et al.,* 2015). Furthermore, the focus on multiple rather than a single experiment is important as Raven (2005) points out that regime change arises through long trajectories of many niche experiments.

Through collaborative research projects, different types of actors learn how to work together. By learning to work together, organizations can learn about the potential for specific technologies under specific market conditions and increase their absorptive capacity for new knowledge. In addition, successful collaboration is self-reinforcing in that it stimulates further collaboration which can ultimately lead to niche wide advances (Powell *et al.*, 1996). The collaborative research projects were funded in part by the public purse. As such, there was the requirement of the projects to publish general learnings arising from the projects in a way which provided value to other network members without compromising the commercial advantage offered by the project. Furthermore, by increasing the connectedness of the network without significantly increasing the level of clustering, knowledge sharing would increase between network clusters, and hence knowledge deriving from each project is likely to flow across the network rather than remain locked in within a particular cohesive subgroup.

In addition to stimulating increased technical and commercial knowledge across the network, network members highly valued the fact that SIR and IBioIC were able to raise awareness of Scotland's wider circular economy transition and general sustainability issues. Educating the niche network on the principles of sustainability and the circular economy are important in steering the niches in-line with the broader circular economy transition.

9.4 Ability of IBioIC and SIR to nurture the niche network: raising expectations

It is important for the success of the niche that network members share credible expectations of the potential success of the technologies driving the niche. Establishing shared expectations within the industrial biotechnology and remanufacturing niche network is challenging. Unlike traditional niches discussed in the SNM literature which are based around a single technology, the process of remanufacturing and industrial biotechnology encompasses a broad range of technologies and stakeholders from several different value chains ranging from automotive, aerospace and textiles to ICT and electronics in the case of remanufacturing and marine, industrial, health and fuels, plastics and chemicals in the case of industrial biotechnology. There are also differing challenges between the two niches. As an embryonic niche network, expectations of the viability of remanufacturing are likely to be low overall and require a high level of awareness raising and evidence of success before the niche gains traction. In contrast, expectations within the Scottish industrial biotechnology niche were exceptionally high. This was based in part due to the rapid global development of biotechnologies and their widespread application combined with the very ambitious Scottish industrial biotechnology roadmap.

If expectations are too low, the niche innovations will struggle to emerge from the niche as they will attract little buy-in and resources from the regime actors. If expectations are too high, innovations will struggle to meet such high standards. Under such extreme conditions, confidence in and political support for the niche would drop quickly, with the result that the niche eventually withers and dies. Therefore, the development and communication of sensible expectations is a critical role of the niche manager.

Dedicated intermediation is needed for expectations to develop within a niche (Raven *et al.,* 2008). This is due to the niche networks being comprised of a heterogeneous group of stakeholders holding different social interests and perspectives. For example, policy actors are likely to have different expectation profiles compared to a technology developer; and the expectations of industrial regime actors may contrast with the expectations of the niche innovators.

The network member survey results highlighted that out of all the intermediary roles SIR played, its ability to articulate sector needs, expectations and requirements was ranked the lowest as value adding activity. This finding is at odds with the results from the IBioIC network member survey where IBioIC’s ability to articulate sector needs and expectations was very high. One hypothesis is that awareness within the remanufacturing network about circular economy and remanufacturing appeared to be low compared to the situation in the industrial biotechnology network where knowledge of the core technology was high and expectations had already been clearly set by the National Industrial Biotechnology Roadmap (Chemical Sciences Scotland 2015). A second hypothesis is that the industrial biotechnology sector is much more dependent on a shared vision of the future in which industrial biotechnology is a mainstream technology used for bio-refining and displaces the current dominant fossil fuel regime unlike the case of the remanufacturing niche, where changes in activities are largely expected to ‘fit and conform’ with the technology regime.

Although SIR was identified as only offering relatively low value with regards to building shared expectations, the role which was most valued by the network members was technology assessment and appraisal in which SIR helped raise the awareness of the potential technological innovations and their legitimacy. Awareness raising may be considered a necessary precursor to raising expectations within the embryonic niche. In addition, the egocentric analysis highlighted the highly central position it held within the network. Being the most central actor in a network comprised of actors from a range of different traditionally disconnected value chains and sectors, SIR was able to broker the bridging of a high number of structural holes relative to any other network actor. As such, SIR has managed to stimulate knowledge and resource exchange to occur between previously disconnected areas of the network.

This suggests that perhaps the remanufacturing network was at a very early stage in its development compared to the industrial biotechnology network. As such, before shared expectations could be articulated, the network required increased awareness of circular economy and remanufacturing in general, increased knowledge sharing and collaboration and experimentation with which to build enough social capital for shared expectations to emerge. It can be argued, however, that the physical existence of SIR was in or of itself an effective tool to help raise expectations by demonstrating the public-sector's confidence in the technologies.

Morone et al. (2015) found that low expectations usually stem from the high level of uncertainty associated with technologies under investigation. Therefore, it is critical that effective knowledge exchange occurs between all types of niche stakeholders to ensure expectations are aligned. In the case of the embryonic remanufacturing niche, it may not be necessary nor sensible for SIR to try to articulate global shared expectations on the topic of remanufacturing. Rather, network members appeared to value the roles and activities which raised awareness of the potential of the niche and which created the conditions for effective knowledge exchange and collaboration between actors. In particular, Schot and Geels (2008) suggest that expectations are substantiated by on-going collaborative projects. Successful projects confirm initial expectations and new actors are more likely to invest or participate in niche activities thereby strengthening the alignment of expectations (Hermans *et al.*, 2013).

As noted above, the significant increase in collaborative research project ties observed in both networks increases the chances of future collaboration and knowledge transfer in the network. However, in addition to these benefits, successful collaborative projects also help to raise and align expectations within each niche. By increasing strong ties between universities and industry with public-sector agencies, the expectations of the niche and circular economy policy makers and implementers are more likely to become aligned.

By increasing the number of collaborative and trust-based ties (such as collaborative research projects, technology transfer and IP transfer) between the triple helix institutions, as well as bridging structural holes across the network, IBioIC and SIR helped to build the foundations in the network for a ‘triple helix consensus space’ to emerge. Ranga and Etzkowitz (2013) outline that a triple helix consensus space enables the build-up of social capital between the institutions. As discussed in Section 4.4.2, increased social capital further enables the evolution of shared expectations and visions and consequently increases capacity for self-governance within protected space networks (Cai 2015). Social capital is also likely to increase the build-up of recombinant knowledge required for successful innovation (Lungeanu and Contractor 2015).

SIR and IBioIC undertook a range of specific activities and events targeted at raising and articulating shared expectations. SIR was influential in the revision of the national Scottish Manufacturing Action plan, in which remanufacturing was identified as a promising area of growth within the Scottish economy and the Scottish Government’s priority area for stimulating innovation. They also maintained a public presence at local and international events, built partner relationships and funded a national remanufacturing award scheme to publicise successful experiments occurring within the niche. IBioIC was one of the main stakeholders involved in the drafting of the National Industrial Biotechnology Roadmap which set out the Scottish Governments ambitious vision for growing the industrial biotechnology network in Scotland. IBioIC also won the right to host the European Industrial Biotechnology conference in Scotland. This conference attracts up to 600 delegates representing hundreds of global leading companies in the field of industrial biotechnology. As such it serves the dual purpose of being able to promote the local niche developments to the global niche as well as raise expectations within the local niche as to the global interest in the niche technologies.

The introduction of the triple helix intermediaries into the network has helped to raise expectations in the niche as a physical representation of the belief in policy. This is particularly so since the systems of governance for IBioIC and SIR were designed to be led by network members and not imposed on them through the traditional top-down policy approach.

On the basis of the empirical evidence borne by the results of the complete SNA of both the industrial biotechnology and remanufacturing networks, and supporting data collected through the survey of network members and focus groups, it is evident that the triple helix-based niche manager model employed by IBioIC and SIR has been effective in terms of nurturing their respective niche innovation networks.

Firstly, IBioIC and SIR were able to foster the conditions for a triple helix consensus space to emerge within the niche by increasing both knowledge and resource flows between the triple helix groups. Secondly, and perhaps more importantly, they were able to stimulate inter-triple helix collaborative activities and experiments which, if successful, could possibly contribute to the emergence of shared expectations and shared learning. By putting in place a governance board which is equally represented by the three triple helix institutions, a triple helix-based niche manager is able play a system level brokering role whilst remaining nested within the niche and crucially remaining a neutral actor. Thirdly, both IBioIC and SIR were able to broker traditionally external actors, such as regime actors and innovation intermediaries, into the network. The brokering role of the intermediaries to draw external actors into the niche should increase the chances of niche expansion and ultimately the reconfiguring of incumbent regimes.

Finally, both IBioIC and SIR were highly central with regards to their structural position within the network. This suggests willingness by the rest of the network actors to use them as a neutral central actors to share information with and connect with other network members. Such a high level of centrality also infers a high level of power and influence that bear on which actors are to enter the network, the choice of the type of collaborative research projects and stakeholders to be involved in such projects, and the setting of expectations. Such power, in theory, would provide a triple helix-based niche manager the ability to steer the trajectory of the niche in line with the broader circular economy dynamics. The results from the network member survey suggest that the network members were happy to grant that power to IBioIC and SIR.

9.5 Nurturing limitations of the triple helix-based niche managers

Although both triple helix-based niche managers were able to positively contribute to network building, increasing shared learning and promoting shared expectations, their impact was restricted for several reasons. Due to the relatively low levels of funding provided to SIR (£1m) and IBioIC (£10m), the intermediaries created more weak ties than strong ties, thereby reducing the scope for collaborative activities with actors outside the niche and ultimately lead to niche expansion. Furthermore, although they appeared to have a high level of influence on the inputs to innovation activities within the network (who participates and what type of collaborative research projects are undertaken), low levels of funding meant that they had very little control over the output from these projects. Therefore, once an innovation enters the market, a triple helix-based niche manager has little control over its development and as such, it could, when scaling up, slow down the transition to a circular economy for a number of unforeseen reasons such as rebound effect or technological lock-in. The influence of triple-helix based niche manager therefore appears largely at the lower end of the technology readiness level spectrum which requires an initial broker to catalyse university-industry R&D and experimentation.

The rather rigid triple helix structure of intermediaries appears to have prevented the intermediaries from incorporating civil society and third sector actors into the network - otherwise known as the quadruple helix (Carayannis and Campbell 2010). Not including civil society groups, NGOs and users risk a mismatch between the technology-push approach and the societal demand for such technologies (Kemp *et al.,* 1998, p. 191).This is a crucial omission considering the significance of civil society as integral component in the choice environment for a circular economy-oriented innovation trajectory. SNM researchers have identified that technology users have a an active role to play in ensuring that niche innovations are widely adopted (Weber and Rohracher 2012). Nonetheless, that is not to say that civil society actors such as non-governmental organisations, charities and social enterprises could not be included on the governance board going forward. Further investigation needs to be done with regards to exploring how civil society may be incorporated into the development of a niche.

Even though both triple helix intermediaries improved the likelihood of niche success by strengthening the network structure and supporting the emergence of a triple helix consensus space, knowledge generation and sharing remained relatively low in both networks and additional efforts in this direction are likely required to reduce uncertainties surrounding the niche technology and aid the successful progression to a ‘Full’ niche. If system change towards the circular economy were to occur, a much higher commitment in resources and funding to the intermediaries would be required to support inter-niche, niche-regime and inter-regime collaboration.

9.6 Ability of IBioIC and SIR to empower circular economy niche protected spaces

As discussed in Section3.4, the transition to circular economy is not only dependent on the internal nurturing of niche networks to stimulate the growth of circular economy inner-loop activities, but also on empowering such niches by supporting niche innovations to compete against incumbent technologies and altering selection environments in favour of the niche innovation. With respect to the circular economy transition, empowering activities must also facilitate niche collaboration with other circular oriented niche and regime networks and promote reflexive knowledge flow between the niche network and public-sector stakeholders responsible for influencing and enforcing policy and legislation which can either restrict or accelerate development of the niche.

Considering the additional empowering activities required for SNM to support a circular economy transition, this thesis sought to test the hypothesis that a triple helix-based niche manager would be an effective policy tool for empowering circular economy-oriented niche innovation networks through supporting niche innovations to compete against incumbent technologies and altering selection environments in favour of the niche innovation.

The remainder of this section outlines how IBioIC and SIR adopted these roles to empower their respective networks by supporting niche innovations to compete against incumbent technologies and alter the selection environment in favour of the niche.

9.6.1 Supporting niche innovations to compete against incumbent technologies

The evidence demonstrated by the social network analysis suggests that both IBioIC and SIR increased collaboration between niche actors (including university researchers and business and industrial entrepreneurs) and actors spanning multiple regimes. For instance, IBioIC brokered knowledge transfer and collaborative research projects between niche innovators and universities with regime actors from the marine, health and food sectors. SIR brokered similar ties with regime actors from the automotive, ICT, aerospace sectors. These collaborative research projects were financially structured so that they are part funded by IBioIC and SIR with part funding also arising from the industry actors in the project. As such, they were able to empower the networks by attracting in external investment and resources from several regimes to the niche.

The empowering effects of collaborative research projects between niche and regime actors are apparent from the results of the complete social network analysis where the number of knowledge transfer and collaborative research project ties between niche and regime actors increased by 71% and 80% respectively. These findings agree with the study by Kivimaa (2014) which argues that the presence of system intermediaries is crucial to trigger regime destabilisation. They also agree with Elzen et al. (2012) which determined that niche-regime hybrid actors, such as innovation intermediaries are critical to technological, network and institutional niche-regime anchoring.

IBioIC and SIR also empowered the niche actors by acting as a gateway broker between the niche network and the wider Scottish innovation system as well as international initiatives and networks. Both received and gave referrals from other innovation system actors such as the Scottish Manufacturing Action Service or Aquaculture Innovation Centre. Another example was SIR's partnership with Zero Waste Scotland who provided referrals for actors who would not traditionally have matched the requirements for participating in the network, but who offered potential for cross-pollination of ideas and knowledge. An example would be the national logistics companies looking for new ways to grow their business by increasing their reverse logistics services for products that can be remanufactured.

IBioIC and SIR were also able to connect the niche networks into global niche developments. IBioIC joined the Bio-Based Industries Consortium which is a European wide initiative to accelerate the uptake of bio-based products by connecting all the niche bio-based innovation networks across Europe. By joining such a consortium, IBioIC spoke on behalf of the Scottish industrial biotechnology network as well as attracted funding from the consortium for local projects and experiments. IBioIC also co-formed the BioPilots UK programme with four other industrial biotechnology innovation centres around the UK. The aim of BioPilots UK was to enhance knowledge transfer and share resources between the regional industrial biotechnology innovation networks in Scotland, England and Wales. IBioIC was also identified during the focus group session as a key player in the publication of the Scottish Industrial Biotechnology Roadmap and influenced the broader National Circular Economy Strategy.

SIR connected niche actors with international networks and programmes such as the Innovate UK Knowledge Transfer Network (KTN) which provides a wide range of sector specific innovation support or the Ellen MacArthur Foundation which connects global businesses with niche innovators. Perhaps the most important outward facing role where SIR connected the network actors with global niche developments was where it acted as an ambassador for the niche network organisations, and as a member of the European Remanufacturing Network which lobbies the European Commission on easing existing barriers to undertaking remanufacturing activities in Europe. These are all examples of outward facing roles which are ideally suited to a triple helix-based niche manager nested within and co-governed by the network actors and is therefore intimately aware of how to marry the internal niche dynamics with external opportunities.

9.6.2 Altering selection environments in favour of the niche innovation

It is apparent from the case studies of IBioIC and SIR that a triple helix-based system of niche governance provides an effective mechanism for altering the selection environments in favour of the niche by assuming the role of ‘policy entrepreneur’ (Gliedt *et al.*, 2018). This is in part due to the versatility of the triple helix-based niche manager who is able to simultaneously assume the role of two types of intermediary necessary to facilitate niche expansion (and hence empowerment): (i) innovation intermediaries; and (ii) policy entrepreneurs (as described in Gliedt *et al.,* (2018)).

Policy entrepreneurs act as key knowledge brokers between science and innovation intermediaries and policy makers. Smink et al. (2015) found that policy entrepreneurs also play a critical gatekeeper role in helping innovation intermediaries to interact and coordinate between different geographical and political levels. Policy entrepreneurs connect informal networks with formal decision making structures by acting as translators (Edelenbos and van Meerkerk 2015). Policy entrepreneurs perform tasks such as encouraging a policy mix for regime change and niche creation, maintaining institutional memory and matching problems with policy solutions.

Both IBioIC and SIR were able to increase knowledge flow between the niche and public-sector stakeholders. Increased knowledge transfer to the public-sector increases the chances for policy to be appropriately introduced or phased out according to the needs of the niche. Both IBioIC and SIR acted as powerful lobbying voice for their respective niche networks and were able influence national policies such as the ‘Making Things Last’ national circular economy strategy and the national Manufacturing Strategy thereby shaping the wider environment in favour of the niche.

Both SIR and IBioIC were also able to attract public and private funding from outside the network due to the close ties with public-sector bodies and industry leaders who sit as observers on the governance board. IBioIC attracted a further £1 million from the Scottish Circular Economy Investment fund to boost the scale-up of successful innovations arising from the collaborative research projects. Furthermore, both IBioIC and SIR worked with Zero Waste Scotland who manage the £18 million circular economy investment fund to support and direct innovators within the niches. Perhaps the most evident example of more closely aligning policy makers and enforces with the niche networks was that in September 2018, IBioIC received a further £11 million funding from the Scottish Government to develop the network up until 2023 (IBioIC 2018).

As discussed in Section 9.1.1, due to the differing impact of the technologies on their respective regime value chains combined with the differing network cultures with regards to the pursuit of open innovation, IBioIC and SIR held differing normative views as to what extent the selection environments should be altered (with regards to ‘fit and conform’ or ‘stretch and transform’ empowerment). IBioIC perceived themselves to be undertaking *only* ‘stretch and transform’ empowerment activities, whereas SIR believed they were undertaking a more balanced approach with mixture of activities which promoted both ‘fit and conform’ and ‘stretch and transform’. When comparing the list of activities identified by SIR and IBioIC for empowering the network, many are very similar. For instance, they both identified case studies and media releases, building international partnerships, informing policy and public outreach as critical empowering activities. However, due to the normative differences, the way in which they approach these activities varied. For example, when informing the public-sector or policies, SIR use the narrative that remanufacturing would ‘boost the manufacturing sector in Scotland’, whereas IBioIC use ‘stretch and transform’ narrative such as ‘plants can be processed to produce biofuels or plastics as an alternative to crude oil’ (IBioIC 2018).

The results suggest that strategically managing a protected niche innovation network requires a combination of both inward and outward facing activities and that the triple helix governance model of IBioIC and SIR strengthened their ability to successfully perform both. As IBioIC and SIR were deeply nested within the protected space network and co-governed by network members, they were able to perform nurturing and empowering activities, as they had intimate knowledge of the network, such as one-to-one consultations and focus groups.

Based on the empirical evidence of the complete SNA of both the industrial biotechnology and remanufacturing networks, combined with supporting data collected through the likes of surveys and focus groups, it is evident that both IBioIC and SIR were effective mechanisms for empowering the niche.

9.6.3 Limitations of the triple helix-based niche manager in empowering a circular economy niche

Although the triple helix-based niche governance model offered many strengths with regards to empowering the niche, several limitations were also identified. Firstly, IBioIC and SIR were given the mandate to focus on early stage innovations by connecting academia with industry (around technology readiness levels (TRL) 1-4)[14]. However, if niche technologies are to succeed and compete on the open market against incumbent technologies, they must be further nurtured and empowered through the higher TRL's. It is unclear from this study whether a triple helix-based niche manager would be able to achieve such support for a wide range of niche technologies, and if not, the question is as to how the triple helix-based niche manager could be used as a mechanism to feed promising technologies in the early stages of development (TRL levels 1-4) into external innovation support services which can support their progression to a higher TRL levels 5-9.

Secondly, since the triple helix-based niche managers are responsible for the overall success of the niche, they cannot be seen to be favouring one technology over another as that would risk diminishing their neutrality within the network. As such, the need to be neutral limits their ability to articulate the specific demands and expectations of individual and perhaps competing technologies within the niche; so they are limited to altering the general selection environment for the niche as opposed to specific niche technologies.

Although both SIR and IBioIC were able to connect the networks to global developments within the same technological niche, there was little evidence to suggest that they were able to connect the niche network to other circular economy-

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[14] Technology readiness levels were formed by NASA and are a "systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology." TRL 1 involves basic principles being observed and reported; TRL 9 – involves actual system "flight proven" through successful mission operations (Mankins 1995).

oriented niche networks in Scotland which would help to further stimulate circular innovation. Some examples may include the combination of industrial biotechnology and additive manufacturing to 3D print bioplastics or the combination of remanufacturing with current industry 4.0 developments such as introducing blockchain programmes into the supply chain to track the flow of products and materials.

A handful of instances were observed where IBioIC and SIR were able to stimulate collaboration between circular niches. For example, SIR connected the remanufacturing niche with the renewable energy niche by establishing and funding a collaborative research project to identify the most economic way to remanufacture wind turbine components (Interface 2018). IBioIC connected the industrial biotechnology niche with the renewable energy niche by part funding a collaborative research project that sought to develop biofuels from algae using cheap renewable energy as the energy source. These examples are however, exceptions to the rule. Nearly all of the collaborative research projects focussed specifically on innovation within the respective niches. It is suggested that this is not necessarily a limitation of the triple helix-based niche governance; rather it reflects the lack of leadership or awareness for the need to take advantage of the potential for recombinant knowledge between different niches.

As outlined in Section 2.3, circular economy innovation policy is only one component of a much wider policy mix required to stimulate a systemic transition to a circular economy. Although this study identified the impact IBioIC and SIR had on national strategies and roadmaps, it did not assess whether they were able to influence the wider mix of policies needed, such as Extended Producer Responsibility, landfill tax or Eco-design rules. As such, there is lack of clarity about the role of a triple helix-based niche manager in aligning niche trajectories in line with changes in the wider policy mix. Further research is required on this topic.

Chapter 10: Conclusions and Recommendations

There is increasing global consensus that a rapid transition to a circular economy is essential if humanity is to remain within safe planetary boundaries. Governments around the world have subsequently developed ambitious circular economy visions and targets. However, how to transition from the current linear system of production-consumption to a circular system remains unknown. What is evident is that such a transition will require new systemic approaches to innovation policy which support the development and proliferation of technologies that challenge the status quo and enable key inner loop activities to become mainstream.

The purpose of this thesis was to understand the extent to which networks of innovation, centred around key inner loop enabling technologies, can be nurtured and empowered through a triple helix-based niche manager. The research approach for this thesis drew predominantly from transition theory. Transition theory excludes the use of linear models to describe complex systemic change and is therefore based around systems thinking. Transition theory has also been described as a meta-theory as it draws from a wide range of existing models, theories and even opposing approaches. This thesis therefore drew from several existing models (namely SNM, the triple helix and system intermediation) to develop the hypothesis that a triple helix-based niche manager may be an effective tool for strategically managing inner loop niche innovation networks in-line with a circular economy transition.

To test this hypothesis, this thesis developed a novel research approach to assess two triple helix-based niche managers being trialled in Scotland as case studies. Their impact on nurturing and empowering national innovation networks centred around the inner loop activities of industrial biotechnology and remanufacturing was measured. This thesis developed a new social network analysis methodology which assessed the niche managers' entire network to empirically measure their impact on a range of inter-organizational relational attributes which are necessary for collaborative innovation to occur. The empirical results of the social network analysis were combined with qualitative data collected from surveys and interviews with the network actors as well as focus groups with the niche manager staff. The mixed methods approach allowed for a detailed understanding of the overall structural impact each triple helix-based niche manager played in their respective network as well as the underlying reasons for their impact.

In the remainder of this chapter, Section 10.1 presents a summary of the key findings of the thesis. Section 10.2 provides recommendations for future practice; and Section 10.3 proposes areas for future research. Finally, Section 10.4 offers concluding remarks on questions arising from the thesis.

10.1 Conceptual underpinnings of the findings

This section lays out the key aspects of this thesis, including the conceptual underpinnings, the methodological contributions and the empirical findings.

10.1.1 Transition to circular economy is best approached through the identification and prioritization of inner-loop activities

The transition to a circular economy will require systemic changes to the economy. It is therefore necessary that deeply embedded path dependencies and lock-ins are disrupted within the socio-technical regimes that underpin the traditional linear ‘make, use, dispose’ economic model. Thus, in the transition process, major shifts would be expected to occur in technological trajectories as a result of innovation, and also in market trajectories as a result of changing socio-economic trends. These trajectories would also be expected to align in a systemic framework to ensure that the use of resources across the economic spectrum increasingly leads to a ‘zero waste’ situation (Webster 2015).

The conceptual argument made in this thesis is that transition to circular economy is best approached through the identification and prioritisation of inner-loop activities, such as reuse, repair and remanufacturing, which aim to retain the embedded value of a product (the energy, materials and labour that were required to make it) for as long as feasibly possible. Current policy attempts to stimulate the growth of such inner-loop activities remain limited in their impact and appear to lack coordination. Furthermore, there is little understanding on how to use policy as a tool to accelerate and steer technological innovation which enables the realisation of these inner-loop value chains.

10.1.2 Triple helix-based niche governance is an effective policy approach for managing inner-loop niche innovation networks

The current SNM model has been demonstrated to have limited effect on regime destabilisation. This thesis therefore argued that the task of SNM is likely to increase in complexity as the circular economy transition requires increased levels of niche-niche, niche-regime and regime-regime collaboration and the cross-sectoral uptake of disruptive circular economy enabling platform technologies such as industrial biotechnology and the blockchain.

As such, this thesis proposed a new approach to SNM which focusses on managing the wider niche in a manner which promotes polycentric niche governance, whilst ensuring reflexive knowledge transfer between the niche and the relevant policy makers and enforcers. Based on these requirements, this thesis proposed the combined adoption of the triple helix approach to innovation and system intermediation within the SNM operational model.

The adoption of the triple helix approach to innovation was argued to be necessary as current inner-loop niche innovation networks are dependent on the development and experimentation of highly complex enabling technologies such as industrial biotechnology or remanufacturing. As such, there needs to be effective coordination and collaboration between the triple helix actors of government (knowledge regulators), universities (knowledge producers), and industry (knowledge users). Or in other words, it is necessary for a consensus space to emerge between the triple helix actors within the niche to allow for ideas, thoughts and collaborative activities to occur – and ultimately for systemic innovation to succeed.

The adoption of system intermediation was argued to be necessary to bridge structural holes between the triple helix actors within the niche; stimulate the growth of trilateral relationships and increase the shared social capital base within the niche thereby increasing the chances for a triple helix consensus space to form. However, system intermediation should also be adopted to steer the niche in line with the wider circular economy transition dynamics at the regional or national level.

This thesis therefore proposed the novel concept of a triple helix-based niche manager as a new form of innovation policy tool to strategically manage niche innovation networks in-line with the broader circular economy transition (Figure 4.6). Such an intermediary would recognise the importance of building a consensus space (or social capital base) between the three triple helix institutions responsible for driving systemic innovation within the niche (government, universities and industry) by brokering knowledge and resource transfer. It would address the challenge of polycentric governance of the niche as it would be co-governed via a revolving governance board comprised of a mixture of the triple helix actors. As the public-sector stakeholders hold a neutral observational position on the board, learnings arising within the niche are more likely to be transferred to policy makers and enforcers thereby increasing reflexivity in niche-oriented policies.

This thesis has conceptually drawn from three separate innovation fields to address the challenge of strategically managing inner-loop niche innovation networks in line with a broader circular economy transition; namely SNM, the triple helix approach to innovation and system intermediation.

The results of the IBioIC and SIR cases studies validated the hypotheses outlined in this thesis. The results demonstrated the uniquely high levels of centrality (influence and power) and connectivity both SIR and IBioIC held within the network. They also empirically demonstrated that the presence of both IBioIC and SIR noticeably increased the level of knowledge and resource flow between the triple helix actors, in particular the increase in high trust based relational attributes such as technology and IP transfer. Moreover, the results demonstrate the unique position they held in which they were deeply nested within the network and were co-governed by the network members. Yet, due to their intimate understanding of the internal dynamics and needs within the network, they were able to perform a wide range of empowering activities which both increased resource transfer into the network from the public-sector and regime organisations, as well as influencing and shaping the policy landscape to further support the expansion of the niche.

10.1.3 The dynamics of the transition to a circular economy is best viewed through a revised multi-level perspective

The thesis also contributed to the conceptual understanding of the transition dynamics associated with a circular economy by incorporating an additional axis of economic breadth to the Multi-Level Perspective (MLP). Based on this conceptual revision of the MLP, the thesis finds that the application of SNM to inner-loop niche innovation networks, while offering a useful tool for supporting niche innovation, lacks the consensus, network reflexivity and social capital base with which to disrupt incumbent socio-technical regimes. As such it lacks the mechanisms with which to impact social functions and activities in wealth creation and organised knowledge production that would pave the way for a circular economy transition.

Based on the revised MLP model, this thesis ventured the hypothesis that the institution of triple helix-based governance for strategic management of inner-loop niche innovation networks would help enhance the disruption of socio-technical regimes associated with the linear model of economic activities. Within this revised conceptual framework and given a triple helix-based system of niche governance, SNM is invoked as a useful mechanism for steering inner-loop niche innovation networks in line with a circular economy trajectory.

10.2 Methodological contributions

A novel methodology was developed for this thesis to assess the impact of IBioIC and SIR, as triple helix-based niche managers, on key nurturing activities (building networks, increasing shared learning and promotion of shared expectations) and empowering activities (supporting niche innovations to compete against incumbent technologies and altering the selection environment in favour of the niche innovations). This section outlines the main methodological contributions of the thesis.

10.2.1 Using complete social network analysis to measure the impact of a triple helix-based niche manager on an inner-loop niche innovation network

The methodology of this thesis is underpinned by the rationale that a niche is comprised of a heterogenous network of actors. As such, to nurture and empower the niche, a triple helix-based niche manager would need to nurture and empower the niche network. As is apparent from a survey of the relevant literature, network performance has received little attention within the topic of collaborative networks for innovation. The majority of studies have focused on the actor or egocentric level as opposed to at the network level as such there is a significant absence of literature on the innovative performance of networks (van der Valk *et al.*, 2011). Past studies have also focussed on industry-industry interactions as opposed to the broader triple helix interactions between public-sector, academia and industry, which Etzkowitz and Leydesdorff (2000) argue is essential for systemic innovation to succeed. To address these limitations, this thesis used the analytical tool of social network analysis (SNA) to measure such an impact.

The benefits of using SNA as a tool to study the effectiveness of SNM activities have been highlighted in a handful of studies. Caniëls and Romijn (2008) argued that SNA can open a 'black box', allowing for more systemic analysis of the niche dynamics. Lopolito et al. (2011) applied SNA to the study of SNM for the purpose of identifying and tracking the development phases of a niche; and Morone et al. (2015) investigated the multi-relational aspects of a niche network. However, these studies remain limited with regards to explaining how SNM was practically operationalised as well as measuring the impact of intermediaries on the nurturing of protected space networks.

In light of the current limited approaches to SNA within SNM, this study sought to employ a more advanced and rigorous approach to using SNA as a tool to study SNM dynamics. It did this by conducting complete social network analyses of two niche innovation networks. Complete social network analysis is viewed by many as the gold standard of SNA (Butts 2008). In particular, complete SNA offers many theoretical benefits regarding the assessment of the role of triple helix-based niche managers in niche innovation networks. The entire protected space network structure can be mapped and empirically analysed to measure key structural properties that facilitate knowledge diffusion and innovative activity including network cohesion, the presence of cohesive subgroups and centralization. It also allows for the identification of where the triple helix-based niche managers are structurally located within the network, how influential they are relative to other network actors, the extent to which they bridge structural holes between cohesive subgroups, and their level of centrality relative to other network actors. In addition, the level of engagement and knowledge transfer between different triple helix actors and institutions can be assessed. Complete SNA thereby offers the ability to map and assess the structure and composition of a protected space at the niche rather than project level, as advocated by Mourik and Raven (2006).

10.2.2 Measuring the impact of a triple helix-based niche manager on multiple relational attributes

In addition to undertaking a complete social network analysis for each niche network, this thesis undertook a complete social network analysis for six different types of relational attributes (frequency of interactions, knowledge transfer, collaborative research projects, technology transfer, cash transfer, and IP transfer).

By collecting data on a mixture of different forms of relational ties, a more detailed understanding of the impact of IBioIC and SIR on key nurturing and empowering activities could be obtained. Furthermore, by including the relational attributes of technology, cash and IP transfer and collaborative research projects, this thesis builds on the study by Morone et al. (2015) which only assessed interaction and knowledge relational ties.

The types of relational attributes were selected to measure the effect of IBioIC and SIR on a range of relational attributes which demand increasing levels of trust between the actors. This was to assess whether an intermediary that was effective at brokering low trust-based relational attributes such as frequent interaction was also effective at brokering trust-based relational attributes such as collaborative research projects and even high-trust based relational attributes such as technology and IP transfer. Furthermore, the 6 relational attributes also allow for a differentiation between interaction (frequent interaction), knowledge transfer (total knowledge transfer, collaborative research projects, IP transfer) and resource transfer (cash and technology transfer).

10.2.3 Measuring the impact of a triple helix-based niche manager on multiple structural characteristics of network

The SNA methodology allowed for the assessment of the impact of each triple helix-based niche manager based on three different approaches: (i) the overall network structure; (ii) inter-relations between triple helix groups; and (iii) the network centrality of the intermediary as described in Table 6.3.

Firstly, the impact of the triple helix-based niche managers on a range of network structure characteristic values was calculated. The network structure characteristics included network cohesion, the presence of cohesive subgroups and network centralisation. The measurement of the changes in these structural characteristics allowed for the evaluation and comparison of the extent to which each triple helix-based niche manager was able to enhance the structure of the network to create the foundations for enhanced knowledge transfer and learning to occur. It also allowed the assessment of how resilient the networks were to the entrance and exit of powerful actors.

The measurement in the changes in relational ties between triple helix groups provided a more specific assessment on the extent to which IBioIC and SIR were able to increase collaboration, knowledge and resource transfer between the triple helix groups. In particular, it allowed for the assessment of the extent to which IBioIC and SIR were able to increase knowledge transfer to public-sector stakeholders and hence build a reflexive learning loop between niche-related policy makers and enforcers.

A critical task of SNM is enabling the niche to alter the evolutionary trajectory of existing incumbent regimes (Hegger *et al.*, 2007). The differentiation between niche and regime actors allowed for the comparison of the changes in relational attributes between niche and regime actors and the rest of the network. This serves the purpose of assessing the extent to which IBioIC and SIR could empower the network by facilitating knowledge and resource transfer between niche and regime actors, as well as assessing the extent to which resources external to the niche are brought into the niche to support the growth of the niche.

Finally, by performing an egocentric network analysis of IBioIC and SIR, this thesis was able to assess the level of network centrality they held relative to all other network members. A high level of centrality suggests a high level of power and influence within the network (Pilar Latorre *et al.*, 2017)

By allowing for the combination of the assessment of changes in the overall network structure, triple helix and niche-regime interaction and triple helix-based niche manager centrality, the complete SNA methodology developed in this thesis offered a useful and pragmatic approach for empirically assessing the ability of a triple helix-based niche manager to nurture and empower a niche innovation network.

The SNA approach did have its limitations however. Firstly, it measured the existence of ties rather than the quality of the ties. For example, the relational tie of knowledge transfer indicates that knowledge transfer occurred between two organisations. However, this does not necessarily mean that the receiving organisation made productive use of such knowledge. Secondly, the SNA approach only measured the existence of relational ties rather than the output from the network in terms of revenue and jobs created. Due to the early stages of the IBioIC and SIR networks, there was not enough time for successful experiments to produce such results. Nonetheless, the SNA approach allowed for a new method to more effectively measure the health of an early stage innovation network as it helps investigate whether the foundations of the network are in place for innovation to arise.

Quantitative analysis using the SNA method is limited in its ability to offer insight into the relational content of the network. By simplifying the relations between actors into numerical data, this approach neglects the equally important questions surrounding "the construction, reproduction, variability and dynamics of complex social ties" (Edwards 2010, 10). In addition, network maps derived from quantitative methods are limited to producing 'snap shots' in time of the network structure, whereas in reality social networks are dynamic and constantly evolving structures (Mønsted 1995, p.206). To this end, supporting qualitative data was collected via interviews, surveys and focus groups, to address the limitations of the complete SNA findings.

10.2.1 Quantifying the impact of triple helix-based niche managers using a mixed methods approach

The most significant methodological contribution of this thesis is in the assessment of the impact of a triple helix-based niche manager on the nurturing and empowering of a niche network through the application of the mixed methods approach of SNA and the analysis of supporting qualitative data elicited through network member surveys and interviews and focus group studies. By asking each organisation to identify which relational ties were either directly formed or significantly strengthened through IBioIC or SIR, it was possible to compare the network characteristic values (such as density, clustering, centralisation) that include the ties formed and strengthened by SIR or IBioIC with the network characteristics without such ties. The empirical impact measured through this technique was then verified through a combination of qualitative network member surveys and interviews as well as focus groups with IBioIC and SIR. The benefits of the mixed methods approach are outlined in Section 6.2.1 and summarised below.

Crossley (2010) refers to the mixed approach as a ‘division of labour approach’ and posits that qualitative analysis is necessary to uncover the social content of the network, as quantitative approaches ‘over simplify’ the social world of the network. The qualitative approach also helps to enhance understanding of the context of the network which cannot be assessed through numerical methods, such as how and why it formed, the motivations of each actor in participating in the network, the dynamics of relations or why certain actors have a high degree of centralization and brokerage. Although a mixed quantitative and qualitative approach to social network analysis is more laborious a task, as it tends to produce ‘messy results’, Lievrouw et al*.* (1987) argue that it provides a much deeper understanding of the network and perhaps reflects the actual ‘messiness’ of most social networks.

The study highlighted that although quantitative SNA allowed for the identification of network boundaries and structure, what is important for a better understanding of the opportunities and barriers to innovation is qualitative analysis through the combination of egocentric network mapping and semi-structured interviews. The combination of network surveys and semi-structured interviews allowed for the assessment of the network members perceptions on the value and range of innovation intermediary activities undertaken by IBioIC and SIR. It offered the ability to explore the reasons for the structural changes observed in the network due to the introduction of SIR and IBioIC. In addition, the focus groups held with IBioIC and SIR management staff helped identify the inward and outward facing activities they undertook and the value they assigned to these roles with regards to their impact on key nurturing and empowering activities.

10.2.2 Application of triple helix-based niche governance in two different niche networks: biological and technical inner loop niches

IBioIC and SIR were selected for empirical case study in this paper for the following reasons. Firstly, industrial biotechnology is a strategic inner-loop activity with regards to biological nutrient flows within the economy; and remanufacturing is a strategic inner-loop with regards to technical nutrient flows (Braungart *et al.,* 2007). As such, a comparison between the two niche networks allowed for greater understanding of the challenges of stimulating both biological and technical 'inner-loop' innovation.

Second, the embedded case studies, which examined two separate protected space networks embedded within the same regional innovation system, fill a gap in the SNM literature. This is because most empirical studies have been criticized for being too concentrated on specific case studies (Caniëls and Romijn 2008). Third, undertaking complete SNA for two circular economy-oriented protected space networks greatly strengthens the ability to evaluate the hypotheses proposed in Section 5.3. Fourth, undertaking a comparative assessment of two case studies also helped overcome the common limitation of SNA whereby it is difficult to determine what an 'optimal' network property value is without comparing it to networks with similar properties (van der Valk *et al.,* 2011). Fifth, assessing niche innovation networks from both the biological and technical domains of the circular economy allows for a comparison between the differing challenges associated with managing different niches.

The comparison of IBioIC and SIR also allowed for a comparison of niches in different maturity phases whereby IBioIC could be described as a proto-niche whereas SIR was in a more embryonic phase of development. Therefore, the comparison allowed for the assessment of the effectiveness of a triple helix-based niche manager in nurturing and empowering niche networks in different stages of maturity.

10.3 Empirical findings

The results of the complete social network analysis which measured six different types of relational attributes between 47 organisations[15] in the industrial biotechnology network and 38 organisations[16] in the remanufacturing network demonstrated the positive impact the triple helix-based niche manager had on the cohesion, the presence of cohesive subgroups and centralization of the niche innovation network. As such, the effectiveness of the intermediary in undertaking the key nurturing activities of building the network, facilitating shared learning and raising expectations were validated. In particular, this thesis demonstrated the ability of a triple helix-based niche manager to foster knowledge exchange and collaboration between triple helix institutions and between niche and regime network actors.

From the discussion, it is apparent that a triple helix-based niche manager can be leveraged as an effective policy tool for nurturing early stage niche innovation networks, not only in the sense of internally nurturing the network, but also as a mechanism for governments to steer the network in line with a broader circular economy trajectory.

10.4 Recommendations for future practice

The findings of this thesis have several implications for how innovation policy may be designed to stimulate a circular economy transition. The results suggest that as triple helix-based niche managers, IBioIC and SIR were able to perform the key nurturing roles of building the network, increasing shared learning and raising expectations. They did this by enhancing the overall network structure to accelerate innovation and stability within the network. Triple helix collaboration and resource transfer increased due to their presence particularly between industry and universities. Indeed, they were key policy mechanisms for linking their respective niches to the broader innovation system as well as increasing coordination between other innovation intermediaries. Moreover, they demonstrated differences in prioritising support to niche and regime actors.

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[15] Four Scottish public-sector stakeholder, 12 academia, 27 industry and four innovation intermediary network member organizations.

[16] Three Scottish public-sector stakeholder, four academia, 27 industry and four innovation intermediary network member organizations.

IBioIC was much more effective than SIR at connecting niche innovators with regime actors. SIR was predominantly focussed in supporting the regime actors such as traditional manufacturers. Both were nonetheless particularly effective at brokering trust-based relational attributes such as collaborative research projects, and technology and IP transfer that are crucial for valuable knowledge to transfer across niche networks. Finally, both IBioIC and SIR held extremely high levels of centrality in their respective networks, which suggests that they were powerful actors in terms of directing knowledge and resource transfer between network actors; communicating success across the networks; choosing which actors enter the networks; and influencing the type of collaborative research projects that took place. Their impact on their respective networks is largely due to the wide range of inward facing roles they undertook, ranging from the one-to-one technical consultations and hosting of specific working groups to funding and brokering collaborative research projects and hosting annual international conferences.

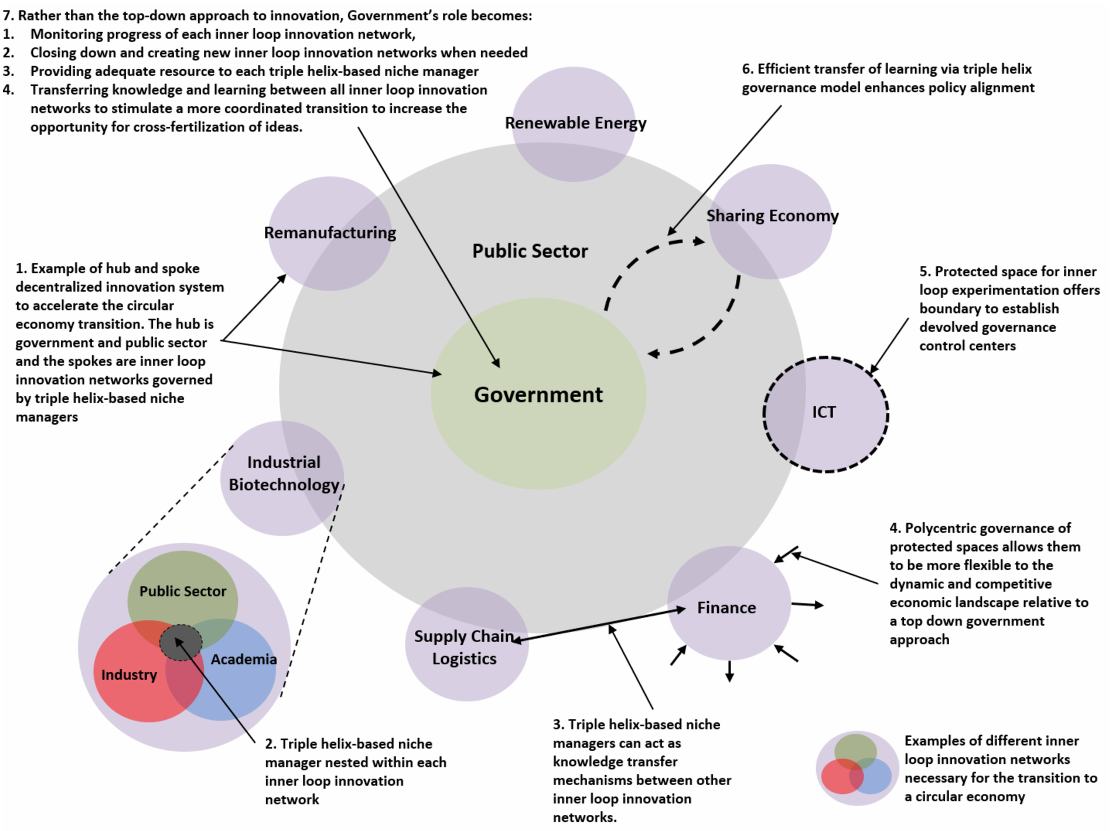
IBioIC and SIR were also influential in empowering their networks. They were able to connect the niche actors with regime actors as discussed elsewhere in this study. However, they were also able to perform a wide range of empowering activities, including directing circular economy funding to the niche; connecting the local niche network with global niche networks; and lobbying and informing policy makers for niche developments and requirements. Strong support from the network for the continued presence of IBioIC and SIR was also evident from the data obtained through network member survey, semi-structured interviews and solicitations from focus groups.

However, the triple helix-based system of niche governance did present some limitations with regards to the nurturing and empowering a niche innovation network for the following reasons. Firstly, the rather rigid triple helix structure of intermediaries constrained the intermediaries from incorporating civil society and third sector actors into the network (otherwise known as the quadruple helix) (Carayannis and Campbell 2010). Not including civil society groups, NGOs and users risks a mismatch between the technology-push approach and the societal demand for such technologies (Kemp *et al.,* 1998, p.191).This is a crucial omission considering the significance of civil society as integral component in the choice environment for a circular economy-oriented innovation trajectory. SNM researchers have identified that technology users have a critical and active role to play in ensuring that niche innovations are more widely adopted (Weber and Rohracher 2012). Therefore, further investigation needs to be done with regards to exploring how civil society may be incorporated into the development of a niche.

Secondly, the introduction of a triple helix-based niche manager into a niche innovation network is a double-edged sword. The high-level network centrality of the intermediaries for a wide range of relational attributes helps to bridge structural holes and increase knowledge and resource flows throughout the network. The downside to this is that if the funding to the intermediaries were to be removed, it would bring in train the risk of network fragmentation due to the over dependency of the network on the triple helix-based niche manager to manage the niche. Therefore, how and when the support from a triple-helix based niche innovation manager may be phased out as a niche begins to compete on a level playing field with the regime is an important consideration for policy makers. In other words, while the ‘infant industry’ argument for protection duly applies to the provision of protected spaces for niche networks to evolve, this privilege has to be withdrawn after a period, lest niche activities fail to evolve into mainstream regime activities.

With respect to the role of triple helix-based niche managers on the wider circular economy transition, governments could support the launch of triple helix-based niche managers to manage numerous innovation networks focussed on key inner loop technologies such as renewable energy, circular finance, information and communications technologies. By devolving governance of innovation in this way, a decentralised hub and spoke circular economy innovation system could be formed as depicted in Figure 10.1. In this model, the circular economy strategy of governments constitutes the hub, and the range of co-governed inner loop innovation networks that address key circular economy challenge areas constitute the spokes. Governments can not only support and fund the establishment of triple helix-based niche managers, but they can also phase out support when the niche innovations become mainstream and are able to compete on a level playing field with incumbent technologies. Developing a devolved hub and spoke circular economy innovation system potentially offers additional advantages including:

1. A reduced demand on government and public sector resources to top-down manage the national innovation system in-line with the broader circular economy transition;
2. Triple helix-based niche managers can act as mechanisms for knowledge transfer between the different inner loop niche innovation networks thereby increasing the chances of cross-fertilisation of ideas and coordination of technological innovations;
3. The co-governance model allows a triple helix-based niche manager to be nested within the network itself and therefore be more flexible and responsive to the ever-changing demands of the wider economic landscape as well as the changing day-to-day needs of the niche itself; and
4. By maintaining a seat on the co-governing board for each triple helix-based niche manager, policy makers are afforded a window into the challenges, success and needs of all the niches. Such learning can be used to better align broader circular economy policy to support the niches.



7. Rather than the top-down approach to innovation, Government's role becomes:
1. Monitoring progress of each inner loop innovation network,
2. Closing down and creating new inner loop innovation networks when needed
3. Providing adequate resource to each triple helix-based niche manager
4. Transferring knowledge and learning between all inner loop innovation networks to stimulate a more coordinated transition to increase the opportunity for cross-fertilization of ideas.

6. Efficient transfer of learning via triple helix governance model enhances policy alignment

1. Example of hub and spoke decentralized innovation system to accelerate the circular economy transition. The hub is government and public sector and the spokes are inner loop innovation networks governed by triple helix-based niche managers

5. Protected space for inner loop experimentation offers boundary to establish devolved governance control centers

4. Polycentric governance of protected spaces allows them to be more flexible to the dynamic and competitive economic landscape relative to a top down government approach

2. Triple helix-based niche manager nested within each inner loop innovation network

3. Triple helix-based niche managers can act as knowledge transfer mechanisms between other inner loop innovation networks.

Examples of different inner loop innovation networks necessary for the transition to a circular economy

Figure 10.1: An example of how the implementation of triple helix-based niche governance within multiple inner loop innovation networks could allow for a devolved 'hub and spoke' innovation system for a circular economy transition

10.5 Recommendations for future research

This section recognises the conceptual, methodological and empirical limitations of this thesis and subsequently recommends opportunities for further research.

10.5.1 Conceptual development

The triple helix-based niche managers assessed in this thesis entirely focussed on the development of niche technologies that are highly scientific and knowledge intensive and as such, the niche is heavily dependent on university science and engineering departments to undertake fundamental technological research and development. Therefore, there is an opportunity to explore how the concept of a triple helix-based niche manager would fare within an inner-loop niche which is not centred around technology but other aspects of society such as wellbeing.

A second area with which the concept should be broadened and explored is how such a triple helix-based niche manager can be used in conjunction with the wider circular economy policy mix. For example, even though a triple helix-based niche manager may help to facilitate collaborative research projects on remanufacturing technologies and processes, there may be conflicting policies and legislation in place (or lack thereof) which fundamentally restrict the practice of remanufacturing. For example, for remanufacturing, it is difficult to acquire spare parts or disassemble products because a producer has designed to prevent disassemble or repair, or else the producer has designed for obsolescence. Until there is legislation requiring producers to design for ease of dissemble and product longevity, remanufacturing will be severely restricted. An example of complimentary policy may therefore be that spare parts are made available for a number of years after product purchase; or mandating manufacturers to provide information to repairers and remanufacturers that can facilitate repair and remanufacturing practices (Maitre-Ekern and Dalhammar 2016).

Power relations are an integral component of societal transitions (Avelino and Rotmans 2009). As such, a third area which requires further exploration with regards to the concept of a triple helix-based niche manager is an assessment of the impact of power dynamics within the niche. This would require looking into how governance decisions were made, and the role of the revolving governance board in facilitating tacit knowledge exchange and perhaps also in balancing power dynamics in niche decision making processes.

Fourthly, the two case studies undertaken in this thesis were embedded within the same innovation system and cultural setting. Therefore, to gain a fuller understanding of the applicability of a triple helix-based niche manager, it is necessary to conduct similar case studies on triple helix niche managers which are embedded in different socio-economic systems and which operate at different scales (local, regional, national, supranational).

Fifthly, the role of a policy entrepreneur is to maintain institutional memory throughout the lifetime of the niche to ensure learning is carried forwards. Additional research is required to assess the extent to which a triple helix-based niche manager could perform the function of the institutional memory for the niche throughout its different development phases.

Sixthly, governing such a complex and systemic transition is likely to be out-with the capabilities of any national government. As such, the introduction of multiple triple helix-based niche managers, each managing different inner loop innovation networks, offers the ability for a government to build a more manageable hub-and spoke innovation system to accelerate the circular economy transition. As such, the practicality and effectiveness of such a devolved innovation system merits further investigation.

Finally, as outlined in Kivimaa et al. (2018), the form and function of an intermediary is rarely static; rather it fluctuates over time as a survival strategy to meet the continually changing needs of their clients. As such, several internal aspects of the intermediaries, such as their source of funding, their governance model and their remit or scope of action must change (Mignon and Kanda 2018). This point is particularly pertinent to SNM, which acknowledges that a niche has a life cycle in which it begins in an embryonic phase, which hosts loosely bound networks and poorly articulated expectations. If the niche technology shows early promise, through the likes of successful experimentation or effective advocacy, additional resources and stakeholders will be attracted to the network and the niche will continue to grow into proto-niche and eventually a full niche. Once the niche technologies have matured and scaled to the point where they can compete on an open market against incumbent technologies, it is necessary to scale down the original shielding, nurturing and empowering measures which helped the niche to flourish in its early development phases. Throughout the niche lifecycle, it is therefore necessary to adapt the type of intermediation services provided in the niche to suit each phase.

The two case studies in this thesis examined the ability for a triple helix-based niche manager to nurture and empower a niche both in the embryonic and proto-niche phases. In theory, one of the key strengths of the triple helix-based niche manager model is that it is governed by a revolving polycentric governance board comprised of the three triple helix institutions. As such, compared to the traditional top-down approach to SNM, the triple helix-based niche manager may be more receptive and agile to the changes within the niche and be able to adjust its intermediation services accordingly. However, further research is required into whether triple helix-based niche governance may be able to nurture and empower the niche as it evolves into a full niche.

10.5.2 Methodological development

Although this thesis was able to shed light on the impact of triple helix-based niche governance on a national niche innovation network, it is not without its limitations. Firstly, by connecting niche actors with regime actors, IBioIC and SIR were, to some extent, able to raise awareness within the network of external regime expectations and changes. However, Schot and Geels (2008) outlined that the success of the niche is linked to linkages with ongoing external processes. By assessing the formation of relational ties between niche actors and traditional industrial regime actors, this thesis provides some clarity on how IBioIC can be used as a mechanism for bridging the gap between internal and external niche processes and actors.

However, Raven (2005) determined that niche developments may be influenced by multiple regimes. This is particularly the case for industrial biotechnology and remanufacturing; and as such, it is very challenging to objectively identify the myriad and prevailing external events and processes which are directly affecting niche development. Therefore, further study is required to shed light on the external process and impacts on the niche, and on the limitations of intermediaries such as IBioIC and SIR to nurture and empower the niche based on such external processes. A key point to note however, is that a niche network still needs to be nurtured regardless of whether or not external events are influencing the niche; and network gaps need to be bridged in order for the niche to respond to the external process. Agency within the network may well arise from external processes. However, there is no way to act on such agency without an intermediary who can mobilise resources and bridge normative gaps between institutions. As such, research on how well an intermediary can achieve that is still valuable. Additional research is also necessary to examine the effectiveness of a triple helix-based niche manager in connecting the niche network actors with wider external changes and expectations; and to measure the effect of processes external to the niche on the niche dynamics.

Secondly, due to the infancy of the niche networks, it was not possible to explicitly identify the impact of the brokering roles of IBioIC and SIR in terms of creating disruptive changes in the regime. As such, additional longitudinal research is required to explore whether such form of intermediation can create disruptive changes and regime destabilisation in the long term.

Thirdly, the methodology does not categorize the type of learning transferred within the network (such as market, commercial, technical or cultural learning) which would offer valuable insight into the role of a triple helix intermediary in nurturing different forms of learning. However, two types of knowledge transfer were addressed with respect to market, technical and cultural issues: tacit and explicit knowledge. Explicit knowledge is knowledge which can be easily expressed and recorded as words, numbers, codes, mathematical and scientific formulae. Tacit knowledge is embedded in the human mind through experience and jobs and which is very difficult to extract and codify. By differentiating between explicit and tacit knowledge transfer, the research partially addresses the challenge of differentiating the different nature of learning. Additionally, by measuring the changes in a range of different types of collaborative relations, the transfer of different categories of knowledge can be inferred. For example, undertaking joint collaborative projects infer high levels of technical knowledge flow and learning. This is based on the work by Levinthal and March (1993) who found that the degree to which firms learn about new opportunities is a function of the extent of their participation in inter-organizational activities.

10.5.3 Empirical development

This study specifically focussed on the role of the triple helix-based niche manager in brokering key relational ties which are conducive to fostering niche innovation. However, the methodology did not assess the direct impact of a triple helix-based niche manager on the innovation output of the niche network; or in other words, the number of technologies and processes which become established in the marketplace. In view of the networks being at their early stage of development, it was decided that the measurement of innovation output would not accurately reflect the level of nurturing and empowerment achieved by the intermediaries since very few innovations would have made it to the marketplace during the time of the study. Nonetheless, as the niches develop and expand, it would be valuable to examine the empirical link between of key relational ties fostering collaboration with the longer-term innovation output of the networks.

10.6 Concluding remark

We now live in one of the most perilous times in the entirety of human history. Our unfettered and wasteful consumption of Earth's resources has led to the highest rates of biodiversity loss since the loss of the dinosaurs 65 million years ago. The IPCC has declared that we only have a decade to prevent run-away climate change which threatens to rock the very foundations of civilisation and life on earth as we know it.

Addressing such monumental challenges requires equally monumental changes to the way we interact with the natural world. One of these monumental changes involves transitioning from the current linear 'take, make, dispose' economic system to one which is circular in nature. Such an economic system would aim to reduce and slow down the rate of human consumption of valuable natural resources by designing out waste, keeping products and materials in use for as long as possible and regenerating natural systems.

Innovation is essential for realising a circular economy. However, current approaches to innovation appear inadequate and are geared towards optimising the current linear system rather than disrupting it. Therefore, if the transition to a circular economy is to be realised within a generation, the approach to innovation must itself be redesigned. It must recognise and adapt to the complex dynamics between niche innovations, socio-technical regimes and wider landscape developments. It must be designed to cope with the evolution from value chains of production-consumption to value webs. It must shift from the traditional top-down approach to governing innovation to a more polycentric form of governance. Finally, it must prioritise the scaling up and widespread adoption of essential ‘inner loop’ circular activities. Therein lies the basis of the thesis, which proposed the concept of a triple helix-based niche manager as an innovation policy tool with which to achieve such requirements.

Overall, this thesis concludes that a triple helix-based system of niche governance can be used as an effective innovation policy tool for nurturing and empowering ‘inner loop’ niche innovation networks in line with a broader circular economy transition. By leveraging the triple helix approach to innovation within a niche innovation network, a more balanced polycentric governance model can be implemented between industry (knowledge users), academia (knowledge producers) and government (knowledge regulators) network members. By moving from a top-down to polycentric governance model, a triple helix-based niche manager organisation becomes nested within the network and can adapt nurturing and empowering activities to the changing needs of the niche. By expanding from the traditional single experiment approach of SNM to nurturing the wider niche containing multiple experiments, the niche manager is better able to foster coordination and collaboration between niche and regime actors thereby increasing the chances of regime reconfiguration. It also allows the niche manager to better steer the niche in-line with wider circular economy transition dynamics. This thesis has also demonstrated the versatility of the approach whereby a triple helix-based niche manager was able play a significant role in nurturing and empowering two very different niche networks existing in different stages of maturity.

This thesis is a call to action. If catastrophic climate change and mass extinction are to be avoided, governments around the world must act now. By launching, testing, refining and scaling the concept of a triple helix-niche manager, governments can begin to restructure their innovation systems to be able to cope with and accelerate the transition to a more circular and sustainable society.

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Appendix I: IBioIC and SIR interview consent form template for Network Member Social Network Analysis interviews

Please consider this information carefully before deciding whether to participate in this research.

Purpose of the research: To understand the network dynamics of the industrial biotechnology sector in Scotland to help policy makers draft appropriate policy to support the network.

What you will do in this research: If you decide to volunteer, you will be asked to participate in one interview. You will be asked several questions. Some of them will be about your relations with other industrial biotechnology organizations in Scotland. With your permission, I will tape record the interviews, so I don't have to make so many notes. You will not be asked to state your name on the recording.

Time required: The interview will take approximately 45 minutes.

Risks: No risks are anticipated.

Benefits: This is a chance for you to tell your story about your experiences concerning the evolution of the IB industry in Scotland. You will also receive detailed feedback on the state of the IB network in Scotland once the research is completed.

Confidentiality: Your responses to interview questions will be kept confidential. At no time will your actual identity be revealed. You will be assigned a random numerical code. Anyone who helps me transcribe responses will only know you by this code. The recording will be erased as soon as it has been transcribed. The transcript, without your name, will be kept until the research is complete.

The key code linking your name with your number will be kept in a locked file cabinet in a locked office, and no one else will have access to it. It will be destroyed upon completion of the research. The data you give me will be used for my PhD Thesis and may be used as the basis for articles or presentations in the future. I won't use your name or information that would identify you in any publications or presentations.

Participation and withdrawal: Your participation in this study is completely voluntary, and you may refuse to participate or withdraw from the study without penalty or loss of benefits to which you may otherwise be entitled. You may withdraw by informing the experimenter that you no longer wish to participate (no questions will be asked). You may skip any question during the interview, but continue to participate in the rest of the study.

To Contact the Researcher: If you have questions or concerns about this research, please contact: Jack Barrie, Level 5 James Weir Building, You may also contact the faculty member supervising this work: Elsa Joao, Level 5 James Weir Building,

Agreement:
The nature and purpose of this research have been sufficiently explained and I agree to participate in this study. I understand that I am free to withdraw at any time without incurring any penalty.

Signature: ____________________________________ Date: __________________

Name (print): ____

Appendix II: Social Network Analysis Formulae

Social network analysis equations used to calculate all structural characteristics

Measure	Equation	Description of Equation
Number of Ties	$L = \sum_{i,j} y_{ij}$	L: Total number of ties across the network y_{ij}: network variable recording data on the relationship from actor v_i to actor v_j. In many applications y_{ij} is binary-valued, taking the value 1 if v_i is tied to v_j and 0 otherwise; in this thesis, y_{ij} was taken to be binary-valued unless otherwise indicated.
Density	$D = \frac{L}{V(V-1)/2}$	V: total number of network actors in the graph D: Actual connections/potential connections
Average Path Length	$l_G = \sum_{i \neq j} \frac{d(v_i; v_j)}{V(V-1)}$	l_G: Average path length – the sum of all shortest paths between two vertices divided by total number of possible paths $d(v_i, v_j)$: represents the length of shortest path exists between two vertices. Average path length therefore sums all shortest paths between all pairs of vertices and divides that by the number of all possible paths.
Network Average Clustering Coefficient (%)	Clustering coefficient for each actor: $Ci = \frac{\lambda_G(v)}{\tau_G(v)}$ Network Average Clustering Coefficient: $\bar{C} = \frac{1}{\lvert V \rvert} \sum_{i=1}^{V} C_i$	Ci: Clustering coefficient for a single actor $\lambda_G(v)$: The number of closed triplets (triangles) of the subgraph of $v \in V(G)$. A triplet consists of three nodes that are connected by either two (open triplet) or three (closed triplet) under $\tau_G(v)$: The number of subgraphs with 2 edges between 3 actors, one of which is v and such that v is incident to both edges. $\bar{C}$: Network Average Clustering Coefficient
Centralization Index	$C_D(G) = \frac{\sum_{i=1}^{\lvert V \rvert}[C_D(v^*) - C_D(v_i)]}{[[\lvert V \rvert^2 - 3\lvert V \rvert] + 2]}$	v^*: Node with highest degree centrality $C_D(v^*)$: Largest observed centralization value
Group density	$D_s = \frac{2L_s}{V_s(V_s - 1)/2}$	D_s: Density of a pre-identified subgroup of G L_s: Total number of ties in the subgroup V_s: Total number of actors in the subgroup
Actor Degree Centrality	$C_D(v_i) = \sum_{j=1}^{V} y_{ij}$	C_D: The number of contacts an actor has in a network
Actor Closeness Centrality	$C_C(v_i) = \left[\sum_{j=1}^{g} d(v_i, v_j)\right]^{-1}$	d: geodesic distance between actors v_i and v_j

Measure	Equation	Description of Equation
Actor Betweenness Centrality	$C_B(v_j) = \sum_{i \neq j \neq k} \frac{g_{ik}(v_j)}{g_{ik}}$	$C_B(v_j)$: Betweenness centrality for actor v_j $g_{ik}(v_j)$: the number of those paths that pass through actor v_j g_{ik}: total number of shortest paths from node v_i to node v_k
Effective Size	$ESi = \sum_j \left[1 - \sum_q p_{iq} m_{jq}\right], q \neq i, j$	ESi: Effective size of the network is the number actors that the actor in question is connected to, minus the average number of ties that each of the other actors have with each other. As such – it is a measure of the extent to which each actor bridges structural holes in the network. Effective size is network size (N) minus redundancy in network. Regarding social capital – the more different regions of the network an actor has ties with, the greater the potential information and control benefits. p_{iq} m_{jq} : Actors network redundancy p_{iq}: is proportion of i’s energy invested in relationship with q, m_{jq} = calculated as j’s interaction with q divided by j’s strongest relationship with anyone

Notes:

v_i = Actor i
v_j = Actor j
G: A graph G=(V,E) is a graph which consits of a set of vertices (actors in this case) (V) with a set of edges (E) between them. Therefore e_{ij} connects actor v_i with actor v_j.
x_{ij}, = the value of the tie from v_i to v_j, on relation x, where i and j ($i \neq j$) range over all integers from 1 to g.
|V| = all network actors in graph G
∈: An element of graph G

Appendix III: Template of adjacency matrix to be filled in

The table below is a template of the adjacency matrix survey that IBioIC and SIR network members were required to complete during the SNA interview

	How frequently do you have contact (on the topic of biotechnology/remanufacturing)? (Email, phone, letter, face-to-face)	Were all of your inter-organisational relations formed through IBioIC and SIR?	Were all of your inter-organisational relations strengthened through IBioIC and SIR?	Do you currently participate in collaborative biotechnology/remanufacturing research projects together?	What level of tacit knowledge (related to biotechnology/remanufacturing) do they transfer to your organization?	What level of explicit knowledge (related to biotechnology/remanufacturing) do they transfer to your organization?	Has there been industrial biotechnology/remanufacturing technology transfer between your organizations in the past 2 years?	Has there been biotechnology/remanufacturing intellectual property transfer between your organizations in the past 2 years?	Has there been biotechnology/remanufacturing cash transfer between your organizations in the past 2 years?
	(1) None, (2) None but in future, (3) Once a quarter, (4) Once a month	(1) No, (2) Partially, (3) Yes	(1) No, (2)Low, (3)Medium, (4)High, (5) Very High	(1) Yes/ (2) No	(1) Poor, (2) Moderate, (3) High	(1) Poor, (2) Moderate, (3) High	(1) None, (2) From you to them, (3) From them to you, (4) Both ways	(1) None, (2) From you to them, (3) From them to you, (4) Both ways	(1) None, (2) From you to them, (3) From them to you, (4) Both ways
Organisation A									
Organisation B									
Organisation C									
Organisation …									

Appendix IV: IBioIC and SIR SNA Results from UCINET 6.1 Analysis

This appendix is split into two sections. The first section presents the overall network, triple helix relations and intermediary centrality network diagrams for IBioIC and SIR in more detail compared to those presented in the main body of the thesis. The second section covers the empirical results of the IBioIC and SIR social network analyses. All the data is provided on a supplementary disc.

Section 1: Please see all the IBioIC and SIR network diagrams in the preceding pages. The sociograms were produced using the software NetDraw by Borgatti (2002).

Section 2: The documents and results from the IBioIC and SIR social network and supplementary data collection and analyses are outlined below are available on the supplementary disc:

Social Network Analysis Raw Data Results

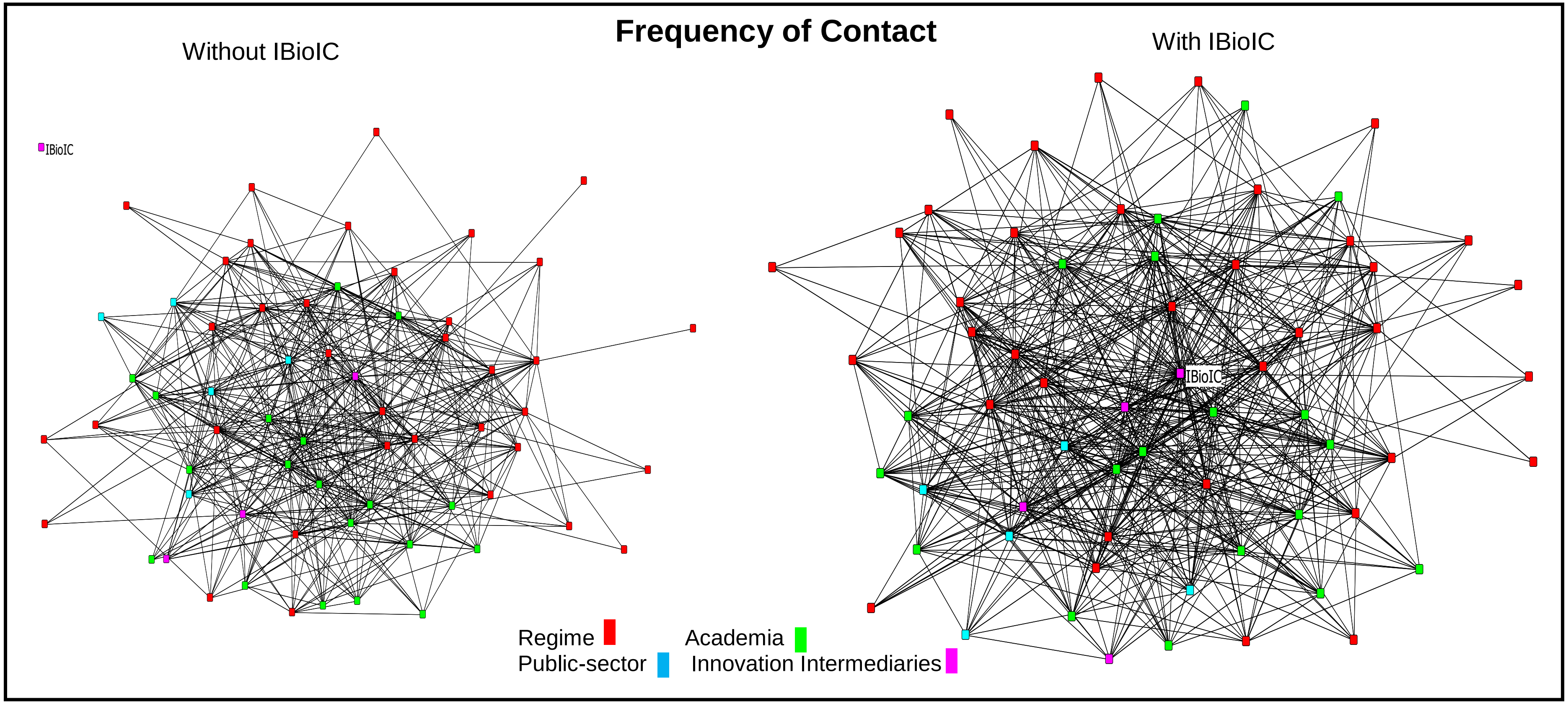
1. Individual network member adjacency matrices
    a. Calculation of total impact adjacency matrix
    b. Calculation of total knowledge
2. Calculation of each attribute value (with and without IBioIC or SIR formed ties):
    a. Structural Characteristics
        i. Cohesive subgroups (Density/Clustering Coefficient)
        ii. Cohesion (Number of ties, Density, Path Length)
        iii. Centralisation (Centralisation index)
    b. Triple helix interaction
        i. Group density
    c. Intermediary Centrality
        i. Degree
        ii. Closeness
        iii. Betweenness
        iv. Effective Size

Supporting Raw Data results

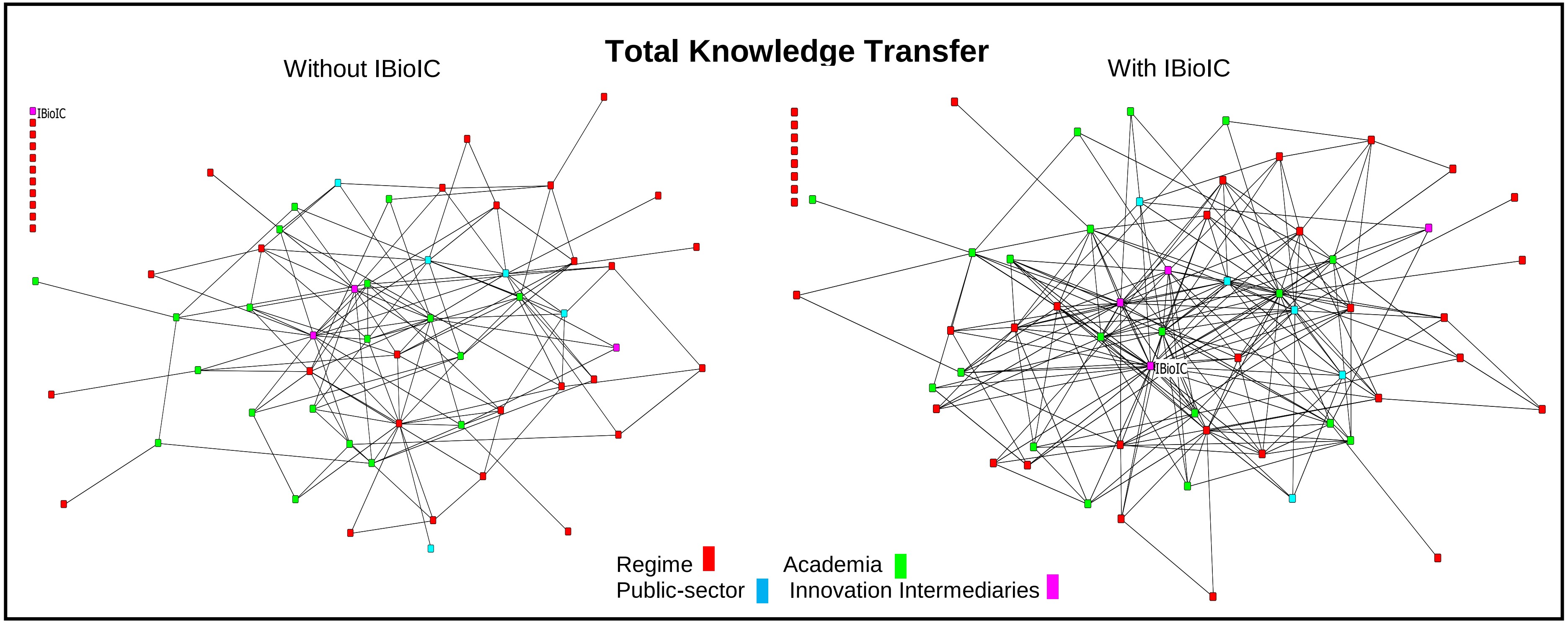
1. IBioIC and SIR Roles Survey
2. IBioIC and SIR Network Members Perceptions Survey
3. IBioIC Industry Members Survey
4. IBioIC and SIR Focus Groups
5. IBioIC and SIR Network Members Areas of Expertise

Section 1

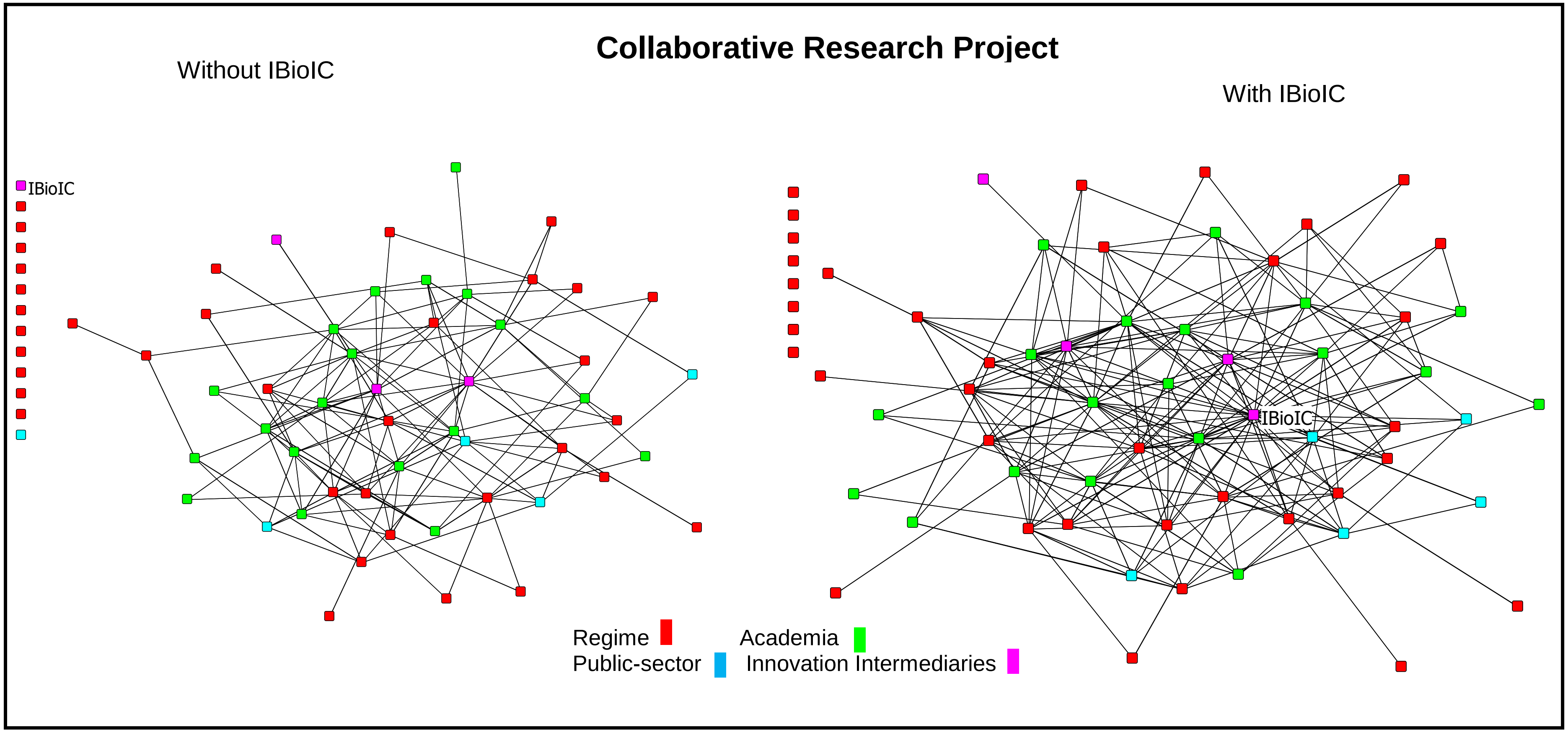
Network diagrams demonstrating inter-organisational ties formed with and without IBioIC for each relational attribute within the industrial biotechnology network (See Figure 7.2 and 7.3 in main text)



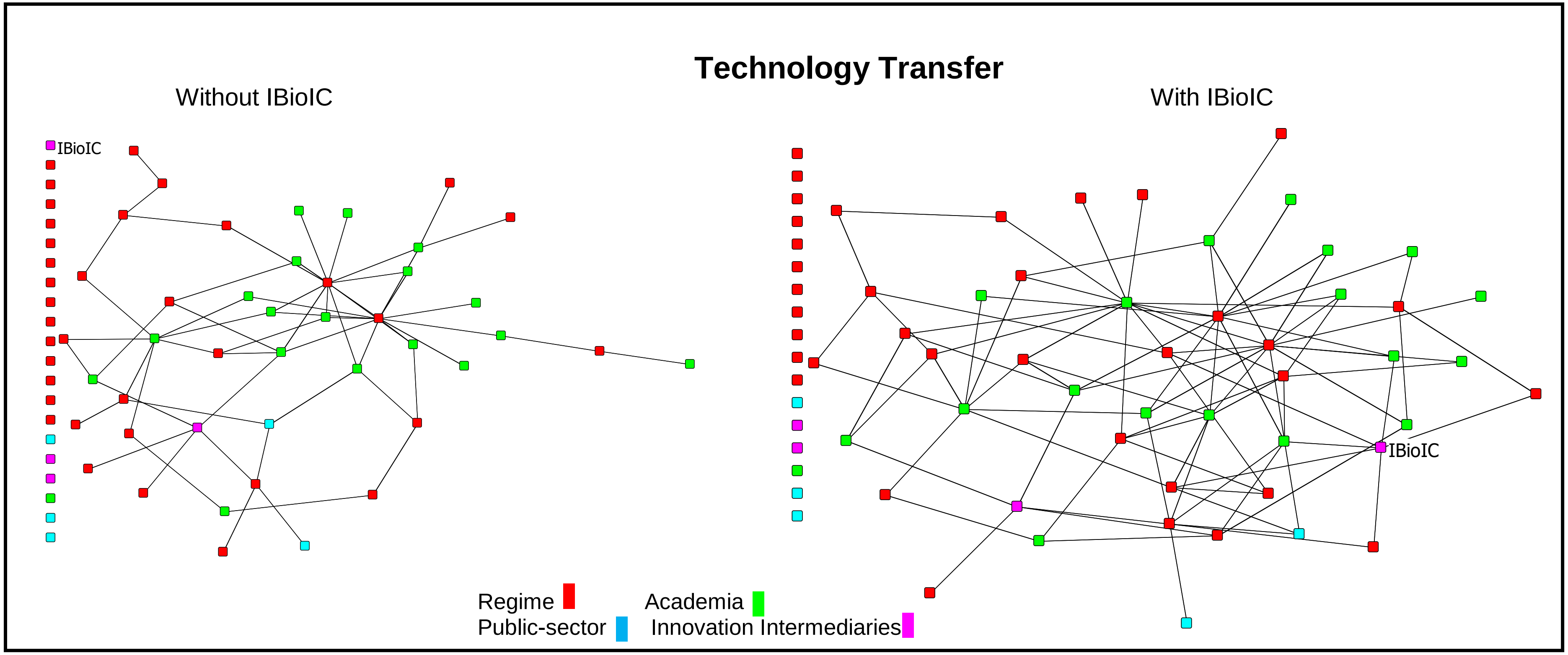
Sociogram diagrams demonstrating the change in the number of frequent contact relational ties with and without IBioIC



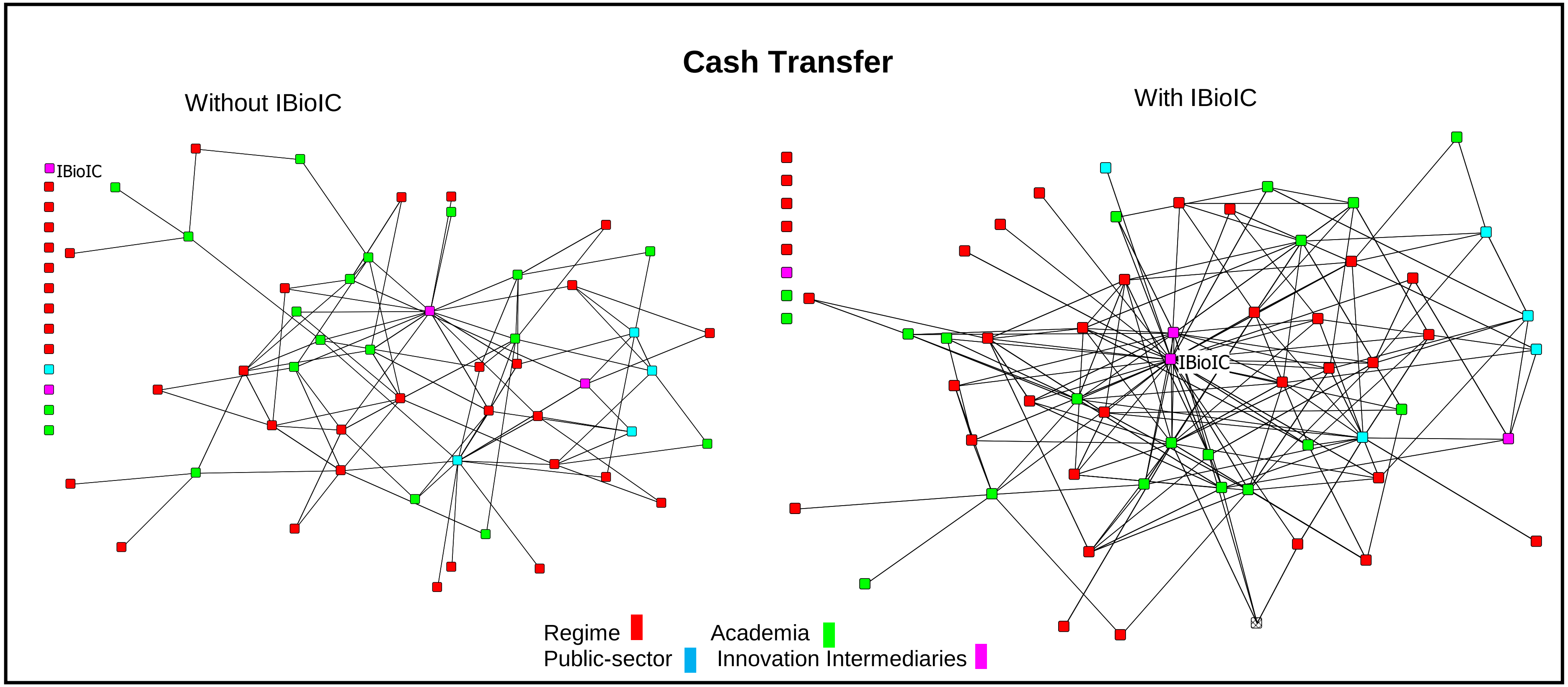
Sociogram diagrams demonstrating the change in the number of total knowledge transfer relational ties with and without IBioIC



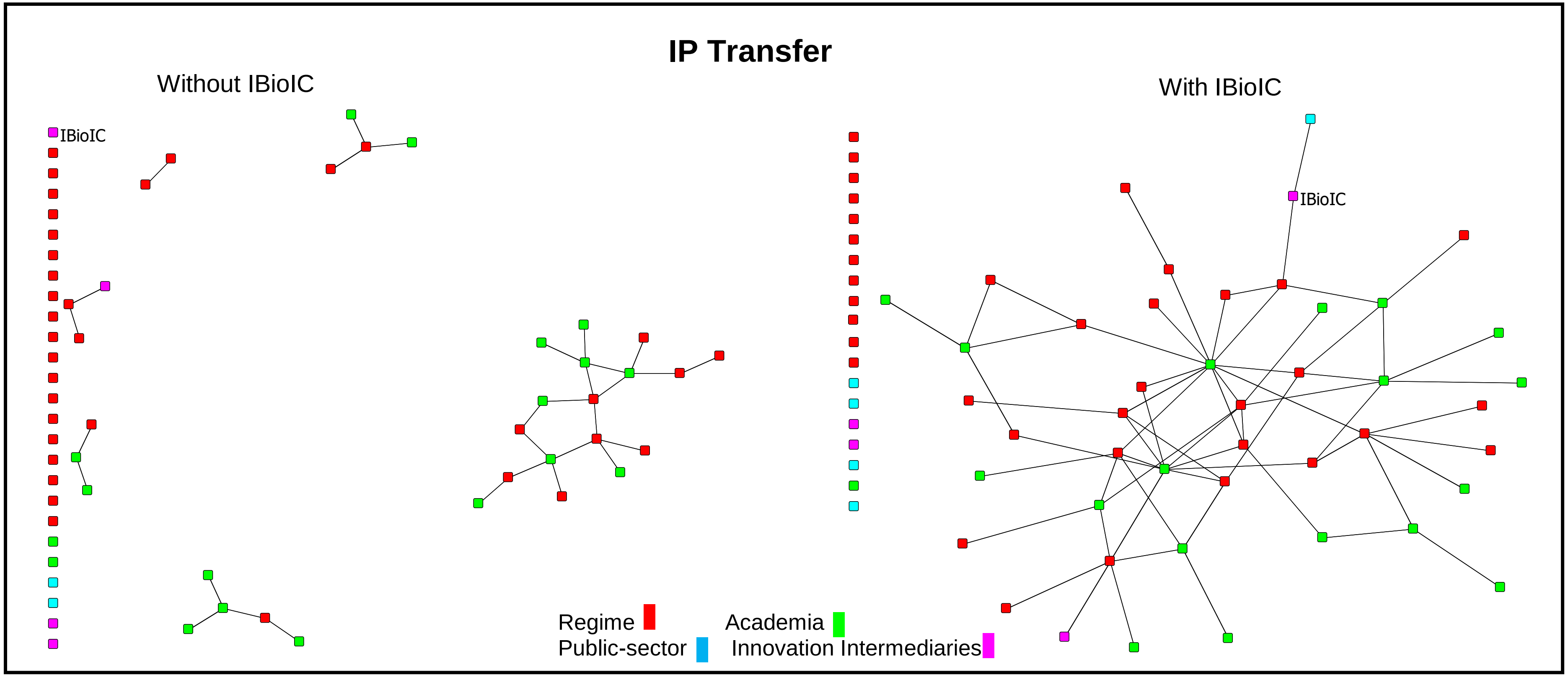
Sociogram diagrams demonstrating the change in the number of collaborative research project relational ties with and without IBioIC



Sociogram diagrams demonstrating the change in the number of technology transfer relational ties with and without IBioIC

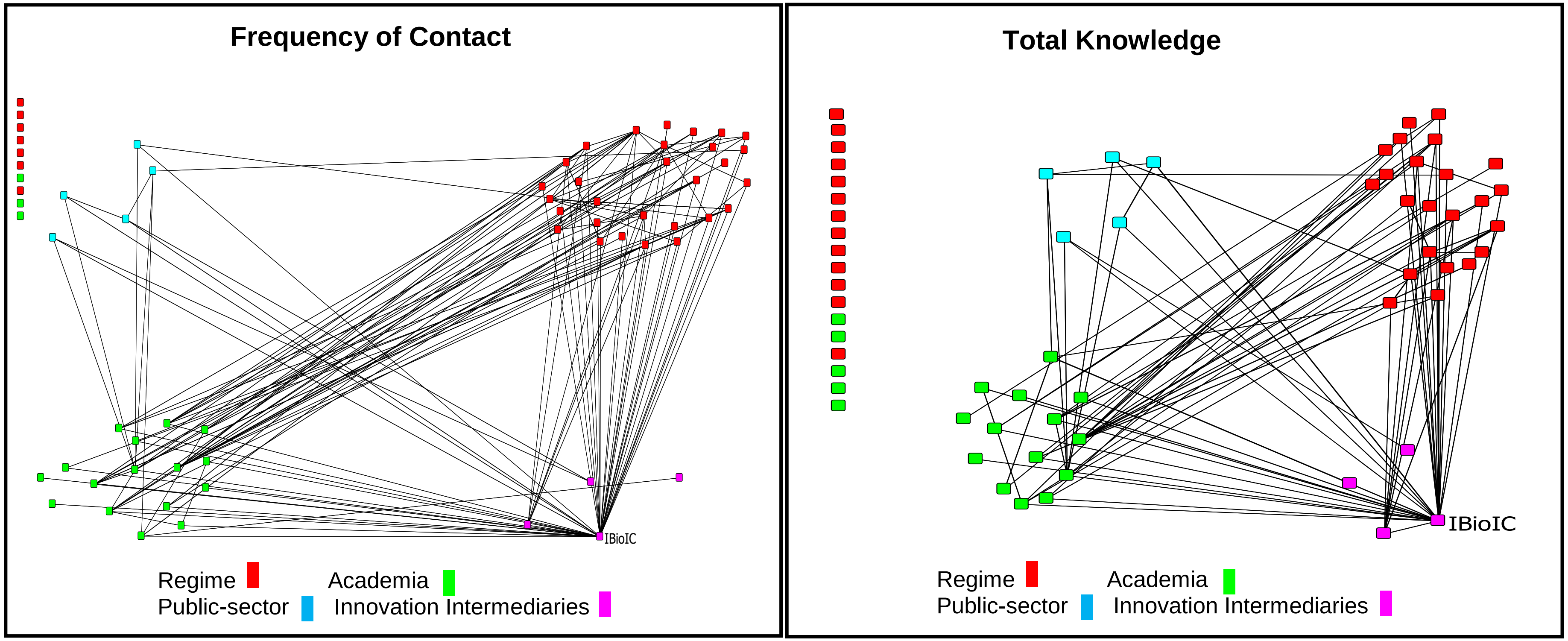


Sociogram diagrams demonstrating the change in the number of cash transfer relational ties with and without IBioIC

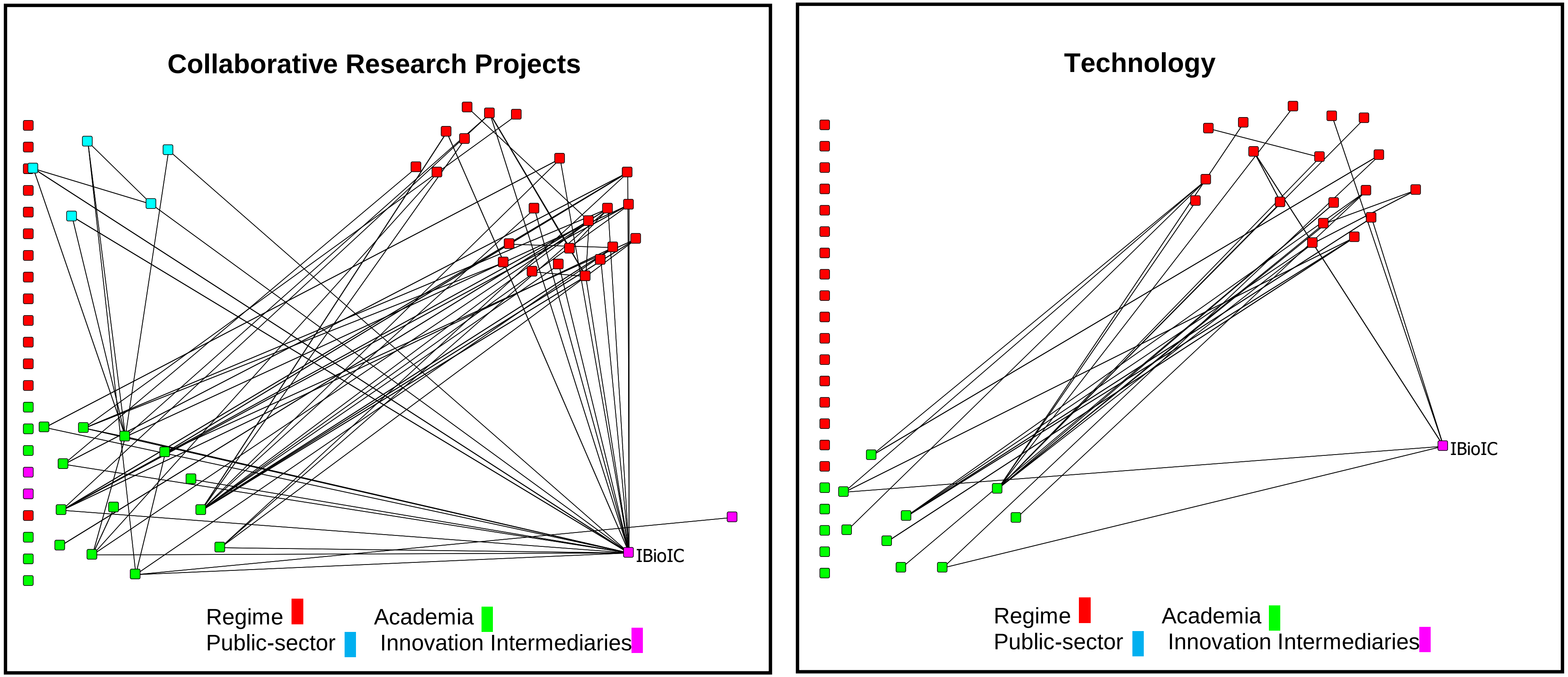


Sociogram diagrams demonstrating the change in the number of IP transfer relational ties with and without IBioIC

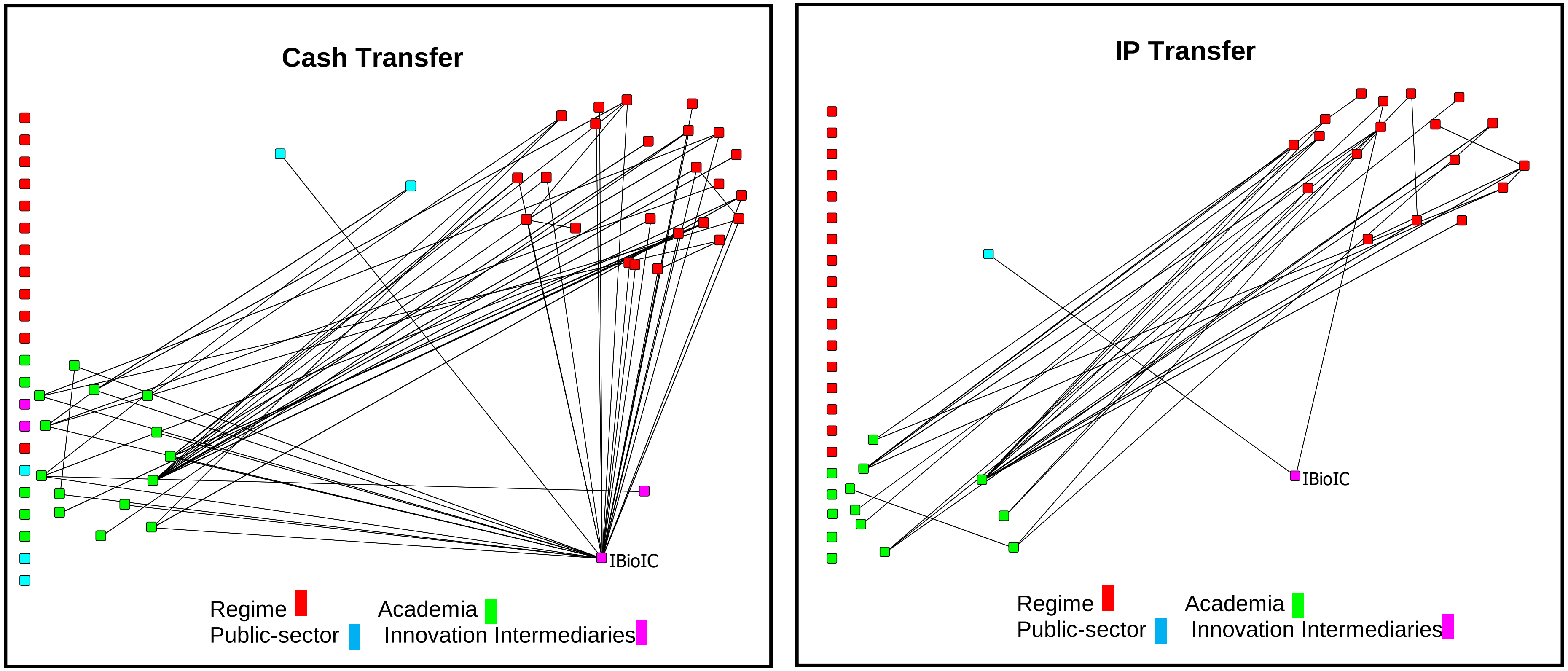
Network diagrams representing the triple helix ties formed for each relational attribute within the industrial biotechnology network due to IBioIC (See Figure 7.4 in main text)



Sociograms displaying the triple helix relational ties formed through IBioIC. Each line represents the formation of a new relational tie between two organizations due to the presence of IBioIC.

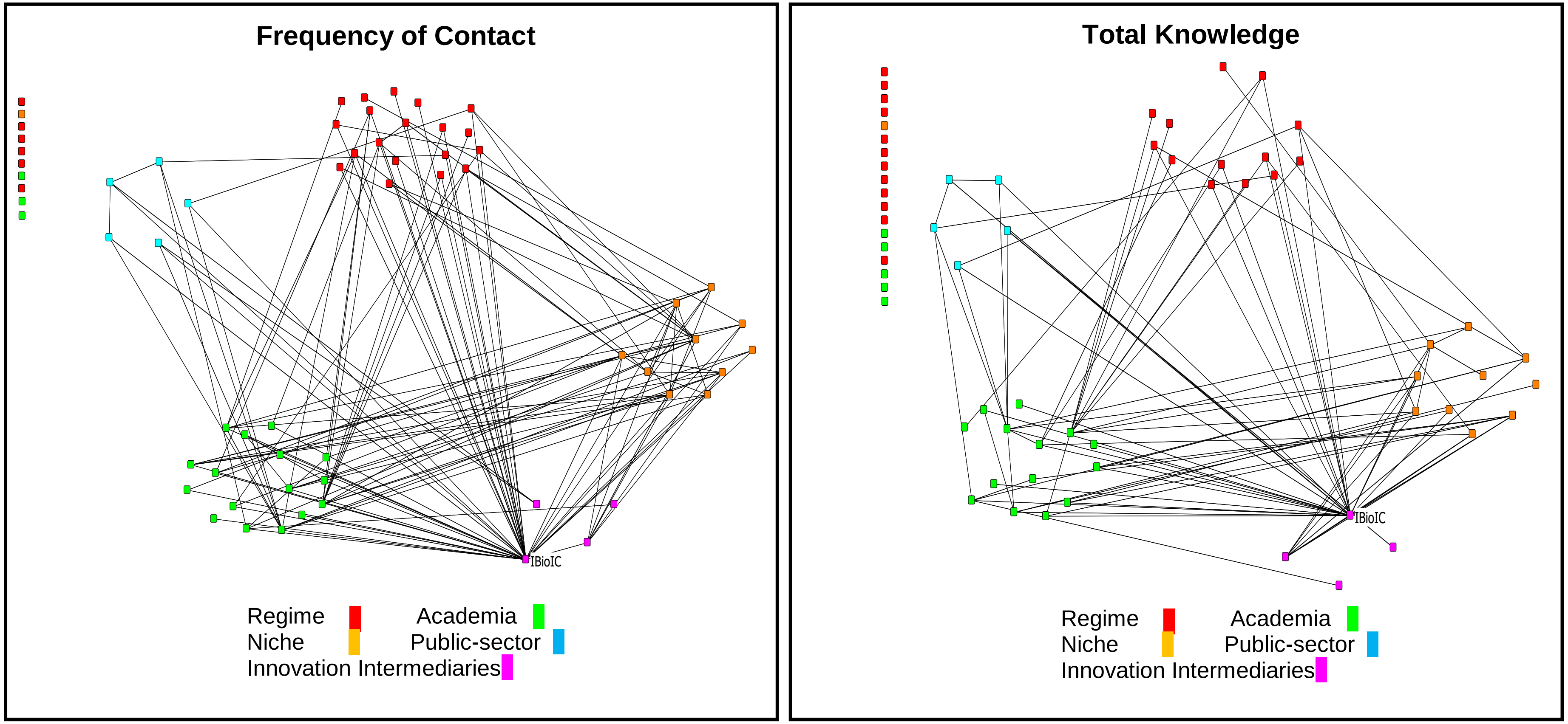


Sociograms displaying the triple helix relational ties formed through IBioIC. Each line represents the formation of a new relational tie between two organizations due to the presence of IBioIC.

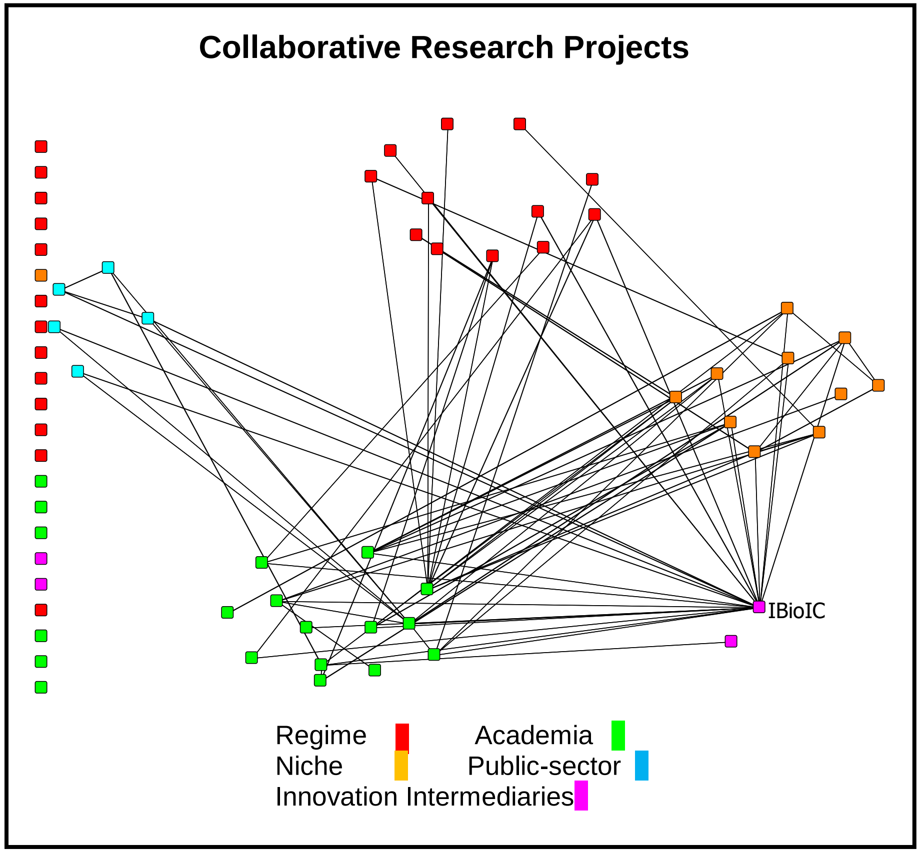


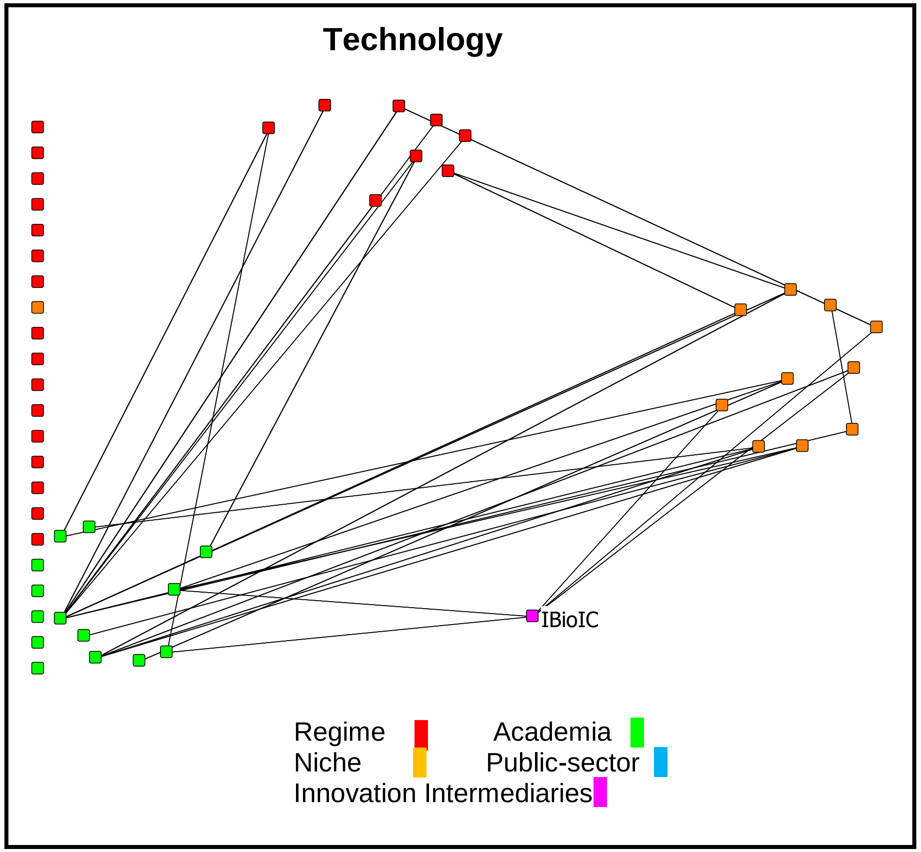
Sociograms displaying the triple helix relational ties formed through IBioIC. Each line represents the formation of a new relational tie between two organizations due to the presence of IBioIC.

Network diagrams representing the niche-regime ties formed for each relational attribute within the industrial biotechnology network due to IBioIC (See Figure 7.5 in main text)

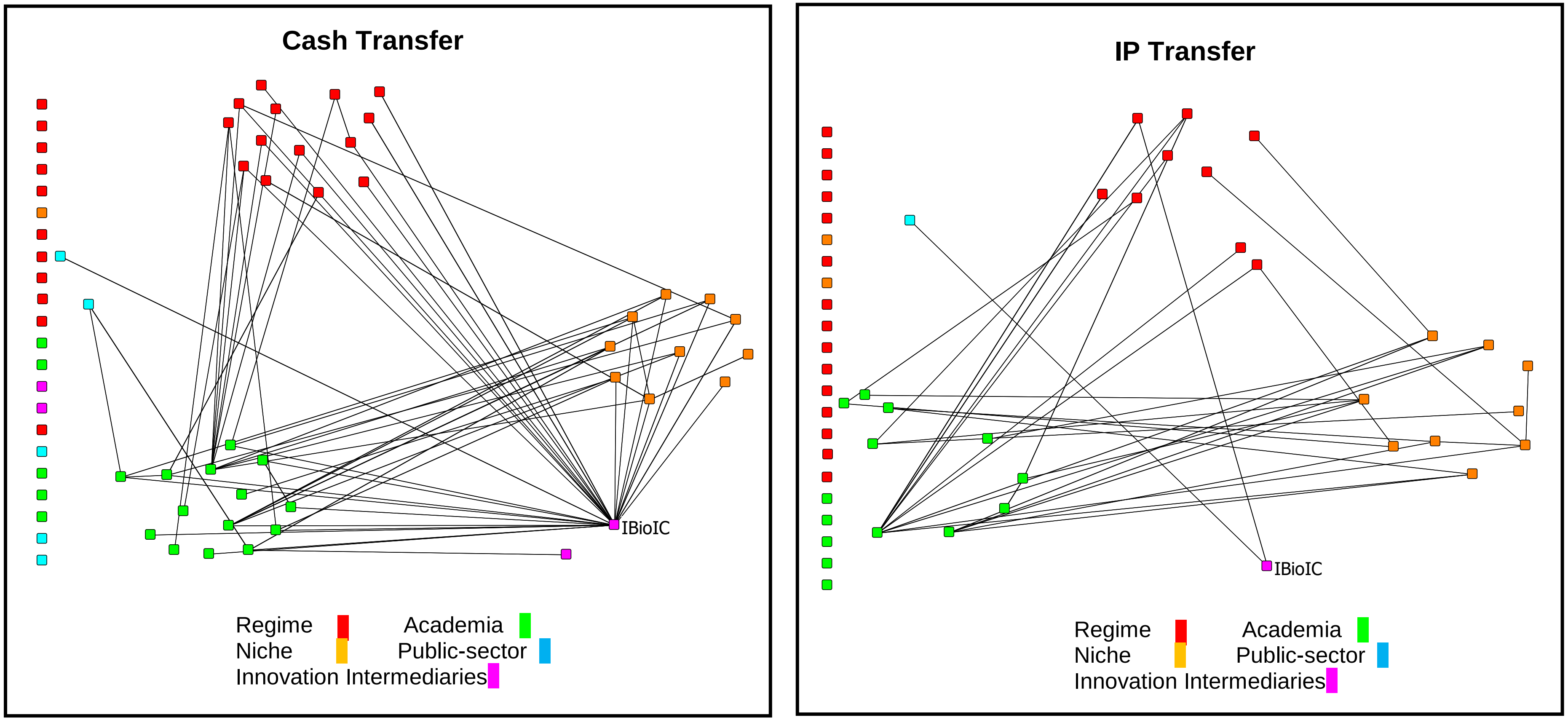


Sociograms displaying the niche-regime relational ties formed through IBioIC. Each line represents the formation of a new relational tie between two organizations due to the presence of IBioIC.



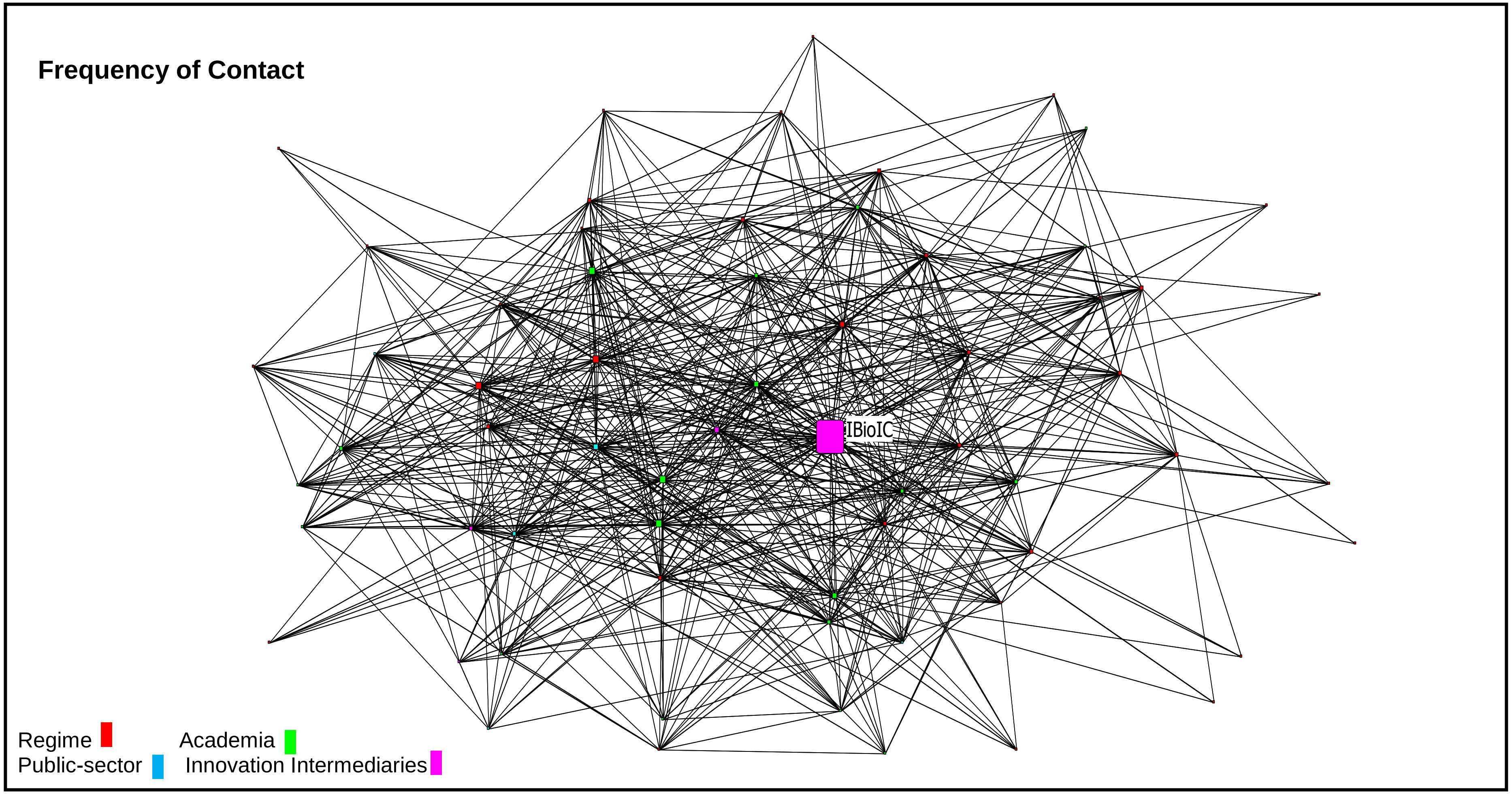


Sociograms displaying the niche-regime relational ties formed through IBioIC. Each line represents the formation of a new relational tie between two organizations due to the presence of IBioIC.



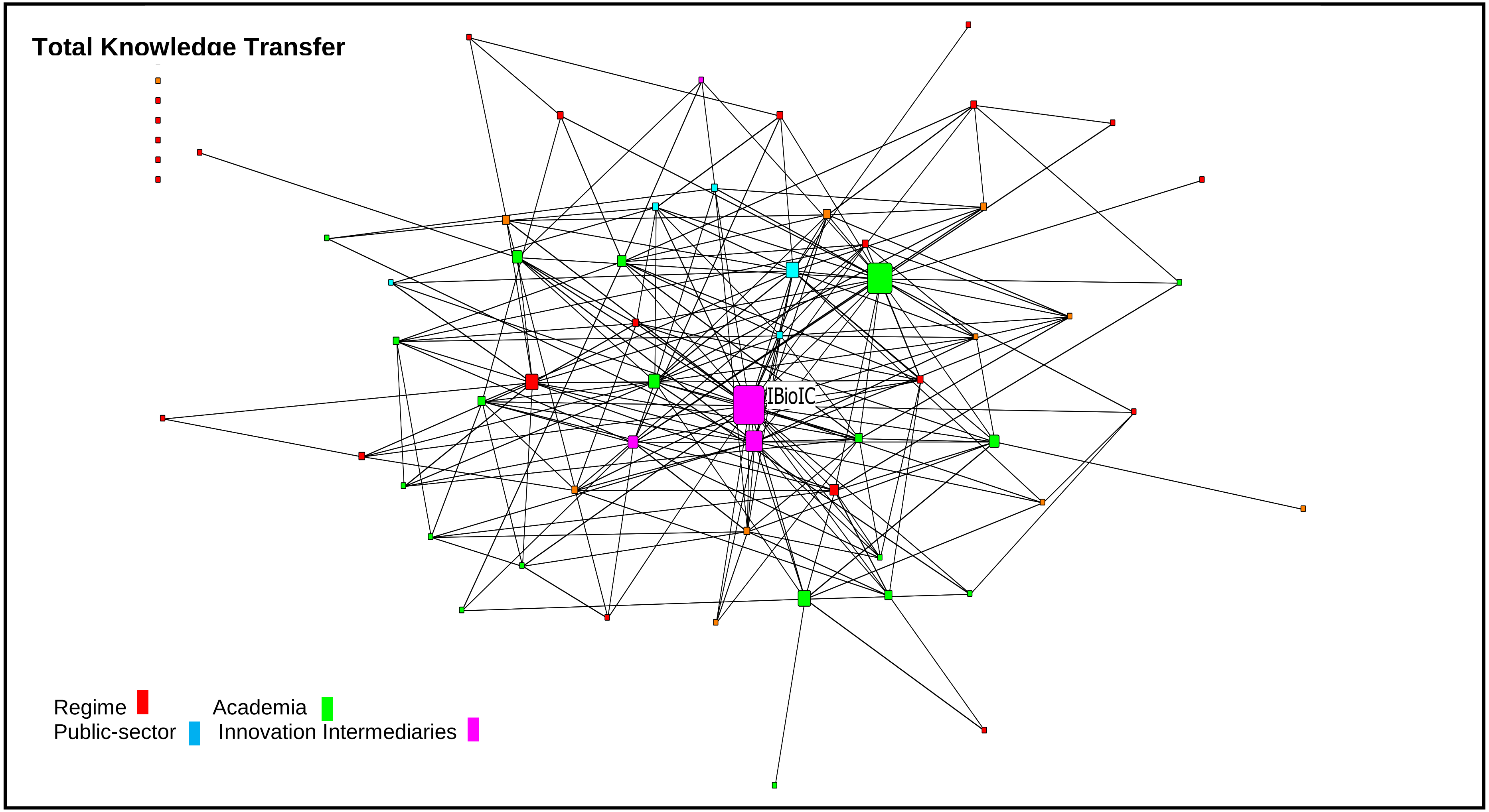
Sociograms displaying the niche-regime relational ties formed through IBioIC. Each line represents the formation of a new relational tie between two organizations due to the presence of IBioIC.

Network diagrams representing the centrality of IBioIC in the industrial biotechnology network for each relational attribute (See Figure 7.6 in main text)

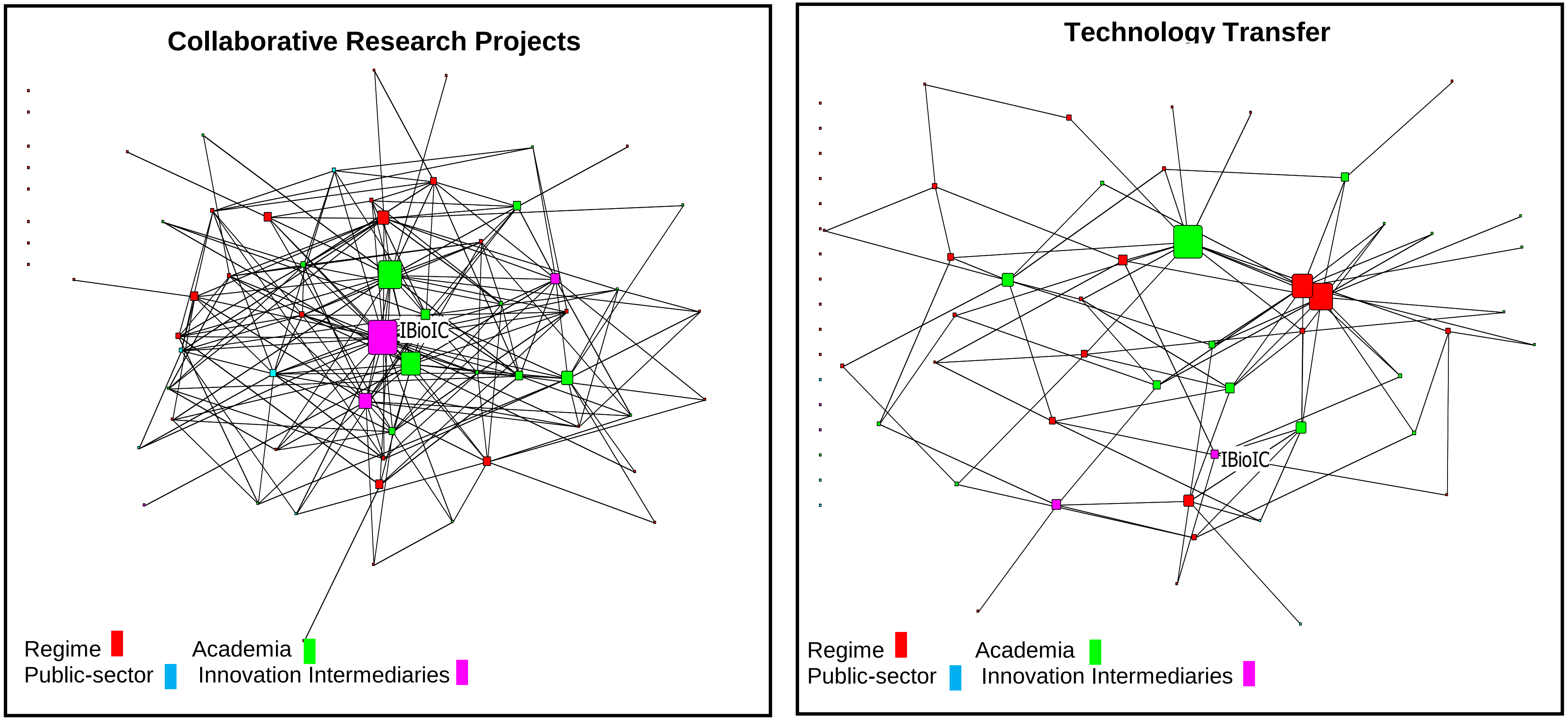


Frequency of Contact

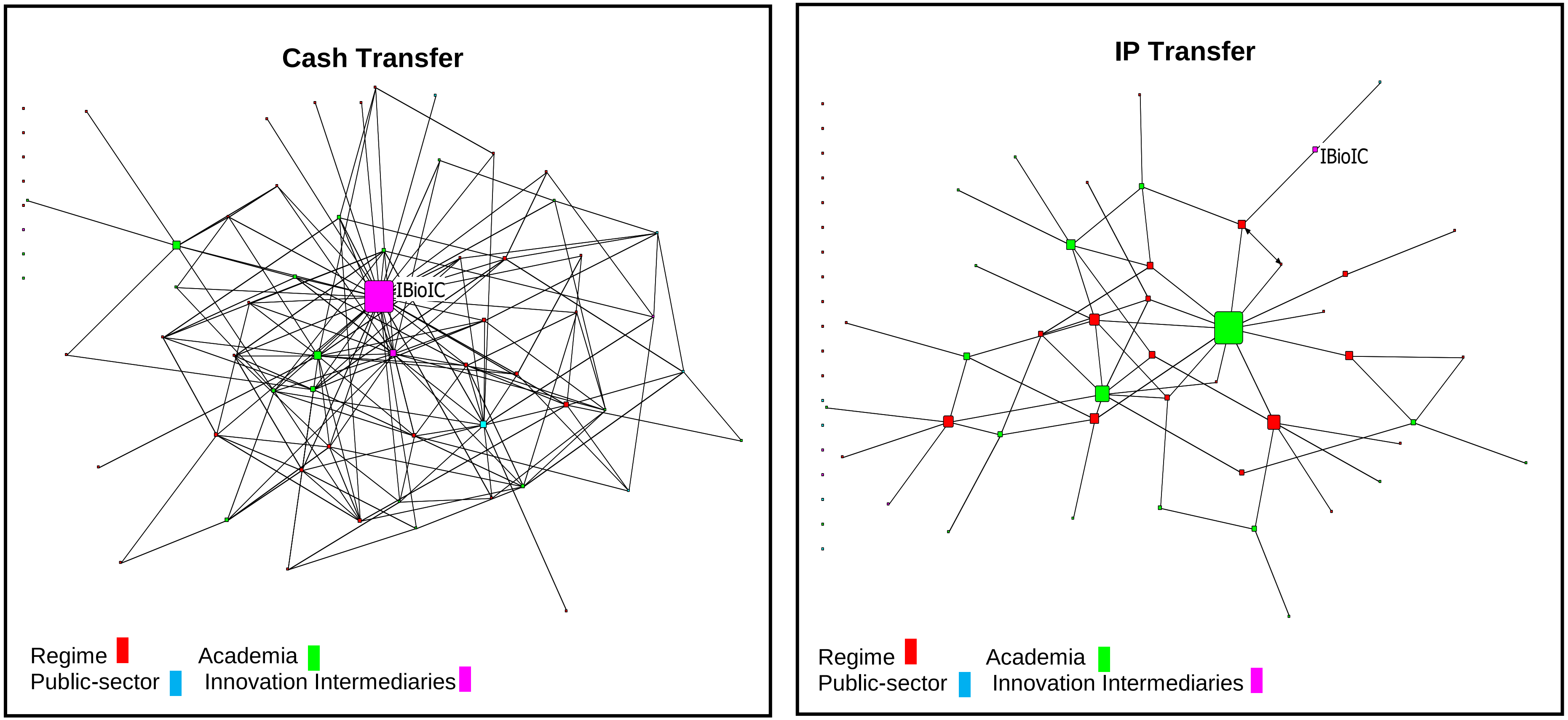
Network diagram of high level of frequency of contact dyadic ties within niche innovation network. Each line represents a connection between two organizations. The size of the actor node is scaled by the value of betweenness of the actor compare to all other network member. IBioIC is the largest node located in the centre of the network.



Network diagram of total knowledge transfer dyadic ties within niche innovation network. Each line represents a connection between two organizations. The size of the actor node is scaled by the value of betweenness of the actor compare to all other network member. IBioIC is the largest node located in the centre of the network.

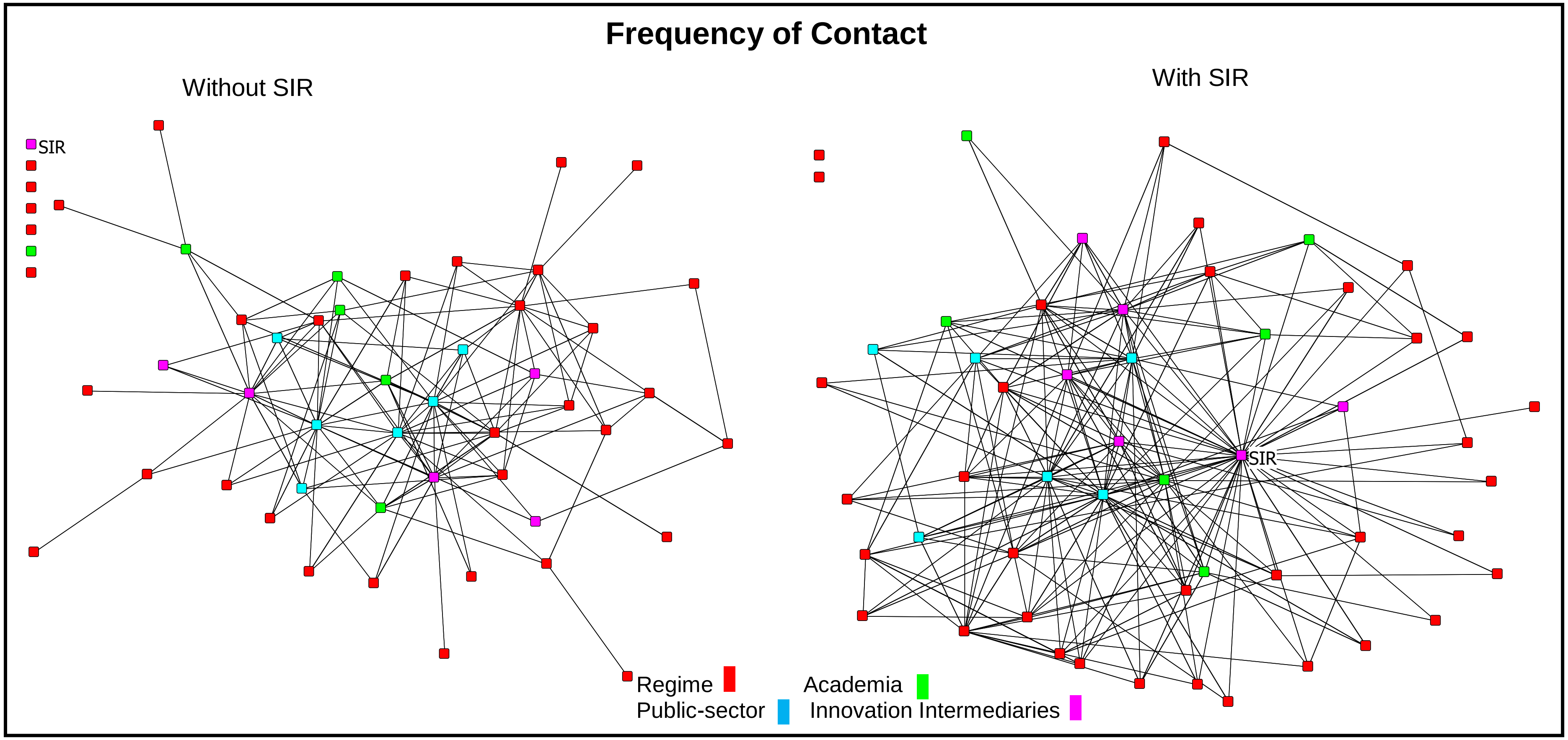


Network diagram of collaborative research project and technology transfer dyadic ties within niche innovation network. Each line represents a connection between two organizations. The size of the actor node is scaled by the value of betweenness of the actor compare to all other network member.

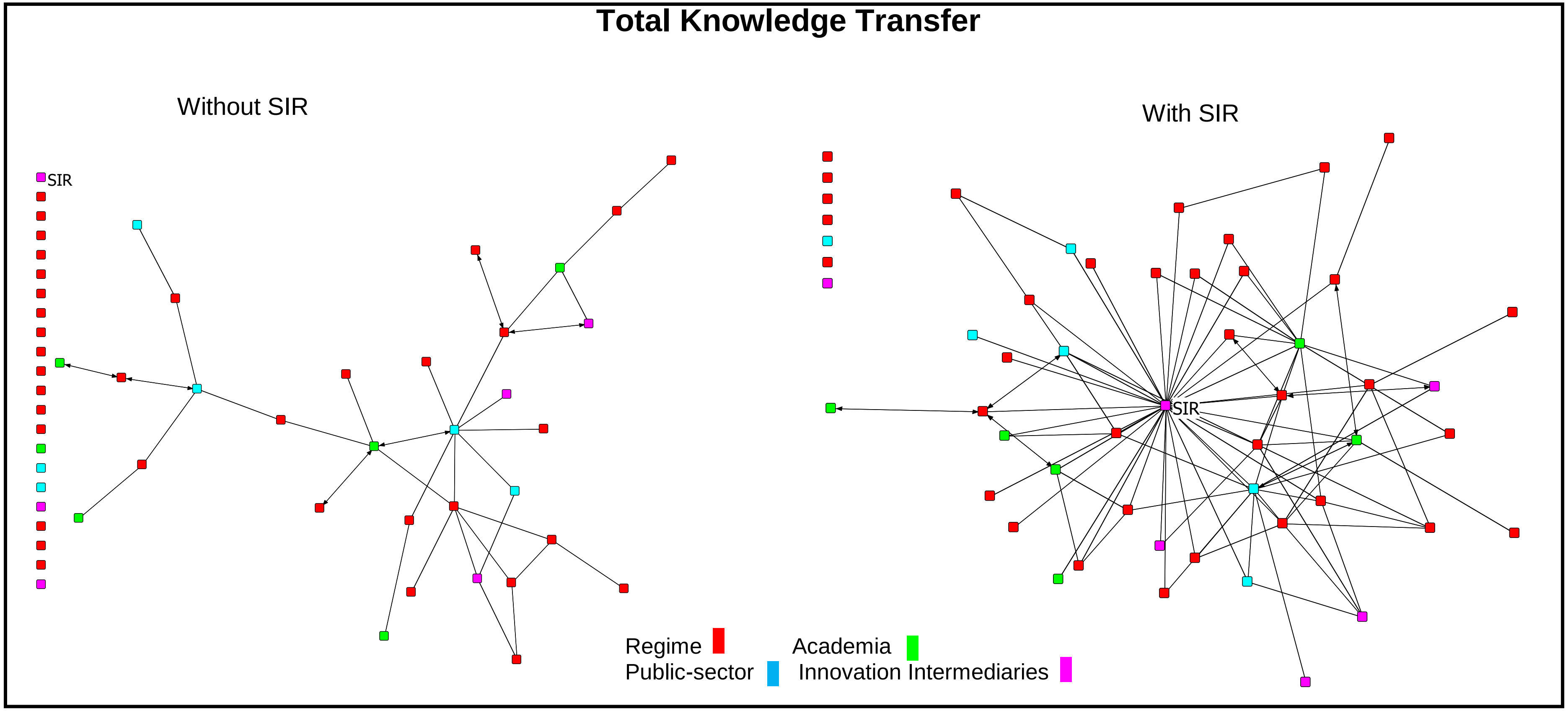


Network diagram of collaborative cash and IP transfer dyadic ties within niche innovation network. Each line represents a connection between two organizations. The size of the actor node is scaled by the value of betweenness of the actor compare to all other network member.

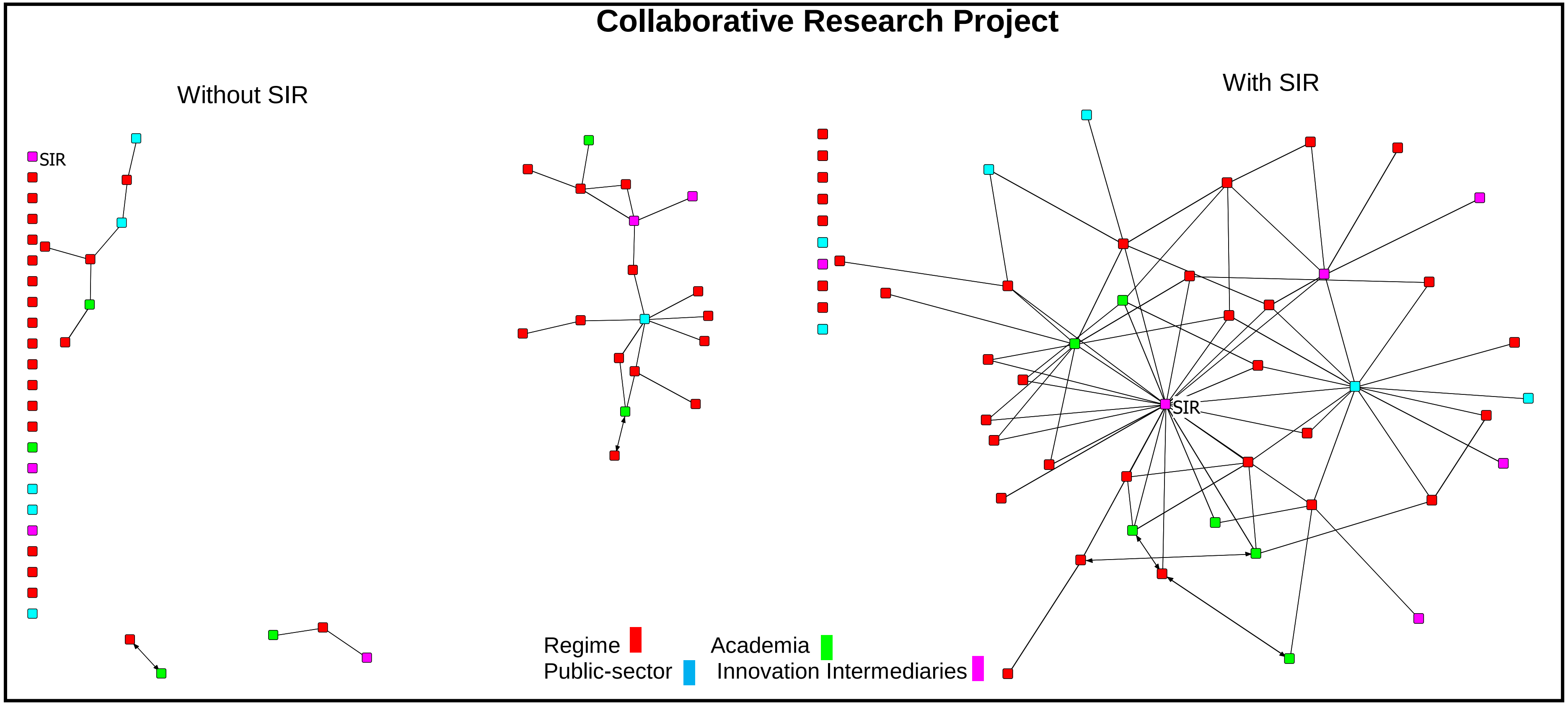
Network diagrams demonstrating inter-organisational ties formed for each relational attribute within the remanufacturing network (See Figure 8.3 and 8.4 in main text)



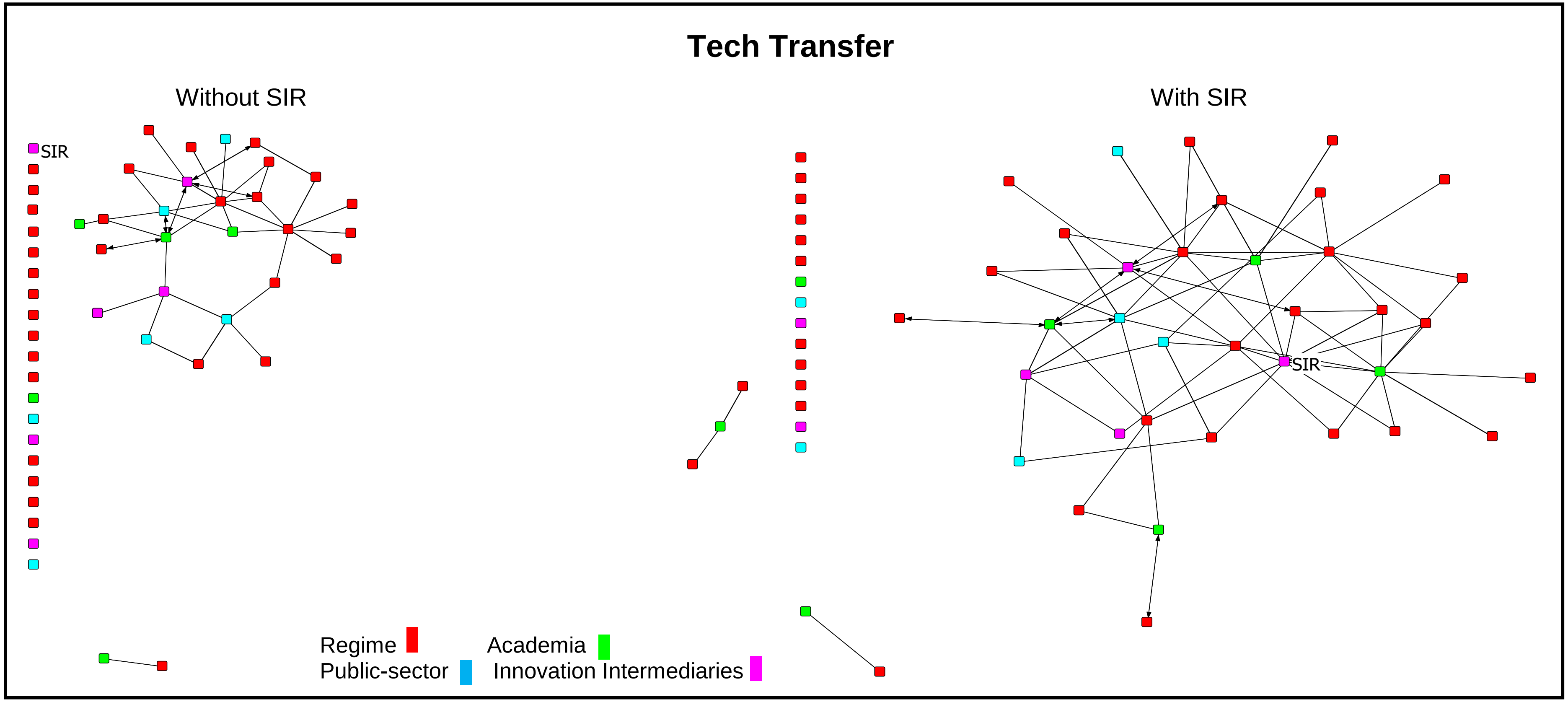
Sociogram diagrams demonstrating the change in the number of frequent contact relational ties formed with and without SIR



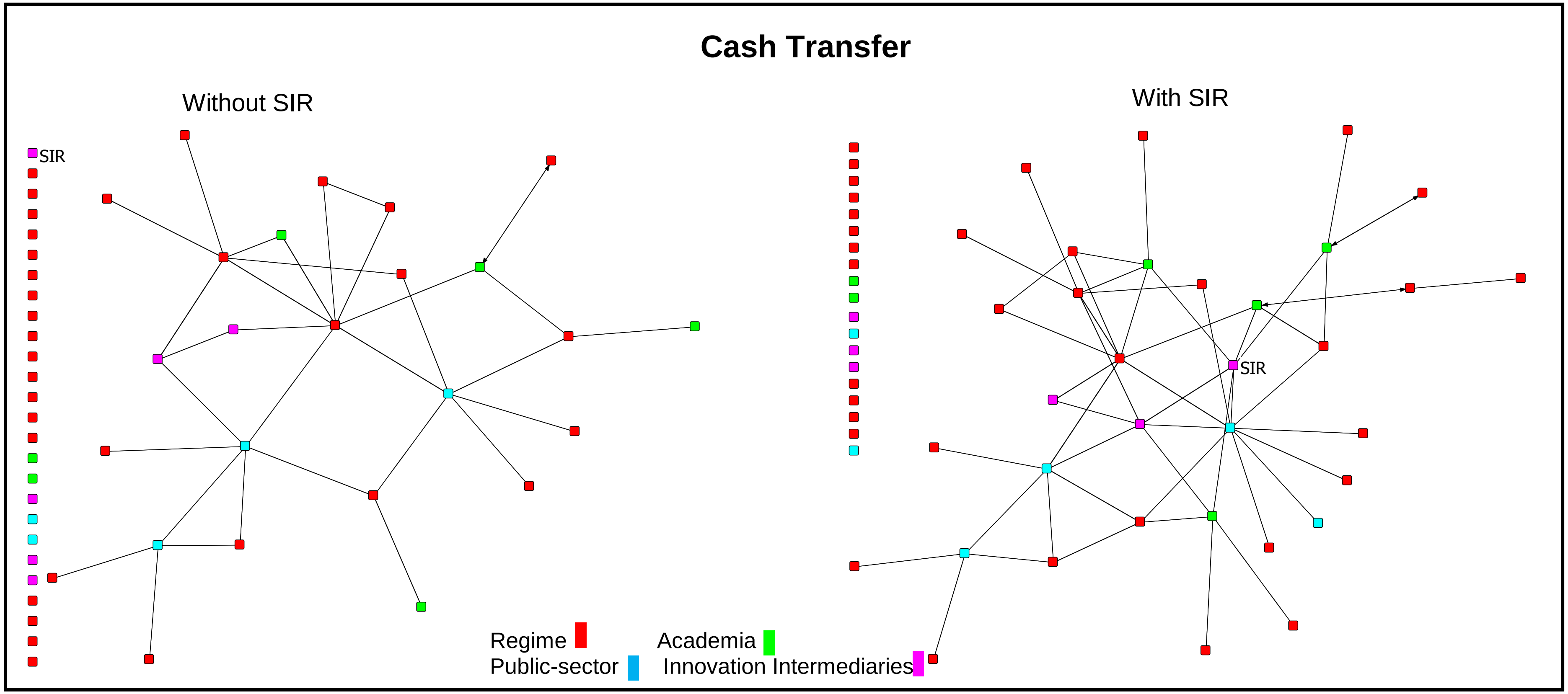
Sociogram diagrams demonstrating the change in the number of total knowledge transfer relational ties formed with and without SIR



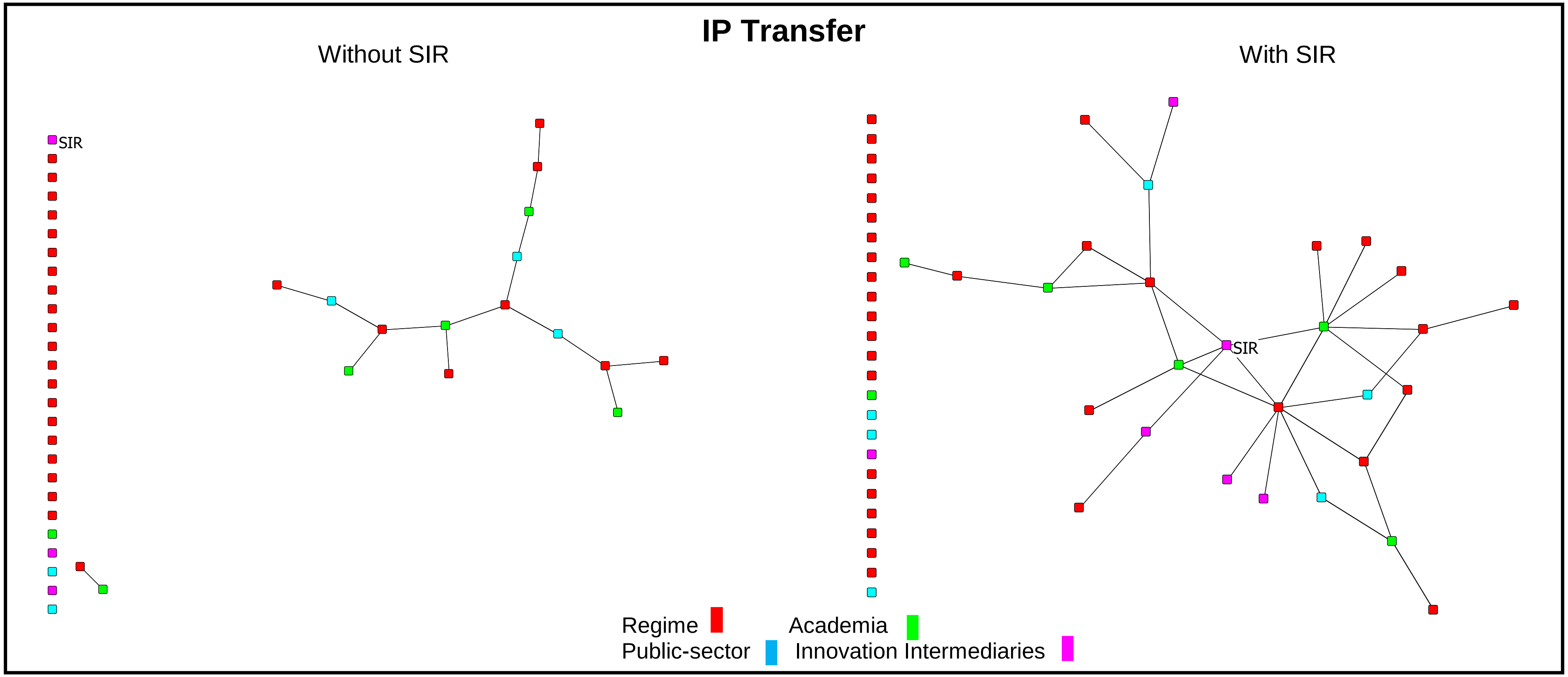
Sociogram diagrams demonstrating the change in the number of collaborative research project relational ties formed with and without SIR



Sociogram diagrams demonstrating the change in the number of technology transfer relational ties formed with and without SIR

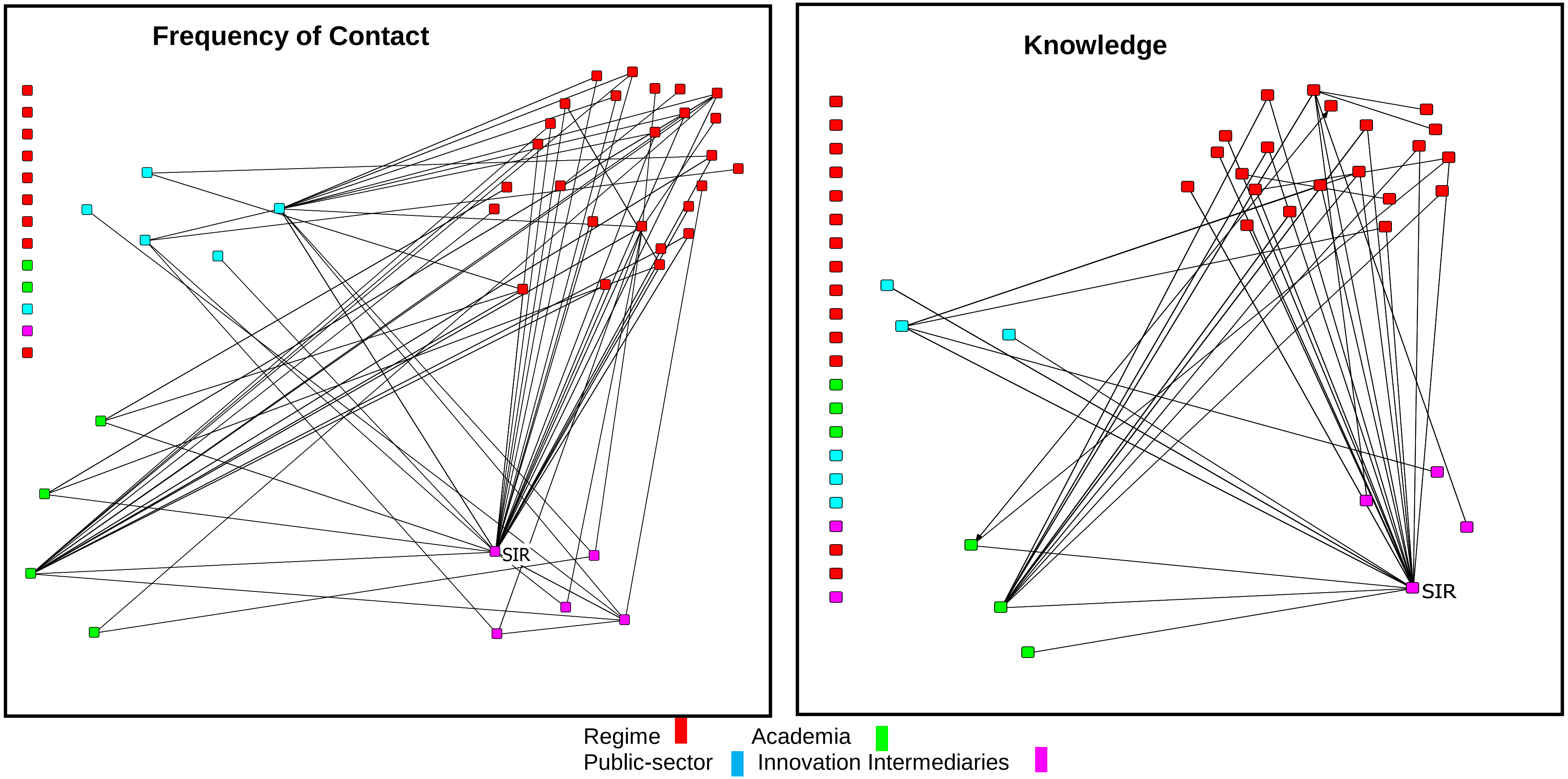


Sociogram diagrams demonstrating the change in the number of cash transfer relational ties formed with and without SIR

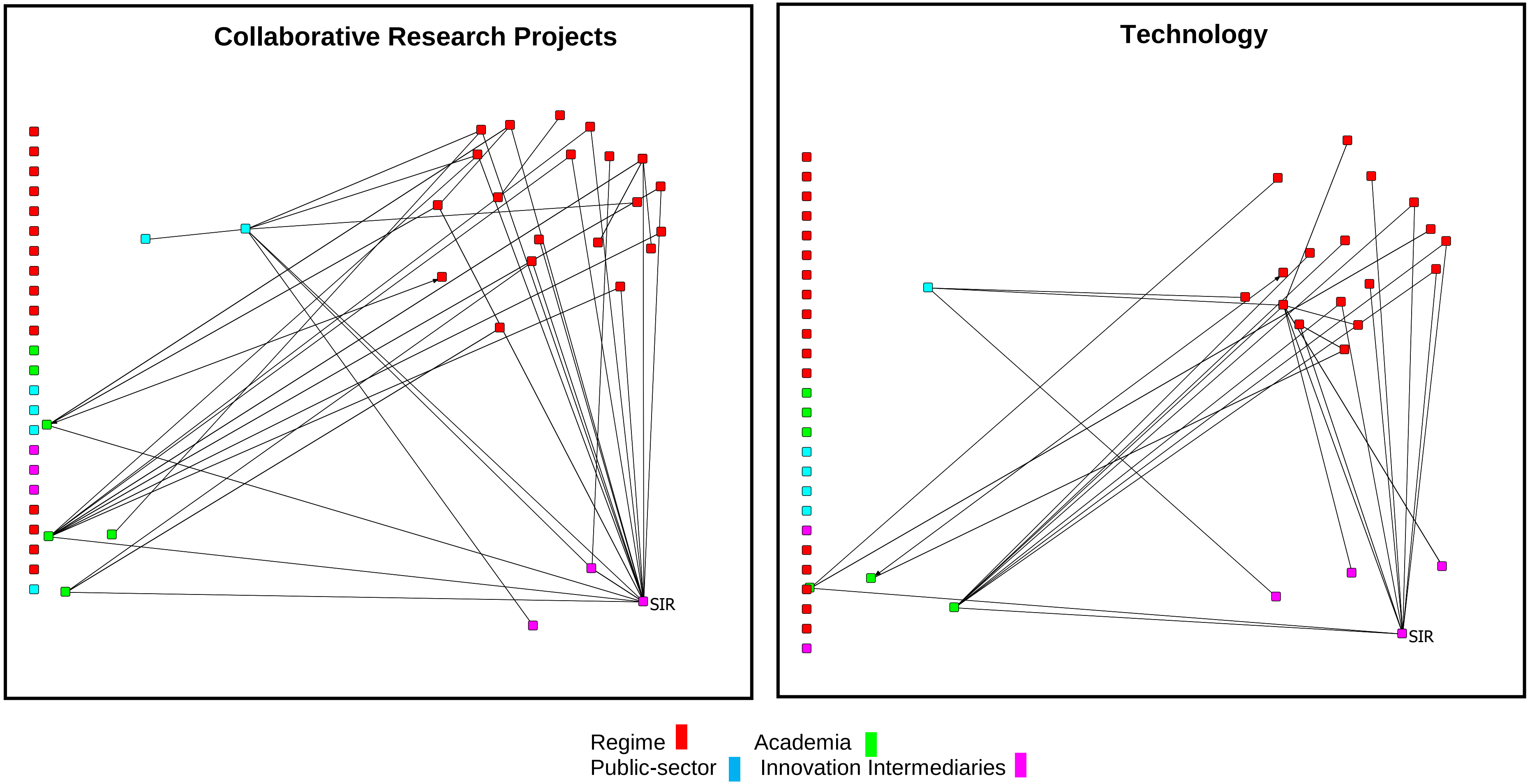


Sociogram diagrams demonstrating the change in the number of IP transfer relational ties formed with and without SIR

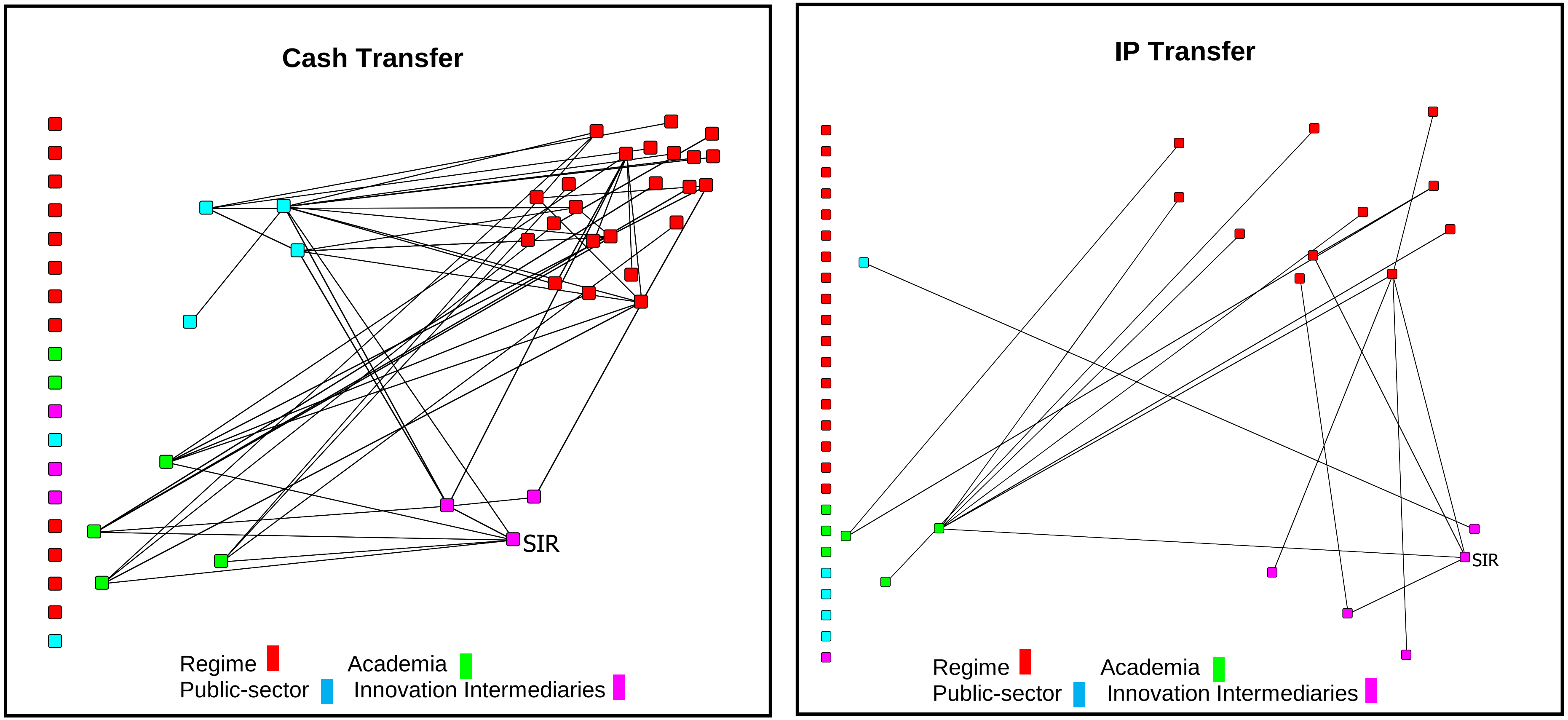
Network diagrams representing the triple helix ties formed for each relational attribute within the remanufacturing network due to SIR (See Figure 8.5 in main text)



Sociograms displaying the triple helix relational ties formed through SIR. Each line represents the formation of a new relational tie between two organizations due to the presence of SIR.

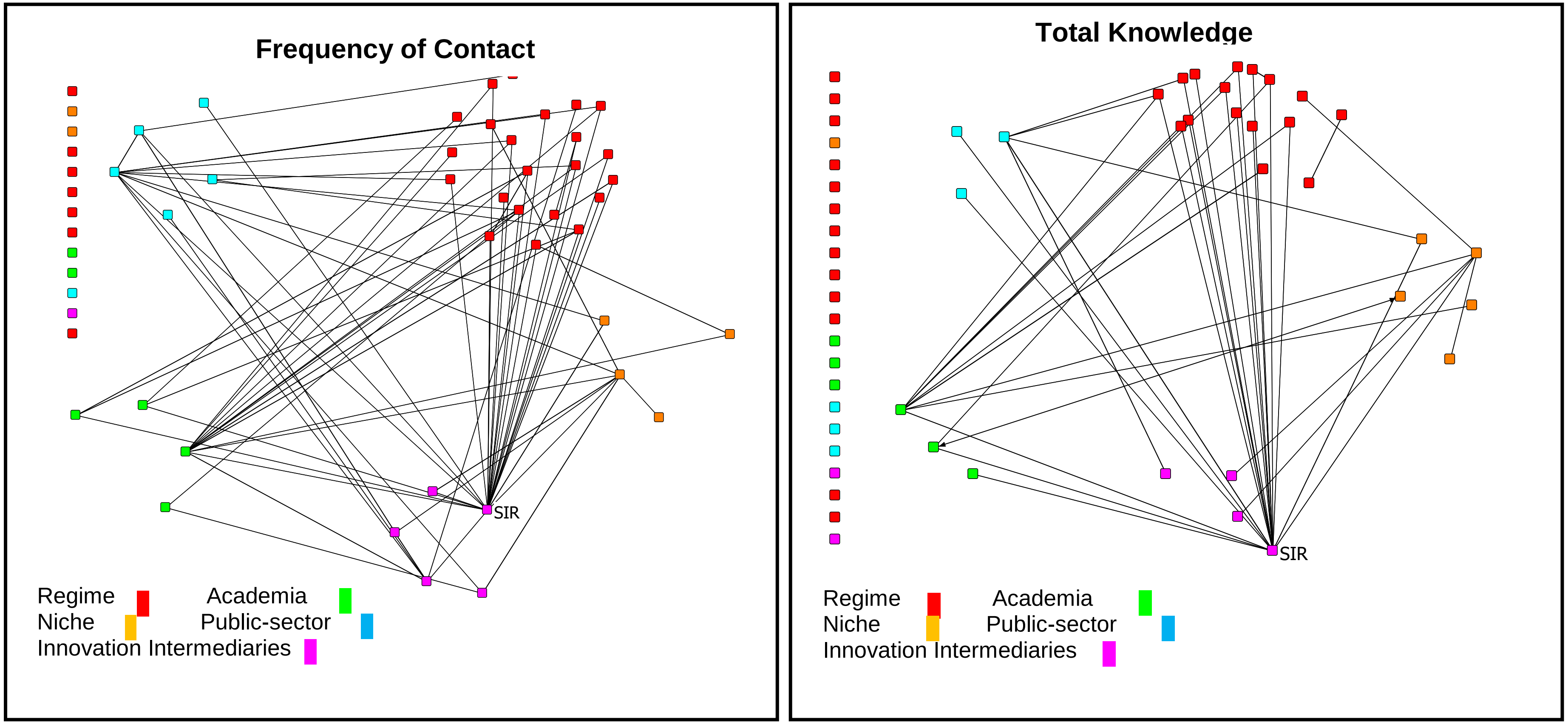


Sociograms displaying the triple helix relational ties formed through SIR. Each line represents the formation of a new relational tie between two organizations due to the presence of SIR.

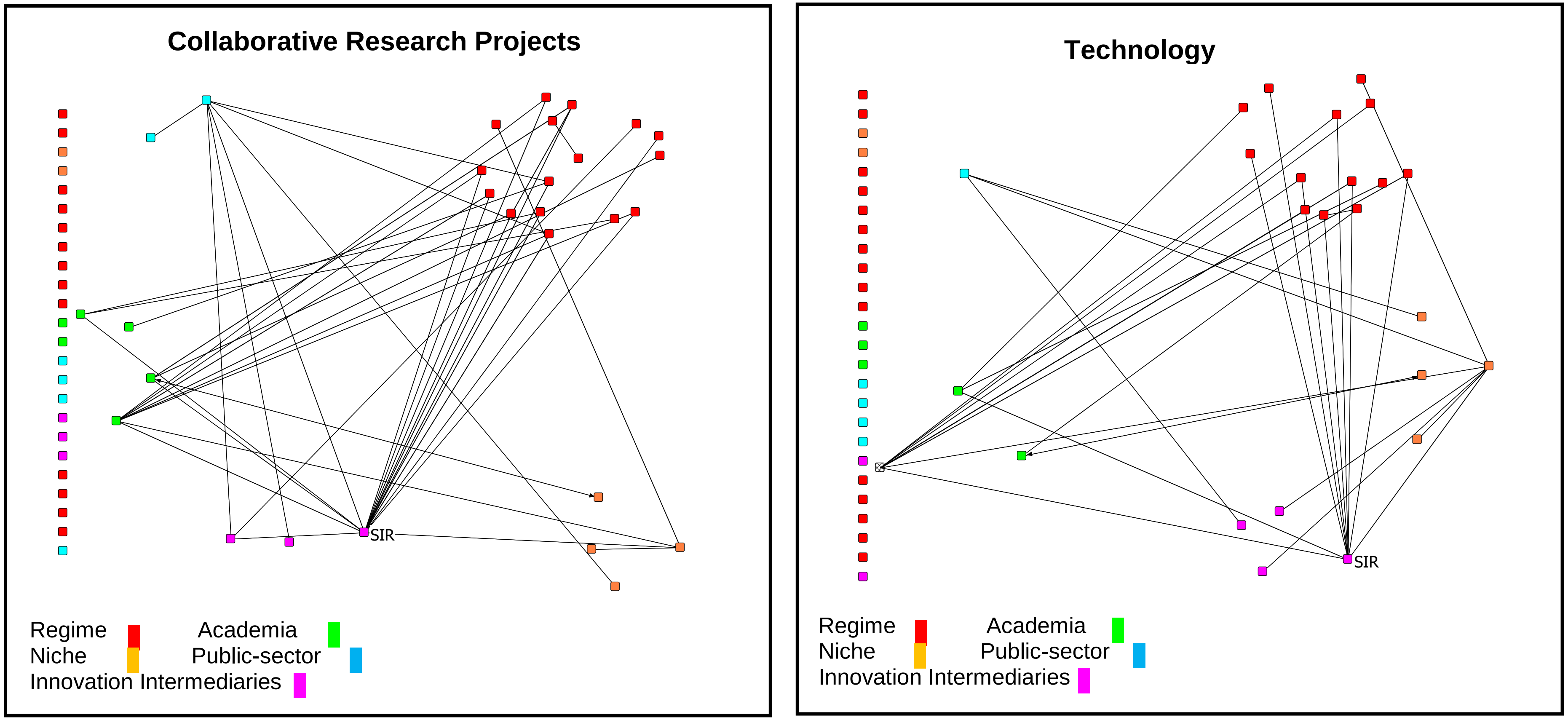


Sociograms displaying the triple helix relational ties formed through SIR. Each line represents the formation of a new relational tie between two organizations due to the presence of SIR.

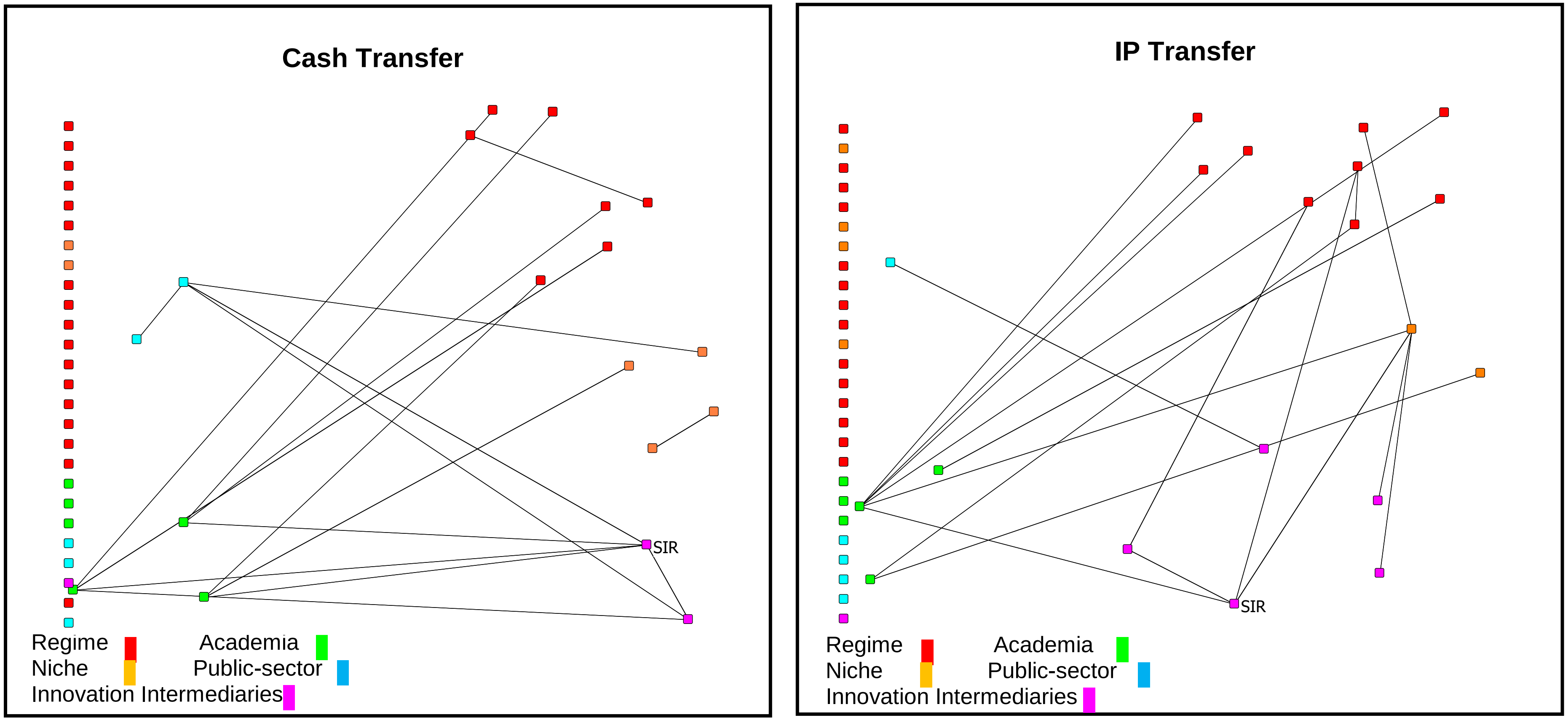
Network diagrams representing the niche-regime ties formed for each relational attribute within the remanufacturing network due to SIR (See Figure 8.6 in main text)



Sociograms displaying the triple helix relational ties formed through SIR. Each line represents the formation of a new relational tie between two organizations due to the presence of SIR.

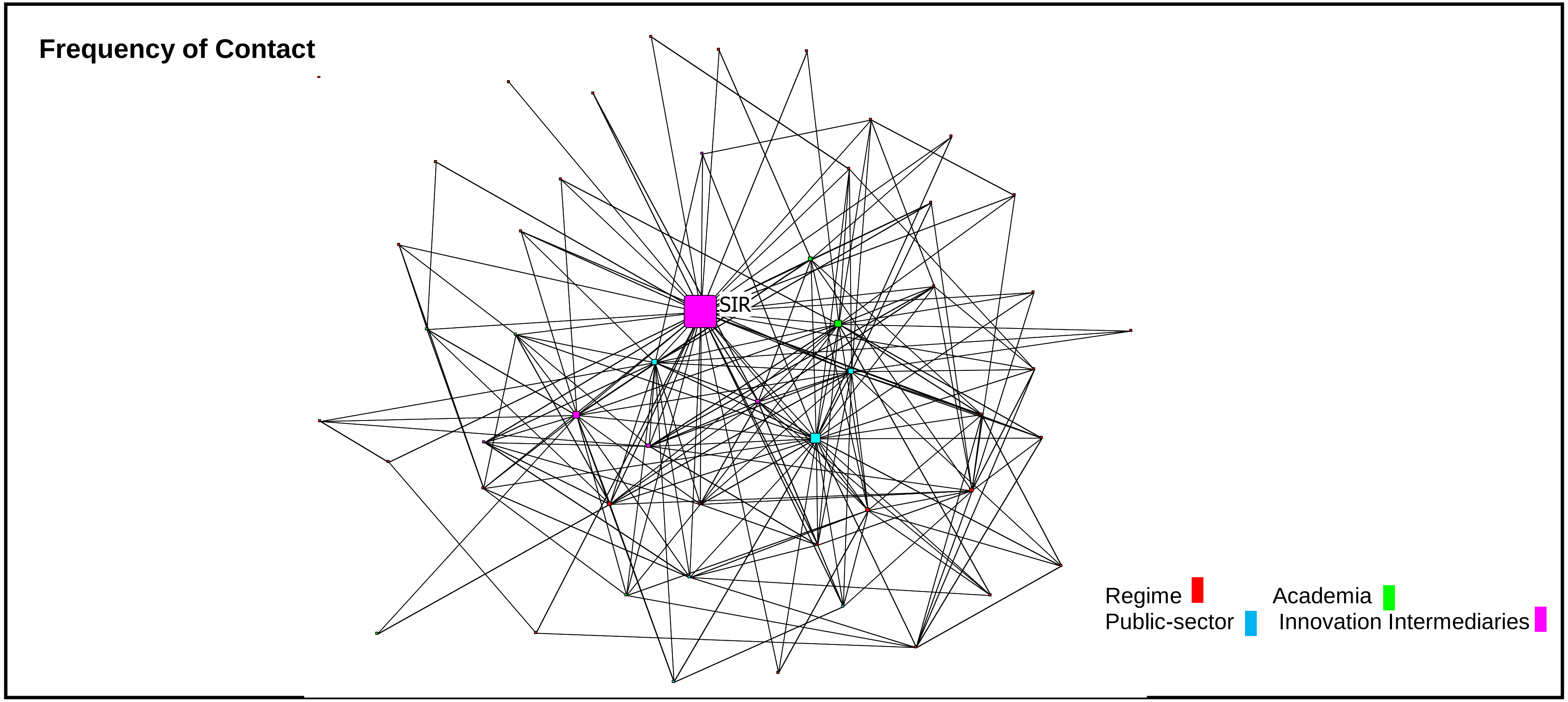


Sociograms displaying the triple helix relational ties formed through SIR. Each line represents the formation of a new relational tie between two organizations due to the presence of SIR.

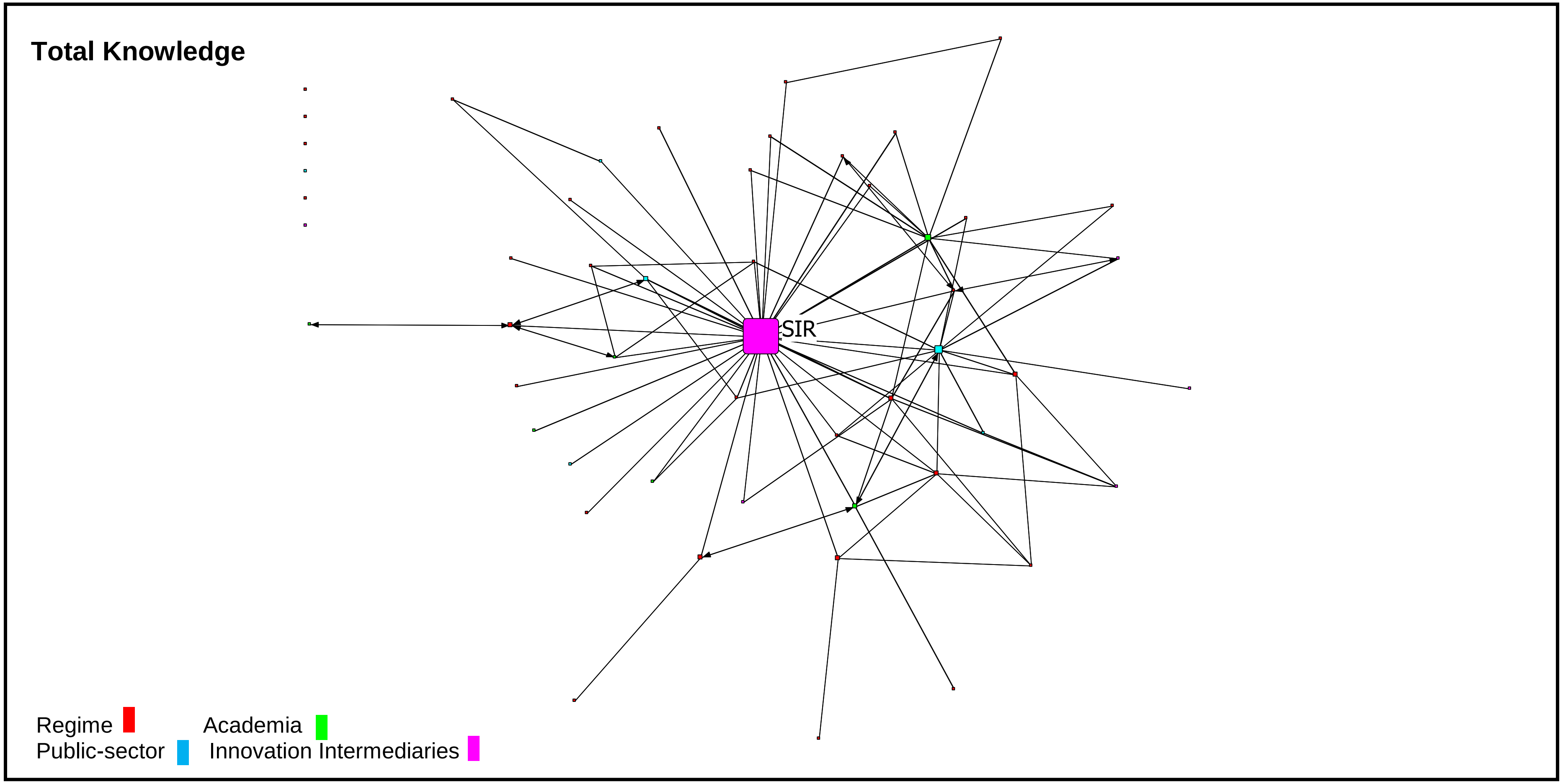


Sociograms displaying the triple helix relational ties formed through SIR. Each line represents the formation of a new relational tie between two organizations due to the presence of SIR.

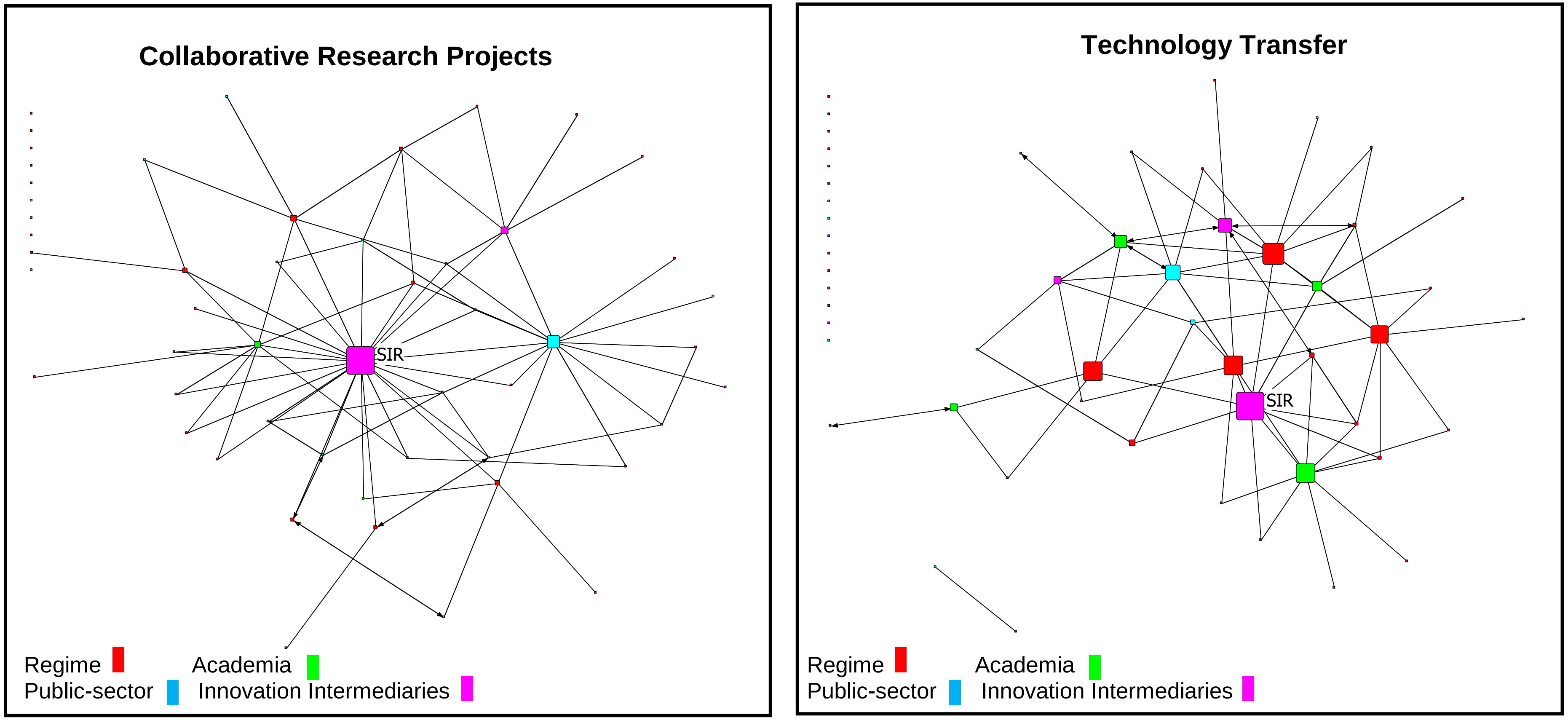
Network diagrams representing the centrality of SIR in the remanufacturing network for each relational attribute (See Figure 8.7 in main text)



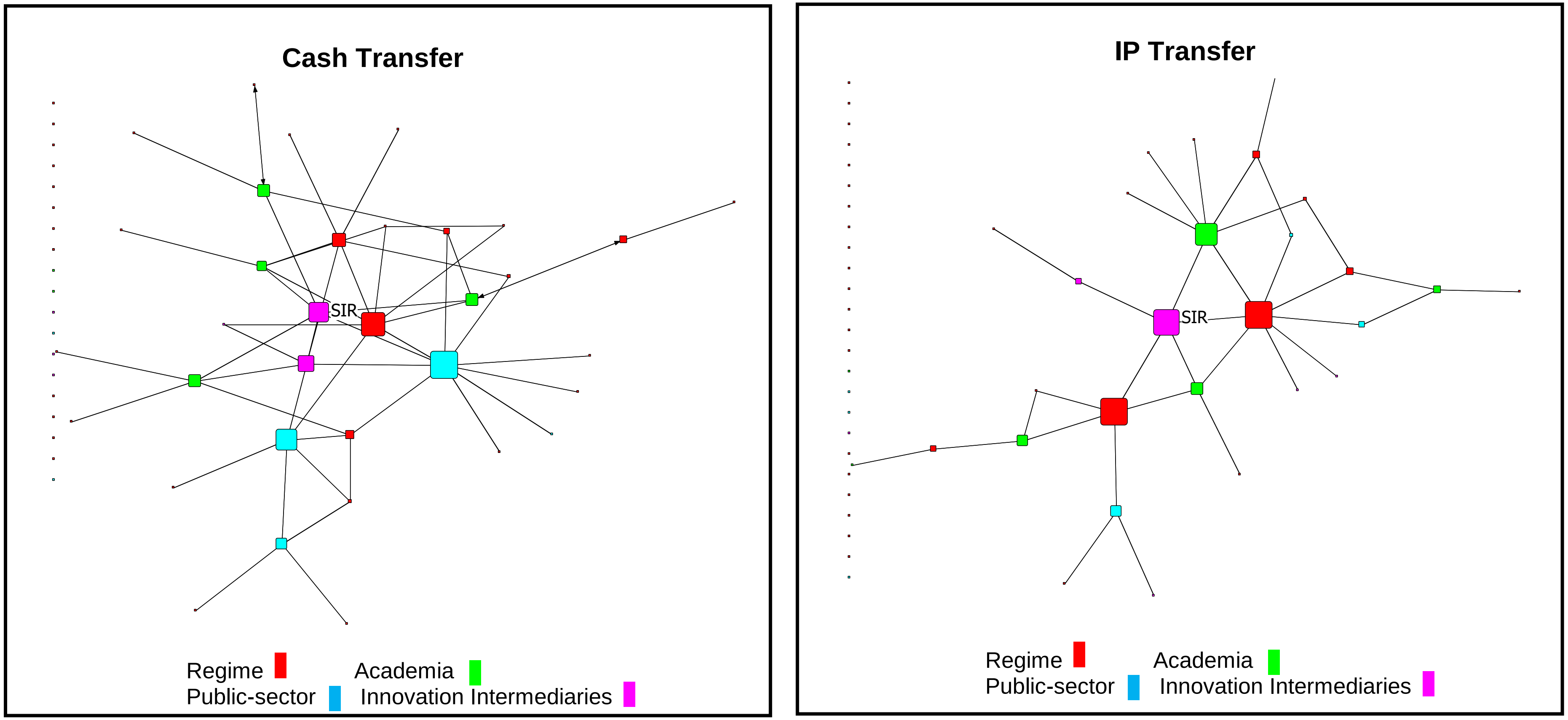
Network diagram of high level of frequency of contact dyadic ties within niche innovation network. Each line represents a connection between two organizations. The size of the actor node is scaled by the value of betweenness of the actor compare to all other network member. SIR is the largest node located in the centre of the network.



Network diagram of high level of total knowledge ties dyadic ties within niche innovation network. Each line represents a connection between two organizations. The size of the actor node is scaled by the value of betweenness of the actor compare to all other network member. SIR is the largest node located in the centre of the network.



Network diagram of high level of collaborative research project and technology transfer ties dyadic ties within niche innovation network. Each line represents a connection between two organizations. The size of the actor node is scaled by the value of betweenness of the actor compare to all other network member. SIR is the largest node located in the centre of the network.



Network diagram of high level of cash and IP transfer ties dyadic ties within niche innovation network. Each line represents a connection between two organizations. The size of the actor node is scaled by the value of betweenness of the actor compare to all other network member.

Section 2

The documents and results from the IBioIC and SIR social network and supplementary data collection and analyses are available on the supplementary disc:

Social Network Analysis Raw Data Results

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