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# Role of Inter-Firm Networks and Relationships in the Adoption and Diffusion of Eco-Innovations to Accelerate the Circular Economy Transition

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# Abstract

Sustaining the world's growing population requires higher levels of consumption of natural resources, resulting in increasing negative impacts on society and the environment. In order to remain within the limits of the planet's capacity to provide resources while ensuring a strong social foundation for society, it is essential to shift towards a circular economy, a holistic and systemic approach to utilize resources more efficiently and sustainably. Transitioning to a circular economy requires the development and widespread adoption of disruptive eco-innovations by firms and their supply chains, which redesign societal behaviors, introduce new business models, and create technological and institutional changes that can transform existing production systems. However, the most pressing barriers that prevent the shift towards a more circular economy and hinder transformative eco-innovations are social and cultural, and there is a need to better understand these dynamics. This thesis proposes an economic sociology perspective to examine these dynamics by highlighting the importance of embedded social and cultural factors within networks and relationships to explain economic behaviors. The overall aim is to investigate the role of embedded social and cultural dynamics within inter-firm networks and relationships in the adoption and diffusion of disruptive eco-innovations that accelerate the circular economy transition. The dissertation is composed of three chapters: first, a review of the literature to explore the various types of inter-firm networks and relationships and how they affect eco-innovation adoption and diffusion; second, a historical case study of Jaguar Land Rover's REALCAR closed-loop recycling initiative to understand how embedded relationships within inter-firm networks influenced circular economy eco-innovation adoption; and third, an agent-based model to analyze the mechanisms and targeting strategies that could enable faster adoption and diffusion of eco-innovations through inter-firm networks. The outcomes of this research highlight the critical role that embedded networks and relationships between firms play in the circular economy transition, and how they can be leveraged by decision-makers to overcome the key social and cultural barriers and more quickly shift to a circular economy.

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Shyaam Ramkumar

# Introduction

The world's population has been growing at a rapid pace, with significant implications for the global economy and wide-reaching consequences for society and the environment. Each year, research has estimated that 80 million people are added to the world's population, the equivalent of 10 cities the size of New York (Tucker, 2020). Projecting this growth rate into the future, the United Nations estimates that the world's population will reach 10.9 billion by 2100 (Adam, 2021). Sustaining this growing population requires higher levels of consumption of natural resources, greater generation of wastes, and increasing negative impacts on the environment (Arachchige and Kumarasinghe, 2021).

Currently, global consumption of resources is equivalent to 1.6 Earths, a measure of how many natural resources are consumed relative to the Earth's capacity to renew and regenerate them. Thus, society is already consuming beyond the planet's capacity to support our growing needs, particularly due to developed countries which have a very high resource use (Arachchige and Kumarasinghe, 2021). If the developing countries follow the same consumption patterns as more developed countries in the future, it is estimated that by 2033 humanity will consume resources equivalent to 2 Earths and by 2050 humanity will be consuming 2.6 Earths worth of resources (Moore et al., 2012).

To understand the impacts of our increasing resource consumption on society and the environment, economists have developed frameworks with various indicators (Raworth, 2017a). According to this framework, we are already overshooting our planetary boundaries and falling short of the social indicators (Raworth, 2017b). Thus, in order to remain within the limits of the planet's ecological ceiling while ensuring a strong social foundation for society in light of our growing global population, it is imperative that we achieve more efficient and regenerative ways to use our resources (Raworth, 2017b). Studies show that reducing worldwide resource use by only 1% could save approximately 840 million tons of metals, fossil fuels, minerals, and biomass annually, 39.2 trillion liters of water, and $80 billion for the global economy (Rubel et al., 2017). However, to achieve these resource reductions, it is necessary to rethink and redesign existing production value chains and consumption models in a more comprehensive way.

## The Circular Economy and the Need for Disruptive Eco-Innovations

The circular economy concept has gained popularity in recent years as among researchers, policymakers, and industry as a way for society to operate more sustainably and better manage its resources through a more holistic and systemic approach. There are many definitions for a circular economy, with one paper (J. Kirchherr et al., 2017b) identifying as many as 114 unique definitions for the concept and synthesizing these definitions as follows:

> "A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations."

Transitioning to a circular economy requires a complete transformation of traditional value chains, which necessitates the development and adoption of disruptive eco-innovations, especially among businesses (Bossle et al., 2016; Kivimaa et al., 2021). Moreover, these eco-innovations need to not only involve novel technologies, but also a redesign of societal behaviors, the introduction of new business models, and the involvement of multiple companies and other stakeholders acting in coordination to create the necessary technological and institutional changes (de Jesus et al., 2019; de Jesus and Mendonça, 2018). In particular, the involvement and support of entrepreneurs and start-ups is crucial. As new entrants into the market, these younger companies tend to adopt more transformative eco-innovations and circular economy business models that introduce technological and social innovations compared to established incumbent firms (Bauwens et al., 2020).

However, there are many barriers that prevent the shift towards a more circular economy and hinder transformative eco-innovations. Researchers and experts in the circular economy highlight the economic (high costs, uncertainty in returns, path-dependency), technological (unavailable technology, lag between development and diffusion), and regulatory (misaligned incentives, undeveloped legal and regulatory frameworks) barriers to the implementation of the circular economy (de Jesus et al., 2019; de Jesus and Mendonça, 2018). However, the most pressing barriers to the circular economy are softer, social and cultural factors – lack of awareness of the circular economy and resistance to change current systems (de Jesus et al., 2019; de Jesus and Mendonça, 2018; J. Kirchherr et al., 2017a). Understanding these social factors and their effects on the adoption and diffusion of circular economy thinking could provide greater insights into ways to overcome these barriers.

## Sociological Analysis as a Lens to Study the Circular Economy Transition

Sociological analysis is key to understand the importance of social and cultural factors in shaping economic behaviors and decisions. Looking at the strength, history, and structure of relations embedded in networks of stakeholders is instrumental to explain their behaviors (Granovetter, 1985). Informal institutions, such as social norms, collective beliefs, and the cultural environment in which individuals and organizations operate, constrains their decision-making and shapes coordination and cooperation for long-term societal development and evolution (Elster, 2015; North, 1990).

Viewing the global economy through this perspective, the structure and nature of the socio-economic relationships between companies across the value chain, consumers, and policymakers can have a significant influence on economic decisions, society's use of materials, and consequently the resulting impacts on the environment (Laurenti et al., 2018). Moreover, given the uncertainty and novelty of circular economy thinking and its disruptive eco-innovations (de Jesus et al., 2019; de Jesus and Mendonça, 2018), these embedded relationships are especially important factors for firms to make the circular economy transition. Pressures from regulations, customer demands for environmental products, motivations to stay ahead of competitors, co-operation with peers, and industry standards, all work in tandem to dictate whether companies across the value chain will adopt eco-innovations and circular concepts (de Jesus and Mendonça, 2018; Hojnik and Ruzzier, 2016).

In particular, understanding and mapping the complex inter-firm network of embedded social relationships between firms (Grandori and Soda, 1995) and the pressures they exert on each other opens interesting opportunities to more quickly diffuse circular economy thinking and enable faster adoption of eco-innovations (de Jesus et al., 2019). Ties and relationships between firms can be defined as joint membership in associations, competitive or cooperative relationships, supplier or economic relationships, and transfers of knowledge and technology (Borgatti and Li, 2009), as well as cognitive and emotional distance, interdependence, and other social linkages (Grandori and Soda, 1995). In addition, characteristics of the inter-firm network such as structural holes, the quality of connections, the centrality of a firm, or clusters and sub-groups of firms can influence the exchange of information and resources between companies (Borgatti and Li, 2009; Grandori and Soda, 1995). The nature of embedded networks and relationships between companies can encourage greater investments and risk taking among firms to develop new technologies and innovations than would be expected by market factors, since they minimize opportunism, enable faster information transfer and problem solving, and reduce uncertainty (Simsek et al., 2003; Uzzi, 1997). These inter-firm dynamics could have important implications for the circular economy transition and warrant further study.

## Aims and Objectives

Therefore, the overall aim of this Ph.D. thesis is to investigate the role of embedded social and cultural dynamics within inter-firm networks and relationships in the adoption and diffusion of eco-innovations, particularly ones that advance circular economy value chains. This research intends to combine studies and models from the existing literature on the drivers of eco-innovation adoption and innovation diffusion with the theories and concepts of social embeddedness within inter-firm networks. In addition, the research aims to utilize a mixed methods approach that combines qualitative and quantitative research methods in order to triangulate and integrate various types of data and information. Studies have shown that such an approach can provide researchers with a more complete and in-depth understanding of complex phenomena (Fielding, 2012; Hussein, 2009). By doing so, the objective is to contribute to the literature on eco-innovation adoption and diffusion and the circular economy by offering a unique perspective on how the networks and relationships between firms can be leveraged to accelerate the transition.

The dissertation is composed of three chapters. Each of these chapters serves to answer three important research questions:

> *RQ1: What are the types of inter-firm networks and relationships described in existing literature and what is the effect on eco-innovation adoption and diffusion?*
> *RQ2: What influence do embedded relationships within inter-firm networks have on the adoption decisions of eco-innovations by firms?*
> *RQ3: How can the network position and structure and nature of inter-firm relationships and networks be leveraged to more quickly diffuse eco-innovations?*

The first chapter is a review of the literature to explore the various types of inter-firm networks and relationships described in existing research and how they affect eco-innovation adoption and diffusion. The literature review screened research on eco-innovations, specifically articles that focus on adoption and diffusion by firms and describe the role of inter-firm networks and relationships. The outcomes of the literature review outlined potential areas for further research to explore how inter-firm networks and relationships can influence eco-innovation adoption and diffusion, which are then covered in the following chapters to answer the research questions outlined above.

The second chapter is a historical case study of Jaguar Land Rover, reproducing a paper published in *sustainability*. The paper conducted qualitative interviews to reconstruct the structure and nature of the relationships between Jaguar Land Rover and its suppliers during the implementation of the REALCAR closed-loop recycling initiative between 2013 and 2017. From this, the research explored the degree to which the embedded relationships between Jaguar Land Rover and its supply chain influenced the adoption of the REALCAR circular economy eco-innovation.

Next, the third chapter develops a theoretical agent-based model that explores the network mechanisms that could accelerate the adoption and diffusion of eco-innovations, reproducing a paper accepted for publication in the *Journal of Cleaner Production*. The paper tested various network-based targeting strategies on generated inter-firm networks with different structures and sizes to understand how focusing on firms with specific network positions and strength of relationships could more quickly diffuse incremental and disruptive eco-innovations. The results of the model provide additional insights into the mechanisms for effective diffusion of circular economy eco-innovations given their higher thresholds for adoption and diffusion.

Finally, the Ph.D. dissertation concludes by synthesizing the outcomes of the three chapters, discussing their main findings in relation to the research questions, and their implications for the adoption and diffusion of disruptive, circular economy eco-innovations.

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# Chapter 1 – Review of the Literature on Eco-Innovations and Inter-Firm Networks and Relationships


## Abstract

The adoption and diffusion of eco-innovations by firms can be influenced by inter-firm networks and relationships. Studies have described how the structure and nature of multiplex embedded relationships between networks of firms can encourage firms to become more aware of and decide to adopt eco-innovations, as well as affect how quickly the adoption of eco-innovations diffuse through inter-firm networks. Existing reviews of the literature on eco-innovation describe the various factors that affect adoption and diffusion among firms; however, they do not focus on the specific role of inter-firm relationships and networks. This paper conducts a literature review of 42 papers to explore the various types of inter-firm networks and relationships described in existing research and how they affect eco-innovation adoption and diffusion. The results show that there is evidence that collaborative, competitive, and customer-supplier relationships within supply chain, industry, and alliance networks have a positive effect on eco-innovation adoption and diffusion. The paper outlines potential areas for further research to explore how inter-firm networks and relationships can influence eco-innovation adoption and diffusion.


## 1.1 Introduction

Research on eco-innovation adoption and diffusion has identified a variety of factors that motivate firms to adopt eco-innovations. Among these drivers, studies have shown that inter-firm networks and relationships between firms affect the decision for eco-innovation adoption (Pellegrini et al., 2019; Triguero et al., 2016). These networks and relationships between firms can be economic, through contractual relationships, as well as social, through relationships of power, trust, competition, collaboration, and knowledge exchange (Borgatti and Li, 2009; Grandori and Soda, 1995; Granovetter, 1985; Ozman, 2009).

The structure and nature of the network of relationships and connections to other stakeholders within a firm's network can play an important role in eco-innovation adoption and diffusion (Bayne et al., 2012; Chen et al., 2019; Del Río González, 2005; Loorbach et al., 2020). Suppliers and business partners encourage firms to adopt pro-environmental behavior (Cainelli et al., 2011; Sáez-Martínez et al., 2016; Triguero et al., 2016). Due to the higher uncertainty of eco-innovations, firms rely on stakeholders within their network to share knowledge, gain financial resources, and mitigate the risks and costs of adopting eco-innovations (Cainelli et al., 2015; Del Río González, 2005; Díaz-García et al., 2015; Mazzanti and Zoboli, 2008; Pellegrini et al., 2019).

Other studies on eco-innovation have utilized theories of institutional isomorphism (DiMaggio and Powell, 1983) to show how peer pressure in inter-firm networks can affect diffusion. Coercive pressures from other companies that firms are dependent on, mimetic pressures to imitate best practices of competitors, and normative pressures from their industry, can motivate firms to adopt eco-innovations (Bag and Gupta, 2017; Hojnik and Ruzzier, 2016; Lin and Sheu, 2012; Sáez-Martínez et al., 2016; Zhu and Sarkis, 2007). Moreover, these pressures are multiplex and can exist simultaneously, shaping firm behavior in different ways (Boons and Howard-Grenville, 2009; Borgatti and Li, 2009).

Existing reviews of eco-innovation adoption and diffusion focus on the varying drivers of eco-innovation (Bossle et al., 2016; Díaz-García et al., 2015; Hojnik and Ruzzier, 2016; Karakaya et al., 2014), including networks and relationships between firms. However, they do not explore the various types of inter-firm networks and relationships that can affect eco-innovation adoption and diffusion. To our knowledge, there exists no review of the literature on the specific role that inter-firm networks and relationships play on the adoption and diffusion process.

Therefore, the aim of this paper is to map the literature on the role of inter-firm networks and firm relationships on the adoption and diffusion of eco-innovation by firms. The paper is structured as follows. A theoretical background is provided on eco-innovations, inter-firm networks and relationships, and the existing research describing their role on innovation and eco-innovation adoption and diffusion. Next, a summary of the research approach and literature review methodology is presented. This is followed by the results of the literature review and analysis of the papers reviewed. Finally, the paper ends with a discussion of the findings and conclusions.

## 1.2 Background

*1.2.1 Definition of Eco-Innovations and Inter-Firm Networks and Relationships*

Current literature describes the concept of eco-innovations as innovations that result in the reduction of negative environmental impacts. Eco-innovations include new or improved products that are made of environmentally friendly materials or designs, processes that reduce resource use and pollution, organizational and management changes that minimize environmental damages, or marketing solutions that promote pro-environmental behaviors (Bossle et al., 2016; Cai and Zhou, 2014; García-Granero et al., 2020; Hasler et al., 2016; Hellström, 2007; Hojnik and Ruzzier, 2016; Karakaya et al., 2014; Kemp and Pearson, 2007; Pereira and Vence, 2012; Rennings, 2000). Reviews of the literature on eco-innovations highlight the varying terms used to refer to them, as studies describe eco-innovations as “eco-innovation”, “green innovation,” “environmental innovation,” “ecological innovation,” or “sustainable innovation” inter-changeably (Díaz-García et al., 2015; Karakaya et al., 2014).

Compared to traditional innovations, eco-innovations face certain barriers that hinder their adoption and more widespread diffusion. Firms who develop and adopt eco-innovations tend to bear higher upfront costs compared to their polluting competitors with potential benefits only realized in the long-term, creating a disincentive for firms to invest time and resources in eco-innovations (de Jesus and Mendonça, 2018; Hojnik and Ruzzier, 2016; Rennings, 2000). Eco-innovations tend to be on average more novel, requiring greater internal resources to overcome existing technical, economic, and regulatory lock-ins, as well as more complex and with higher levels of uncertainty, requiring greater external resources from other stakeholders who may have varying interests and motivations (Cainelli et al., 2015; de Jesus and Mendonça, 2018; Laurenti et al., 2018).

Studies on eco-innovation have explored the various drivers and factors that motivate firms to adopt, primarily internal firm factors and external factors. Internal factors include firm size, business benefits, technological capacity, environmental culture, and the leadership and ownership structure. While external factors include regulations, market demand, stakeholder pressures, industry networks, supply chain relationships, and technological development (Bossle et al., 2016; Díaz-García et al., 2015; Hojnik and Ruzzier, 2016). Among the less studied factors that could influence a firm's decision to adopt eco-innovations are the relationships with other firms in its network.

Inter-firm networks and relationships are modes of organizing and coordinating economic activities between firms that emerge as a result of firms trying to take advantage of differentiation and asymmetry of knowledge and resources (Grandori and Soda, 1995). The types of relationships and links between firms can be economic, as well as social (Borgatti and Li, 2009; Grandori and Soda, 1995). The social and behavioural inter-firm relationships can be embedded in the economic relationships between firms, influencing certain firm behaviours and economic outcomes (Granovetter, 1985).

The position and structure of the inter-firm network and the characteristics and quality of inter-firm relationships can enable and constrain the activities and decisions of firms (Casanueva and González, 2004; Ozman, 2009), imposing various coercive pressures due to dependency on other organizations, mimetic pressures to imitate more successful organizations for legitimacy, and normative pressures influenced by credentials and professionalization on companies to change their goals or develop new practices (DiMaggio and Powell, 1983). These embedded pressures can exist at different levels and operate simultaneously through multiple layers of relationships, resulting in varying factors that affect and shape firm behaviour (Boons and Howard-Grenville, 2009; Borgatti and Li, 2009).

### *1.2.2 Existing Research on Eco-Innovations and Inter-Firm Networks and Relationships*

Research on eco-innovation have described how inter-firm networks and relationships are drivers for eco-innovation adoption and diffusion. Interactions with external partners and stakeholders can encourage firms to be more aware of eco-innovations and adopt pro-environmental practices (Cainelli et al., 2011; Pellegrini et al., 2019; Sáez-Martínez et al., 2016; Triguero et al., 2016). Cooperation with external partners, suppliers, and other stakeholders within their network allows firms to share knowledge and resources to mitigate the risks and costs of adopting novel eco-innovations (Cainelli et al., 2015; Del Río González, 2005; Díaz-García et al., 2015; Mazzanti and Zoboli, 2008). Pressure from regulators, competitors, and industry peers, which are embedded in the structure and nature of a firm's network of relationships, affect the adoption and diffusion of eco-innovations (Bag and Gupta, 2017; Bayne et al., 2012; Chen et al., 2019; Lin and Sheu, 2012; Sáez-Martínez et al., 2016; Zhu and Sarkis, 2007).

Existing reviews of the literature on eco-innovation adoption and diffusion suggest that networks and relationships between firms play an important role. Bossle et al. (2016) mention how many studies have shown that organizations "compare themselves to their peers and try to behave in accordance with the standards and norms" in the industry, and "cooperation with suppliers, clients, competitors" and other stakeholders are important drivers when it comes to eco-innovation adoption. Díaz-Garcia et al. (2015) review some studies at the Meso level to look at firm-level interactions, summarizing that customer requirements, cooperation and knowledge sharing with suppliers, local and foreign stakeholders, and industry peers have been explored as factors for eco-innovation adoption. Karakaya et al. (2014) conduct a review of studies on the diffusion of eco-innovations among consumers instead of firms but note that "more insights are needed from sociology of diffusion to understand the diffusion of eco-innovations" and the effect of networks and relationships. Hojnik and Ruzzier (2016) review studies on the drivers of eco-innovation among firms, finding mentions of research that describe pressures from competitors, business partners, and other stakeholders as key factors in the adoption and diffusion stage of eco-innovations.

However, these reviews of the literature do not make the role of inter-firm networks and relationships the focus of their study, despite highlighting their importance on eco-innovation adoption and diffusion. To our knowledge, there is no literature review that classifies the various types of inter-firm networks and relationships mentioned in existing research and measures the effect they have on eco-innovation adoption and diffusion based on previous studies. Therefore, this paper aims to conduct a literature review exploring the types of inter-firm networks and relationships have been studied in the literature on eco-innovation adoption and diffusion and their effect on eco-innovation adoption and diffusion, in order to identify potential areas for further research.

## 1.3 Research Approach

Data for the literature review was collected from the Scopus database. First, a meta-search was conducted to screen journal articles by searching the title, abstract, and keywords utilizing specific search terms. Next, the abstracts of the resulting 439 articles were analyzed to ensure they were relevant to the study resulting in 90 articles to be evaluated further. This was followed by an initial review of the papers to ensure that they were relevant, yielding 42 research papers. Finally, an in-depth content analysis was conducted to code and evaluate the research papers and answer the research questions proposed. Figure 1.1 presents an overview of the research approach.

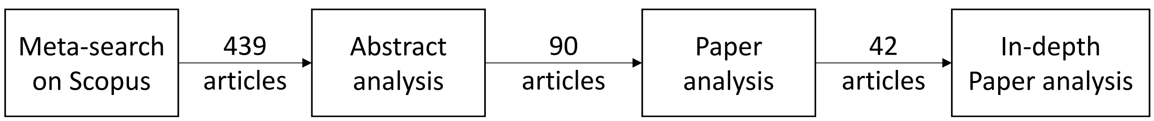


**Figure 1.1.** Research approach. Steps taken to screen relevant literature for analysis.

### *1.3.1 Screening Methodology*

Previous reviews of the literature on eco-innovation describe various methods for identifying relevant literature using keywords such as “eco-innovation”, “green innovation,” “environmental innovation,” “ecological innovation,” or “sustainable innovation” (Díaz-García et al., 2015; Karakaya et al., 2014). In addition, existing literature reviews use additional keywords to focus on specific aspects of the literature, creating a multi-layered set of screening criteria (Hojnik and Ruzzier, 2016). The screening methodology utilized in this study followed a similar approach, with three layers of search terms.

The first layer consists of the various terms for eco-innovations as described in the literature. The second layer consists of various terms for adoption and diffusion, in order to focus the literature search on the adoption and diffusion of existing eco-innovations rather than the development of new eco-innovations. Lastly, the third and fourth layers consist of various terms to describe inter-firm networks and relationships. The screening terms are summarized in Table 1.1 below.

**Table 1.1.** Screening keywords used in search of Scopus database.

| **Screening Layer** | **Search Terms** |
|---|---|
| Eco-innovation terminology | eco-innovation<br>green innovation<br>environmental innovation<br>ecological innovation<br>sustainable innovation |
| Adoption and diffusion terminology | adoption<br>diffusion<br>implementation<br>uptake |
| Firm terminology | firm<br>business<br>inter-organization<br>supply chain |
| Network and relationship terminology | network<br>networking<br>interdependence<br>relationship<br>ties<br>embedded |

These search terms in the different layers were finally combined and entered into Scopus to screen specifically for journal articles by searching the title, abstract, and keywords as follows:

*(Eq. 1)* *TITLE-ABS-KEY ( ( "eco" OR "green" OR "environmental" OR "sustainable" OR "ecological" ) AND ( "innovation" ) AND ( "adoption" OR "diffusion" OR "implementation" OR "uptake" ) AND ( "firm" OR "business" OR "inter-organization" OR "supply chain" ) AND ( "network" OR "networking" OR "interdependence" OR "relationship" OR "ties" OR "embedded" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) )*

The results of the meta-search yielded 439 articles whose abstracts were then analyzed further. Key search terms in Table 1.1 were highlighted within the abstracts to ensure that they were relevant and addressed the research questions. Based on this analysis of the search terms within the abstracts, articles were categorized as “Relevant,” “Maybe Relevant,” or “Not Relevant” to the study, resulting in 90 articles that could be of interest. These 90 papers went through an additional selection process and key search terms were once again highlighted within the main text to that the articles focused on adoption of eco-innovations and considered the role of inter-firm networks and relationships in their research method. This finally resulted in 42 papers – summarized in Table 1.2 – which were analyzed in greater detail using a coding framework.

**Table 1.2.** Final selection of articles from the screening process.

| **Authors** | **Title** | **Year** | **Journal** |
|---|---|---|---|
| Afshar Jahanshahi A., Al-Gamrh B., Gharleghi B. | Sustainable development in Iran post-sanction: Embracing green innovation by small and medium-sized enterprises | (2020) | Sustainable Development |
| Agi M.A.N., Nishant R. | Understanding influential factors on implementing green supply chain management practices: An interpretive structural modelling analysis | (2017) | Journal of Environmental Management |
| Borghesi S., Cainelli G., Mazzanti M. | Linking emission trading to environmental innovation: Evidence from the Italian manufacturing industry | (2015) | Research Policy |
| Burki U., Ersoy P., Najam U. | Top management, green innovations, and the mediating effect of customer cooperation in green supply chains | (2019) | Sustainability (Switzerland) |
| Cai W., Li G. | The drivers of eco-innovation and its impact on performance: Evidence from China | (2018) | Journal of Cleaner Production |
| Cai W.-G., Zhou X.-L. | On the drivers of eco-innovation: Empirical evidence from China | (2014) | Journal of Cleaner Production |
| Cainelli G., Mazzanti M., Montresor S. | Environmental Innovations, Local Networks and Internationalization | (2012) | Industry and Innovation |
| Cainelli G., Mazzanti M., Zoboli R. | Environmental innovations, complementarity and local/global | (2011) | International Journal of Technology, Policy and Management |

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|---|---|---|---|
| | cooperation: Evidence from North-East Italian industry | | |
| Ceschin F. | Critical factors for implementing and diffusing sustainable product-Service systems: Insights from innovation studies and companies' experiences | (2013) | Journal of Cleaner Production |
| Chen Y.J., Lan C.-Y. | Stochastic diffusion analysis for sustainable green innovation | (2013) | International Journal of Automation and Smart Technology |
| Chu Z., Wang L., Lai F. | Customer pressure and green innovations at third party logistics providers in China: The moderation effect of organizational culture | (2019) | International Journal of Logistics Management |
| El-Kassar A.-N., Singh S.K. | Green innovation and organizational performance: The influence of big data and the moderating role of management commitment and HR practices | (2019) | Technological Forecasting and Social Change |
| Evans S., Vladimirova D., Holgado M., Van Fossen K., Yang M., Silva E.A., Barlow C.Y. | Business Model Innovation for Sustainability: Towards a Unified Perspective for Creation of Sustainable Business Models | (2017) | Business Strategy and the Environment |
| Farhangi M.H., Turvani M.E., van der Valk A., Carsjens G.J. | High-tech urban agriculture in Amsterdam: An actor network analysis | (2020) | Sustainability (Switzerland) |
| Galbreath J. | Drivers of Green Innovations: The Impact of Export Intensity, Women Leaders, and Absorptive Capacity | (2019) | Journal of Business Ethics |
| García-Granero E.M., Piedra-Muñoz L., Galdeano-Gómez E. | Measuring eco-innovation dimensions: The role of environmental corporate culture and commercial orientation | (2020) | Research Policy |
| Grekova K., Bremmers H.J., | The mediating role of environmental innovation in the relationship between | (2013) | Journal on Chain and Network Science |

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|---|---|---|---|
| Trienekens J.H., Kemp R.G.M., Omta S.W.F. | environmental management and firm performance in a multi-stakeholder environment | | |
| Hansen O.E., Sondergard B., Meredith S. | Environmental innovations in small and medium sized enterprises | (2002) | Technology Analysis and Strategic Management |
| Hasler K., Olfs H.-W., Omta O., Bröring S. | Drivers for the adoption of eco-innovations in the German fertilizer supply chain | (2016) | Sustainability (Switzerland) |
| Haverkamp D.-J., Bremmers H., Omta O. | Stimulating environmental management capability deployment: The case of the Dutch food and drink industry | (2009) | Journal on Chain and Network Science |
| Hong P., Kwon H.-B., Roh J.J. | Implementation of strategic green orientation in supply chain | (2009) | European Journal of Innovation Management |
| Hwang B.-N., Huang C.-Y., Wu C.-H. | A TOE approach to establish a green supply chain adoption decision model in the semiconductor industry | (2016) | Sustainability (Switzerland) |
| Jakhar S.K. | Stakeholder Engagement and Environmental Practice Adoption: The Mediating Role of Process Management Practices | (2017) | Sustainable Development |
| Jové-Llopis E., Segarra-Blasco A. | Why does eco-innovation differ in service firms? Some insights from Spain | (2020) | Business Strategy and the Environment |
| Karaman Kabadurmus F.N. | Antecedents to supply chain innovation | (2020) | International Journal of Logistics Management |
| Le Y., Hollenhorst S., Harris C., McLaughlin W., Shook S. | Environmental management: A study of Vietnamese hotels | (2006) | Annals of Tourism Research |
| Lin C.-Y., Alam S.S., Ho Y.-H., Al-Shaikh M.E., Sultan P. | Adoption of green supply chain management among SMEs in Malaysia | (2020) | Sustainability (Switzerland) |
| Nair A., Yan T., Ro Y.K., Oke A., | How Environmental Innovations Emerge and Proliferate in Supply Networks: A Complex Adaptive Systems Perspective | (2016) | Journal of Supply Chain Management |

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|---|---|---|---|
| Chiles T.H., Lee S.-Y. | | | |
| Pereira A., Vence X. | Key business factors for eco-innovation: An overview of recent firm-level empirical studies | (2012) | Cuadernos de Gestion |
| Qi G.Y., Shen L.Y., Zeng S.X., Jorge O.J. | The drivers for contractors' green innovation: An industry perspective | (2010) | Journal of Cleaner Production |
| Silvestre B.S. | A hard nut to crack! Implementing supply chain sustainability in an emerging economy | (2015) | Journal of Cleaner Production |
| Stekelorum R., Laguir I., Elbaz J. | Transmission of CSR requirements in supply chains: investigating the multiple mediating effects of CSR activities in SMEs | (2019) | Applied Economics |
| Tate W.L., Ellram L.M., Gölgeci I. | Diffusion of environmental business practices: A network approach | (2013) | Journal of Purchasing and Supply Management |
| Thomas M., Costa D., Oliveira T. | Assessing the role of IT-enabled process virtualization on green IT adoption | (2016) | Information Systems Frontiers |
| Tong X. | Diffusion of lead-free soldering in electronics industry in China | (2007) | Zhongguo Renkou Ziyuan Yu Huan Jing/ China Population Resources and Environment |
| Tong X., Shi J., Zhou Y. | Greening of supply chain in developing countries: Diffusion of lead (Pb)-free soldering in ICT manufacturers in China | (2012) | Ecological Economics |
| Triguero A., Moreno-Mondéjar L., Davia M.A. | Eco-innovation by small and medium-sized firms in Europe: From end-of-pipe to cleaner technologies | (2015) | Innovation: Management, Policy and Practice |
| Triguero A., Moreno-Mondéjar L., Davia M.A. | Leaders and Laggards in Environmental Innovation: An Empirical Analysis of SMEs in Europe | (2016) | Business Strategy and the Environment |
| Yang Z., Lin Y. | The effects of supply chain collaboration on green innovation performance: An interpretive structural modeling analysis | (2020) | Sustainable Production and Consumption |

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|---|---|---|---|
| Zhang L., Xue L., Zhou Y. | How do low-carbon policies promote green diffusion among alliance-based firms in China? An evolutionary-game model of complex networks | (2019) | Journal of Cleaner Production |
| Zhang M., Zeng W., Tse Y.K., Wang Y., Smart P. | Examining the antecedents and consequences of green product innovation | (2020) | Industrial Marketing Management |
| Zhang Y., Sun J., Yang Z., Wang Y. | Critical success factors of green innovation: Technology, organization and environment readiness | (2020) | Journal of Cleaner Production |

### *1.3.2 Content Analysis*

The final set of 42 articles were analyzed using content analysis, in order to answer the research questions regarding the types of inter-firm networks and relationships and their effect on eco-innovation adoption and diffusion. Content analysis is a data analysis method that helps describe various types of qualitative data through a systematic approach. By following a structured method, content analysis allows researchers to focus on specific aspects of written text and analyze the meaning and quantify the frequency of key words and phrases in order to answer their research questions (Rose et al., 2015; Schreier, 2012).

A key step in content analysis is the development of a coding framework, a categorization and classification system to analyze the qualitative data. The coding framework can consist of categories and sub-categories that specify the key concepts and terms that are of interest to answer the research question. These categories and sub-categories can be defined based on existing literature or based on the data and articles being analyzed (Rose et al., 2015; Schreier, 2012).

For this study, the coding framework was developed in both a concept-driven and an inductive, data-driven way. The categories were first defined using the search terms outlined in the screening methodology in Table 1.1 and further developed based on the initial review of the abstracts and papers during the screening process. Following the literature on content analysis (Rose et al., 2015; Schreier, 2012), the coding framework was revised and refined through the screening process to ensure that the coding framework is exhaustive and able to provide insights to answer the research questions. The final coding framework used for this study is outlined in Table 1.3.

**Table 1.3.** Key categories and sub-categories in the coding framework used to analyze the literature.

| Coding Category | Coding Sub-category | Description |
|---|---|---|
| Journal Name | | Name of journal where the article was published |
| Publication Year | | Year of publication of the article |
| Theoretical foundations | Complex adaptive systems | References to theories of complex adaptive systems and non-linear dynamics in adoption and diffusion through networks |
| | Contingency theory | References to contingency theory and situational decision-making based on many factors when firms decide to adopt eco-innovations |
| | Diffusion theory | References to diffusion of innovations theory and the factors that affect how innovations spread through networks of firms |
| | Drivers of Eco-innovation | References to literature on the determinants and internal and external factors that motivate firms to adopt eco-innovations |
| | Embeddedness | References to the theory of contextualization of economic behaviors due to embedded social relationships and networks |
| | Game theory | References to game theory and the rationalization of decisions based on expected payoffs and utility gains |
| | Institutional theory | References to institutional theory and the coercive, normative, and mimetic pressures that affect and constrain firm behaviors |
| | Network theory | References to research on the structural characteristics of the relationships and connections that comprise networks of firms |

| | | |
|---|---|---|
| | Resource-based view | References to research on the use of firm resources and capabilities to gain competitive advantage as a basis for its decision-making |
| | Stakeholder theory | References to the influence on firm decision-making and behaviors to meet the needs of internal and external stakeholders |
| | Strong and weak ties | References to the nature of the relationships between firms and how it affects firms' ability to gain new knowledge and make decisions |
| | Technology Organization Environment | References to technological, organizational, and environmental factors that influence firm decisions to adopt innovations |
| | Transaction Cost Theory | References to the theory of contractual mechanisms and relationships between firms as a basis for their decision-making |
| Study type | Qualitative Analysis / Case Study | Utilizes a case study or qualitative analysis research approach |
| | Literature Review | Conducts a review of literature |
| | Quantitative Analysis | Performs regression analysis or other quantitative approaches |
| | Simulation Tools and Models | Develops agent-based models or utilizes other simulation tools |
| | Frameworks | Constructs a theoretical, conceptual, or analytical framework |
| Type of firms | Startup | Young companies or entrepreneurs |
| | SME | Small- or medium-sized business |
| | Multi-national Large Company | Corporations, multi-national firms |
| Adoption/Diffusion of Eco-innovations | Adoption | Adoption, implementation, uptake of eco-innovations by firms |
| | Diffusion | Transmission, dissemination of eco-innovations in firm networks |

| | | |
|---|---|---|
| Type of inter-firm relationships | Collaborative relationship | Collaboration, cooperation, or coordination between firms |
| | Competitive relationship | Competition, imitation, or competitive advantage between firms |
| | Customer relationships | Customer or buyer demands, requirements, pressures on firms |
| | Supplier relationship | Supplier or seller demands, requirements, pressures on firms |
| | Local relationships | Relationships and ties between firms are local |
| | International relationships | Relationships and ties between firms are international |
| Inter-firm relationship characteristics | Strength of relationship | Strength and longevity of relationships and ties between firms |
| | Formal contractual relationship | Relationships between firms based on formal contracts |
| | Informal social relationship | Relationships between firms based on social connections, trust, etc. |
| Type of inter-firm network | Alliance network | Partnerships, joint ventures, or knowledge exchange between firms |
| | Supply chain network | Supply chain, production, or manufacturing networks of firms |
| | Industry network | Industry associations or business group networks of firms |
| Inter-firm network characteristics | Network position | Centrality and mentions of the position of firms in the network |
| | Network structure | Density, degree, and mentions of structure of the firms' networks |
| Effect on adoption and diffusion | No effect | Factor has no effect on adoption of eco-innovations |
| | Negative effect | Factor has a negatively effect on the adoption of eco-innovations |
| | Positive effect | Factor has a positively effect on the adoption of eco-innovations |

Using this coding framework, the papers were analyzed using the MAXQDA computer-aided text analysis software to highlight portions of the text that related to each of the coding sub-categories. Each coding sub-category was treated as a binary variable to indicate whether the concept is present or absent in the text. Text related to the "Effect on adoption and diffusion" sub-categories were coded such that they overlapped with the other codes, in order to allow for more complex analyses of co-occurrences to determine how the literature portrays the effect of inter-firm relationships and networks on the adoption and diffusion of eco-innovations (Krippendorff, 2003).

## 1.4 Results

The results of the content analysis of the 42 articles, which focus on the adoption and diffusion of eco-innovations and mention the role of inter-firm networks and relationships, are presented below. A tabulation of the absolute frequency of the coding sub-categories was calculated and visualized in bar charts, and in the case of the "Year of Publication," in a line graph (Krippendorff, 2003). First, an overview of the papers is presented to highlight key journals, publications over time, theoretical foundations, types of analyses conducted, types of firms studied, and whether they study the adoption or diffusion of eco-innovations. This is followed by an analysis of the types of inter-firm networks and relationships, their characteristics, and the effect on the adoption and diffusion of eco-innovations mentioned in the literature.

### *1.4.1 Overview of Selected Articles*

An overview of the journals in which the selected papers were published is presented in Figure 1.2. The analysis shows that a large number of the articles were published in the Journal of Cleaner Production and sustainability compared to the other journals. Many of the journals are focused on sustainability and environmental issues, though there are also journals that focus on innovation, marketing, and business.

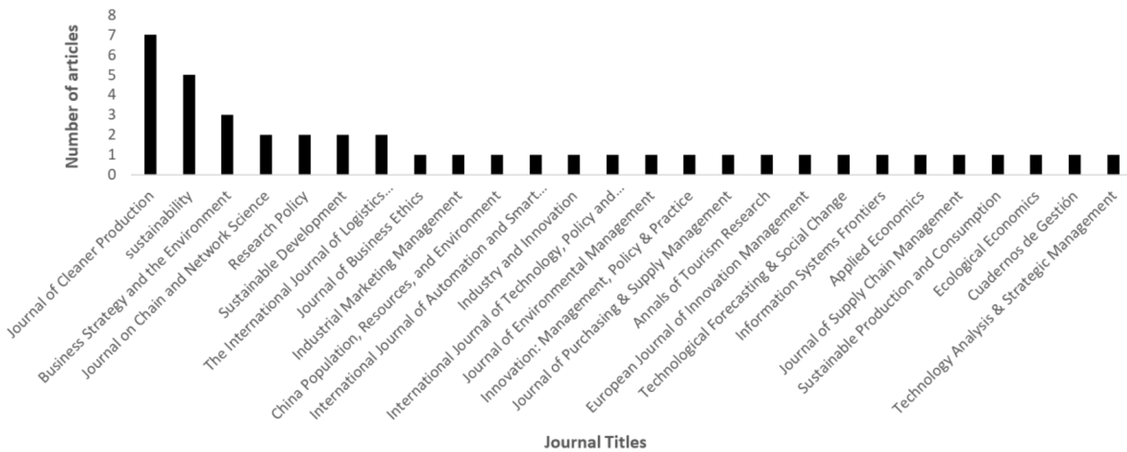


**Figure 1.2.** The top journals for the selected publications.

Looking at the year of publication of the articles, in Figure 1.3, there is a growing trend in the research on adoption and diffusion of eco-innovations that mention inter-firm networks and relationships. There a clear increase in the number of articles studying this topic starting from 2014. In particular, many articles focusing on this topic were published in the past year, with nine of the 42 papers published in 2020.

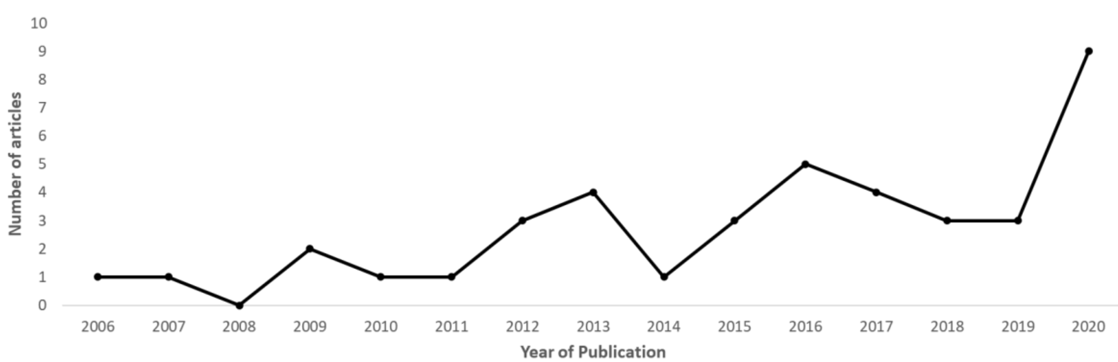


**Figure 1.3.** Year of publication for selected articles.

Figure 1.4 summarizes the various theoretical foundations referenced in the selected literature. Many articles reference theories and concepts related to the drivers of eco-innovation and the motivations of firms to adopt based on internal firm factors and external pressures from various stakeholders. There are also a lot of references to the resource-based view theory, describing how firms decide to adopt eco-innovations based on its ability to give them a competitive advantage and provided they have sufficient resources and capabilities. Diffusion theory is also mentioned by many articles, referencing the previous literature on how the characteristics of innovations and the characteristics of the adopters determine the rate of diffusion and spread of innovations. Among the top theoretical foundations, there are also a lot of references to institutional theory and research on the various coercive, mimetic, and normative pressures that organizations face which impact their decision to adopt eco-innovations.

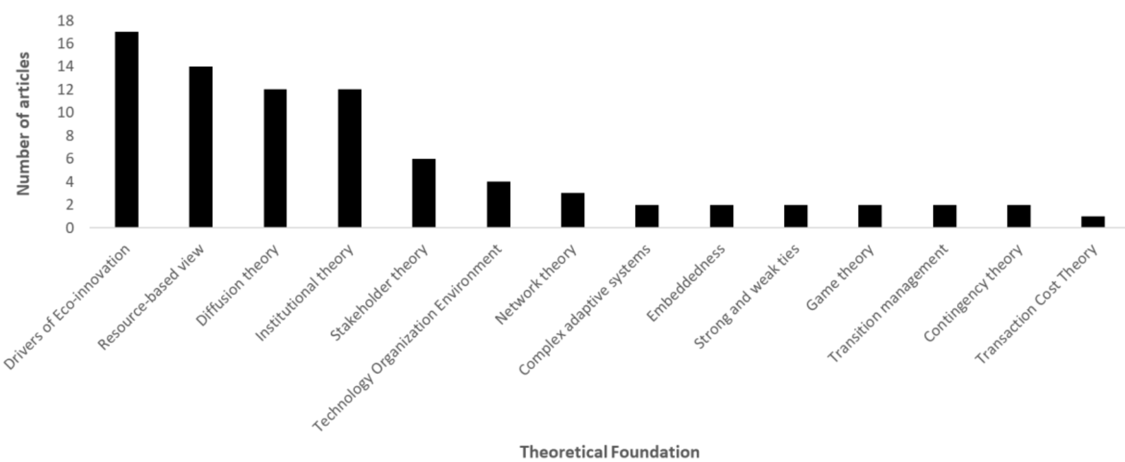


**Figure 1.4.** Theoretical foundation referenced in selected articles.

As shown in Figure 1.5, the selected papers primarily utilized quantitative analysis. These papers employed regression analysis to determine the effects of different factors and drivers, including inter-firm networks and relationships, on eco-innovation adoption or diffusion. There were some papers that focused on qualitative case study analyses that described how the relationships and networks between firms encouraged eco-innovation adoption and diffusion. As well as a few papers that focused on the development of theoretical frameworks for how networks and relationships could affect eco-innovation adoption. Among the screened papers, few articles focused on developing simulation tools and models that focused on the how inter-firm networks and relationships could affect eco-innovation adoption and diffusion.

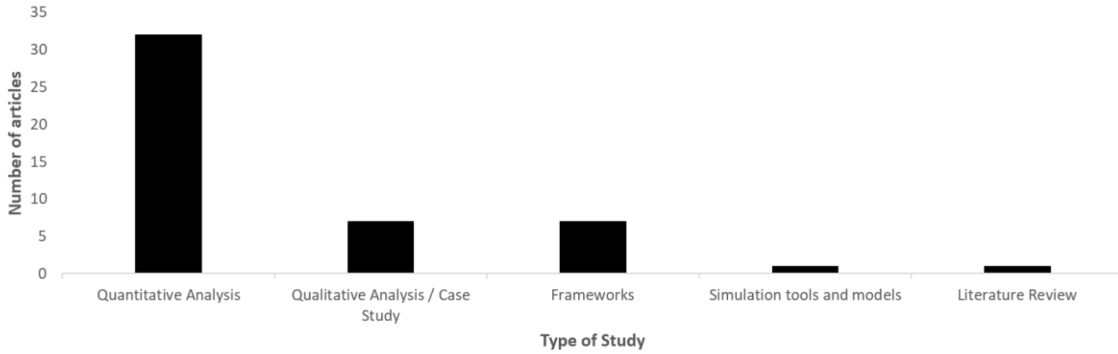


**Figure 1.5.** Types of analyses conducted in the selected articles.

The selected articles mainly studied small- and medium-sized enterprises (SMEs) and multi-national or large companies. As highlighted in Figure 1.6, few of the studies focused on startups, likely due to the young age of the companies and lack of established inter-firm networks and relationships.


**Figure 1.6.** Types of firms studied in the selected articles.

Among the selected literature, the majority of articles studied the adoption and implementation of eco-innovations by firms and the specific firm-level factors that affect these decisions. However, many papers also discussed the diffusion of eco-innovations and how eco-innovations spread through networks of firms, exploring individual firm-level adoption decisions but also external factors, such as relationships among firms and pressures from outside forces. Figure 1.7 summarizes the number of articles focused on the adoption vs. the diffusion of eco-innovations.


**Figure 1.7.** Focus of selected articles on adoption vs. diffusion of eco-innovations.

Subsequent results show the frequency of mentions of the coding sub-categories related to inter-firm networks and inter-firm relationships mentioned in Table 1.3. The frequency of mentions is a better metric to show how often specific inter-firm networks and types of inter-firm relationships are described in the selected articles to gain an understanding of their relevance and importance to the adoption and diffusion of eco-innovations (Krippendorff, 2003). In addition, as mentioned in Section 1.3.2, the following figures highlight co-occurrences of these terms with the "Effect on adoption and diffusion" coding sub-categories in Table 1.3. This provides insights into the positive, negative, or neutral effect of various inter-firm networks and relationships on eco-innovation adoption and diffusion.

### *1.4.2 Analysis of Inter-Firm Relationships and Characteristics*

As shown in Figure 1.8, the selected literature described the role various types of relationships between firms played in the adoption and diffusion of eco-innovations. The most frequent relationships mentioned in the articles focused on business customers, whose demands and requirements for environmentally friendly products and services motivated or, in some cases, forced firms to adopt eco-innovations and spread the adoption of eco-innovations throughout the supply chain (Afshar Jahanshahi et al., 2020; Borghesi et al., 2015; Burki et al., 2019; Cai and Li, 2018; Cai and Zhou, 2014; Chu et al., 2019; El-Kassar and Singh, 2019; Galbreath, 2019; Hansen et al., 2002; Jakhar, 2017; Lin et al., 2020; Nair et al., 2016; Pereira and Vence, 2012; Qi et al., 2010; Stekelorum et al., 2019; Tate et al., 2013; Tong, 2007; Tong et al., 2012; Triguero et al., 2016, 2015;

M. Zhang et al., 2020; Y. Zhang et al., 2020). There were a few articles that suggested that customer relationships didn't have any effect on the decision to adopt, particularly for certain eco-innovations like clean technologies or managerial eco-innovations (Borghesi et al., 2015; Burki et al., 2019; Cainelli et al., 2012; Chu et al., 2019; Haverkamp et al., 2009; Jové-Llopis and Segarra-Blasco, 2020; Pereira and Vence, 2012; Qi et al., 2010; Tong, 2007). A few papers also suggested that requirements from customers, especially from larger firms, could have a negative effect among small- or medium-sized enterprises by creating significant pressures that lead to difficulties in the adoption and implementation of eco-innovations (Stekelorum et al., 2019), or if the customers' lack environmental awareness discourages their supply chains from adopting eco-innovations (Chu et al., 2019).

Additional mentions in the literature discussed the role of suppliers in influencing eco-innovation adoption and diffusion. Some articles described how suppliers can have a positive effect on the adoption and diffusion of eco-innovations by making firms aware of new eco-innovations, sharing, collaborating closely to implement eco-innovations, and disseminating knowledge through the supply chain (Afshar Jahanshahi et al., 2020; Borghesi et al., 2015; Cainelli et al., 2011; Hansen et al., 2002; Hasler et al., 2016; Hong et al., 2009; Jakhar, 2017; Nair et al., 2016; Silvestre, 2015; Stekelorum et al., 2019; Tong et al., 2012; Yang and Lin, 2020; M. Zhang et al., 2020). On the other hand, a few papers also discussed how firms that are dominated by their supplier relationships, particularly in the service sector, have no effect or a negative effect on eco-innovation adoption by acting as bottlenecks (Hasler et al., 2016; Haverkamp et al., 2009; Jové-Llopis and Segarra-Blasco, 2020; Stekelorum et al., 2019).

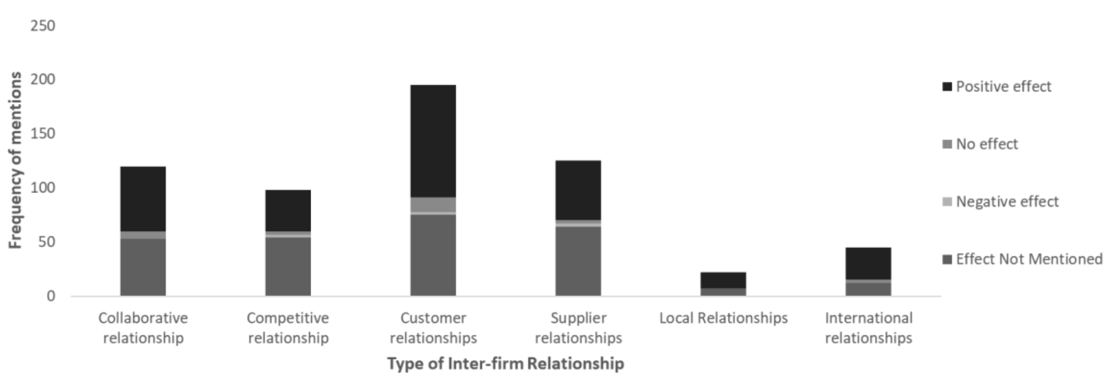

**Figure 1.8.** Frequency of mentions of types of inter-firm relationships in selected articles.

Collaborative relationships between firms were also mentioned frequently in the literature as having a positive effect on the adoption and diffusion of eco-innovations. Partnerships, the development of shared visions, and the exchange of knowledge and support between firms facilitate cooperation and motivate firms to adopt and implement eco-innovations, as well as spreads the awareness of eco-innovations throughout the network (Afshar Jahanshahi et al., 2020; Agi and Nishant, 2017; Burki et al., 2019; Cainelli et al., 2012, 2011; Ceschin, 2013; Chen and Lan, 2013; Farhangi et al., 2020; Grekova et al., 2013; Hasler et al., 2016; Haverkamp et al., 2009; Hwang et al., 2016; Jakhar, 2017; Jové-Llopis and Segarra-Blasco, 2020; Nair et al., 2016; Pereira and Vence, 2012; Silvestre, 2015; Yang and Lin, 2020; M. Zhang et al., 2020). A few articles noted that cooperative and collaborative relationships between firms does not have an effect on eco-innovation adoption in certain cases, such as energy efficiency or green managerial innovations (Burki et al., 2019; Grekova et al., 2013; Jové-Llopis and Segarra-Blasco, 2020).

The selected articles also described competitive relationships between firms as a motivator for the adoption and diffusion of eco-innovations. Some papers highlighted the positive effect of firms' desire to maintain an advantage over their competitors, which leads them to adopt new eco-innovations to keep ahead and preempt the competition, as well as to imitate competitors who have successfully adopted eco-innovations in order to not fall behind the competition (Cai and Li, 2018; Cai and Zhou, 2014; Cainelli et al., 2011; Chu et al., 2019; El-Kassar and Singh, 2019; García-Granero et al., 2020; Hong et al., 2009; Hwang et al., 2016; Jakhar, 2017; Karaman Kabadurmus, 2020; Le et al., 2006; Lin et al., 2020; Pereira and Vence, 2012; Thomas et al., 2016). However, a few papers mentioned that competitive relationships did not have any effect, or had a negative effect, on the adoption and diffusion of eco-innovations due to rivalry and knowledge leakages that do not stimulate innovation, and the adoption of eco-innovations can change the market structure and existing competitive relationships which can deter innovation (Cainelli et al., 2012; Chen and Lan, 2013; Haverkamp et al., 2009; Karaman Kabadurmus, 2020; Le et al., 2006).

Mentions of local and international relationships had the lowest frequency in the selected literature. Some studies discussed differences in requirements in overseas markets for imports, demands from international and multi-national companies, and international investments as having a positive effect on the adoption and diffusion of eco-innovations among firms (Cainelli et al., 2012, 2011; Farhangi et al., 2020; Galbreath, 2019; Hwang et al., 2016; Jakhar, 2017; Karaman Kabadurmus, 2020; Pereira and Vence, 2012; Tong, 2007; Tong et al., 2012). A few studies stated that local relationships between firms strengthened cooperation and the exchange of knowledge and resources, which positively affected the adoption and diffusion of eco-innovations (Cainelli et al., 2012, 2011; Jakhar, 2017; Silvestre, 2015; Stekelorum et al., 2019; Tong, 2007; Tong et al., 2012).

In Figure 1.9, the frequency of mentions of the characteristics of the inter-firm relationships in the literature is analyzed. Formal contractual relationships which involved the formal exchange of goods and services, reporting and certification standards, and incentive and rating systems, were described in a large majority of the papers to have a positive effect on the adoption and diffusion of eco-innovations by motivating firms to adhere and comply to their obligations (Agi and Nishant, 2017; Cai and Zhou, 2014; Chu et al., 2019; Galbreath, 2019; Hansen et al., 2002; Hwang et al., 2016; Nair et al., 2016; Qi et al., 2010; Silvestre, 2015; Stekelorum et al., 2019; Tate et al., 2013; Tong et al., 2012; Yang and Lin, 2020; M. Zhang et al., 2020). However, one paper noted that excessive control within these relationships was shown to have no effect or even a negative effect on the adoption of eco-innovations by constraining innovative activities and ignoring more social aspects of the relationships between firms (M. Zhang et al., 2020).

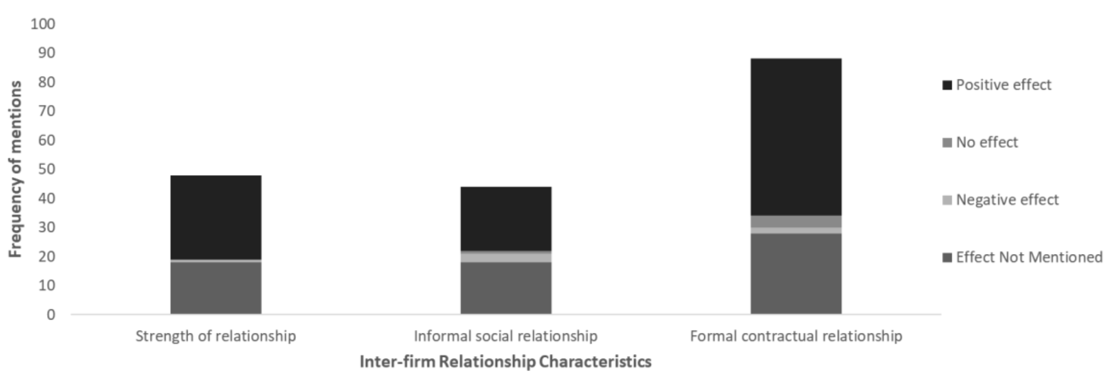


**Figure 1.9.** Frequency of mentions of inter-firm relationship characteristics in selected articles.

There were also many mentions of the strength of the relationships between firms. Close and long-term interactions between firms facilitates greater receptivity towards and more rapid implementation of new business strategies and innovations and were shown to have a positive effect on the adoption and diffusion of eco-innovations (Afshar Jahanshahi et al., 2020; Agi and Nishant, 2017; Burki et al., 2019; Cai and Zhou, 2014; Cainelli et al., 2012; Haverkamp et al., 2009; Hwang et al., 2016; Nair et al., 2016; Silvestre, 2015; Stekelorum et al., 2019; Tate et al., 2013; Thomas et al., 2016; Tong et al., 2012; Triguero et al., 2015; Yang and Lin, 2020; Zhang et al., 2019). One paper highlighted that firms with strong external relationships could potentially have a negative effect on eco-innovation adoption and diffusion if these relationships make them reluctant to develop new knowledge and implement new ideas (Cai and Zhou, 2014).

Lastly, informal social relationships between firms were also described in the literature to affect the adoption and diffusion of eco-innovations but had the lowest number of mentions. Face-to-face interactions and daily conversations between firms that built social capital, as well as connections with other firms based on mutual trust, satisfaction, and reputation were mentioned to have a positive effect on the adoption and diffusion of eco-innovations by improving the exchange of knowledge and resources (Afshar Jahanshahi et al., 2020; Agi and Nishant, 2017; Farhangi et al., 2020; Hwang et al., 2016; Nair et al., 2016; Pereira and Vence, 2012; Tong et al., 2012; Triguero et al., 2016; Yang and Lin, 2020; M. Zhang et al., 2020). A few papers suggested that personal relationships and informal connections between firms can have a negative effect on eco-innovation adoption and diffusion, particularly if there are imbalances in the level of trust and commitment and if there aren't formal measures for enforcement (Stekelorum et al., 2019; M. Zhang et al., 2020).

### *1.4.3 Analysis of Inter-Firm Networks and Characteristics*

Compared to inter-firm relationships, the selected literature had fewer mentions of various types of inter-firm networks and their effect on eco-innovation adoption and diffusion. As Figure 1.10 shows, a large number of mentions related to supply chain, production, or manufacturing networks of firms influencing the adoption of eco-innovations. The majority of the articles highlighted the positive effect that connections within a firm's production system had and the crucial role it played in encouraging companies to adopt eco-innovations (Agi and Nishant, 2017; Burki et al., 2019; Cainelli et al., 2011; Grekova et al., 2013; Hasler et al., 2016; Haverkamp et al., 2009; Nair et al., 2016; Pereira and Vence, 2012; Silvestre, 2015; Stekelorum et al., 2019; Triguero et al., 2015; Yang and Lin, 2020), as well as how eco-innovations diffuse and spread through these networks (Tate et al., 2013; Tong, 2007). A few studies found a negative effect (Hansen et al., 2002; Nair et al., 2016), since large supply chain networks could present challenges for some firms to effectively implement certain eco-innovations. And other studies found that supply chain networks had no effect on decisions to adopt eco-innovations (Jové-Llopis and Segarra-Blasco, 2020), in particular for firms that provide services and for earlier adopters of eco-innovations (Triguero et al., 2016).

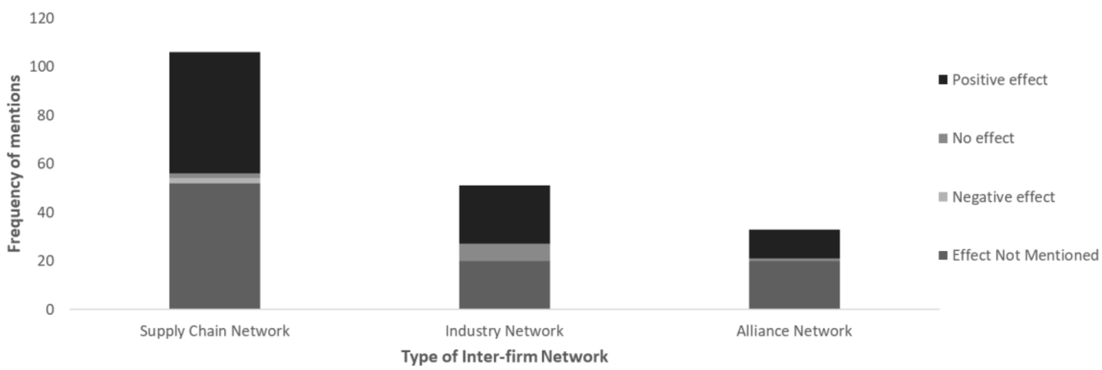


**Figure 1.10.** Frequency of mentions of types of inter-firm networks in selected articles.

The industry network of a firm, such as industry associations or business networks, were also frequently mentioned in the selected articles. Many studies described the positive effect of these networks in the adoption and diffusion of eco-innovations by enabling the exchange of new information and providing needed resources and support, especially for small- and medium-sized enterprises (Agi and Nishant, 2017; Borghesi et al., 2015; Cainelli et al., 2012; Evans et al., 2017; Farhangi et al., 2020; Grekova et al., 2013; Hansen et al., 2002; Hasler et al., 2016; Nair et al., 2016; Pereira and Vence, 2012; Tate et al., 2013; Tong et al., 2012; Triguero et al., 2016). Other studies found that the support of industry networks and associations had no effect in eco-innovation adoption, particularly for service firms and firms located in areas that do not have established industrial connections (Cainelli et al., 2012; Grekova et al., 2013; Jové-Llopis and Segarra-Blasco, 2020).

Lastly, a few papers mentioned the role of alliance networks, formed through partnerships, joint ventures, or knowledge exchange between firms, on eco-innovation adoption and diffusion. Some articles described the positive role that alliances networks played by developing agreements and standards, enabling knowledge transfer, and facilitating coordination to more easily implement and adopt eco-innovations and accelerate their diffusion (Agi and Nishant, 2017; Borghesi et al., 2015; Ceschin, 2013; Farhangi et al., 2020; Pereira and Vence, 2012; Tong et al., 2012; Triguero et al., 2016; Yang and Lin, 2020). One paper (Triguero et al., 2016) found that alliance networks, similar to supply chain and industry networks, did not make too much of a difference for early adopters of eco-innovations and was more relevant for laggards.

The results of calculating the frequency of mentions of the characteristics of the inter-firm networks, presented in Figure 1.11, showed that the network position of firms had a large number of mentions in the selected literature. The majority of these mentions highlighted the positive effect that a particular firm's position in the network – such as their centrality in terms of number of connections and level of influence in the network, role as bridges between firm clusters, proximity to highly influential companies in the network, or position upstream or downstream in the supply chain network – had on the decision to adopt eco-innovations and propagate the diffusion of eco-innovations (Ceschin, 2013; Farhangi et al., 2020; Hansen et al., 2002; Hasler et al., 2016; Nair et al., 2016; Silvestre, 2015; Stekelorum et al., 2019; Tate et al., 2013; Tong, 2007; Tong et al., 2012). On the other hand, a few papers also mentioned that a firm's weaker network position or role within the supply chain network could create disincentives that negatively affect their decision to adopt eco-innovations or have no major effect on their adoption decision (Hansen et al., 2002; Hasler et al., 2016; Nair et al., 2016).

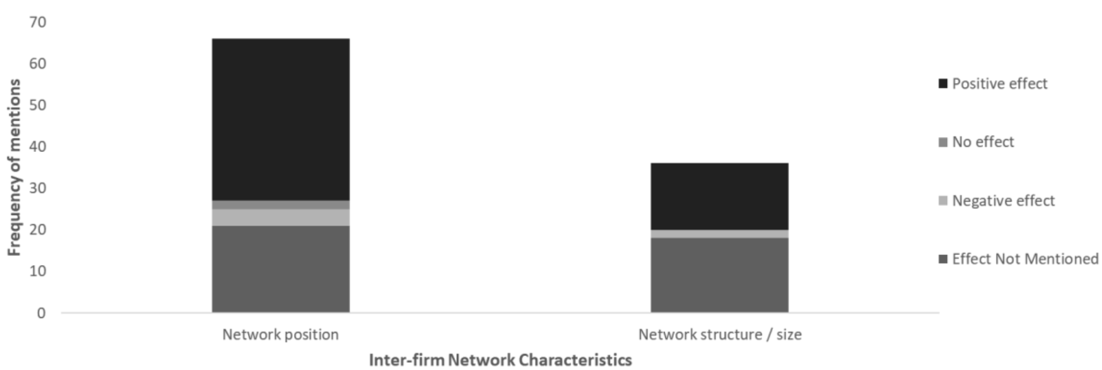

**Figure 1.11.** Frequency of mentions of inter-firm network characteristics in selected articles.

Many papers also described the role that the structure and size of the inter-firm network had on the adoption and diffusion of eco-innovations. The configuration of established relationships between firms, such as the multidimensional composition of various heterogenous linkages, the inclusion of a broad range of different firms, as well as close linkages among a large number of firms can diffuse eco-innovations more quickly and positively effect firms within the network to adopt (Ceschin, 2013; Hansen et al., 2002; Hasler et al., 2016; Nair et al., 2016; Tate et al., 2013; Tong, 2007; Tong et al., 2012; Triguero et al., 2016; Zhang et al., 2019). A few papers described how small networks can negatively affect adoption by limiting awareness of eco-innovations, and conversely that having too many clusters and tiers of firms within an extended inter-firm network can hinder the diffusion of eco-innovations (Hansen et al., 2002; Nair et al., 2016).

## 1.5 Discussion and Conclusions

Existing research on has explored the various of drivers and factors that motivate firms to adopt and diffuse eco-innovations. Reviews of the literature on eco-innovation have mapped out the various internal firm factors, such as firm size, business benefits, technological capacity, environmental culture, and external factors, such as regulations, market demand, stakeholder pressures, industry networks, supply chain relationships, and technological development. However, there has been less of a focus on the specific role of inter-firm networks and relationships on eco-innovation adoption and diffusion.

This literature review attempted to fill in this gap in the research. The paper aimed to conduct a literature review to identify the types of inter-firm networks and relationships that could influence eco-innovation adoption and diffusion. In addition, this paper measured the effect of different network structures and types of relationships in influencing eco-innovation adoption and diffusion. By doing so, this study identified additional gaps in the current understanding of eco-innovation adoption and diffusion and areas for further research, highlighting the potential to use various qualitative and quantitative research methods to gain deeper insights into how inter-firm networks and relationships can influence the adoption and diffusion of eco-innovations (Fielding, 2012; Hussein, 2009).

The majority of the articles selected for the literature review conduct a quantitative analysis while only some articles develop a case study, and Chapter 2 contributes to this body of research by presenting a case study of Jaguar Land Rover. Few articles focused on developing simulation tools and models, representing a potential gap in the research which is addressed in Chapter 3 where an agent-based model is developed. Many of the articles selected for the literature review reference drivers of eco-innovation and diffusion theory, which also form the theoretical foundation in Chapter 3, as well as institutional theory and the coercive, mimetic, and normative pressures that impact business decisions, which is further explored in Chapter 2.

The results of the literature review showed that there are many mentions in the selected literature of the role that relationships between firms play in the adoption and diffusion of eco-innovations. In particular, customer-supplier relationships based on formal contractual obligations seemed to have the greatest number of mentions and were described as having a positive effect on eco-innovation adoption and diffusion. In Chapter 2, this is studied further through a case study of Jaguar Land Rover and how the formal relationships between Jaguar Land Rover as a customer and the firms in their supply chain influenced the rate of adoption of an eco-innovation they wished to implement.

In addition, the results indicated the role of inter-firm networks in the adoption and diffusion of eco-innovations. Supply chain and industry networks were mentioned as having a positive effect on eco-innovation adoption, which is explored further in Chapter 2 with the case study of Jaguar Land Rover and their supply chain. In addition, the position of the firm within the network was frequently mentioned as having a positive effect on eco-innovation diffusion. This is explored in more detail in Chapter 3, which develops an agent-based model to understand how targeting specific firms based on their network characteristics and position can lead to faster diffusion of eco-innovations through inter-firm networks.

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# Chapter 2 – Influence of Inter-Firm Network Relationships on Circular Economy Eco-Innovation Adoption[1]

## Abstract

Research has shown that inter-firm networks and relationships play a key role in innovation adoption; however, these concepts have not specifically been applied to study their role in the adoption of circular economy eco-innovations. This paper considers whether the embedded relationships within inter-firm networks also influence circular economy eco-innovation adoption. Using a historical case study of the REALCAR closed-loop recycling initiative, by Jaguar Land Rover, from 2013 to 2017, the paper conducted qualitative interviews to reconstruct the structure and nature of the relationships between Jaguar Land Rover and its suppliers. This was complemented with a network regression analysis to determine the influence of these relationships on the adoption and implementation decisions of the closed-loop recycling process by the suppliers of Jaguar Land Rover. The results show that Jaguar Land Rover's relationship as a key customer, facilitation of knowledge sharing among peer suppliers, and resistance from suppliers impacted by changing supply chain relationships played a role in the adoption decisions and adoption timeframe of the REALCAR closed-loop recycling innovation. This has implications for companies and supply chains to consider leveraging the inter-firm relationships embedded in their supply chain networks to accelerate the adoption of circular economy eco-innovations.

## 2.1 Introduction

Reducing the environmental impact and waste of our current global supply chains requires a transformation of how resources are used to produce goods and services. It is necessary to shift supply chains towards a model where resources are recovered and

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[1] This chapter is a reproduction of Ramkumar, S., 2020. Influence of Inter-Firm Network Relationships on Circular Economy Eco-Innovation Adoption. Sustainability 12, 7607. https://doi.org/10.3390/su12187607

circulated back into the production process. A more circular use of resources has been gaining momentum in recent years as an alternative approach to the current economic model. Defined as the circular economy, it is an economic system that aims to reduce, reuse, recover, and recycle materials in production and consumption processes (Kirchherr et al., 2017).

Specifically, a circular production approach creates closed-loops to ensure that wasted resources at each step of the supply chain are recovered and recycled (de Jesus and Mendonça, 2018). An ideal closed-loop recycling process returns any waste material back into the production process, as close as possible to the source of the waste. It significantly reduces the environmental impact of production by minimizing the need for new virgin resources and the treatment of generated waste, while improving profitability (Winkler, 2011).

To achieve this, there is a need to better understand how to engage actors within the supply chain towards a common closed-loop strategy (Khitous et al., 2020) and adopt eco-innovations that can make the value chain more circular (de Jesus and Mendonça, 2018). Implementing closed-loops effectively and at scale requires the involvement of multiple stakeholders in the supply chain and the alignment of various economic, technical, and environmental factors between these companies (Winkler, 2011). Exploring the network of relationships and connections between these firms can uncover ways to coordinate the implementation and adoption of innovative closed-loop recycling processes to achieve a more circular supply chain.

Previous research has shown that inter-firm networks play a crucial role in innovation adoption (Ozman, 2009). The embedded relationships and ties within the network of firms, such as hierarchical relations, competitive or cooperative relationships, supplier or economic relationships, and transfers of knowledge and technology (Borgatti and Li, 2009), enable firms to adapt to changing conditions and make important decisions regarding the implementation of innovations. However, these concepts are used in a limited fashion to understand the diffusion and adoption of eco-innovations (Karakaya et al., 2014) that focus on a circular economy, such as closed-loop recycling.

Compared to normal innovations, eco-innovations have higher levels of novelty and uncertainty (Cainelli et al., 2015). As a result, the networks and relationships between firms could be an even more important factor for them to gain knowledge and support in the adoption of eco-innovations (Díaz-García et al., 2015). While the literature often focuses on the internal and external drivers for adoption and the management of eco-innovations (Karakaya et al., 2014), more research is needed on how the eco-innovation behavior of networks of firms and the socio-economic structure of interactions between firms and stakeholders across the supply chain influence the effective implementation of circular economy eco-innovations (Laurenti et al., 2018; Rennings, 2000).

To fill this gap, this paper aims to explore how the embedded relationships within the inter-firm network of companies across a supply chain influence the adoption of closed-loop recycling eco-innovation. The paper uses a historical case study approach to study the network of suppliers of Jaguar Land Rover during the implementation of the REALCAR closed-loop recycling initiative between 2013 and 2017. Through qualitative interviews with managers and employees of Jaguar Land Rover and their suppliers, the paper reconstructs the dynamics and changing structure and nature of the relationships between companies as they adopted REALCAR. Information from the interviews combined with additional data provided by interviewees was used to conduct a network regression analysis to further explore the influence of supplier relationships on the adoption timeframes of REALCAR. By focusing on circular economy eco-innovations, specifically closed-loop recycling, using a mixed-methods approach of qualitative interviews and network analysis, the paper contributes to the existing research on embeddedness, inter-firm networks, and eco-innovation adoption.

The rest of the paper provides a review of relevant literature on the relevance of inter-firm networks and embedded relationships to innovation adoption, as well as the unique characteristics of circular economy eco-innovations that spur the research question. Next, a brief introduction to the Jaguar Land Rover REALCAR closed-loop recycling initiative as an eco-innovation case study is presented. This is followed by a summary of the qualitative research methodology and an overview of the network regression analysis conducted. The findings from the interviews and the results of the network regression are then presented. Finally, the paper ends with a discussion of the results and conclusions.

## 2.2 Literature Review

Eco-innovations are a key pathway to achieving sustainable production systems, closed-loop supply chains, and product-service systems that lead to a more circular economy. Based on a review of 114 definitions of circular economy, Kirchherr et al. (2017) define it as "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes." While eco-innovation is defined as "the production, application or exploitation of a good, service, production process, organizational structure or management or business method that is novel to the firm or user and which results, throughout its life cycle, in a reduction of environmental risk, pollution and the negative impacts of resource use compared to relevant alternatives" (Kemp and Pearson, 2007). Circular economy eco-innovations such as closed-loop recycling ensure that wasted resources at each step of the supply chain are recovered and recycled back into the production process, as close as possible to the source of the waste, creating resource loops (Winkler, 2011). Such innovations involve entire value chain transformations that employ new methods of production to ensure resources are recirculated and preserved, so that their value is recovered (de Jesus and Mendonça, 2018; Hellström, 2007).

The processes through which such innovations emerge and spread throughout the different industries are complex, iterative, and evolutionary. Generally, such innovations involve the interaction of a network of organizations which contribute and exchange knowledge and resources to generate, adopt, and disseminate new products and processes (Malerba and McKelvey, 2020). These firms have different contexts, constraints, and incentives to innovate, which are not always aligned with profit-seeking motivations and are influenced by various economic, social, and structural factors. All of these elements result in systems of innovation (Edquist and McKelvey, 2000), and understanding the dynamics of such interactions and relationships of the inter-firm networks within these systems is crucial to influence the wider adoption of circular economy eco-innovations.

### *2.2.1 Inter-Firm Networks and Relationships in Innovation Adoption*

Inter-firm networks are defined in the literature as modes of organizing and coordinating economic activities between firms. They emerge as a result of firms trying to take advantage of the differentiation and asymmetry of knowledge and resources, creating an interdependence between firms (Grandori and Soda, 1995). The types of relationships and links in these inter-firm networks can be economic, through the contractual transaction and interchange of resources, as well as social, resembling the social ties between individuals. For firms, these social ties can be hierarchical relations of authority and power, competitive or cooperative relationships, transfers of knowledge and technology, interpersonal ties between employees and interlocking directorates, or joint membership in associations (Borgatti and Li, 2009; Grandori and Soda, 1995)

According to Granovetter (1985), these social and behavioral inter-firm ties are embedded in economic relations between firms, explaining economic outcomes. The position and structure of the network of social ties (structural embeddedness) and the characteristics and quality of these relations (relational embeddedness) (Casanueva and González, 2004; Ozman, 2009) can enable and constrain particular activities and decisions of firms. Institutional theory suggests that the structure and nature of these relationships can impose various coercive pressures due to the dependency on other organizations, mimetic pressures to imitate more successful organizations for legitimacy, and normative pressures to change their goals or develop new practices (DiMaggio and Powell, 1983). Moreover, these ties are multiplex and can exist simultaneously and shape firm behavior in different ways (Boons and Howard-Grenville, 2009; Borgatti and Li, 2009).

Research has shown how inter-firm networks and embedded social relations are critical to the adoption of innovation. Ozman (2009) states that innovation is a collective and evolving process in which the networks and relationships between firms play a key role. Inter-firm networks allow companies to access necessary resources, as well as to learn from, and imitate, other firms, particularly ones they trust and are socially connected to. Embedded relations in inter-firm networks influence the propensity of firms to “innovate, take risks, and act proactively” (Simsek et al., 2003). Like individuals, firms use their interactions with other firms within their network to make sense of others’ behaviors and to make decisions. The structure of inter-firm networks, inter-firm dependence, and the strength, frequency, and quality of ties with other firms are important factors that determine firm-level entrepreneurial behavior (Simsek et al., 2003).

For example, Dhanaraj and Parkhe (2006) point out how hub firms, that are centrally located in their network and have a certain level of power, can act in a leadership capacity to orchestrate innovation. These firms utilize their network position and relations to bring together resources from their network members, share knowledge to parts of the network where it is needed, and manage the relationships to enhance socialization within the network. In this way, hub firms foster the adoption of innovation by making use of the structure and nature of the formal and informal relationships within their inter-firm network.

Research by Öberg (2019) focuses on six case studies of companies that adopted incremental, radical, or disruptive innovations and the characteristics of their business networks. The paper found that incremental innovations that create improvements utilize existing networks and strong social ties. On the other hand, radical innovations that bring new ideas to the market are brought about by a focal party utilizing weak ties and changing roles of current business partners. Lastly, disruptive innovations that challenge the existing structure are brought about by strengthening ties with new entrants and weakening ties with current partners. Moreover, these innovations, in turn, can affect the structure and nature of the relationships in the network.

Robertson, Swan, and Newell (1996) explore the adoption and diffusion of innovation in computer-aided production management (CAPM) technology using a case-study approach of three companies. Using theories of institutional isomorphism (DiMaggio and Powell, 1983), their research explored whether the adoption of CAPM technology is influenced by coercion from other organizations the companies are dependent on, imitation of peer firms that have successfully adopted the technology, and industry norms that pressure them to adopt in order to seem legitimate. Their analysis found that the adoption of CAPM innovation was influenced by embedded inter-firm network relationships, such as suppliers that pushed the technology, informal contacts with other firms which implemented the technology, and professional associations that firms were connected to.

### *2.2.2 Relevance for Eco-Innovation Adoption*

The factors that influence innovation adoption are also important for eco-innovations; however, they "will probably not influence the same variables with the same strength" (Bossle et al., 2016). Compared to normal innovations, eco-innovations have higher levels of novelty and uncertainty (Cainelli et al., 2015), since companies tend to bear higher costs in order to create greater societal benefits, which puts them at a disadvantage relative to their polluting competitors (Hojnik and Ruzzier, 2016). Therefore, companies require greater internal capabilities and resources to adopt eco-innovations (Bossle et al., 2016; Cainelli et al., 2015; Pellegrini et al., 2019; Triguero et al., 2016). In addition, companies also face greater external pressures from regulatory factors and market demand from customers to overcome the low incentives to adopt eco-innovations (Bossle et al., 2016; Díaz-García et al., 2015; Pellegrini et al., 2019).

The existing research on eco-innovations mentions the importance of stakeholders and inter-firm networks for awareness and adoption. Eco-innovations require greater external knowledge and cooperation with partners than traditional innovations (Hojnik and Ruzzier, 2016). Due to the higher uncertainty of eco-innovations, it is even more important for firms to cooperate with external partners, suppliers, and other stakeholders within their network to share knowledge, gain financial support, and mitigate the risks and costs of adopting novel eco-innovations (Cainelli et al., 2015; Del Río González, 2005; Díaz-García et al., 2015; Mazzanti and Zoboli, 2008; Pellegrini et al., 2019). Inter-firm networks can influence the internal and external decision criteria for eco-innovation adoption (Pellegrini et al., 2019), as suppliers and business partners within a firm's network encourage firms to be more aware of, and adopt, a pro-environmental behavior (Cainelli et al., 2011; Sáez-Martínez et al., 2016; Triguero et al., 2016).

Additional research utilizing institutional and stakeholder theory suggests that there is evidence of coercive, mimetic, and normative pressures within a firm's network on eco-innovation adoption. Firms are influenced by pressures from regulations and customer demands, motivations to stay ahead of their competitors, co-operation with their peers, and industry standards, all of which can dictate whether they adopt eco-innovations (Bag and Gupta, 2017; Lin and Sheu, 2012; Sáez-Martínez et al., 2016; Zhu and Sarkis, 2007). The structure and nature of the network of relationships and connections to other stakeholders in which these pressures are embedded play a significant role in eco-innovation adoption (Bayne et al., 2012; Chen et al., 2019).

However, there is no explicit research focusing on how embedded relationships in inter-firm networks influence circular economy eco-innovation adoption. More theoretical and empirical approaches for evaluating eco-innovation behaviors by networks of firms and relevant stakeholders are needed (Rennings, 2000; Williamson et al., 2006). A deeper understanding of how the socio-economic structure of interactions within a network of businesses and other stakeholders could influence the effective adoption and implementation of circular economy material flows lacks a strong link and acceptance among researchers (Laurenti et al., 2018). The relevance of theories regarding the mechanisms through which such eco-innovations get adopted and diffused through social norms and social networks is not yet established (Karakaya et al., 2014).

Circular economy eco-innovations such as closed-loop recycling are sensitive to interactions and inter-related developments between businesses, society, and institutions due to their systemic nature (de Jesus and Mendonça, 2018; Rennings, 2000). Such eco-innovations must build on, and modify, existing management and production structures, coordination processes, and social aspects to be successful (Hellström, 2007). Therefore, it is important to understand how the structure and nature of the relationships within inter-firm networks influence the decision to adopt circular economy eco-innovations.

This paper aims to address this area of research on eco-innovation adoption and circular economy. The research intends to utilize previous evidence and theories on the role of embedded relationships within inter-firm networks on the adoption of innovations and eco-innovations to study the adoption of closed-loop recycling. The objective is to determine the importance of these factors given the differences in characteristics of eco-innovations compared to traditional innovations.

## 2.3 Materials and Methods

### *2.3.1 Case Study of Jaguar Land Rover's REALCAR*

In order to explore the role of embedded relationships in inter-firm networks on circular economy eco-innovation adoption, this paper utilizes a case study approach. As mentioned by Uzzi (1997), this approach provides rich data to conduct a detailed analysis of inter-firm ties and their dynamics. Though the approach has "moderate generalizability" (Uzzi, 1997), the strength of the case study approach is that it fills gaps of knowledge present in more quantitative statistical and modelling methods (George, 2005). Moreover, it enables the study of concepts and indicators that have no quantitative measure, such as power dynamics, culture, trust, and other factors embedded in relationships and networks.

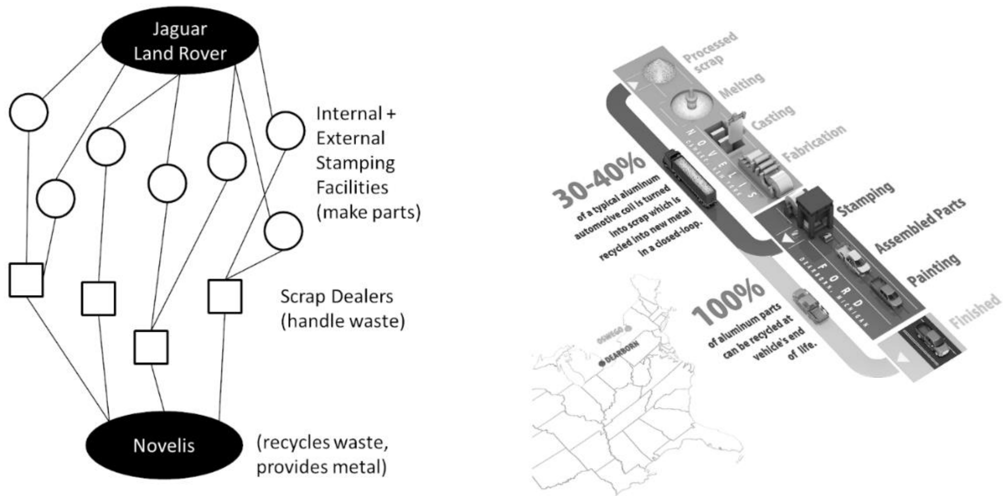
Specifically, the paper studies the case of the Jaguar Land Rover REALCAR closed-loop recycling project. The REALCAR project was an initiative by Jaguar Land Rover and a variety of stakeholders and partners that came together to develop a process to collect, recycle, and reuse aluminum waste material in the production of automobile bodies. When it was developed and implemented, REALCAR was one of the first best-practice examples of a successful, large-scale implementation of closed-loop recycling within the automotive supply chain. Moreover, it paved the way for other automakers such as Ford, BMW, and Audi to implement similar initiatives later on.

The history of the REALCAR project can be traced back to 2002, when Jaguar Land Rover decided to produce automobiles from aluminum instead of steel, the traditional material used by automakers. Aluminum was chosen to "reduce weight, improve fuel consumption and tailpipe emissions and reduce costs to the user" (Cassell et al., 2016). Since aluminum is more expensive and energy-intensive than steel, Jaguar Land Rover started looking for ways to reduce these costs and impacts, particularly as Jaguar Land Rover shifted more of their production towards aluminum (Ludwig, 2020).

Around 2007, after realizing that a key way to achieve this goal was to utilize recycled aluminum at every stage of production, Jaguar Land Rover developed the REALCAR project. Receiving 1.3 million British pounds in funding from a collaborative R&D grant by the UK government's Innovate UK program, Jaguar Land Rover brought together a consortium of supply chain partners—aluminum producer Novelis, technology consultant Innoval, body stamping supplier Stadco, Brunel University, and others. Together, they researched and developed a new type of aluminum alloy, RC5754, that could utilize recycled waste aluminum material collected from the production process of car bodies without sacrificing performance. This enabled Jaguar Land Rover to recycle the nearly 50% of aluminum waste from the production of their automobiles and recover 90–95% of the value of the material, significantly reducing costs by millions of pounds (Scamans, 2016).

However, to fully achieve the benefits of this research and reach their target of using 75% recycled aluminum in their cars by 2020, Jaguar Land Rover needed to move beyond the R&D phase and implement the REALCAR approach across their supply chain. This included implementing the approach in Jaguar Land Rover's own internal production facilities, but more importantly in the production facilities of its external suppliers. REALCAR's implementation required investments in new equipment as well as modifications of existing processes, with Jaguar Land Rover investing more than £7 million across their three facilities, Novelis investing £6 million in their Latchford recycling plant, and nine other external suppliers also making investments and changes to their operations (Ludwig, 2020).

With these investments, Jaguar Land Rover's internal stamping facilities and external stamping suppliers were able to separate and collect waste aluminum material from the production of automobile car bodies. The new equipment and processes aimed to minimize the contamination of the aluminum waste with steel and other metals. Once collected, the scrap was then baled and transported by scrap dealers, which sent the material by truck to Novelis's Latchford recycling plant. Here, the waste material was re-melted and recycled to produce new aluminum sheets, which were then provided to the stamping facilities to produce new car parts (Ludwig, 2020). Figure 2.1, below, provides an overview of this process, as well as an image showing the implementation for Ford, which happened much later than the Jaguar Land Rover REALCAR initiative but follows a similar approach.




(**a**) (**b**)

**Figure 2.1.** A conceptual overview of the REALCAR supply chain. (**a**) Supply chain diagram of the stakeholders involved in the REALCAR closed-loop recycling process and their roles; (**b**) Process diagram of REALCAR implementation at Ford (Novelis Inc, 2015).

Previous research on the REALCAR closed-loop recycling process has focused on the environmental benefits, technical innovation, and financial investments (Horton et al., 2018). In addition to these aspects, there was also a need to coordinate the supply chain network, since REALCAR transformed the value flow within the supply chain network and not all companies benefitted equally. Jaguar Land Rover and Novelis needed to consider the incentives and opportunities for the whole value chain and manage their supplier relationships to effectively engage them to adopt the REALCAR approach (Cassell et al., 2016). Therefore, REALCAR is an ideal case to understand the role that relationships between firms in the supply chain network play in the adoption of a novel innovative process for closed-loop recycling.

*2.3.2 Qualitative Study*

To better understand the role of embedded relationships and inter-firm networks in the adoption of the REALCAR closed-loop recycling approach by the suppliers of Jaguar Land Rover, a qualitative research method was first followed. Similar to the approach taken by Robertson, Swan, and Newell (1996), the interviews were intended to explore the nature of the relationships and network ties among the different actors and the role they played in the adoption of REALCAR. Through these interviews, the paper gained a description of the sequence of events that led to the adoption of REALCAR and identified emerging patterns that might fit with the existing theory on embedded relationships in inter-firm networks and innovation.

The interviews consisted of a series of semi-structured questions and were conducted for approximately 1–1.5 h over the phone. The topics covered during the interview were based on the types of embedded relationships discussed in the literature, such as hierarchical relations of authority and power, competitive or cooperative relationships, transfers of knowledge and technology (Borgatti and Li, 2009; Grandori and Soda, 1995), and on the structure and quality of the relationships (Casanueva and González, 2004; Ozman, 2009). Interviewees were asked about:

- Timelines for the adoption of the REALCAR approach
- Motivations for the adoption and implementation of REALCAR
- Nature of relationship between Jaguar Land Rover and internal and external stamping facilities
- Nature of relationship, knowledge sharing between internal and external stamping facilities
- Nature of relationship with scrap dealers
- Ease of implementation in terms of costs, logistics, technical capabilities, contracts, etc.

The interviews were conducted with executives, managers, and employees who were involved in the implementation phase of REALCAR from 2013 to 2017. The interviewees were identified through the snowball technique as outlined by Borgatti and Li (2009) in the context of a supply chain. Initial interviews with key decision-makers from Jaguar Land Rover who led the implementation of REALCAR revealed contacts within Jaguar Land Rover, Novelis, internal stamping facilities, external stamping supplier facilities, and scrap dealers. These contacts were then interviewed and asked to provide additional contacts at the various firms.

In total, 61 individuals within Jaguar Land Rover, Novelis, 3 internal stamping facilities, 12 external stamping supplier facilities owned by 7 external stamping suppliers, and 5 scrap dealers were identified. However, due to difficulties in interviewing many of the individuals, who had since transferred from their roles, retired, whose contact information was outdated, or who refused to be interviewed due to confidentiality issues, only 17 interviews were conducted. A summary of the number of individuals identified and interviewed by company type is provided in Table 2.1.

**Table 2.1.** Summary of interviewees identified and interviewed.

| **Company Category** | **Number of Companies/Facilities** | **Number of Individuals Identified** | **Number of Individuals Interviewed** |
|---|---|---|---|
| Jaguar Land Rover | 1 | 19 | 9 |
| Novelis | 1 | 5 | 3 |
| Internal Stamping Facilities | 3 | 4 | 2 |
| External Stamping Supplier Facilities | 12 facilities<br>7 suppliers | 23 | 2 |
| Scrap dealers | 5 | 10 | 1 |
| **Total** | **22** | **61** | **17** |

Though the number of interviews conducted was lower than the number of individuals identified, the perspectives of the different types of firms involved in the REALCAR project were sufficiently covered. Moreover, relevant information regarding the inter-firm relationships and network structure were provided by key decision-makers interviewed from Jaguar Land Rover and Novelis, who had oversight and contacts with many of the stakeholders involved in REALCAR.

Interviewees were informed in writing of the purpose of the study, and letters of consent were provided for the interviewees to sign. These documents stated that their responses and the information provided would be treated confidentially and any details which would reveal the identity of the individuals interviewed would not be mentioned or disseminated in the research. In addition, following the approach by Öberg (2019), the interviews were supplemented with newspaper items, press releases, and email exchanges with some of the interviewees, to get additional information on the relationships and network ties between firms, as well as to triangulate information received from the different sources.

Similar to the approach taken by Uzzi (1997), the information gathered from the interviews was interpreted based on expectations and theories derived from the literature review. A coding framework was developed to identify three categories of embedded relationships. First, hierarchical relations of authority and power and coercive pressures were coded to identify whether Jaguar Land Rover used their network position and power as customers to encourage the stamping facilities to adopt REALCAR. Second, mimetic pressures were coded to identify whether competitive and cooperative relationships, as well as interlocks between the stamping facilities, encouraged knowledge sharing, learning, and imitation of best practices that influenced the adoption of REALCAR. Third, changes in the structure and nature of the relationships between the different firms, such as changes to existing contracts or changes to the roles of the companies, were coded to identify their effects on the adoption of REALCAR. The interview notes and transcriptions were analyzed using a qualitative data analysis software, QDA Miner, using this coding framework. In the process of analyzing the interviews conducted, the framework was modified and refined based on the literature and the information from the interviews.

### *2.3.3 Network Regression Analysis*

Unfortunately, few of the scrap dealers were able to be interviewed due to confidentiality issues and non-disclosure agreements. However, during the interviews, some interviewees provided supplementary historical data related to REALCAR, such as the adoption timeframes of the different stamping facilities from 2013 to 2017, information on which scrap dealers were contracted to handle the waste from each stamping facility at the time, and additional characteristics of the stamping company facilities. Follow-up exchanges with interviewees also uncovered the scrap dealers with which they had difficult negotiations due to resistance to the REALCAR closed-loop approach. Further analysis of this data seemed necessary to better understand the influence of scrap dealer relationships on the adoption of REALCAR.

From the literature, researchers note the potential for network analysis to complement a qualitative case study approach and gain a deeper understanding of embedded network relationships (Coviello, 2005). Edwards (2010) points out the benefits of combining qualitative research and network analysis through a literature review of different studies which employed mixed-method approaches. These studies describe how information gathered from ethnographic observations or semi-structured interviews can be quantified into relational network data. Such a mixed-method approach enables the exploration not only of the structure and form but also of the content and processes of network relationships, enabling triangulation to create a narrative that offers greater context.

Consequently, this paper also chose to utilize the information from the interviews and the supplemental data provided by interviewees to conduct a network regression analysis using the Multiple Regression Quadratic Assignment Procedure (MR-QAP) technique, to complement the qualitative interviews. Rather than conducting regressions of dependent and independent variables as in traditional statistics, the MR-QAP method performs regressions of the dyadic ties or relationships between two actors within a network (Borgatti et al., 2013). This network regression method is superior to traditional Ordinary Least Squares (OLS) techniques for dyadic relationship data, as it removes any biases from structural autocorrelation (Krackhardt, 1988).

The network regression sought to understand if two stamping suppliers had the same scrap dealer or if they both faced resistance from their scrap dealers, then how similar was their time-to-adoption in months for the REALCAR approach to be implemented. The unit of analysis for the network regression were the 3 internal Jaguar Land Rover and 12 external supplier stamping facilities—a total of 15 facilities. The ties between these nodes were the dependent network variable, the difference in time-to-adoption of REALCAR between stamping facilities, and the independent network variables, common scrap dealers among stamping facilities, and resistance from the scrap dealers. Figure 2.2 illustrates the dependent and independent network variables.


**Figure 2.2.** Network diagram illustrating the Multiple Regression Quadratic Assignment Procedure (MR-QAP) network regression to test whether the structure and nature of the stamping facilities' relationships with scrap dealers influenced the time-to-adoption of REALCAR. The nodes are the 15 internal and external stamping facilities, while the ties represent the dependent and independent network variables.

To more accurately test the influence of scrap dealer relationships, a network regression model was developed to include other control factors that could influence adoption timeframes. The model followed the approach outlined in Hollenstein and Woerter (2008), which used a regression model to identify the influence of different firm characteristics on the adoption and diffusion of technology. However, since we are considering a circular economy eco-innovation, factors relevant to circular economy eco-innovation adoption described in the literature were considered—firm size, firm learning, technological implementation, and financial costs, as well as leadership and governance (Bossle et al., 2016; Hollenstein and Woerter, 2008; Zamfir et al., 2017).

Firm size, measured in the literature by the number of employees or turnover (Hollenstein and Woerter, 2008; Zamfir et al., 2017), was not available at the stamping facility level, and therefore the difference in the size of scrap generated was used as a proxy for firm size. The difference in the order of implementation of REALCAR was used to capture firm learning of best practices by later adopters. Whether two stamping facilities faced significant capital investment or process changes was used to capture implementation factors. The difference in logistics costs was used as a proxy for financial costs. Lastly, whether two stamping facilities were owned by the same company acted as a proxy to capture governance and leadership factors. Figure 2.3 outlines the network regression model and the network variables used.

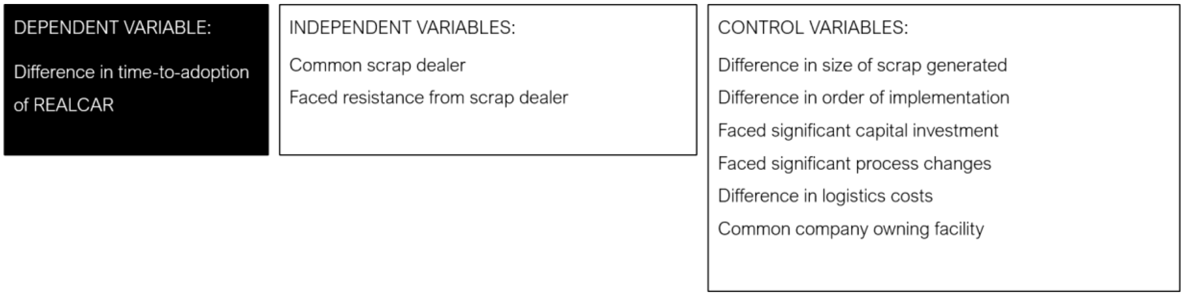



**Figure 2.3.** Overview of the network regression model and the network variables.

To gather data for these network variables, an Excel database was first created, where each row represented a stamping facility and each column represented the information needed to compute the network regression variables. This Excel database was first populated using the supplementary data tables, provided through follow-up email exchanges with some of the interviewees, and captured the following information:

- Date of first discussions with the stamping facility and date of REALCAR implementation (the difference between these dates was the facility's time-to-adoption in months)
- Scrap dealer contracted to the stamping facility
- Size of scrap generated per month by the stamping facility, in tons
- Order of the stamping facility's implementation of REALCAR, from 1 to 15
- Logistics costs for the stamping facility, in GBP per ton
- The company which owned the stamping facility

Next, information on the resistance from the scrap dealers, whether the stamping facility faced significant capital investment, and whether the stamping facility faced significant process changes was derived from the interviews. A similar approach to that of Mckether et al. (2009) was used to convert interview data into social network data. The interviews were transcribed using the software QDA Miner and coded for references to scrap dealer resistance, significant capital investment, and significant process changes for each of the 3 internal and 12 external supplier stamping facilities. If there was any mention of resistance from scrap dealers, capital investment, or process changes for a stamping facility in the interviews, the value in the appropriate column in the Excel database was 1; otherwise it was 0.

As in the approach followed by Coviello (2005), this network database was shared with interviewees who provided the data and who had sufficient knowledge of all the relationships within the supply chain network. The data was revised as necessary until the information captured was deemed accurate. This ensured that the data was credible and valid and increased confidence in the network analysis.

Once the Excel database was finalized, the network variables were calculated in the form of adjacency matrices, as outlined in the literature (Borgatti et al., 2013). These adjacency matrices contained the 15 stamping facilities along the rows and columns of the matrix. For each of the network variables, the information in each cell of the corresponding adjacency matrix was populated as follows:

- Difference in time-to-adoption: absolute value difference in time-to-adoption in months between two stamping facilities
- Common scrap dealer: 1 if two stamping facilities used the same scrap dealer, 0 otherwise
- Faced resistance from scrap dealer: 1 if two stamping facilities both faced resistance from their scrap dealer, 0 otherwise
- Difference in size of scrap generated: absolute value difference in the size of scrap generated in tons between two stamping facilities
- Difference in order of implementation: absolute value difference in the order of implementation between two stamping facilities
- Significant capital investment: 1 if two stamping facilities both made significant capital investments, 0 otherwise
- Significant process changes: 1 if two stamping facilities both made significant process changes, 0 otherwise
- Difference in logistics costs: absolute value difference in logistics costs in GBP per ton between two stamping facilities
- Common company owning facilities: 1 if two stamping facilities were both owned by the same company, 0 otherwise

The descriptive statistics for these network variables are summarized in Table 2.2.

**Table 2.2.** Descriptive statistics for network regression variables.

| Variable | Min | Max | Mean | Std. Dev. |
|---|---|---|---|---|
| **Dependent Variable** | | | | |
| Difference in time-to-adoption | 0 | 18 | 7.68 | 5.55 |
| **Independent Variables** | | | | |
| Common scrap dealer | 0 | 1 | 0.30 | 0.46 |
| Faced resistance from scrap dealer | 0 | 1 | 0.27 | 0.44 |
| Control Variables | | | | |
| Difference in size of scrap generated | 0 | 1391 | 376.21 | 367.17 |
| Difference in order of implementation | 1 | 14 | 5.33 | 3.40 |
| Faced significant capital investment | 0 | 1 | 0.10 | 0.29 |
| Faced significant process changes | 0 | 1 | 0.20 | 0.40 |
| Difference in logistics costs | 0 | 68 | 19.92 | 15.62 |
| Common company owning facility | 0 | 1 | 0.11 | 0.32 |

**Note:** There were 210 observations.

The adjacency matrices for the dependent, independent, and control variables were then used to conduct the network regression using the Double Dekker Semi-Partialling MR-QAP algorithm in the software, UCINET (Borgatti et al., 2013). The technique permutes multiple versions of the dependent variable adjacency matrix by randomly rearranging the data in the rows and columns. This creates independent variations of the dependent network variable with the same properties—mean, standard deviation, etc. Using this method, a sample of observations is generated for the network regression analysis. Since a larger sample of permutations provides more stable results, 10,000 permutations were specified in the UCINET software, following the example outlined in Borgatti, Everett, and Johnson (Borgatti et al., 2013). Performing a statistical analysis of these permutations enables us to see if the correlation between the variables is due to chance, or if there is a statistically significant correlation (Lee et al., 2010).

## 2.4 Results

The results from the qualitative research follow the coding framework, which focused on three main relationships in the REALCAR network. The first is the coercive pressure from Jaguar Land Rover and how they used their network position and hierarchical relationships of authority and power as customers to encourage the stamping facilities to adopt REALCAR. The second is the mimetic pressure of peer stamping facilities, exploring how competitive and cooperative relationships, as well as interlocks between the stamping facilities, encouraged the learning and imitation of best practices and influenced the adoption of REALCAR. The third is the influence of scrap dealers, to determine if the changing structure and nature of these relationships had any effect on the adoption of REALCAR. Finally, the results from the network regression analysis to further explore the influence of the scrap dealer relationships are presented.

### *2.4.1 Coercive Pressures from Jaguar Land Rover on the Adoption of REALCAR*

As described earlier, Jaguar Land Rover approached its suppliers to implement the REALCAR closed-loop approach across the supply chain and realize its benefits. Many interviewees mentioned the business benefit to Jaguar Land Rover, as the financial value and reduced environmental impact were big drivers for the implementation. However, there needed to be sufficient volumes and throughput to achieve these benefits. As one manager from Jaguar Land Rover stated, "it was within Jaguar Land Rover's interest to be able to roll this out extensively…there is no point putting in massive conveyor belts and separation activities in a facility if you are only going to be separating a small amount of material."

To achieve a sufficient scale, stamping suppliers were the most important stakeholders to get on board. One interviewee stated that "it was in their interest to get their Tier 1 stampers to do it", and another mentioned that they needed to convince the stamping suppliers that REALCAR was important to the future strategy of Jaguar Land Rover. Thus, the focus of Jaguar Land Rover was to engage in discussions with their internal stamping facilities and external stamping suppliers to implement REALCAR.

Internal stamping facilities were "more straightforward since Jaguar Land Rover had a direct impact on them," as a manager from Jaguar Land Rover stated. Interviewees from Jaguar Land Rover and the internal facilities mentioned that necessary investments in equipment and workforce training to separate and collect the waste scrap material were made. There was little pushback against the adoption of REALCAR according to the interviewees, since the approach made business sense and any investments in these facilities in terms of capital and process changes were very quickly paid back.

For the external stamping suppliers, a team of Jaguar Land Rover managers, external consultants, as well as the purchasing team from Jaguar Land Rover set up meetings and visits with all the external stamping supplier facilities, by order of size, to scale REALCAR quickly. Interviewees mentioned that a few external stamping suppliers were positive and understood the financial and environmental benefits of REALCAR, while others did not understand the closed-loop approach, and some did not want to do it. According to a manager at Jaguar Land Rover, many stamping suppliers were not focused on circular economy or sustainability and were more concerned about "getting press parts out at the right quality… they weren't overly fussed about scrap."

Thus, to get their supply chain to adopt REALCAR, Jaguar Land Rover leveraged their position as customers to pressure suppliers that were dependent on them or that saw a potential for additional business, created requirements for future suppliers, and gave financial incentives to suppliers to ease the burden and the costs of implementing REALCAR. Figure 2.4 summarizes the mentions of the various coercive pressures coded from the interviews.

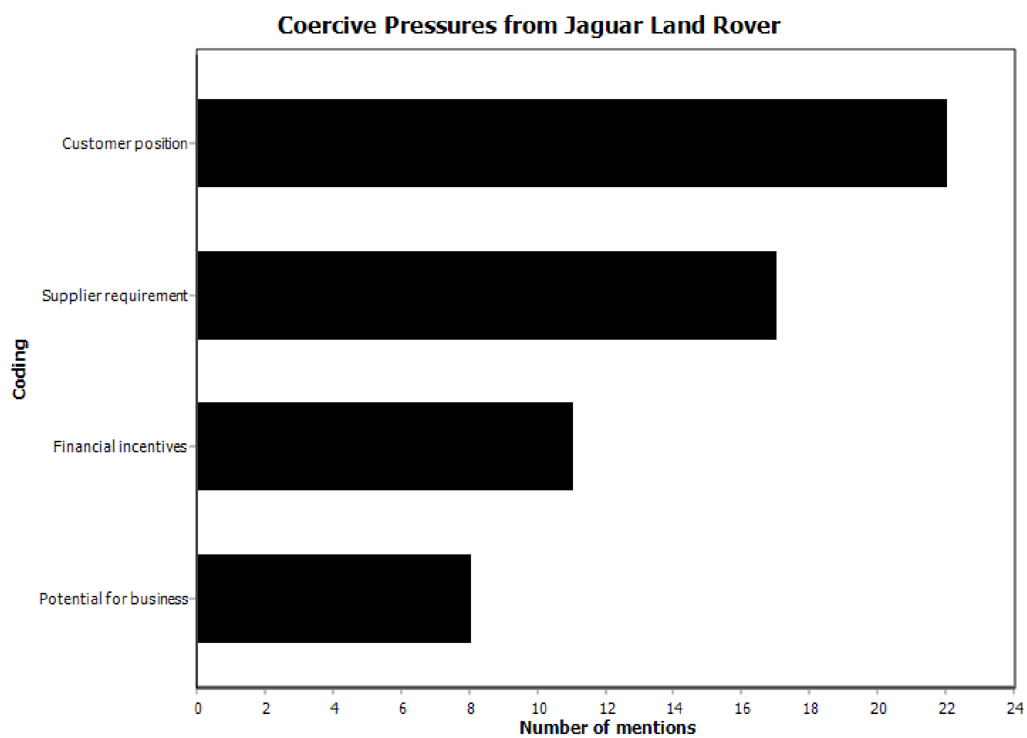



**Figure 2.4.** Coded mentions in interviews of coercive pressures from Jaguar Land Rover on suppliers to adopt REALCAR.

The majority of interviewees mentioned that Jaguar Land Rover is a big customer upon which external stamping suppliers were dependent, which compelled them to adopt REALCAR. They stated that in the UK, Jaguar Land Rover was the only mass volume automobile manufacturer using aluminum, so many companies were "strategic suppliers" which were exclusively stamping aluminum for them. Some external stamping suppliers had other customers that used steel, so while Jaguar Land Rover was not the majority of their overall business, it still represented a sizeable portion. As one interviewee stated, "when your biggest customer wants something, you try somehow to make it happen." So, there was "willingness to accommodate and adapt the processes" to implement the REALCAR closed-loop in order to "please Jaguar Land Rover" and maintain a positive relationship, according to a manager at an external stamping supplier.

Since Jaguar Land Rover was an important customer, they were able to request and direct their suppliers to adopt REALCAR. An executive at Jaguar Land Rover mentioned that the adoption of REALCAR became a "procurement rule for all pressing plants in the UK" and "a requirement for all their suppliers." There needed to be a commitment by the external stamping suppliers to participate in the REALCAR closed-loop and "there was never going to be a point where [suppliers] could say no since they could lose business," as another interviewee stated.

There was "no direct financial benefit" from REALCAR for the external stamping suppliers, since "they don't really make money out of it," according to an interviewee from an external stamping supplier. Thus, to encourage the adoption of REALCAR by external stamping suppliers, Jaguar Land Rover provided financial incentives to their suppliers. For some of the external stamping supplier facilities, there were minimal changes needed in their existing production processes to implement REALCAR, and Jaguar Land Rover would cover the costs for scrap separation. For other external stamping supplier facilities that needed more investment, some interviewees mentioned that "Jaguar Land Rover offered financial assistance for any CAPEX projects" that needed to be implemented to separate the scrap for REALCAR. Therefore, for many stamping suppliers, there was "no reason not to" implement the collection and separation of scrap for REALCAR, and it was a small price to pay to keep their business with Jaguar Land Rover.

Interviewees also mentioned that some external stamping suppliers saw a potential for business from the adoption of REALCAR. They recognized that Jaguar Land Rover was increasingly shifting towards recycled aluminum and understood that this was their new strategic direction. As a result, stamping suppliers and scrap dealers hoped that adopting REALCAR would enable them to grow their business and get further access to Jaguar Land Rover's supply chain. Others recognized the value of scrap and saw REALCAR as "a huge de-risking strategy when it comes to market movements," according to a manager from an external stamping company since they "didn't have to worry about negotiating prices and contracts to get rid of the aluminum waste."

Overall, it was apparent from the interviews that Jaguar Land Rover had a strong position as a customer in their supply chain. This enabled them to exert coercive pressures to influence their suppliers to adopt the REALCAR closed-loop approach. Suppliers had to adopt REALCAR to satisfy Jaguar Land Rover as a customer or risk losing their business relationship. However, this did not come at a huge cost to the stamping suppliers and even offered the possibility for additional future business.

### *2.4.2 Mimetic Pressures among Peer Stamping Suppliers on the Adoption of REALCAR*

During the interviews, interviewees were asked about the nature of the relationships between the internal stamping facilities and external stamping supplier facilities. These questions were focused on identifying whether there were any competitive pressures to adopt REALCAR, any sharing of learning and best practices, and any employee interlocks between suppliers that enabled knowledge transfer. A summary of the coded mentions of these peer relationships is shown in Figure 2.5.

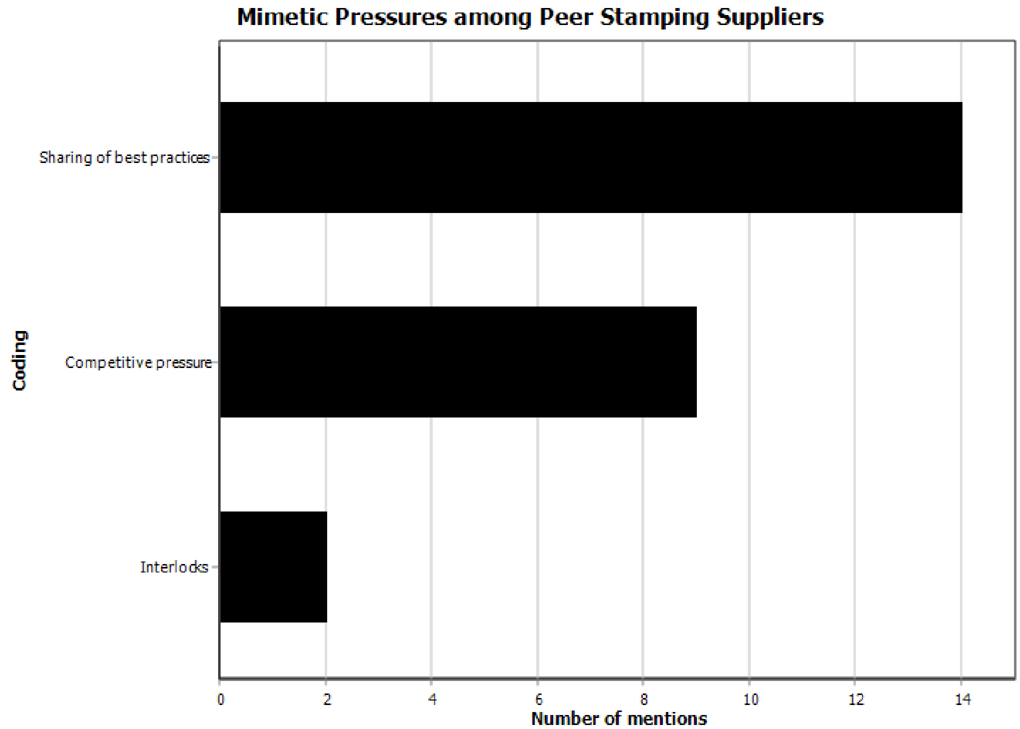



**Figure 2.5.** Coded mentions in interviews of mimetic pressures among peer stamping suppliers to adopt REALCAR.

There were mentions of cooperative relationships and sharing of best practices during the interviews, but primarily among the three internal stamping facilities of Jaguar Land Rover. There was one internal facility that was highly advanced and first implemented REALCAR, and this facility exchanged knowledge and information to implement the same systems and processes in the other two internal facilities. As an operations manager from the internal facility stated, "I went over and did the trials… we used the same conveyor company … it helped with commonality between the three of us." Later on, as the other two internal facilities became more advanced, systems and processes were shared with the first, facilitating cross-learning.

When asked about the sharing of best practices among external stamping suppliers, interviewees mentioned that during the early stages of the implementation, Jaguar Land Rover hosted seminars and workshops to introduce REALCAR. During these events, managers from the internal stamping facilities and some external stamping supplier facilities which implemented the REALCAR approach were asked to "stand up and explain it to [their peers] and show [their peers] the process," according to a manager from an external stamping facility. External stamping suppliers were also invited to visit the internal stamping facilities of Jaguar Land Rover to understand how REALCAR was implemented and apply those learnings. However, external stamping suppliers did not exchange knowledge or best practices among each other, since, as one interviewee from an external stamping supplier stated, “naturally, we can’t have our competitors walk around our facilities, showing them our intellectual property.”

As the implementation of REALCAR progressed, Jaguar Land Rover created a best-practice booklet based on the experiences of early adopters, which was updated as more and more stamping facilities implemented REALCAR. Consequently, as one manager described, “later [external stamping facilities] became easier because it was easier to tell them what to do.” Another manager from Jaguar Land Rover who was involved in the discussions with the external stamping suppliers mentioned that it also became easier to convince suppliers to adopt REALCAR, likely due to the accumulated best practices from previous adopters.

Mentions of the influence of competitive pressures between stamping suppliers on the adoption of REALCAR were mixed. A few interviewees suggested that competitive pressures played some role in the decision to adopt REALCAR by suppliers. According to an interviewee from Jaguar Land Rover, competitive pressures were likely “much more important at the beginning of the project as it was very innovative and a new thing.” One of the interviewees from an early adopter stated: “as a supplier partner, we always like to be at the forefront and lead not follow.”

Other interviewees mentioned that there was no evidence of explicit competitive relationships. One manager stated that though external stamping companies were competitors, adopting REALCAR “because they say that if they did it, they would have a competitive advantage, I’ve never seen that.” Interviewees described that the adoption of REALCAR was largely due to a fear of being cut out from the process by Jaguar Land Rover, suggesting a greater influence from Jaguar Land Rover rather than other competitors.

There were a few mentions during the interviews that engineers and suppliers talked to each other, hinting at the possibility of interlocking relationships. Interviewees mentioned that much of the REALCAR project was more bottom-up than top-down. This was confirmed through desk research on the 61 individuals reported in Table 2.1 to determine their roles at the time of REALCAR's implementation, from 2013 to 2017. The majority of individuals were managers, as shown in Figure 2.6.

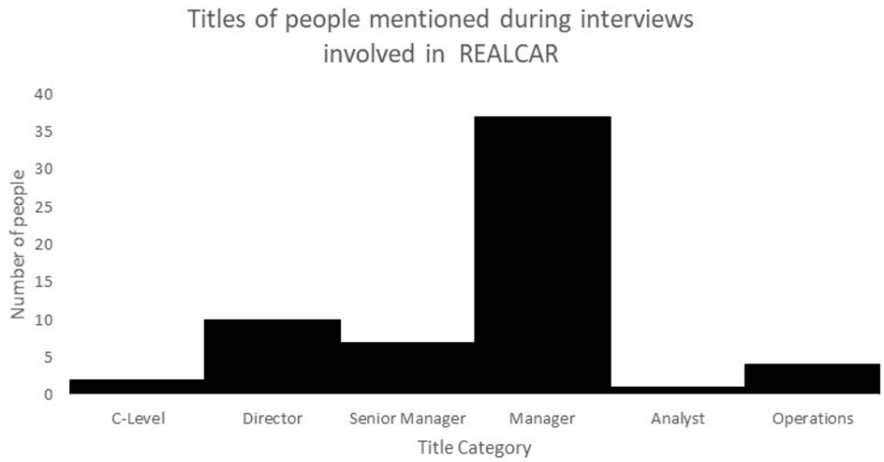



**Figure 2.6.** Roles of the 61 individuals identified in the research who were involved in REALCAR across the supply chain between 2013 and 2017.

Therefore, rather than identifying interlocking relationships at a board or executive level, which could indicate a flow of knowledge and information between firms, as with the analysis of Mizruchi (1996), potential interlocks at the manager level were explored. Desk research using the public LinkedIn profiles of the 61 individuals was conducted to understand whether there was any movement from one stamping supplier to another during the timeframe of REALCAR from 2013 to 2017. However, the majority of individuals worked in the same company during the timeframe of REALCAR, and there was only one case of a manager moving from one external stamping supplier to another. This suggested that the transfer of information due to interlocks at the employee level likely did not play a role in the adoption of REALCAR.

Based on the results from the interviews, there was no clear evidence that competitive pressures or interlocks among the stamping suppliers influenced the decision to adopt REALCAR. While there was evidence of sharing of best practices among the suppliers, this was mainly facilitated by Jaguar Land Rover. They tried to encourage learning and knowledge sharing in the supply chain network by inviting external stamping suppliers to their internal facilities and asking them to share their experiences with REALCAR at seminars and workshops. Through the best-practices document that was started by Jaguar

Land Rover and updated throughout the implementation, it became easier for later stamping facilities to learn from, and implement, the best practices of previous adopters.

### *2.4.3 Changing Structure and Nature of Scrap Dealer Relationships on the Adoption of REALCAR*

Of the various ties in the Jaguar Land Rover supply chain network, the relationships with the scrap dealers that handled the waste material were the most affected by the REALCAR project. The dynamics of these relationships between Jaguar Land Rover, the stamping facilities, and the scrap dealers placed various pressures on the adoption decisions of REALCAR. Figure 2.7 summarizes the coded mentions during the interviews regarding the changing structure and nature of scrap dealer relationships during REALCAR.

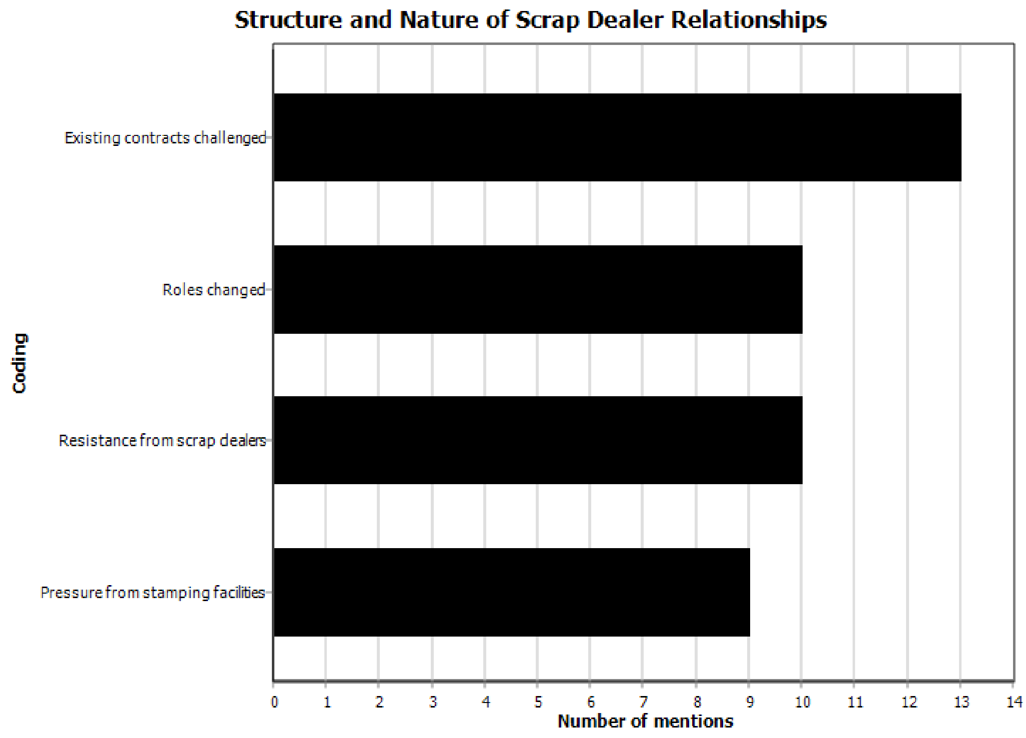



**Figure 2.7.** Coded mentions in the interviews regarding the changing structure and nature of the relationships with scrap dealers.

Many of the external stamping suppliers and scrap dealers had long-term relationships and existing contracts that were challenged by the new REALCAR approach. "Some of them had in the contract that the scrap belongs to them…so the materials and scrap generated was part of the service fee…this was a hurdle that we had to go step-by-step…to see how to change those contracts," as one interviewee stated. Jaguar Land Rover had to identify the scrap dealers contracted to their suppliers and have separate meetings with them to determine "how to take over the scrap stream," according to a manager at Jaguar Land Rover. According to another manager, some of these meetings became quite heated and "we were escorted out of the premises."

This was because the role of the scrap dealer changed in REALCAR's closed-loop model. As one interviewee mentioned, REALCAR altered the "ownership and power control between the people selling the aluminum sheet and the people selling or buying back the scrap." Figure 2.8 illustrates how the supply chain relationships differed under REALCAR, particularly for the scrap dealers.

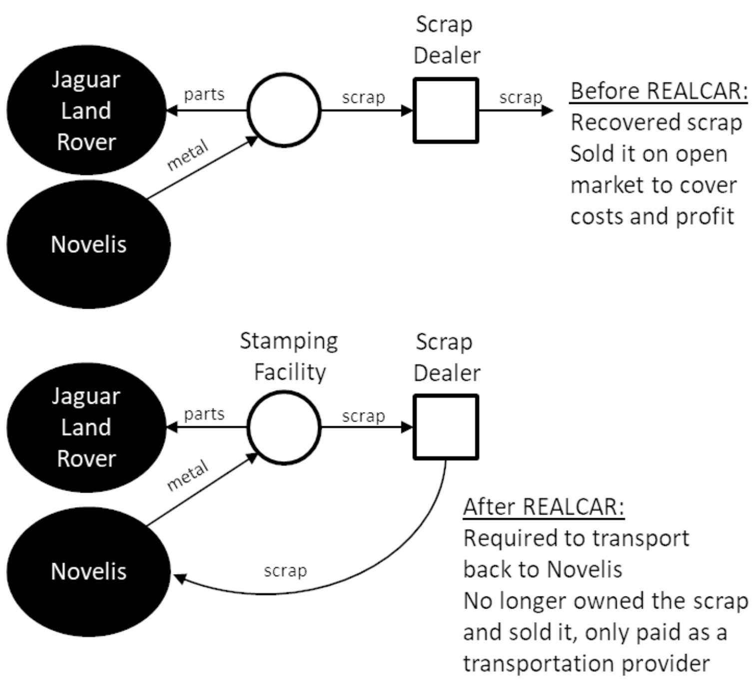



**Figure 2.8.** Diagram of the changing nature of the relationships and the role of scrap dealers in the supply chain under REALCAR.

Before REALCAR, scrap dealers made a business of providing equipment to stamping facilities to collect the scrap and then selling it on the open market to cover their costs and make a profit. Under REALCAR, they were asked to change their business model to get paid for the transportation of the aluminum waste, what they called "running wheels." As one interviewee described, "originally they would have maybe bought the metal for 900 a ton and sold it for 1000 and made a profit of 100, but now maybe they would get 14 a ton." Another interviewee said the scrap dealers, particularly the smaller ones, probably "don't know the true costs" of their operations and likely were not sure "if they are actually making money or not" with their new role in the closed-loop process.

Moreover, Jaguar Land Rover, Novelis, and the external stamping suppliers had different preferred scrap dealers they wanted to work with. According to one interviewee from Jaguar Land Rover, this created "frosty relationships" among certain scrap dealers and resulted in difficulties in negotiating the adoption of REALCAR. A few of the larger external stamping suppliers that had more leverage tried to make compromises and negotiate agreements with Jaguar Land Rover and Novelis to maintain relationships with their preferred scrap dealers.

A few scrap dealers understood the benefits of REALCAR quite quickly and, according to an interviewee involved in discussions, "realized that in the future the ultimate goal is recycling" and that "they could get introduced to new business this way as well." However, some of the smaller, more local scrap dealers tried to hinder the adoption of REALCAR by paying more for the scrap from the external stamping suppliers or committing to buying scrap months in advance. Thus, a few of the external stamping suppliers which had agreed to adopt REALCAR "started dragging their feet," according to this interviewee, and "became obstructive and delayed the process" for the adoption of REALCAR.

As a result, the relationships between Jaguar Land Rover, the external stamping suppliers, and the scrap dealers became strained due to REALCAR. Multiple interviewees mentioned that for the external stamping suppliers, the relationship with Jaguar Land Rover was more important than the relationship with the scrap dealers, and as one interviewee from Jaguar Land Rover stated, "it was a touchy subject." An interviewee from a scrap dealer mentioned that REALCAR "was always going to happen, and it made a lot of sense because it was a direction coming from Jaguar Land Rover…it was inevitable.”

Just as Jaguar Land Rover put pressure on external stamping suppliers to adopt REALCAR or lose the contract, external stamping suppliers put pressure on the scrap dealers. One interviewee from an external stamping supplier said they told their scrap dealer that “this was the way forward and they should embrace it otherwise they could lose the contract.” In some cases, stamping facilities had to change their scrap dealers to adopt REALCAR without any problems. Ultimately, scrap dealers relented to the adoption of REALCAR, since “they realized they needed to get on board or they would get nothing,” as one manager from an external stamping supplier stated.

From the interviews, it was clear that the structure and nature of the relationships with the scrap dealers in Jaguar Land Rover’s supply chain network were changed due to REALCAR. Scrap dealers had to alter their business model and role in the network, which caused them to push back and strain existing relationships with the external stamping suppliers and Jaguar Land Rover. External stamping suppliers placed more importance on the relationship with Jaguar Land Rover than their scrap dealers, so when they were pressed to adopt REALCAR, this cascaded to the scrap dealer as well.

### *2.4.4 Results of the MR-QAP Network Regression*

The changing structure and nature of the relationships of the scrap dealers was a particularly interesting outcome from the qualitative research. On the one hand, scrap dealers seemed to resist and tried to delay the adoption of the closed-loop approach, but on the other hand, they faced pressure from Jaguar Land Rover and the stamping suppliers to accept their role in the REALCAR model and keep their business. This was further explored through the MR-QAP network regression analysis to test how significant a role the relationships with scrap dealers played in influencing the adoption timeframes of REALCAR.

The results of the MR-QAP regression are shown in Table 2.3. The model’s R-squared is 0.35, and the adjusted R-squared is 0.32, suggesting that there are more variables that we have not measured which could be influencing the dependent variable (Borgatti et al., 2013). However, since 32% of the observed variation can be explained by the variables included and the P(r2) is highly significant, the results of the model are worth exploring to complement the qualitative analysis and gain a better understanding of the role of the scrap dealer relationships.

**Table 2.3.** MR-QAP network regression on the dependent variable, difference in time-to-adoption.

| Variable | Std. Coeff. | P-Value |
|---|---|---|
| **Independent Variables** | | |
| Common scrap dealer | −0.21 | 0.02** |
| Faced resistance from scrap dealer | −0.43 | 0.002*** |
| **Control Variables** | | |
| Difference in size of scrap generated | −0.12 | 0.08* |
| Difference in order of implementation | 0.19 | 0.04** |
| Faced significant capital investment | 0.08 | 0.13 |
| Faced significant process changes | −0.03 | 0.31 |
| Difference in logistics costs | 0.10 | 0.12 |
| Common company owning facility | −0.08 | 0.19 |

**Notes:** There were 210 observations. The analysis was done with 10,000 permutations. The R-Squared is 0.35, the adjusted R-squared is 0.32, and P(r2) is 0.001. *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively.

As the results show, scrap dealer resistance has the largest influence on time-to-adoption and is the most statistically significant variable, with a 99% confidence level. The high, negative standardized coefficient means that any two stamping facilities facing resistance from their scrap dealers had similar adoption timeframes to implement REALCAR, controlling for other factors. This provides additional quantitative evidence for what emerged during the qualitative interviews, suggesting that resistance from scrap dealers did play an important role in how long it took for the stamping facilities to adopt REALCAR.

In addition, the common scrap dealer variable was also significant at a 95% confidence level. It also had a high, negative standardized coefficient, suggesting that any two stamping facilities that shared a common scrap dealer were more likely to have similar time-to-adoption of the REALCAR closed-loop approach, controlling for other factors. Thus, in addition to explicit resistance from the scrap dealers, it seems that other aspects of the relationship with the scrap dealers and their reactions to REALCAR also played a role in influencing the adoption timeframes of the stamping facilities to implement the closed-loop approach.

Among the control variables, the difference in the order of implementation had a positive and statistically significant effect, with a 95% confidence level. The positive standardized coefficient showed that stamping facilities that are further apart in terms of the order of implementation were more dissimilar in terms of time-to-adoption, perhaps suggesting an effect of firm learning. Although the potential size of scrap had a negative relationship with time-to-adoption, it was only statistically significant at a 90% confidence level. The remaining control variables did not seem to have a statistically significant relationship with the difference in time-to-adoption between stamping facilities.

## 2.5 Discussion and Conclusions

The qualitative interviews and the network analysis of the REALCAR case study describe the importance of embedded relationships in the adoption of circular economy eco-innovations such as closed-loop recycling. Compared to traditional innovations, the novel processes and investments required for the REALCAR eco-innovation, the uncertainty of the economic benefits for Jaguar Land Rover's suppliers, and the changing nature of the relationships within the supply chain meant that there were differences in incentives and motivations for the adoption of REALCAR among Jaguar Land Rover and their suppliers. As a result, the coercive pressures by Jaguar Land Rover to encourage suppliers to adopt REALCAR, their facilitation of the exchange of best practices, and the resistance from scrap dealers to their new role played a significant role in influencing the timeframes for the adoption of REALCAR.

For Jaguar Land Rover, the decision to implement the REALCAR eco-innovation had clear financial and environmental benefits. Using recycled aluminum from the closed-loop process enabled them to achieve their goals of creating more lightweight and fuel-efficient vehicles, reducing environmental emissions, and lowering production costs (Cassell et al., 2016). However, as described in the literature (Cainelli et al., 2011; Del Río González, 2005), novel eco-innovations like REALCAR, which affect the whole supply chain, required the intense cooperation of Jaguar Land Rover's suppliers.

Therefore, it was in Jaguar Land Rover's interest to convince as many of their suppliers as quickly as possible to adopt the closed-loop approach to fully realize its benefits.

The suppliers of Jaguar Land Rover, on the other hand, did not have the same motivations. While some of the stamping facilities understood the environmental benefits, the majority had low financial and environmental drivers to adopt REALCAR, as it was not a part of their core business. To overcome this, the nature of the relationships between Jaguar Land Rover and its suppliers was especially important. The research by Williamson (2006) shows that SMEs will not voluntarily adopt eco-innovations unless it satisfies criteria for business performance such as satisfying their customers' needs, because many companies do not perceive a clear benefit in being environmentally responsible (Sáez-Martínez et al., 2016). Furthermore, a study on automotive suppliers describes how customer requirements are one of the major factors in their participation in green initiatives, as well as, to a certain extent, cooperative supplier relationships and investments from their customers (Caniëls et al., 2013). As such, Jaguar Land Rover's pressure as a customer, their creation of supplier requirements, and their provision of financial incentives were all needed to offset the costs of capital investments and process changes to incentivize their suppliers to adopt REALCAR.

Moreover, while traditional innovation and eco-innovation literature describes competitive pressures to adopt innovation and the use of networks to learn from, and imitate, the best practices of peers and competitors (Bossle et al., 2016; Del Río González, 2005; Hojnik and Ruzzier, 2016; Ozman, 2009; Robertson et al., 1996; Simsek et al., 2003), there was no clear evidence of this happening in the case of REALCAR. Rather than any competitive pressures, the motivation of suppliers to adopt was primarily the fear of being cut out of the relationship with Jaguar Land Rover. External stamping facilities had no interest in exchanging best practices, relying instead on learning from Jaguar Land Rover's internal stamping facilities and utilizing their best practices document. This is likely also due to the low financial and environmental motivations for the majority of the stamping facilities to adopt the REALCAR eco-innovation. Jaguar Land Rover had to leverage their position and relationship as customers and act as a hub firm (Dhanaraj and Parkhe, 2006) to orchestrate the exchange of knowledge among internal and external stamping facilities.

Lastly, scrap dealers were the most affected by the REALCAR closed-loop approach. The new process changed the structure and nature of the relationships in Jaguar Land Rover's supply chain and altered the scrap dealers' role and their business model. While a few of the scrap dealers recognized this shift and accepted REALCAR, many scrap dealers were against it and even tried to hinder the adoption of the closed-loop approach by trying to entice stamping facilities with better terms. The results of the network regression showed that this resistance from the scrap dealers had a significant effect on the adoption timeframes of the stamping facilities, controlling for other factors. In the end, it took heated discussions as well as coercive pressures from Jaguar Land Rover and the stamping facilities before the scrap dealers had to either accept their new role or lose their contracts.

The results from this case study show how the embedded relationships and ties between firms in supply chain networks that influence innovation adoption are likely to play an even stronger role in eco-innovation adoption. Circular economy eco-innovations like closed-loop recycling require the cooperation and alignment of the economic and environmental goals of the entire supply chain (Winkler, 2011), particularly the close partnership and collaboration of suppliers (Chiou et al., 2011; Thorlakson et al., 2018) and their customers (Burki et al., 2019). However, the goals of the various stakeholders may not be aligned, as was the case with REALCAR. While there were a few suppliers that understood the financial and environmental benefits of REALCAR, many did not have these motivations to adopt and largely complied to keep their business, and some even acted to hinder the adoption. In this case, companies like Jaguar Land Rover that wish to push the adoption of an eco-innovation across their supply chain need to take into account the embedded relationships and the structure and nature of their supplier networks. By understanding their position and the strength of their relationships within their supply chain network and the changing dynamics of inter-firm network relationships, companies can exploit favorable conditions, improve conducive factors, or remove obstacles to accelerate the adoption of circular economy eco-innovations.

Although this paper's exploration of the single case study of REALCAR cannot be generalized to all eco-innovations, nor was that the intent of this research, it does provide an example of a particular circular economy eco-innovation, i.e., closed-loop recycling. Further research is warranted to determine whether such embedded relationships in inter-firm networks play a role in other types of circular economy eco-innovations. As in the case of REALCAR, coercive pressures from power dynamics in customer relationships, mimetic pressures from peer learning, and the changing structure and nature of relations with suppliers in inter-firm networks could influence the adoption and time-to-adoption of eco-innovations in other cases. Perhaps additional structural and relational embedded relationships reported in the literature, such as hierarchical relations of authority and power, competitive or cooperative relationships, interpersonal ties and interlocking directorates, or joint membership in associations (Borgatti and Li, 2009; Casanueva and González, 2004; Grandori and Soda, 1995; Ozman, 2009) could impose various multiplex pressures (Boons and Howard-Grenville, 2009; DiMaggio and Powell, 1983) on circular economy eco-innovation adoption.

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# Chapter 3 – Diffusion of Eco-Innovation through Inter-firm Network Targeting: An Agent-Based Model[2]

## Abstract

To address increasingly urgent global environmental challenges, there is a need for rapid and widespread adoption of eco-innovations. Previous research has shown that targeting key initial adopters using network-based strategies is an effective way to increase the adoption and diffusion of innovations; however, these models have not specifically been applied to the diffusion of eco-innovations through inter-firm networks. Therefore, this paper develops an agent-based model that tests various network-based targeting strategies on generated inter-firm networks with different parameters to understand mechanisms that could boost and accelerate the adoption and diffusion of eco-innovations. The results show that targeting firms with high degree or high influence could more quickly diffuse incremental eco-innovations, while targeting neighbors of adopters is a better strategy for more radical eco-innovations with greater barriers to adoption. This has implications for policymakers, companies, and startups who wish to accelerate eco-innovation adoption and diffusion to create positive societal impacts.

## 3.1 Introduction

Radical and disruptive transitions in our current socio-technical systems are necessary to address the growing urgency of environmental challenges. Large and rapid transformational changes within a short timeframe are required in the institutions, networks, and behaviors of organizations within existing sectors and value chains to make them more environmentally sustainable (de Jesus et al., 2019; Kivimaa et al., 2021; Loorbach et al., 2020). Facilitating the shift towards more environmentally sustainable value chains requires firms to adopt and diffuse eco-innovations, developing new

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products, processes, or organizational changes that reduce negative environmental impacts (de Jesus and Mendonça, 2018; Loorbach et al., 2020, Silvestre and Ţîrcă, 2019).

Through the adoption of disruptive eco-innovations, companies can play a key role in mitigating the negative environmental impacts of their activities, as well as guide consumption through the supply of environmentally friendly products and services (Bossle et al., 2016; Kivimaa et al., 2021). However, two-thirds of eco-innovations are in small market niches, and only one third have scaled to affect change in society, highlighting that there is not a lack of eco-innovations but the need to diffuse these innovations more quickly (Clausen and Fichter, 2019; Fichter and Clausen, 2021). Understanding how to scale such eco-innovations more effectively is essential to create the momentum to transform existing systems (Loorbach et al., 2020).

Many barriers hinder the adoption of eco-innovation in the value chain. These barriers are particularly pronounced for eco-innovations due to the double-externality problem (Rennings, 2000). In addition to knowledge externalities that enable competitors to learn from implementation challenges, the adoption of eco-innovations also creates positive environmental externalities at a cost to the firm, which puts the firms at a disadvantage compared to their polluting competitors (Cainelli et al., 2015; Hojnik and Ruzzier, 2016). As a result, firms could either postpone or disregard the adoption of eco-innovations, thus making it more difficult for these innovations to scale and realize their positive societal impacts.

Research on eco-innovation adoption and diffusion has identified a variety of internal and external factors that motivate firms to adopt eco-innovations. Among these drivers, studies have shown that inter-firm networks and relationships influence the decision criteria for eco-innovation adoption (Pellegrini et al., 2019; Triguero et al., 2016), but these factors are often less studied (Karakaya et al., 2014). Networks and relationships form an integral part of theories and models of innovation diffusion, particularly agent-based simulation models that are better suited to study the influence of networks and relationships on the adoption and diffusion process (Kiesling et al., 2012; Rogers, 1983; Zhang and Vorobeychik, 2019). Research has also shown that the structure and position of key players (Banerjee et al., 2013; Borgatti, 2006; Mbaru and Barnes, 2017) can affect the rate of adoption and diffusion of innovation (Barbuto et al., 2019; Beaman et al., 2018; Nöldeke et al., 2020; van Eck et al., 2011).

However, existing research on the diffusion of eco-innovations do not focus on the effect of targeting key players on the adoption and diffusion process, and few studies that explore the targeting of key players on innovation adoption and diffusion focus on eco-innovations. Therefore, we aim to explore whether eco-innovations can be more effectively diffused through inter-firm networks by utilizing existing models of innovation diffusion which target key early adopters. Our paper aims to contribute to the existing literature on eco-innovations by establishing a modelling framework that combines research on the drivers of eco-innovation adoption and models of innovation diffusion focused on key initial adopters, opening the way for further research in this area.

This study develops a theoretical agent-based model (Squazzoni, 2012) that explores how various network-based targeting strategies affect eco-innovation adoption and diffusion, varying important model parameters to reflect greater disincentives for the adoption of eco-innovations. The results of our model provide additional insights into the mechanisms for effective diffusion of eco-innovations given their higher thresholds for adoption and diffusion. Instead of targeting firms with a high degree centrality or firms with high influence (Barbuto et al., 2019; Beaman et al., 2018; Nöldeke et al., 2020; van Eck et al., 2011), our model shows that it is better to focus on neighbors of adopters to yield higher rates of adoption of eco-innovations.

The paper is structured as follows. Section 2 presents a review of the literature on eco-innovation adoption, inter-firm networks, innovation diffusion, and agent-based diffusion models. Bringing together these various streams of literature were key to provide solid theoretical foundations to our model and develop the research questions. Section 3 presents a description of the model developed in this paper - its assumptions and dynamics and the setup of the simulations. Section 4 reports the results of the simulations and an analysis of the outcomes. Finally, Section 5 presents a discussion of the results, suggestions for future research, and Section 6 concludes with the implications of the research.

## 3.2 Literature Review

### *3.2.1 Drivers of Eco-innovation*

There is no common definition for eco-innovation, but the literature describes the concept of eco-innovations as innovations that result in the reduction of negative environmental impacts. Such innovations develop new or improved products that are made of environmentally friendly materials or designs, processes that reduce resource use and pollution, organizational and management changes that minimize environmental damages, or marketing solutions that promote pro-environmental behaviors (Bossle et al., 2016; Cai and Zhou, 2014; García-Granero et al., 2020; Hasler et al., 2016; Hellström, 2007; Hojnik and Ruzzier, 2016; Karakaya et al., 2014; Kemp and Pearson, 2007; Pereira and Vence, 2012; Rennings, 2000). For this paper, we consider the definition of eco-innovation to be the development and implementation of a product, process, or business method that is novel to the firm, and which results in a reduction of environmental risk, pollution, and the negative impacts of resource use throughout its lifecycle compared to relevant alternatives (Kemp and Pearson, 2007).

This definition of eco-innovations is focused on outcomes and can include a wide range of innovations that make incremental changes to existing products or make more radical changes to systems of production (Kemp and Pearson, 2007, Hellström, 2007). Incremental eco-innovations focus on increasing the eco-efficiency of existing products and processes, for example: environmental management schemes to monitor issues of material use, energy, water, and waste; recycling and reuse of internal production waste to create existing products or new byproducts; monitoring application of fertilizers in agriculture, etc. More radical innovations that create new environmentally friendly products and processes or restructure existing value chains, for example: new method for water purification which replaces chemical purification; renewable energy generation using solar and wind technologies; robotic weeding systems that eliminate the need for fertilizers, etc. (Kemp and Pearson, 2007, Hellström, 2007).

The adoption of eco-innovations is considered a transitional pathway to reducing environmental impacts and creating a more sustainable society (de Jesus and Mendonça, 2018). Eco-innovations play a key role in creating incremental and radical system changes and technological paradigms that can contribute to meeting the sustainability targets of society (Rennings, 2000). More widespread adoption and diffusion of eco-innovations among firms can play a key role in minimizing their environmental impact, as well as introducing products, services, and practices that can guide more environmentally sustainable consumption (Bossle et al., 2016).

Eco-innovations face certain barriers that hinder their adoption and more widespread diffusion. Research on eco-innovations has shown that they face a “double-externality” problem, creating both knowledge and environmental externalities that create a disincentive for adoption (Rennings, 2000). On one hand, like other innovations, firms that invest time and resources to adopt eco-innovations create knowledge externalities that allow their competitors learn about implementation challenges and make it easier for them to adopt. On the other hand, unlike other innovations, firms that adopt eco-innovations create positive environmental externalities that create long-term societal benefits at the cost of the company, putting them at a disadvantage compared to their polluting competitors (Hojnik and Ruzzier, 2016; Jaffe et al., 2005; Rennings, 2000).

Different eco-innovations face the double-externality problem in varying degrees. Incremental eco-innovations that substitute hazardous substances, design more eco-efficient products, and implement processes to save energy, waste and material or reduce emissions, can generate positive environmental benefits at minimal costs to the firm (Rennings, 2000). However, more radical eco-innovations such as renewable energy generation technologies, robotic weeding, etc. require greater changes and investments in economic, social, and production systems over longer timeframes in order to be adopted and diffused (Rennings, 2000; Hellström, 2007). The higher costs compared to existing alternatives and greater externalities and exploitation from possible competitors associated with radical eco-innovations result in lower incentives and pressures for their adoption (Hasler et al., 2016).

As a result, to overcome the double-externality problem and encourage the adoption of eco-innovations, particularly more radical eco-innovations, literature on the drivers of eco-innovation highlights how the adoption decision of firms for incremental and radical eco-innovations is determined by internal firm factors and external factors, as summarized in Table 3.1 below.

**Table 3.1.** Internal and external drivers of eco-innovation adoption.

| | Factors | Source |
|---|---|---|
| **Internal Factors** | Firm size<br>Business benefits<br>Technical capability<br>Environmental leadership and culture | Cainelli et al., 2015; Cai and Zhou, 2014; Bossle et al., 2016; Hojnik and Ruzzier, 2016; Del Río González, 2005; Galliano and Nadel, 2015; Triguero et al., 2016; Díaz-García et al., 2015; Pereira and Vence, 2012 |
| **External Factors** | Regulation<br>Market demand<br>Technology<br>Inter-firm relationships and networks | |

Among the external factors that influence the adoption of eco-innovations, some studies have identified the importance of relationships and inter-firm networks to counteract the disincentives to adopt eco-innovations. Firms influence each other's decision criteria for eco-innovation adoption (Pellegrini et al., 2019), as suppliers, customers, and business partners encourage and compel firms to adopt pro-environmental behavior in order to maintain their business relationships (Cainelli et al., 2011; Sáez-Martínez et al., 2016; Triguero et al., 2016). Firms must cooperate with other stakeholders with whom they have strong relationships to share knowledge, gain financial resources, and mitigate the risks and costs of adopting eco-innovations (Cainelli et al., 2015; Del Río González, 2005; Díaz-García et al., 2015; Mazzanti and Zoboli, 2008; Pellegrini et al., 2019; Pyka, 2002). The structure and nature of the network of relationships and connections to other stakeholders within a firm's network can also play a significant role in eco-innovation adoption and diffusion (Bayne et al., 2012; Chen et al., 2019; Del Río González, 2005; Loorbach et al., 2020; Laurenti et al., 2018). Studies that attempt to model the importance of networks and relationships on the widespread adoption and diffusion of eco-innovations utilize existing models of innovation diffusion due to their ability to better analyze the role of external social influence (Kiesling et al., 2012).

### *3.2.2 Models of Innovation Diffusion*

The role of networks and relationships has been widely explored in theories and models of innovation diffusion (Rogers, 1983). In macro-level diffusion models, the propensity for the adoption of innovations depends on whether other connected firms in the network have adopted (Mansfield, 1961), theorizing that external bandwagon pressures will nudge firms to adopt (Abrahamson and Rosenkopf, 1997). Complex contagion models (Centola and Macy, 2007; Lengyel et al., 2020; Watts, 2002) take this a step further to propose that the diffusion of innovations is dependent on an absolute or fractional threshold of exposure to multiple connected firms that have adopted before firms are compelled to adopt themselves.

Additional innovation research has developed agent-based simulation models that incorporate these decision-making factors to understand how innovations spread and diffuse. Agent-based modelling is a computerized simulation modelling technique that focuses on the interactions of a collection of agents to examine collective outcomes. These agents represent actors in a real-world system and utilize a set of rules and attributes to make individual decisions based on personal preferences, signals from other agents, the local environment, etc. (Salgado and Gilbert, 2013). Compared to the macro-diffusion models that use differential equations, agent-based models are better suited to study the influence of firm-level adoption drivers and the complex social network of relationships among agents on the adoption and diffusion process. Agent-based models also allow for stochasticity by utilizing multiple simulation runs to get a distribution of outcomes and test varying values of model parameters that are more difficult to analyze with macro-diffusion models (Kiesling et al., 2012; Zhang and Vorobeychik, 2019).

Agent-based eco-innovation diffusion models have explored the drivers of eco-innovation adoption highlighted in Table 3.1, where agents adopt innovations based on internal factors such as benefits and capability, as well as various external factors related to the relationships and networks between agents (Kiesling et al., 2012; Zhang and Vorobeychik, 2019). The decision to adopt an innovation incorporates network and relationship factors based on the share of connected agents and actors that adopt the innovation within the agent's network or the system (Pegoretti et al., 2012). A summary of agent-based models studying the effect of networks and relationships on the adoption and diffusion of eco-innovations is provided in Table 3.2.

The rate of adoption and diffusion can also depend on the structure of the network and the position of the initial adopters. Research has identified that there are key players with certain network positions and centrality measures who can serve as critical injection points (Ballester et al., 2006; Banerjee et al., 2013; Borgatti, 2006) to more effectively diffuse information through networks. Identifying these key players and developing strategies to target them could influence the spread of information and the adoption of innovations (Mbaru and Barnes, 2017). Recent studies using agent-based innovation diffusion models have utilized the concept of key players and injection points to understand their influence on the diffusion process, highlighted in Table 3.2.

However, as Table 3.2 shows, agent-based models that study the effect of relationships and networks on the diffusion of eco-innovations do not focus on inter-firm networks and/or do not consider the effect of targeting key players on the adoption and diffusion process. While agent-based models that explore the targeting of key players on innovation adoption rarely focus on eco-innovations or on inter-firm networks. There exists little research on the effect of targeting initial adopters by focusing on the structure of inter-firm networks and relationships and the network positions of the firms on the adoption and diffusion of eco-innovations. Unlike the networks and relationships between individuals and households, inter-firm networks and relationships are modes of organizing and coordinating economic activities, and thus the structure and nature of these networks is different (Grandori and Soda, 1995).

**Table 3.2.** Agent-based models of eco-innovation diffusion and targeting key players.

| **Model type** | **Existing research & gaps** |
|---|---|
| Agent-based models of the effect of networks and relationships on eco-innovation adoption and diffusion | Günther et al. (2011) model the diffusion of a novel biomass fuel on consumers, not firms, through mass marketing, not targeting of key players.<br>Tran (2012) explores network influence on energy innovation diffusion among individuals, not firms, and does not consider targeting key players.<br>McCoy and Lyons (2014) explore network influence on electric vehicle adoption among Irish households, not firms, and do not consider key players.<br>Robinson and Rai (2015) briefly mention the impact of specific central nodes on solar adoption among households, but do not study firm networks.<br>Zheng and Jia (2017) explore the adoption of industrial symbiosis among firms through promoter firms, but do not focus on targeting key players. |

| | |
|---|---|
| | Ernst and Briegel (2017) study the diffusion of green electricity among consumers, not firms, through mass messaging, not targeting of key players.<br>Kandiah et al. (2019) model the adoption of water reuse through interactions of social clusters of households, not firms, and do not consider key players. |
| Agent-based models focused on targeting key players | van Eck et al. (2011) study how opinion leaders influence the diffusion of innovations among individuals, not firms, and do not study eco-innovations.<br>Beaman et al. (2018) find that targeting farmers with high centrality affects the diffusion of pit planting, but do not focus on firms or eco-innovations.<br>Barbuto et al. (2019) focus on how targeting farmers on network measures affects diffusion of sustainable mulching, but do not focus on firm networks.<br>Nöldeke et al. (2020) model how targeting select farming households diffuses agricultural information, but do not focus on firms or eco-innovations. |

Therefore, by combining the above streams of research on the drivers of eco-innovation adoption and agent-based models of innovation diffusion focused on key initial adopters, this paper aims to contribute to eco-innovation literature by better understanding how network-based targeting strategies can affect the diffusion of an eco-innovation through inter-firm networks and help overcome the double-externality problem. Against this backdrop, we develop an agent-based simulation model to investigate the following research questions:

1. How does the choice of network-based strategies to target initial adopters influence the diffusion of an eco-innovation?
2. How well do different network-based targeting strategies perform under different thresholds for adoption and diffusion, and different parameters of the inter-firm network?

## 3.3 Model Description

The simulation model described below is programmed in Netlogo 6.1.1 (Wilensky, U., 1999) and features a set of agents, representing firms that are potential adopters of an eco-innovation, embedded in a network of collaborative relationships. The model is developed as an "abstract" agent-based model (Squazzoni, 2012) to study the general phenomena of network-based targeting strategies on eco-innovation adoption and diffusion through inter-firm networks. We chose this method, as it allows us to perform multiple simulations to better compare the influence of different network-based targeting strategies on the adoption and diffusion of eco-innovations, while accounting for the firm-level adoption drivers and the characteristics of inter-firm relationships and networks. Therefore, the model focuses on a limited set of factors and aspects, excluding other external factors affecting a firm's decision to adopt eco-innovations, such as regulations, market demand, and technological development (Bossle et al., 2016; Díaz-García et al., 2015; Hojnik and Ruzzier, 2016).

During the initialization of the model, firms are populated based on a specified number of firms in the network. Each firm is assigned an Environmental Orientation [EO] factor that represents the firm's internal factors for adopting the eco-innovation described in the literature, such as business benefits, technological and environmental capacity, ownership structure, environmental culture, and leadership (Bossle et al., 2016; Díaz-García et al., 2015; Hojnik and Ruzzier, 2016; Triguero et al., 2016). The firm's EO is static throughout the model and is a floating-point number from 0 to 1 drawn from a random normal distribution with a mean of 0.5 and a standard deviation of 0.1. Though this distribution is theoretically generated in the model, it is based on empirical data on the environmental scores of companies globally to act as a proxy for the firm's internal factors for eco-innovation adoption (Ecovadis, 2020).

Finally, the initialization creates undirected links between the firm agents forming an inter-firm network. The links between firms are assumed to be partnerships, collaborative alliances, and the exchange of knowledge and information (Grandori and Soda, 1995; Ozman, 2009), which are generated based on specific network structures shown in Figure 3.1. The links between the firms are assigned a non-zero weight [weight] from 0 to 1, drawn from a random uniform distribution, to reflect the strength of the relationship between the firms (Delre et al., 2010; Jensen et al., 2015; Zheng and Jia, 2017). For model simplicity, we assume that the links and their weights are static and do not change throughout the model run.

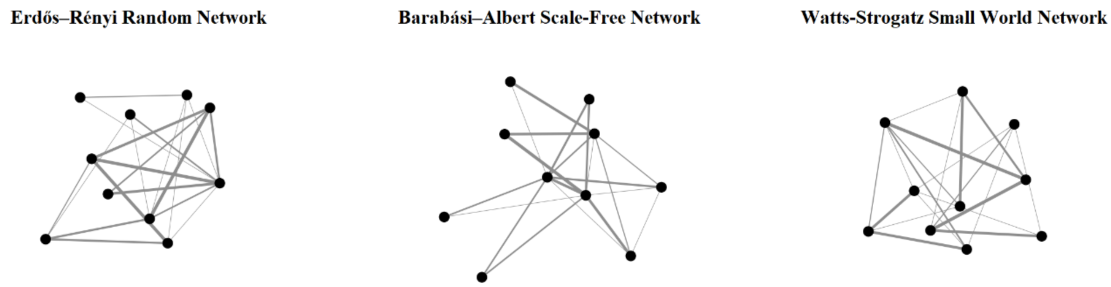


**Figure 3.1.** Network Structures. The model generates inter-firm networks using the Erdős–Rényi Random Network, Barabási–Albert Scale-Free Network, and Watts-Strogatz Small World Network models, illustrated here with 10 firms.

The network structures represent the spectrum of network models that capture inter-firm relationships in supply chains and have been analyzed in previous innovation diffusion models studying the influence of networks (McCullen et al., 2013; Yu et al., 2020). The Erdős–Rényi Random Network (Erdős and Rényi, 1960) generates links between firms using a random algorithm and is generally used as a benchmark. The Barabási–Albert Scale-Free Network (Barabási and Albert, 1999) generates links between firms with a power-law degree distribution, with a large number of links among a few firms as hubs. Empirical studies have shown that the Barabási–Albert Scale-Free Network represents the network structure and topology of many real-world supply chain networks and inter-firm networks, such as the automotive industry, food supply chains, pharmaceutical industry, and electronics supply chain (Perera et al., 2017, Okamura and Vonortas, 2006). Lastly, the Watts-Strogatz Small World Network (Watts and Strogatz, 1998) generates links between groups of firms with a more even degree distribution to model communities and group interaction among firms. Studies on the diffusion of knowledge and innovation among firms in different industries using data on strategic inter-firm alliances has shown that alliance and knowledge networks display characteristics similar to the Watts-Strogatz Small World Network model across a variety of industries from aerospace and automotive, chemicals and pharmaceuticals, and technology (Schilling and Phelps, 2007).

After the initialization of the model, the simulation follows a two-phase information and adoption process (Abrahamson and Rosenkopf, 1997), over 100 time steps. A key assumption in our model is that firms adopt the eco-innovation only if certain conditions are met. First, in the information phase, firms need information about the existence of the eco-innovation, which occurs through network-based targeting or if contact with their connected neighbors who have adopted [PP] exceeds a certain globally defined information threshold [IT] (Centola and Macy, 2007; Lengyel et al., 2020; Watts, 2002). Second, when deciding to adopt the eco-innovation, the firms' internal decision-making heuristics, which covers internal firm factors [EO], as well as peer pressure from connected neighbor firms who have already adopted [PP], must exceed a certain globally defined adoption threshold [AT]. This follows the literature on innovation diffusion, where the concept of adoption thresholds represents the utility of adopting the innovation, and firms only decide to adopt if their individual utility based on their internal factors and social influence from neighbors exceeds the value of the threshold (Delre et al., 2010; Kiesling et al., 2012; van Eck et al., 2011; Zhang and Vorobeychik, 2019). Thus, under low threshold values, firms are more likely to have a positive utility from adopting the innovation, while under high threshold values, firms are less likely to have a positive utility from adopting the innovation. The phases are illustrated in Figure 3.2 and elaborated in the following sub-sections.

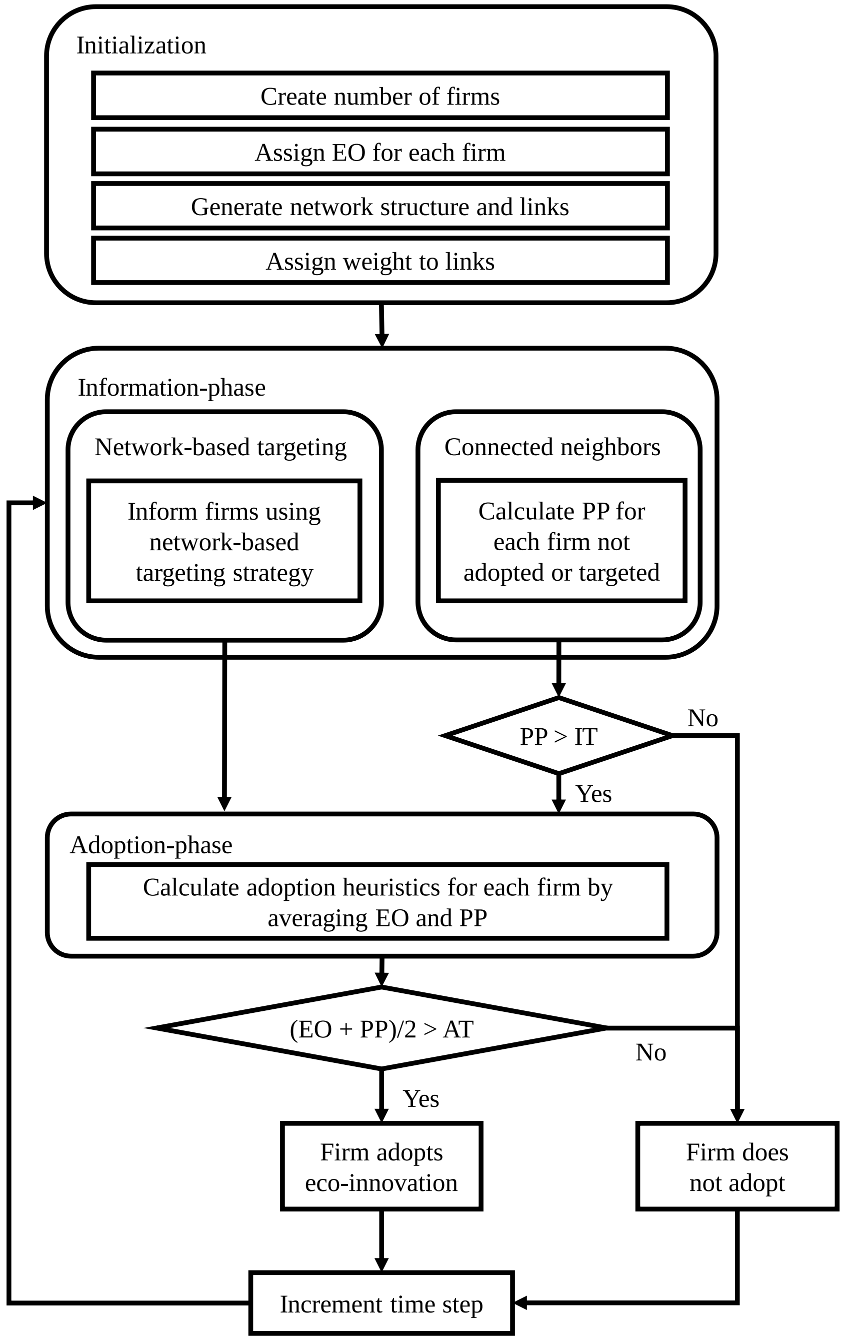


**Figure 3.2.** Model flowchart. The model is first initialized and then follows a two-phase information and adoption process.

### *3.3.1 Information-Phase: Network-Based Targeting*

We assume that firms have no prior knowledge of the eco-innovation and are informed by an agent outside the network using a selected network-based targeting strategy. The model specifies a set of six targeting strategies adapted from existing literature (Beaman et al., 2018; Leone and Christodoulopoulou, 2015; Nöldeke et al., 2020; van Eck et al., 2011), shown in Table 3.3. The Random strategy selects firms at random and is meant to act as a benchmark. The first set of network-based strategies target firms based on various network measures: High Degree targets non-adopter firms with the highest number of connections [degree] and High Influence targets non-adopter firms which have the highest average weight of links [influence]. The second set of network-based strategies target neighbors of adopter firms, which may be relevant when information about the inter-firm network is scarce. Random Neighbor targets neighbors of adopters at random, Degree Neighbor targets neighbors of adopters with the highest number of connections [degree], and Influence Neighbor targets neighbors of adopters with the highest average weight of links [influence]. We tested additional network-based strategies, such as High Betweenness and Betweenness Neighbor which utilized betweenness centrality, but we excluded them from the analysis for the sake of readability as they did not provide interesting results.

**Table 3.3.** Network-based targeting strategies. We specify a series of strategies to target firms based on network measures.

| **Strategy** | **Description** |
|---|---|
| Random | Non-adopter firms targeted based on random selection, benchmark strategy |
| High Degree | Non-adopter firms with the highest *degree* network measure are targeted |
| High Influence | Non-adopter firms with the highest *influence* network measure are targeted |
| Random Neighbor | Non-adopter firms are randomly targeted until there is a first adopter, then neighbors of adopters are randomly selected |
| Degree Neighbor | Firms are randomly targeted until there is a first adopter, then neighbors of adopters with the highest *degree* network measure are targeted |
| Influence Neighbor | Firms are randomly targeted until there is a first adopter, then neighbors of adopters with the highest *influence* network measure are targeted |

The targeting strategies follow a continuous active seeding approach (Sela et al., 2018). Instead of targeting an initial subset of the inter-firm network and allowing the eco-innovation to diffuse without any other intervention, firms are targeted at every time step. Targeted firms are informed about the eco-innovation, after which they decide whether they want to adopt the eco-innovation. Firms that have not adopted are only targeted once.

### *3.3.2 Information-Phase: Connected Neighbors*

The diffusion of information about the eco-innovation in the model follows existing research on fractional threshold complex contagion models (Centola and Macy, 2007; Lengyel et al., 2020; Watts, 2002). According to complex contagions, for firms to be informed and triggered to adopt, they require multiple sources of exposure to connected neighbors who have already adopted. In addition, fractional thresholds allow both adopting and non-adopting neighbors to exert influence, such that a certain number of adopters relative to non-adopters is needed to trigger adoption (Centola and Macy, 2007).

At every time step, each firm that has not adopted the eco-innovation and not targeted by the network-based targeting strategy will be exposed to connected neighbor firms that have adopted. We use the approach taken in previous models of innovation diffusion (Delre et al., 2010; van Eck et al., 2011), where the pressure from peers that have adopted [PP] is calculated for each firm i as the link-weighted percent of connected neighbor firms who have adopted by time step t, as shown in Eq. 1. If $PP_{i,t}$ exceeds a globally specified information threshold [IT], then the firms will be informed about the eco-innovation.

(Eq. 1) $$PP_{i,t} = \frac{\sum weight_{adopting\ neighbors\ at\ time\ t}}{\sum weight_{all\ neighbors}}$$

### *3.3.3 Adoption-Phase*

Once informed, the firms decide to adopt the eco-innovation based on their internal factors, EO, their external pressures from peers that have adopted, PP, and the adoption threshold, AT. In existing agent-based models of innovation adoption and diffusion, the adoption heuristics of the firm is determined by a weighted average of their internal factors and external social influence from neighbors (Delre et al., 2010). For simplicity, we adopted this approach but specified a weight of 0.5, taking an average of EO and PP. Thus, for each firm i at time step t, if the average of the firm’s environmental orientation $EO_i$ and the firm’s pressure from peers $PP_{i,t}$ exceeds the globally defined adoption threshold [AT], then it will adopt the eco-innovation, as shown in Eq. 2 below.

(Eq. 2) $$adopt_{i,t} = \begin{cases} true, \ if \ \frac{EO_i + PP_{i,t}}{2} > AT \\ false, \ otherwise \end{cases}$$

It is possible for a firm to not adopt initially because it does not meet the adoption threshold but adopt later in the simulation when more of the firm's neighbors have adopted. Once a firm adopts, it cannot undo its decision to adopt, and it remains an adopter until the end of the simulation. For more information and details about the model, the model code has been uploaded on the CoMSES model library and can be accessed there ("CoMSES Computational Model Library," 2021).

## 3.4 Results

To answer the research questions, we run various simulations to test how the network-based targeting strategies described in Section 3.1 affect the number of firms adopting the eco-innovation under specific model parameters, described in Table 3.4. We focus the analysis on how the six strategies perform across the three network structures specified in Figure 3.1 under different values for the global information threshold and global adoption threshold since this influences the initial number of adopters and the ease of information flow through the network, allowing us to test more stringent thresholds for adoption of eco-innovations that better reflects the double-externality problem and greater disincentives for adoption. For ease of comparability and analysis, we specify 100 firms within a single connected network component of firms with an average network degree of 6 undirected links per firm, based on previous empirical research on collaboration and alliance networks among firms within different industries (Okamura and Vonortas, 2006; Schilling and Phelps, 2007).

**Table 3.4.** Simulation Model Parameters. The following model parameters are tested to analyze the number of adopters when following different network-based targeting strategies.

| **Model Parameter** | **Description** |
|---|---|
| Network Structures | Erdős–Rényi Random<br>Barabási–Albert Scale-Free<br>Watts-Strogatz Small World |
| Global Information Threshold | 0.4 – 0.6 |
| Global Adoption Threshold | 0.25 – 0.3 |
| Number of Firms | 100 firms |
| Average Degree | 6 undirected links per firm |
| Number of Network Components | 1 connected network component of firms |

Certain parameters of the model are randomly generated. Therefore, to account for any effects of this randomization, we run the model 1000 times for every combination of model parameters. The results of the 1000 model runs are then averaged to compare the average number of adopters under the different network-based strategies.

Since there are no adopters at the beginning of the simulation, at different global adoption threshold levels, the number of firms who will adopt at time t = 0 will depend entirely on their environmental orientation. When AT = 0.25, 50% of the firms exceed the threshold to adopt at time 0, so we select it as a low threshold value as it reflects the probabilistic adoption rates used in previous agent-based models of innovation diffusion (Bohlmann et al., 2010). Additional values of AT = 0.27, where 35% of firms exceed the threshold to adopt at time 0, and AT = 0.30, where 16% of firms exceed the threshold to adopt at time 0, were selected as medium and high thresholds to test the effects of further constraining adoption rates. Table 3.5 presents the number of potential adopter firms at t = 0 under the different global adoption threshold values.

**Table 3.5.** Initial potential adopters by threshold level. The number of firms who exceed the adoption threshold at time 0, assuming a population of 100 firms, averaged over 1000 simulations

| **Adoption Threshold AT** | **Number of initial potential adopters** |
|---|---|
| 0.25 | 50 firms |
| 0.27 | 35 firms |
| 0.30 | 16 firms |

The global information threshold reflects the fraction of neighbors who need to adopt before a firm becomes informed about the eco-innovation. We select an information threshold of IT = 0.5 as the medium threshold value based on existing research on fractional thresholds (Lengyel et al., 2020). Low and high threshold values of IT = 0.4 and IT = 0.6 are selected to relax and constrain this threshold to test the effects on the number of adopters following different network-based targeting strategies.

Taking these global adoption and information threshold values into consideration resulted in nine combinations of threshold values, which aim to capture the spectrum of incremental and radical eco-innovations and the varying degrees to which they face the double-externality problem and difficulties in adoption and diffusion. These combinations were simulated across the three network types - Erdős–Rényi Random, Barabási–Albert Scale-Free, and Watts-Strogatz Small World - to reflect the varying types of inter-firm networks and relationships found across different industries in empirical studies (Perera et al., 2017; Okamura and Vonortas, 2006; Schilling and Phelps, 2007). The results for the nine combinations of global adoption and global information threshold values for each of the three network types are shown in Figures 3.3 to 3.5 below.

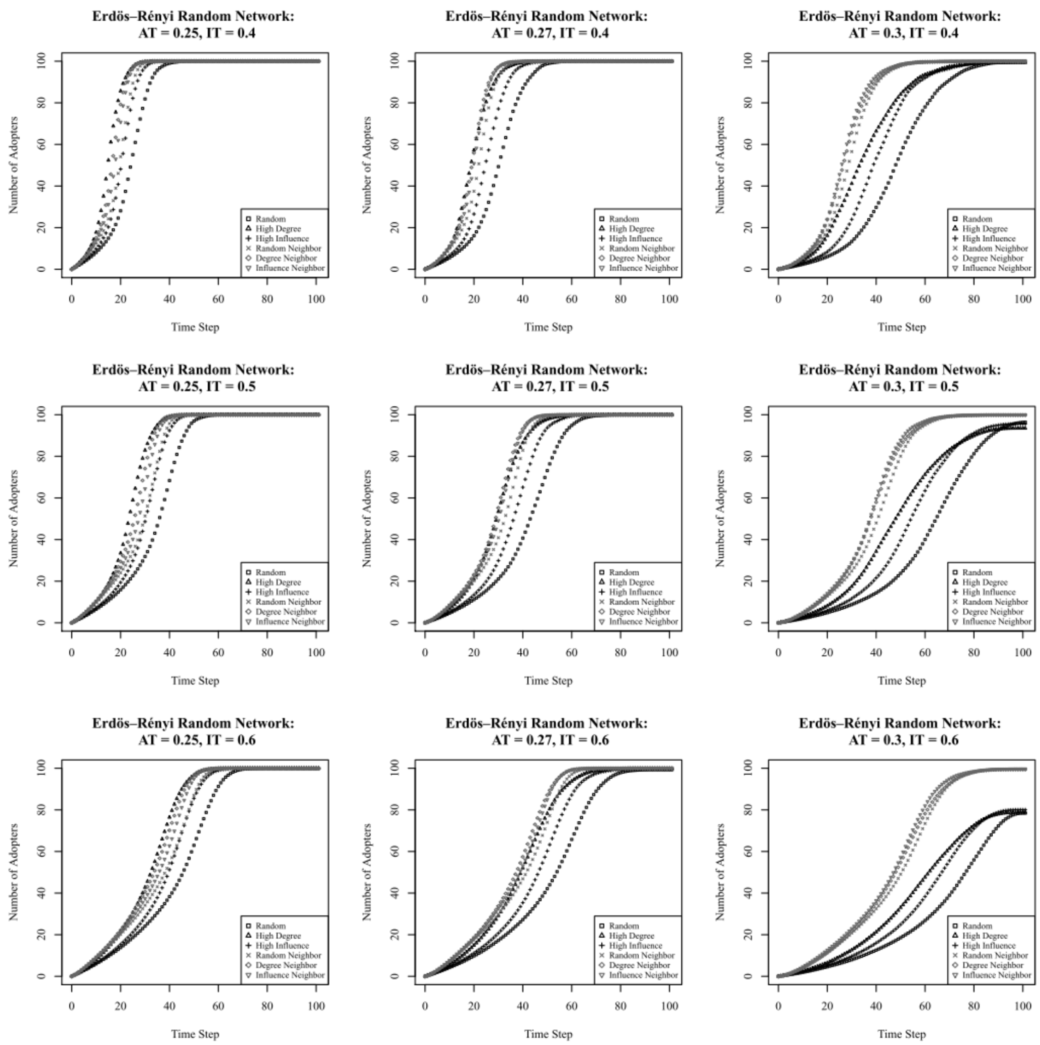


**Figure 3.3.** Varying the Global Adoption and Information Thresholds – Random Network. Shows the number of adopters over time under different network-based targeting strategies averaged over 1000 simulations with 100 firms connected through the Erdős–Rényi Random network structure with an average degree of 6, and varying global adoption threshold values of 0.25, 0.27, and 0.3 and global information threshold values of 0.4, 0.5, and 0.6.

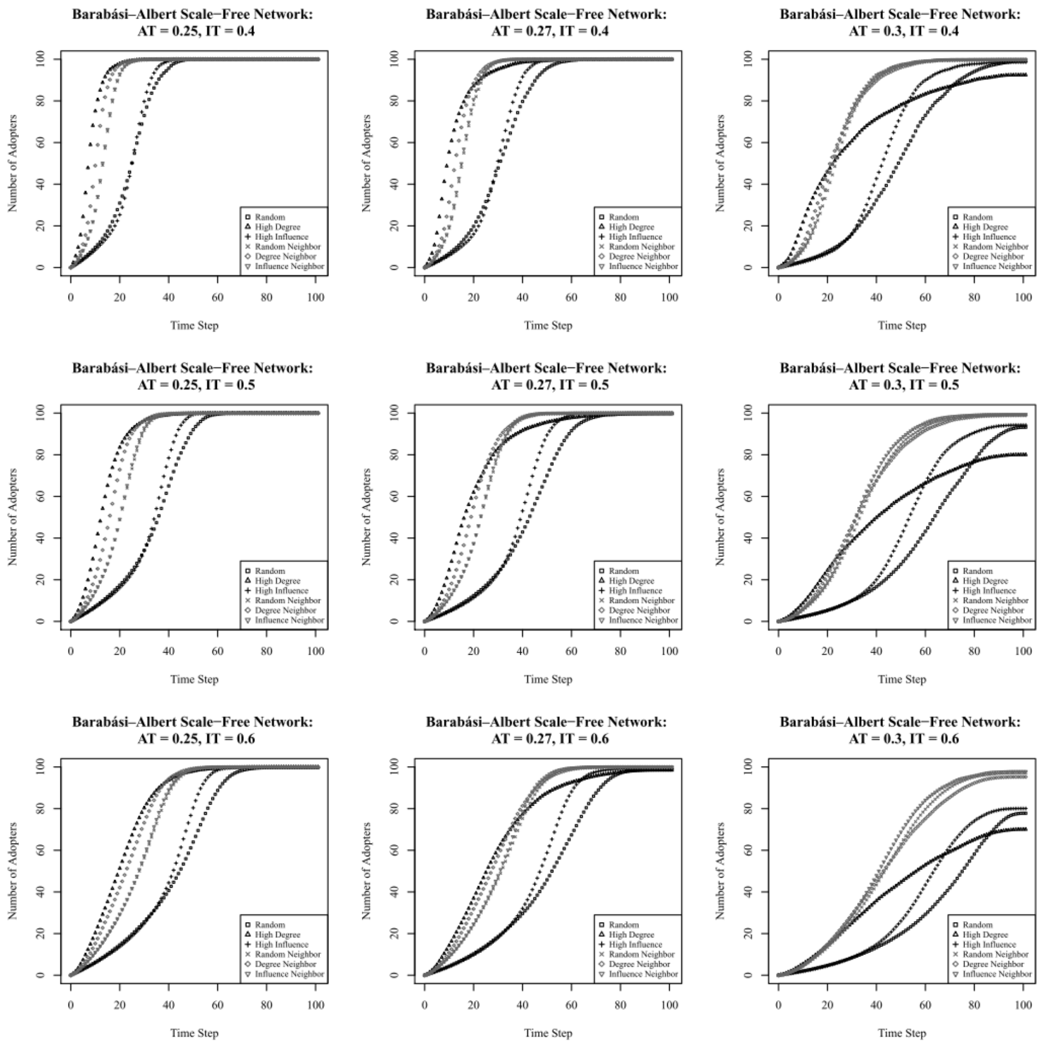


**Figure 3.4.** Varying the Global Adoption and Information Thresholds – Scale-Free Network. Shows the number of adopters over time under different network-based targeting strategies averaged over 1000 simulations with 100 firms connected through the Barabási–Albert Scale-Free network structure with an average degree of 6, and varying global adoption threshold values of 0.25, 0.27, and 0.3 and global information threshold values of 0.4, 0.5, and 0.6.

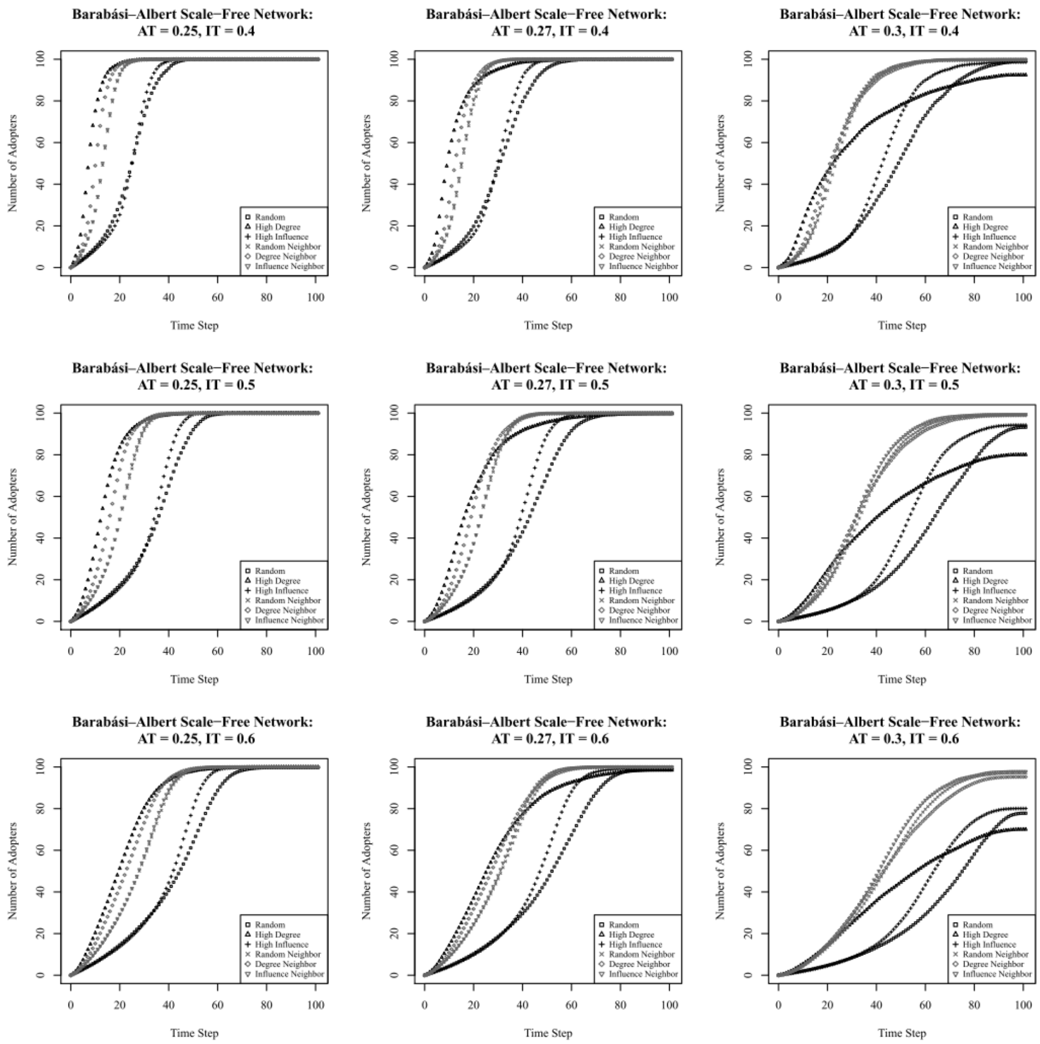


**Figure 3.5.** Varying the Global Adoption and Information Thresholds – Small World Network. Shows the number of adopters over time under different network-based targeting strategies averaged over 1000 simulations with 100 firms connected through the Watts-Strogatz Small World network structure with an average degree of 6, and varying global adoption threshold values of 0.25, 0.27, and 0.3 and global information threshold values of 0.4, 0.5, and 0.6.

Detailed results from two extremes – Low Threshold (AT = 0.25, IT = 0.4) and High Threshold (AT = 0.3, IT = 0.6) are explored in more detail to understand the adoption and diffusion dynamics.

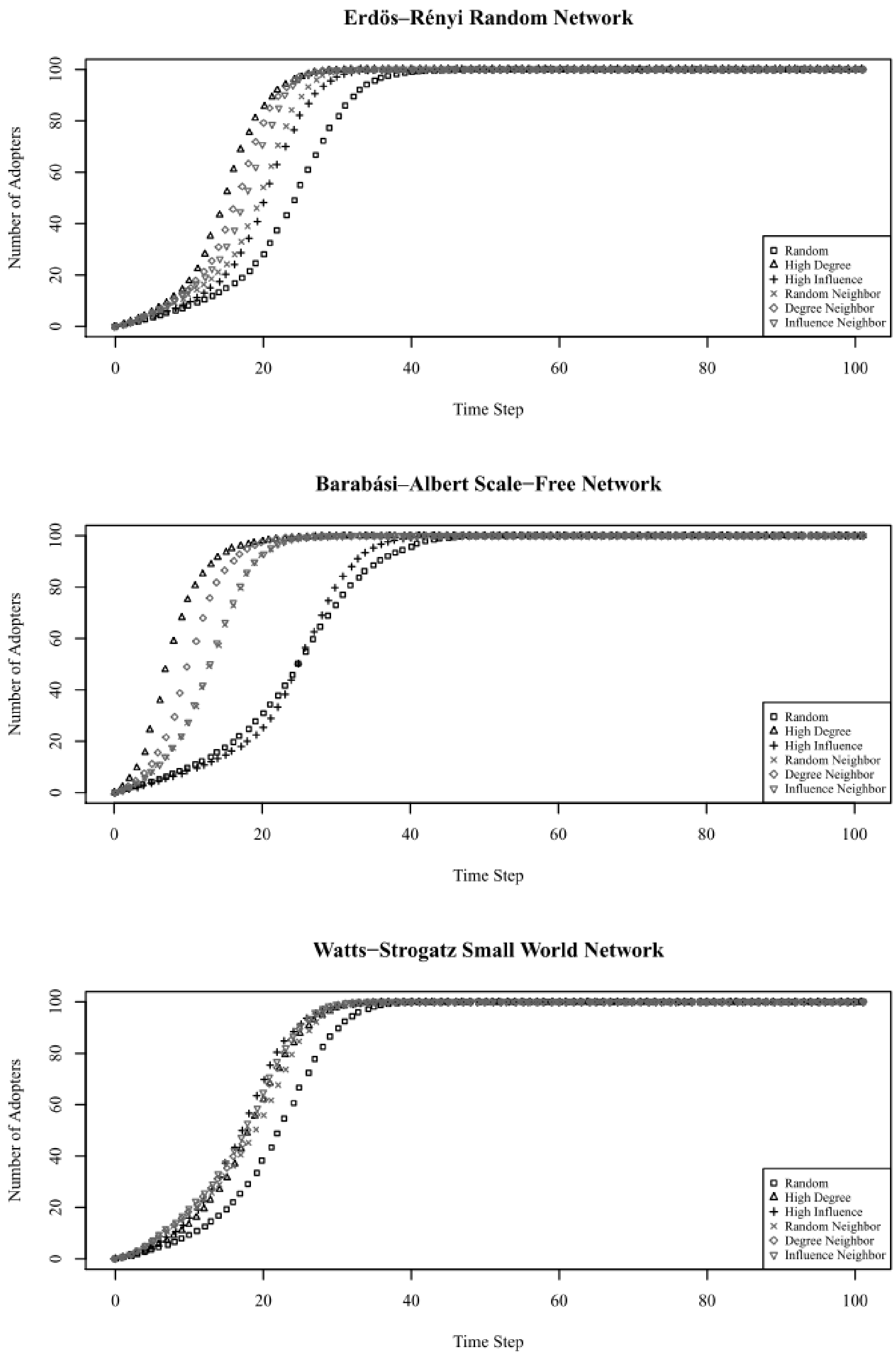


**Figure 3.6.** Low Threshold Results. Shows number of adopters over time under different network-based targeting strategies averaged over 1000 simulations with 100 firms connected through the three network structures with an average degree of 6, global adoption threshold of 0.25, global information threshold of 0.4.

As Figure 3.6 shows, in the Low Threshold scenario, all 100 firms adopt the eco-innovation quickly. The results provide insights into our first research question. If the choice of network-based targeting strategies described in Section 3.1 did not matter, we might expect to see no differences in the adoption curves compared to the Random strategy. However, the network-based strategies show similar S-shaped patterns with differences in the speed of adoption compared to the Random strategy, indicating that the choice of strategy does influence the adoption of the eco-innovation.

Comparing the adoption rates of the network-based targeting strategies across the different network types, the strategies that focus on the degree of firms, High Degree and Degree Neighbor, yield the fastest rates of adoption in the Erdős–Rényi Random and Barabási–Albert Scale-Free networks. This is likely because under low thresholds, once firms with a high degree adopt, they spread information about the eco-innovation to more of their connected neighbors in the Knowledge-phase, making them ideal to target as initial adopters. The advantage of the strategies that target firms with a high degree is especially apparent in the Barabási–Albert Scale-Free Network where links between firms are generated with a power-law distribution (Barabási and Albert, 1999) so firms with a high degree have a large number of connections and are therefore able to inform and pressure more of their peers to adopt the eco-innovation.

The strategies that focus on the influence of firms, High Influence and Influence Neighbor, do not perform as well in the Erdős–Rényi Random and the Barabási–Albert Scale-Free networks. Particularly in the Barabási–Albert Scale-Free Network, the High Influence strategy has a similar adoption curve as the Random strategy and the Influence Neighbor strategy has a similar adoption curve as the Random Neighbor strategy. To explain this, it is important to note that since the weight of the link between firms is drawn from a random uniform distribution from 0 to 1 and is independent of the number of links, the more connections a firm has, the more likely its influence, the average weight of its links with its neighbors, is closer to the average value of 0.5. Thus, the High Influence strategy targets firms which have fewer connected neighbors. Consequently, even if the high influence firms do adopt, they are not able to spread information about the eco-innovation to many of their connected neighbors.

In the Watts-Strogatz Small World Network, the links between firms are generated based on groups of firms, and the degree of the firms are more evenly distributed. Since firms in this network structure have similar numbers of connections, the weight of the link between firms becomes more important when spreading the information to connected neighbors and in pressuring neighbors to adopt. Therefore, the High Degree and Degree Neighbor strategies focusing on the degree of firms do not have as strong of an advantage, and the influence strategies, High Influence and Influence Neighbor, perform the best.

Under the Low Threshold scenario, the strategies that focus on neighbors of adopters – Random Neighbor, Degree Neighbor, and Influence Neighbor – exhibit a middling performance compared to other targeting strategies. They do not yield the fastest levels of adoption, but they also perform better than the Random strategy. However, in the High Threshold scenario where the adoption and information thresholds are set to their high values, results are very different, see Figure 3.7.

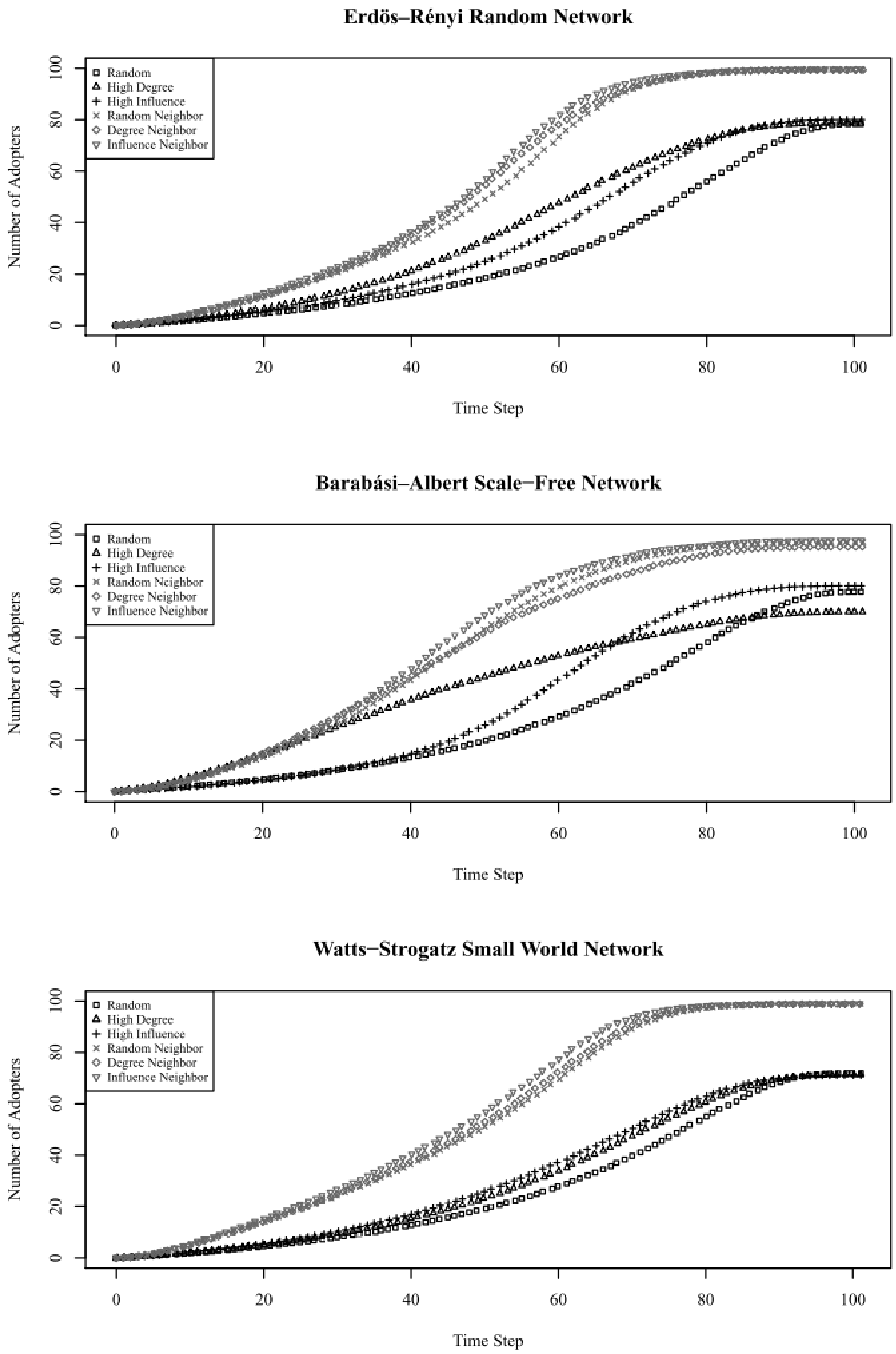


**Figure 3.7.** High Threshold Results. Shows number of adopters over time under different network-based targeting strategies averaged over 1000 simulations with 100 firms connected through the three network structures with an average degree of 6, global adoption threshold of 0.3, global information threshold of 0.6.

In the High Threshold scenario, it is the neighbor strategies that achieve near 100% adoption rates across all network structures. This result seems counterintuitive, as we expect that neighbors of adopters will most likely already be informed about the eco-innovation. Thus, targeting neighbors of adopters might seem redundant since they will eventually adopt due to the spread of information and pressure from their connected peers who adopt.

Among the neighbor strategies, the Influence Neighbor strategy performs slightly better than Random Neighbor and Degree Neighbor across all network types. We expect given the results of the Low Threshold scenario in the Erdős–Rényi Random and the Barabási–Albert Scale-Free networks where the degree of firms enables greater diffusion of the eco-innovation, the Degree Neighbor would perform the best. In the Watts-Strogatz Small World Network, the fast adoption rate of Influence Neighbor is expected, since the weight of the link between firms is more important when spreading information to connected neighbors and in pressuring neighbors to adopt the eco-innovation in this network structure.

The other network-based targeting strategies, on the other hand, exhibit much slower rates of adoption and only achieve adoption levels of 60-80% in the High Threshold scenario. The High Degree strategy which performed the best in the Erdős–Rényi Random and the Barabási–Albert Scale-Free networks under the Low Threshold scenario, has one of the slowest adoption curves in the High Threshold scenario. It performs even worse than the Random strategy in the Barabási–Albert Scale-Free Network over the course of the simulation. The High Influence strategy which yielded the fastest adoption rate in the Watts-Strogatz Small World Network under the Low Threshold scenario performs only slightly better than the Random strategy in the High Threshold scenario.

In order to explain the differences in these results, we first explore the number of components of adopters for each network-based strategy. Previous research has described percolation within networks of innovation adoption (Zeppini and Frenken, 2018), where potential adopters form components within the broader network, a sub-network of adopters. If two firms which are not connected to each other and whose immediate neighbors are not connected to each other adopt, then these adopting firms would create two separate components of adopters. Once a firm that is connected to both components or sub-networks adopts, then there will be a single connected component of adopters.

Figure 3.8 shows how the various network-based targeting strategies form different connected network components of adopters over the course of the model run in the High Threshold scenario. The neighbor strategies only form a single connected network component of adopters by focusing on neighbors of adopters, while the other network strategies create multiple components of adopters in the beginning since they reach out to different parts of the network based on the degree or influence of the firms, before converging to a single component of adopters by the end of the simulation as the firms connected to the multiple sub-components adopt. The difference in the number of components of adopters between the neighbor strategies and the other network-based targeting strategies explains why the neighbor strategies are more effective in the High Threshold scenario.

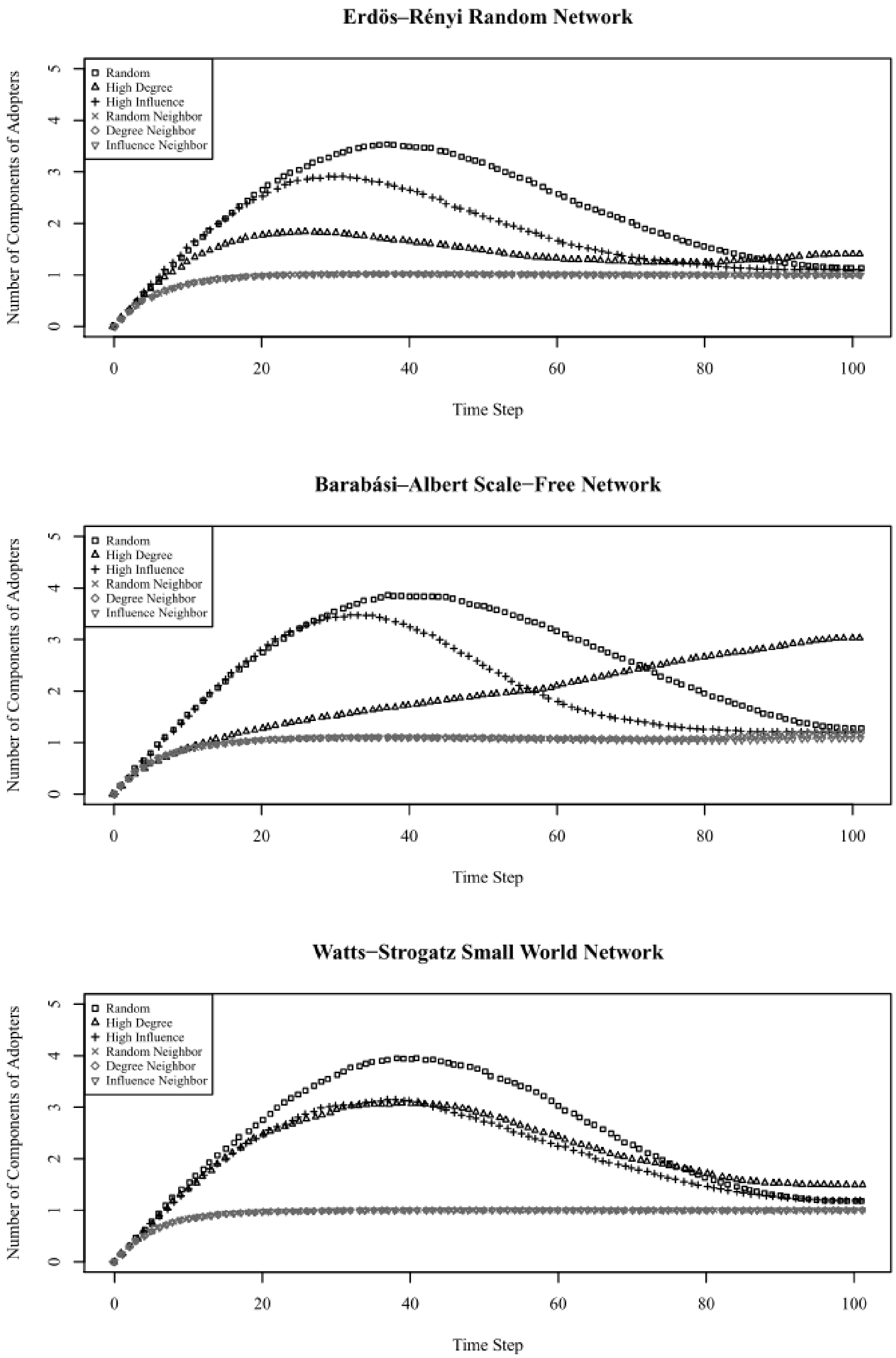


**Figure 3.8.** Number of network components of adopters. Shows number of connected components of adopters under different network-based targeting strategies averaged over 1000 simulations with 100 firms connected through the three network structures with an average degree of 6, global adoption threshold of 0.3, global information threshold of 0.6.

As shown in Table 3.5, when the global adoption threshold is high, there are fewer firms that will adopt the eco-innovation at the beginning of the simulation. The high information threshold also makes it more difficult for information about the eco-innovation to spread among neighbors of adopters. By finding a firm that adopts and then targeting neighbors of these adopters, the neighbor strategies make use of the positive peer pressure effect among adopters and their neighbors that overcomes the high information and adoption thresholds. Following this targeting strategy creates a growing single connected network component of adopters over time that generates greater positive peer pressure effects and leads to faster and higher levels of adoption. The Influence Neighbor strategy performs better than the other neighbor strategies in the High Threshold scenario since the stronger weight of the links between the adopters and the neighbor firms targeted makes the positive peer pressure effects stronger and the likelihood of adoption and diffusion greater.

On the other hand, the other network-based targeting strategies target firms in different parts of the network, creating multiple disconnected components of adopters. By doing so, they are not able to create the positive peer pressure effects among adopters and their connected neighbors to overcome the high thresholds for information diffusion and adoption. This explains why the High Degree, High Influence, and Random strategies do not perform as well and do not achieve 100% adoption rates in the High Threshold scenario.

There is also a second explanation for why the High Degree and High Influence strategies have slower rates of adoption and lower adoption levels in the High Threshold scenario. As mentioned at the beginning of Section 4, the results of our model are averaged across 1000 simulation runs and there is variability across each of the individual model runs. Figure 3.9 shows that when comparing the variability of the results in the High Threshold scenario, the High Degree strategy has the highest standard deviation in the number of adopters in the Erdős–Rényi Random and Barabási–Albert Scale-Free networks, while High Influence has nearly the highest standard deviation in the Watts-Strogatz Small World Network. The neighbor strategies have lower variability in the number of adopters over time across the 1000 simulation runs.

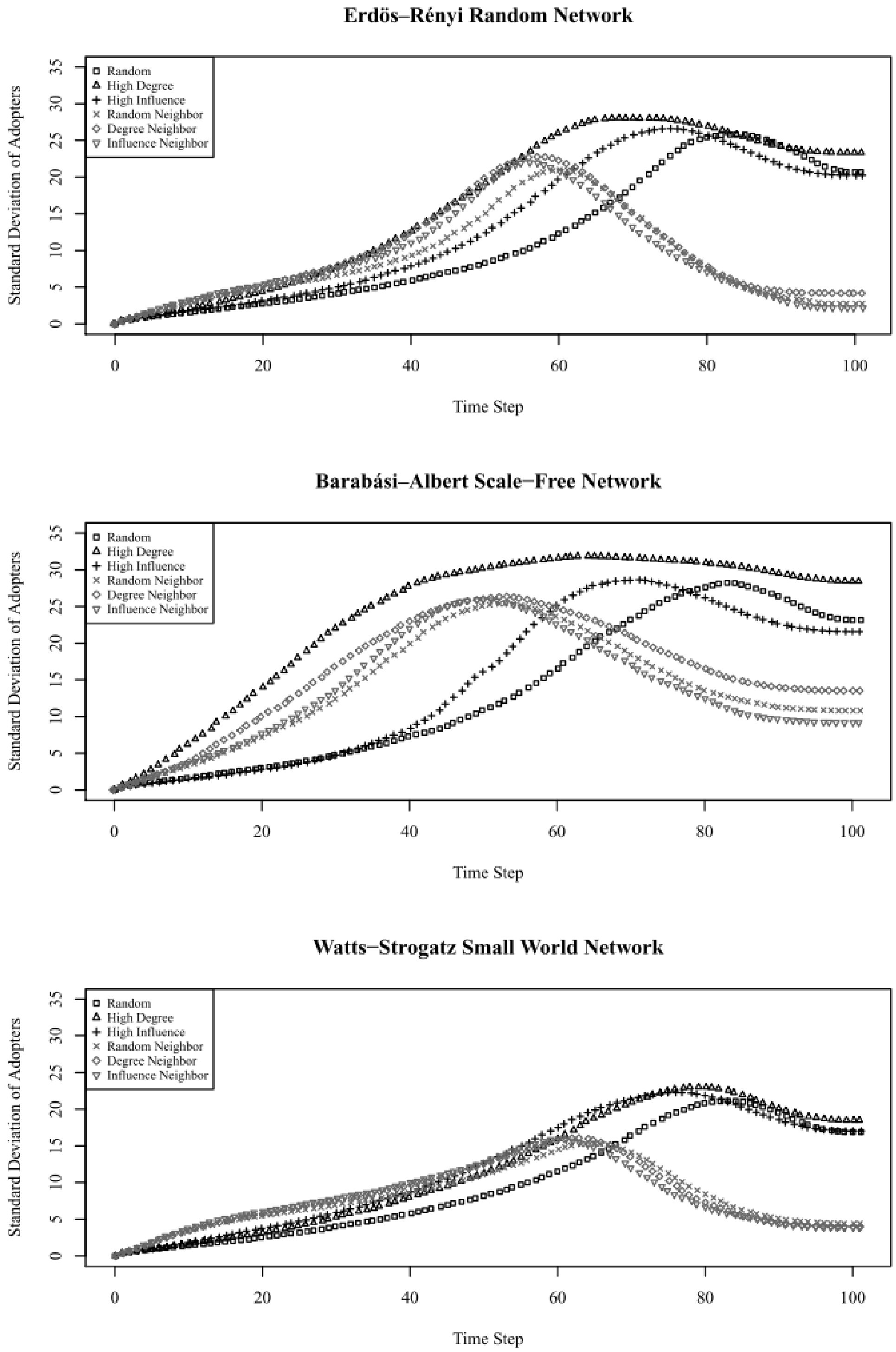


**Figure 3.9.** Standard deviation of adopters. Shows variation in the number of adopters under different network-based targeting strategies over 1000 simulations with 100 firms connected through the three network structures with an average degree of 6, global adoption threshold of 0.3, global information threshold of 0.6.

In the High Threshold scenario, a greater number of neighbors need to adopt before firms with a high degree will be informed about or adopt the eco-innovation. This is especially pronounced in the Barabási–Albert Scale-Free Network in which firms with a high degree have lots of connected neighbors. For these high degree firms to adopt when targeted at the beginning of the simulation, their environmental orientation needs to be sufficiently high to overcome the high adoption threshold.

Thus, in certain model runs if the high degree firms targeted by the High Degree strategy have a sufficiently high environmental orientation, then they will adopt and diffuse the eco-innovation to their neighbors, creating a cascade of new adoptions. However, in other model runs if the high degree firms targeted at the beginning of the simulation have a low environmental orientation, then they do not adopt, and the eco-innovation fails to diffuse through the network. This variability in the results leads to an average adoption rate of 60-80% across the 1000 simulation runs.

Similarly, in the Watts-Strogatz Small World Network where the degree of the firms is more evenly distributed and the weight of the links is a more important factor, close neighbors need to adopt before the high influence firms will be informed about or adopt the eco-innovation. In certain model runs, if the high influence firms targeted by the High Influence strategy have a sufficiently high environmental orientation, they will adopt and diffuse the eco-innovation. But in other model runs, if the high influence firms have a low environmental orientation, then they will not adopt, leading to variability in the results and an average adoption rate of 60-80% across the 1000 simulation runs in the High Threshold scenario.

On the other hand, the neighbor-based targeting strategies have more consistent levels of variability across the 1000 model runs in the High Threshold scenario. In the early stages of the simulation, the variability increases as the neighbor strategies find an initial adopter firm. However, once the first adopter firm is found, by targeting neighbors of adopters, growing a single connected network component, and making use of the positive peer pressure effects, the neighbor strategies increase the likelihood of adoption and diffusion of the eco-innovation and reduce the variability across model runs over time.

To better understand these differences in the High Threshold scenario, we analyze the model further by varying additional network parameters – the number of connected network components of firms, the number of firms, and the number of connections between firms – to see if the results change. To test changing the number of connected network components of firms, we test 3 and 5 equally sized components of firms. To test changing the network size, we test the model with 50 and 500 firms. To test changing the number of connections, we vary the network degree to an average degree of 4 and 8, based on previous research on collaboration and alliance networks among firms within different industries (Okamura and Vonortas, 2006; Schilling and Phelps, 2007).

As mentioned earlier, one potential reason why the network-based targeting strategies that focus on neighbors of adopters achieve high adoption levels is that they focus on a single connected network component of firms. Since the model parameters specify a single connected network component of firms, we test whether the results would be different if there were multiple disconnected network components of firms. We explore whether the advantage of these neighbor strategies would be reduced in networks with multiple components of firms.

Considering the network variables to create multiple connected network components of firms and as the differences between the neighbor and non-neighbor strategies is more obvious, we repeatedly generate Watts-Strogatz Small World networks with an average degree of 2 until we achieve a network structure with 3 and 5 components of firms. We maintain the high global adoption threshold of AT = 0.3 and high global information threshold of IT = 0.6, and we run 1000 model runs with 100 firms and test the six targeting strategies. The results from the simulation runs are shown in Figure 3.10.

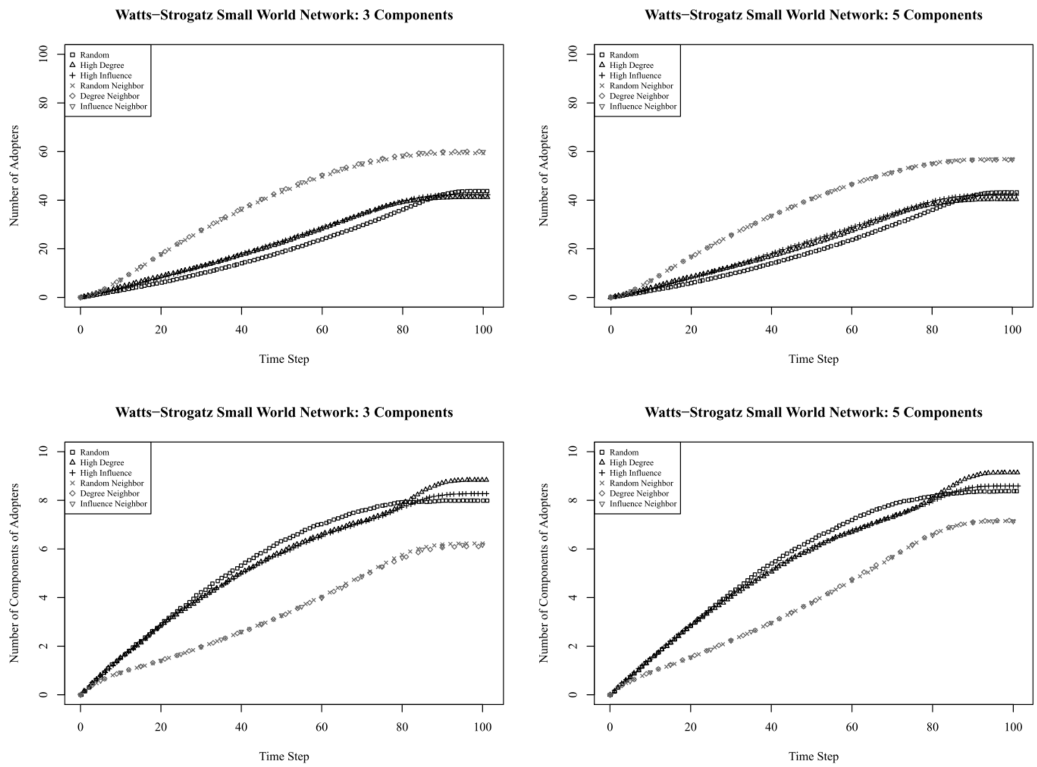


**Figure 3.10.** Varying the number of network components. Shows components of adopters over time under different network-based targeting strategies averaged over 1000 simulations with 100 firms connected through a Small World network with 3 and 5 clusters of firms, an average degree of 2, global adoption threshold of 0.3, global information threshold of 0.6.

The results show that while the network-based targeting strategies that focus on neighbors of adopters no longer achieve near 100% adoption rates, they still maintain their advantage over the other network-based targeting strategies. As Figure 3.10 shows, the neighbor-based targeting strategies have the smallest number of connected components of adopters, which likely means they focus on one connected component of firms at a time before they reach out to the other components. This limits the spread of information about the eco-innovation to other network components through peers, resulting in lower levels of adoption. However, as before, the neighbor strategies are still able to get a higher number of adopters compared to the other network-based strategies since they focus on neighbors of adopters who are more likely to adopt.

In addition, we also vary the number of firms, testing 50 and 500 firms, as well as the average degree of the inter-firm network, testing an average degree of 4 and 8, while maintaining the high values for the global adoption and information thresholds. The results from varying these model parameters are not drastically different from the results in Figure 3.7 for the High Threshold scenario, therefore we do not reproduce them here. The network-based targeting strategies that focus on neighbors of adopters, particularly Influence Neighbor, still perform better than the other network-based strategies under these parameters. A more detailed elaboration of these results is provided in the Appendix.

### 3.5 Discussion

The results from the Low Threshold scenario in Section 4, reflect the outcomes highlighted in the literature discussed in Section 2 on the role of key players in innovation diffusion. Previous agent-based models that have utilized network-based targeting strategies have identified that agents with high degree centrality measures have positive and significant impacts and perform the best in achieving the highest and fastest rates of adoption of innovations (Barbuto et al., 2019; Beaman et al., 2018; Nöldeke et al., 2020; Robinson and Rai, 2015), similar to the outcomes shown in Figure 3.6 for Erdős–Rényi Random and Barabási–Albert Scale-Free networks. In other models, opinion leaders who have a higher influence on other agents and have strong weighted links to other agents are found to spread information faster and increase the rates of adoption over the network (van Eck et al., 2011), similar to the outcomes shown in Figure 3.6 for the Watts-Strogatz Small World Network. Eco-innovations that are more incremental likely face lower thresholds for adoption and information diffusion, and thus targeting strategies focused on network centrality measures, High Degree and High Influence, could increase diffusion.

As mentioned in Section 2, more radical eco-innovations require greater internal and external firm resources (Cainelli et al., 2015; de Jesus and Mendonça, 2018; Del Río González, 2005; Hellström, 2007) to overcome the double-externality problem (Rennings, 2000). Therefore, they have higher thresholds for adoption and diffusion due to the lower incentives and pressures for their adoption (Hasler et al., 2016). Consequently, the results from the High Threshold scenario in Section 4 are more relevant when considering the greater disincentives for more radical eco-innovations, such as renewable energy technologies or new environmentally friendly products and processes that restructure existing value chains.

At high thresholds for adoption and diffusion, it is not the High Degree or High Influence strategies that yield the greatest levels of adoption. Instead, the network-based targeting strategies focused on neighbors of adopters significantly outperform the other network-based strategies, presenting different outcomes from the agent-based models mentioned earlier. In addition, among the neighbor strategies, it is Influence Neighbor, targeting neighbors of adopters with strong connections, which is slightly more effective than the Degree Neighbor and Random Neighbor strategies. As the results from Section 4 show, the advantage of the neighbor strategies over the other network-based targeting strategies remains regardless of changes to the inter-firm network parameters, even when there are multiple clusters of potential adopter firms.

These results seem to be consistent with existing research on the role of inter-firm networks and relationships in eco-innovation adoption, described in Section 2. Studies show that close relationships with partners in their inter-firm networks provide a space for firms to exchange knowledge and information, generating a receptive mindset towards adoption (Díaz-García et al., 2015; Pellegrini et al., 2019) and reducing some of the risks and transaction costs of implementing eco-innovations (Del Río González, 2005; Mazzanti and Zoboli, 2008). Firms that adopt eco-innovations tend to have stronger and more intensive external network relationships (Bag and Gupta, 2017; Cainelli et al., 2015), as the structure and position of the firm within their network can affect the strength and frequency of pressures exerted on them to adopt eco-innovations as well as to what extent the eco-innovations will spread through the network (Bayne et al., 2012; Chen et al., 2019).

The outcomes of our model provide additional insights into the mechanisms for effective diffusion of eco-innovations, particularly more radical eco-innovations with higher thresholds for adoption and diffusion. Instead of targeting firms with a high number of connections or a high level of influence, it is better to focus on close inter-firm relationships among neighbors of adopters to yield higher rates of adoption. Doing so would leverage the strong relationships between adopters and their neighbors to gradually encourage more firms to adopt, creating a domino effect to accelerate the spread of eco-innovations through inter-firm networks.

It should be noted, however, that the outcomes of our model are likely dependent on the choice of theories of eco-innovation adoption and innovation diffusion utilized in the model. As described in Section 3, the model simplifies the various internal adoption factors (Bossle et al., 2016; Díaz-García et al., 2015; Hojnik and Ruzzier, 2016; Triguero et al., 2016) into a single randomly generated EO term and only considers the effects of networks and relationships as external factors. Accounting for internal factors such as firm size, technological capacity, and leadership in more detail and more external eco-innovation adoption decision factors such as regulations, market demand, and technological development (Bossle et al., 2016; Díaz-García et al., 2015; Hojnik and Ruzzier, 2016) would have made the model more complex and difficult to interpret. However, the addition of these factors could influence the results of the model.

Moreover, our model's adoption process follows a particular approach presented in the innovation diffusion literature that combines internal and external influences (Delre et al., 2010; van Eck et al., 2011), while other approaches utilize simple decision rules and heuristics, probabilities, state transition approaches, or cognitive theories of behavior (Kiesling et al., 2012; Zhang and Vorobeychik, 2019). The diffusion process in our model follows theories of complex contagions and fractional thresholds using global thresholds (Centola and Macy, 2007; Lengyel et al., 2020; Watts, 2002), while other approaches utilize heterogeneous thresholds at the agent level or follow theories of Independent Cascades to proactively spread innovations among neighbors (Goldenberg et al., 2001; Kempe et al., 2003; Kiesling et al., 2012; Zhang and Vorobeychik, 2019). Selecting these alternative processes for adoption and diffusion in our model could yield different results.

The modelling framework established in our paper provides a pathway to further research that explores how eco-innovations can be more effectively diffused through inter-firm networks by targeting key adopters. Future extensions or modifications to the model could further explore how the network-based targeting strategies would influence the adoption and diffusion of eco-innovations under the more complex model dynamics and alternative processes mentioned earlier. The model could also be modified to remove the continuous active seeding approach (Sela et al., 2018) and test the effectiveness of the network-based strategies given a limited number of resources for targeting. For ease of analysis, the model only allows the use of one targeting strategy during the course of the simulation, but the mixing and switching of strategies during the simulation, which we considered but did not incorporate due to added complexity. In future models, the possible mixture of strategies by firms could be empirically estimated in case of specific eco-innovations. Eq. 2 in the model could also be further analyzed to test different weights for the average of EO and PP to calculate the adoption heuristics of the firm (Delre et al., 2010). Another direction to explore could be to explore ecosystems of innovation with multiplex relationships with other firms and stakeholders in the supply chain (Lazzarini et al., 2001), incorporating the concept of negative ties to reflect competitive relationships and rivalry (Harrigan et al., 2020).

## 3.6 Conclusions

The inter-firm relationships within a firm's network are important elements of the innovation adoption and diffusion process, acting as important signals and spaces for the exchange of information. Research on eco-innovation have utilized these concepts to show that inter-firm networks and relationships are important drivers for eco-innovation diffusion and additional studies have shown that the rate of adoption and diffusion is influenced by targeting key players with certain network positions and centrality measures, who can serve as critical injection points. However, these studies have not focused on inter-firm networks and/or have not considered the effect of targeting key players on the adoption and diffusion process of eco-innovations.

In this paper, we bring together these streams of research, in order to understand how leveraging the information about the structure and nature of the inter-firm relationships within a firm's network and targeting specific firms using network-based strategies can boost the rates of adoption and diffusion of eco-innovations, particularly more radical eco-innovations that face greater hurdles for adoption and diffusion. The results show that the choice of targeting strategies can affect how quickly and effectively various eco-innovations diffuse through different inter-firm networks. For eco-innovations that are more incremental and likely face lower thresholds for adoption and information diffusion, targeting strategies focused on network centrality measures, High Degree and High Influence, could increase diffusion. While for more radical eco-innovations that have high thresholds for adoption and diffusion, targeting strategies focused on neighbors of adopters could increase diffusion.

The theoretical model in this paper generated networks and relationships based on algorithms and parameters for relationships in the existing literature, though with some empirically informed parameters. This has been cited as a common shortcoming of such models, as they do not reflect real-world network structures (Barbuto et al., 2019); however, the aim of this paper was to create a starting point for the exploration of how network-based targeting strategies could influence the widespread diffusion of various eco-innovations and help overcome the disincentives for adoption. The practical application of this model likely requires a significant amount of effort in collecting network data and identifying the relationships between firms, ideally by means of in-depth interviews to accurately map the connections (Akbarpour et al., 2020; Beaman et al., 2018).

Such an undertaking can potentially be made easier by utilizing public and private databases, social media platforms, and press releases by firms to gather the landscape of firms who might be interested in a particular eco-innovation and how they are connected through alliances, joint membership, collaborative initiatives, etc. (Okamura and Vonortas, 2006; Schilling and Phelps, 2007). The application of this model on real-world network data might yield useful insights for policymakers, companies, and startups, who wish to diffuse and scale the adoption of their eco-innovations. By mapping out the inter-firm network and developing a more targeted strategy to approach firms based on their structure and position in the network, it is possible to achieve greater levels of adoption and diffusion through industries and value chains. Since the more widespread adoption and diffusion of new, more radical eco-innovations by firms is a critical pathway to combat global environmental challenges and transition towards a less environmentally impactful society, this approach could provide more effective ways to spread the adoption of eco-innovations, environmental technologies, and practices.

## 3.7 Appendices

### *3.7.1 Results from varying the number of connections*

We maintained the high global adoption threshold and high global information threshold values and varied the number of connections between firms. We changed the average degree of the inter-firm network from 6 undirected, reciprocal links to 4 links and 8 links. We ran the model 1000 times with 100 firms connected under different network structures – Erdős–Rényi Random, Barabási–Albert Scale-Free, and Watts-Strogatz Small World – and tested the six targeting strategies. The results from the simulation runs are presented in Figure 3.A1 below.

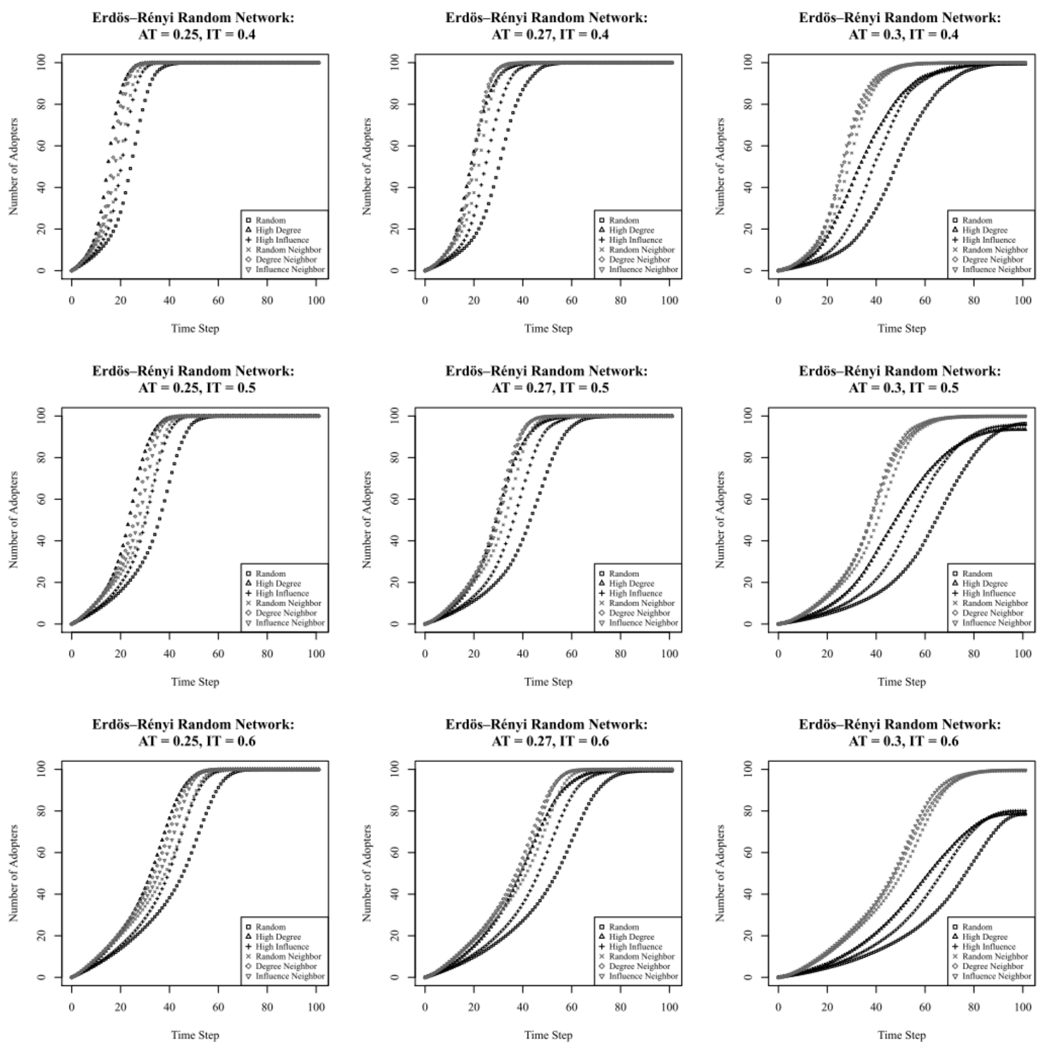


**Figure 3.A1.** Varying the Degree of the Inter-Firm Network Simulation Results. Shows the number of adopters over time under different network-based targeting strategies averaged over 1000 simulations with 100 firms connected through Erdős–Rényi Random, Barabási–Albert Scale-Free, and Watts-Strogatz Small World network structures with an average degree of 4 and 8, and global adoption threshold of 0.3 and global information threshold of 0.6.

When we change the average degree to 4, there are fewer connections between firms in the network and firms have a smaller number of neighbors. As a result, the overall levels of adoption are lower for the non-neighbor strategies, as the diffusion of information through connected neighbors is not as widespread. The strategies focusing on neighbors of adopters still achieve high adoption rates, since neighbors of adopters will have a higher PP and are therefore not only more likely to exceed their adoption threshold, but also inform connected neighbors.

As the average degree increases to 8 and there are more connections between firms, the diffusion of information through connected neighbors is more widespread and all network-based targeting strategies achieve faster and higher levels of adoption. The strategies that focus on firms with high influence, High Influence and Influence Neighbor perform better compared to the strategies that focus on firms with a high degree. This is likely because more neighbors need to adopt before a high degree firm will adopt and before information can spread through connected neighbors. However, by focusing on influential firms with stronger connections and lower degree values, these strategies succeed in identifying firms that more easily exceed their adoption threshold and can exert greater pressure on their neighbors to be informed about and consider adoption of the eco-innovation.

### *3.7.2 Results from varying the number of firms*

We maintained the high global adoption threshold and high global information threshold values and varied the size of the inter-firm network. We changed the number of firms, running the model with 50 firms and 500 firms. The length of the model runs depend on the number of firms, so the model runs with 50 firms lasted 50 time steps, while the model runs with 500 firms lasted 500 time steps. We maintained the high global adoption threshold of AT = 0.3 and high global information threshold of IT = 0.6, and we ran 1000 model runs with firms connected under different network structures – Erdős–Rényi Random, Barabási–Albert Scale-Free, and Watts-Strogatz Small World – with an average degree of 6 and tested the six targeting strategies. The results from the simulation runs are shown in Figure 3.A2.

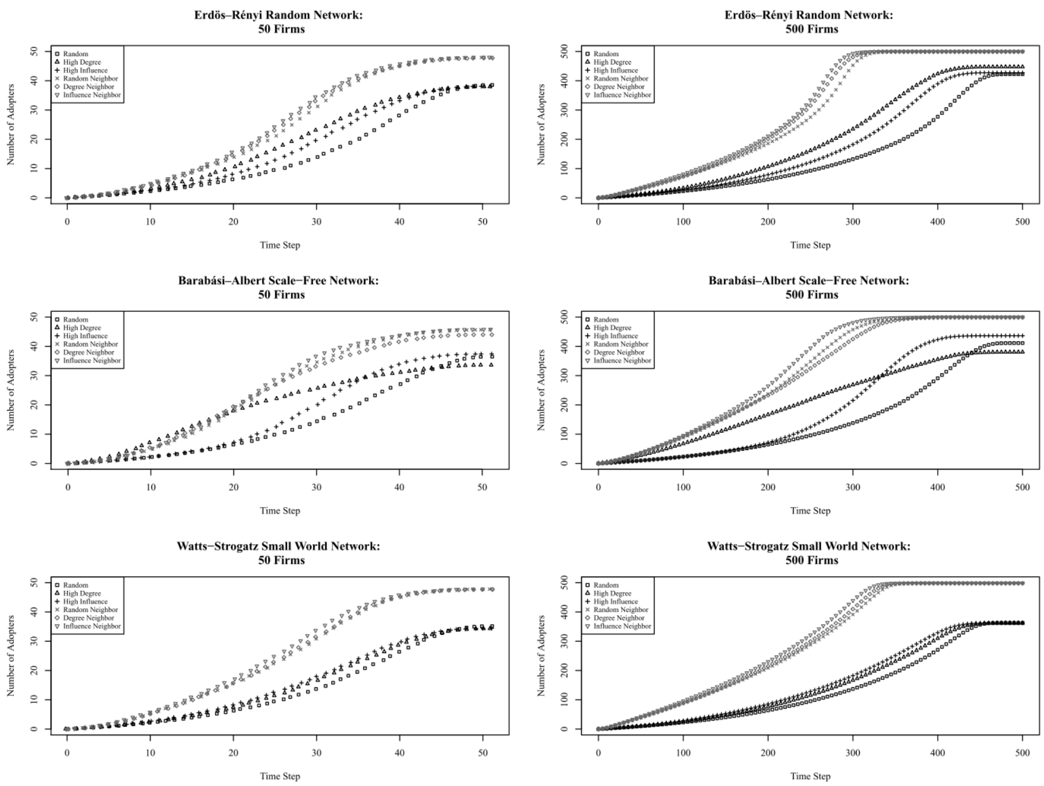


**Figure 3.A2.** Varying the Size of the Inter-Firm Network Simulation Results. Shows the number of adopters over time under different network-based targeting strategies averaged over 1000 simulations with 50 firms and 500 firms connected through the Erdős–Rényi Random, Barabási–Albert Scale-Free, and Watts-Strogatz Small World network structures with an average degree of 6, and global adoption threshold of 0.3 and global information threshold of 0.6.

Reducing the size of the inter-firm network to 50 firms and maintaining the average degree of 6 undirected, reciprocal links gives a higher density of connections. Therefore, we might expect similar results to the results from increasing the average degree, which also increases the density of the network. However, the relative differences between the various network-based strategies are very similar to the results with 100 firms only with a smaller number of adopters. The targeting strategies that focus on neighbors of adopters, particularly Influence Neighbor, continue to yield a higher number of adopters compared to the other strategies.

Increasing the size of the network to 500 client firms and an average degree of 6 reduces the density of the network. Therefore, we might expect similar results to the results from reducing the average degree. However, the results are quite different due to a large number of firms, which makes the spread of information through connected neighbors much slower. The neighbor strategies, especially Influence Neighbor, yield a larger number of adopters and very quickly reach 100% adoption, since they focus on a single adoption cluster where neighbors of adopters are more likely to adopt and connected neighbors are more likely to be informed. The degree strategies, High Degree and Degree Neighbor, perform relatively poorly in the Barabási–Albert Scale-Free Network, since the highest degree clients have upwards of 70-80 neighbors in some cases, making it harder to convince them to adopt and resulting in higher variability in adoption across simulation runs.

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# Discussion and Conclusions

In this section, the findings of the previous chapters are synthesized to answer the three key research questions established in the Introduction, and the implications of the research are discussed. The three questions this dissertation set out to answer were:

> *RQ1: What are the types of inter-firm networks and relationships described in existing literature and what is the effect on eco-innovation adoption and diffusion?*
> *RQ2: What influence do embedded relationships within inter-firm networks have on the adoption decisions of eco-innovations by firms?*
> *RQ3: How can the network position and structure and nature of inter-firm relationships and networks be leveraged to more quickly diffuse eco-innovations?*

Through the outcomes of the literature review in Chapter 1, RQ1 can be answered. The review of the literature revealed many mentions in the literature of various types of inter-firm networks and relationships that could influence eco-innovation adoption and diffusion as well as identified their effect. Inter-firm relationships mentioned in the literature included customer and supplier relationships, collaborative and cooperative relationships, competitive relationships, and local and international relationships between firms, which could have different levels of strength and longevity, and which could be formal and contractual in nature or informal and social. In particular, customer-supplier relationships based on formal contractual obligations seemed to have the greatest number of mentions and were described as having a positive effect on eco-innovation adoption and diffusion. Inter-firm networks mentioned in the literature were alliance and partnership networks, supply chain and production networks, and industry association and business group networks, which could have different characteristics like structure, size, and specific positions of firms. The literature most frequently mentioned supply chain and industry networks and the network positions of firms has having a positive effect on eco-innovation adoption.

Based on the findings of the literature review in Chapter 1, a case study approach to further explore the embedded social factors within the formal contractual relationships between customers and suppliers seemed to be a good approach to answer RQ2. Thus, in Chapter 2, a historical case study of the Jaguar Land Rover was conducted, focusing on the relationships between Jaguar Land Rover as a customer and other firms in their supply chain network and how it influenced the adoption of REALCAR, a circular economy, closed-loop recycling eco-innovation. The results of the research highlighted how Jaguar Land Rover's motivations to accelerate the implementation of REALCAR resulted in them placing coercive pressures on their suppliers, leveraging their position as customers and their formal contractual relationships. A unique finding from this study was the resistance from scrap dealers, who were most affected by REALCAR since it changed the structure and nature of the existing relationships in the supply chain and affected their position in the network. A network regression analysis found that the level of resistance from scrap dealers played a significant role in delaying the adoption decisions of suppliers, as they tried to hinder the implementation of REALCAR by leveraging their embedded relationships with the suppliers. Thus, it is important to take such dynamics into consideration in order to more effectively implement circular economy eco-innovations through supply chain networks.

The results from Chapter 1 identified a research gap since few articles in the literature review focused on developing simulation tools and models. Therefore, to answer RQ3, a theoretical agent-based model was developed in Chapter 3 to understand how targeting specific firms based on their network position, the strength of inter-firm relationships, and the structure and size of inter-firm networks can lead to faster diffusion of incremental and disruptive eco-innovations. The model showed that targeting firms with high degree, in terms of number of inter-firm relationships, or high influence, with strong inter-firm relationships, could more quickly diffuse incremental eco-innovations. While targeting neighbors of adopters is a better strategy for more radical eco-innovations with greater barriers to adoption. The outcomes of the agent-based model provided insights into the mechanisms for effective diffusion of eco-innovations, particularly more radical eco-innovations which advance the circular economy. By leveraging the strong relationships between adopters and their neighbors to gradually encourage more firms to adopt, it is possible to create a domino effect which can accelerate the spread of disruptive eco-innovations through inter-firm networks and accelerate the shift to a circular economy.

## Implications of the Research Outcomes

The conclusions from this research, particularly the studies conducted in Chapters 2 and 3, have important implications for the circular economy transition. Given the urgency of the global environmental and social challenges outlined in the Introduction, there is a growing interest among companies and policymakers to implement circular economy thinking and eco-innovations to address these issues (de Jesus and Mendonça, 2018; Khitous et al., 2020; Kirchherr et al., 2017). The insights from this Ph.D. research could potentially aid these decision makers in developing business strategies and policies that can accelerate the adoption and diffusion of disruptive eco-innovations and more quickly transform global value chains to become more circular.

The case study in Chapter 2 emphasizes how implementing the circular economy requires the involvement of multiple stakeholders who have varying goals and interests, as well as embedded social and cultural pressures that affect their decision-making. In order for companies like Jaguar Land Rover more effectively enable the adoption of circular economy eco-innovations within their supply chain networks, they need to map their network position, the strength of their relationships with their suppliers and other stakeholders, as well as the changing dynamics of these inter-firm relationships and networks. In doing so, companies can gain a better understanding of the potential reactions of the firms in their network, identify favorable conditions and conducive factors, and, most importantly, determine possible barriers and obstacles that could delay and hinder the adoption of disruptive circular economy eco-innovations. These dynamics can potentially be further explored through additional research and techniques such as evolutionary game theory approaches, which as seen in Figure 1.4 has not been applied extensively to this topic, to understand how to design the right incentive structures and coordination schemes (Ji et al., 2015) to encourage firms in supply chain networks to adopt eco-innovations faster.

In addition, the results of the simulation model in Chapter 3 show how this information could be utilized for eco-innovation diffusion. By gaining an understanding of the strength and quality of relationships between firms and their level of willingness and resistance, companies could identify firms in their supply chains and inter-firm networks that could more quickly diffuse these eco-innovations. Particularly for disruptive circular economy eco-innovations, which have high social and cultural barriers for adoption and diffusion, knowing which firms are key adopters and targeting their neighbors with whom they have close relationships could help overcome these barriers and pressures, yielding faster rates of diffusion. As noted in the conclusions in Chapter 3, the simulation model could be elaborated in future research to capture more complex dynamics that could provide further insights into the role of networks and relationships. Aspects such as eco-innovation adoption costs vs. benefits, network formation and evolution, competition from other eco-innovations, and other industry dynamics could be incorporated in future expansions (Chang, 2015), as well as scaling the model with thousands of firms to more accurately reflect the size and scope of various industry and supply chain firm networks.

Though the focus of this Ph.D. thesis is on inter-firm networks and relationships, which might imply that the research is relevant only for companies, the results could apply to policymakers as well. Governments at the national, local, and city level are looking for policies and regulations to address key environmental and social challenges, especially ones that involve partnerships and collaboration with companies and firms (Grytsyshen et al., 2019; Milios, 2018; Winans et al., 2017). The conclusions from the case study in Chapter 2 and the agent-based model in Chapter 3 could aid policymakers as they try to understand how to more effectively involve companies in the circular economy transition. Implementing new circular economy initiatives that require the compliance and engagement of businesses could be aided by a deeper understanding of the embedded relationships between firms and the structure of their inter-firm network. Similar to what was mentioned earlier in the context of business strategies, policymakers could leverage this knowledge to identify key drivers and barriers to adoption, as well as identify potential industry partners that could more quickly and easily spread innovative circular economy policies.

As mentioned in the discussion of the conclusions of Chapter 3, the effort required to identify and map the embedded social and cultural factors in inter-firm networks and relationships could be significant. However, a coordinated effort by companies and policymakers to establish databases and gather information from key stakeholders on the structure and nature of their inter-firm relationships and networks could serve as a valuable resource for developing more effective strategies and policies to accelerate the circular economy transition. The outcomes of this dissertation suggest that such an undertaking is worthwhile in order to quickly transform our current production systems through widespread adoption and diffusion of disruptive eco-innovations. In doing so, we can achieve a more circular economy and mitigate the strains on our planetary resources while ensuring societal needs are met.

## Contributions to Economic Sociology Research

This dissertation also makes important contributions to the economic sociology research agenda. The use of both qualitative and quantitative research methods in this study emphasizes how a mixed methods approach can provide a more in-depth understanding of complex social phenomena. In addition, this research demonstrates how sociological analysis can address key environmental and social issues by guiding policy and decision-making.

Using a mixed-methods approach is essential to triangulate and synthesize various types of information and perspectives and gain a more complete understanding of the specific topic of study (Fielding, 2012; Hussein, 2009). In this dissertation, a literature review was first employed to gain an overall understanding of the current state-of-the-art on the topic of eco-innovations and inter-firm networks and relationships. The use of content analysis provided a structured, quantitative method to analyze the qualitative data from the literature and yielded key insights into potential gaps and areas for further research.

The research approach employed in Chapter 2, further shows how a mixed methods approach can yield greater context. By complementing the interviews in the case study with a quantitative network regression, it was possible to build on the findings from the qualitative analysis. The results of the regression analysis enabled triangulation of the level of influence of inter-firm relationships and their effect on eco-innovation adoption.

Finally, Chapter 3 highlights how computational models can explore mechanisms and examine outcomes under different conditions in ways that empirical research and observational studies are not able to. Much of the literature referenced in Chapter 1 Chapter 3 were based on quantitative analyses and qualitative case studies, with few formal models. Through the theoretical agent-based model developed in Chapter 3, it was possible to analyze different adoption threshold scenarios that represented incremental and radical eco-innovations and provide further evidence of the importance of close, embedded relationships in firm networks for eco-innovation diffusion.

Furthermore, this study demonstrates how economic sociology theories and concepts can be applied to provide a deeper understanding of the environmental and social impacts of current economic production and consumption systems and how to address them. The focus of this research was to utilize these theories to examine the role of embedded relationships and networks between firms on the adoption of eco-innovations to accelerate the circular economy transition. However, sociological analysis has the potential to offer greater insights into individual behaviors, social constructs, and institutional considerations that can explain the context and nature of our current global economy. Through this lens, it is possible to uncover ways to change the root causes of economic decisions and transition to more sustainable models that reduce environmental impacts on planetary resources and improve social foundations to support our growing future population.

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