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ALLIANCE NETWORK STRATEGIES FOR CROSS-INDUSTRY COLLABORATION AND THE INTERNATIONALISATION OF R&D IN THE SEMICONDUCTOR INDUSTRY

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DECLARATION

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

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ABSTRACT

The overarching goal of this thesis is to explain, through conceptual and empirical analyses, how companies might utilise network strategies to facilitate achieving their desired outcomes from cross-industry and international collaboration in the semiconductor industry.

This research objective was achieved by creating a novel conceptual framework, combining theories from the fields of strategy and international business (IB) with theoretical concepts and methodological tools from network science. The aim of this approach was to advance the integration of social network analysis (SNA) into the fields of strategy and IB, and improve our understanding of the strategic and internationalisation decisions made by modern businesses.

This research is accomplished over three separate but connected studies. Disentangling the complexity of the overall semiconductor industry network, the first study finds that architectural network properties differ substantially between value chain stages, which may relate to the facilitatory role of distinct network configurations in the creation of alternative governance mechanisms and the implementation of different inter-organisational routines and processes at distinct stages of the semiconductor value chain. The tactical configuration of alliance relations does form a critical part of the alliance strategies of chipmakers, as the second study finds that chipmakers utilise integrated and protective triadic tactics to implement distinct alliance strategies, such as establishing cross-industry bridges for R&D collaboration. These complex network tactics might, by enhancing governance, facilitate maximising the R&D outcomes of strategic alliances in the face of environmental uncertainties created by industry pressures; as well as improving the cross-border coordination of cross-industry technology transfers and knowledge exchanges. The third study finds, namely, that chipmakers also execute their hybrid R&D internationalisation strategies through triadic tactics, which may point at the strategic utility of triads in overcoming such challenges inherent in creating (novelty) value through international R&D collaboration.

These findings contribute to the fields of strategic management and IB in explaining the mechanisms underpinning companies' network strategies and showing that companies utilise complex network tactics to pursue their strategic goals.

Keywords: *Strategic alliances, networks, triads, cross-industry R&D collaboration, international R&D collaboration*

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1. INTRODUCTION

1.1. Research motivation

Over the past years there has been a growing debate among academics and industry analysts alike on the role of strategic alliances and, increasingly, of alliance networks to the competitiveness of the firm (Gulati, 1998; Gulati et al., 2000; Gomes-Casseres, 2003; Contractor and Reuer, 2014; Kim et al., 2016; KPMG, 2018). Strategic collaboration within and across industries as well as within and across national and regional borders has become the cornerstone of the innovation and internationalisation strategies of many modern companies.

Traditionally, the process of selecting the 'best' partner or partners was considered the core of any alliance formation. The answer to the question what defines the 'best' partner(s) is debatable, but is driven in principle by the partner's ability to contribute to the achievement of the alliance's strategic goal, whether this is to minimise cost or maximise value through the alliance (Zajac and Olsen, 1993). The success of the alliance broadly depends on the partners' ability to bridge organisational differences, align their strategic vision and goals, and integrate operations, inter-personal relations and cultures (Kanter, 1994; Das and Teng, 2000). These aspects of alliance integration are, however, not captured by the partner selection approach in the traditional strategy literature; which is, therefore, not capable of adequately explaining the success of alliances.

The traditional partner selection principles are inherent in established theories and frameworks, such as the resource-based view of alliances (Eisenhardt and Schoonhoven, 1996; Das and Teng, 2000) and the dynamic capabilities perspective (Teece et al., 1997), which were designed to guide analysing the formation of strategic alliances. Adequately explaining the success of alliances, however, also requires analysing the relational configuration of alliances through a relational view (Dyer and Singh, 1998) and a network perspective (Coleman, 1988; Burt, 1992).

Using the traditional frameworks, most research has approached explaining the formation of alliances exclusively from a dyadic partner selection perspective, without any explicit consideration for (1) the other partners of the firm, (2) the partners of the potential partner and (3) the presence of alliances between the firm's existing partners and the potential partner (e.g. Anand and Khanna, 2000; Colombo et al., 2006; Lavie and Rosenkopf, 2006; Van Beers and Zand, 2014; Cabral and Pacheco-de-Almeida, 2019). Though, if we accept the premise that the firm's sources of competitive advantage are increasingly located beyond its ownership boundaries (Dyer and Singh, 1998; Alcácer et al., 2016), then sharing access to these sources with other companies may or may not be desirable in view of the firm's long-term competitive strategy – depending on its long-term strategic vision and goals. The firm's ability to derive competitive advantage from their alliances is therefore not merely determined by access to partner-specific assets (Rowley and Baum, 2008), as has predominantly been argued; but rather by access to these assets *in combination* with how the alliance relations are configured and governed by the firm at the network level. This shifts the basis for the firm's competitiveness toward its *network advantage* (Greve et al., 2014), away from exclusively firm-specific advantages (Caves, 1971) and collaboration advantages (Kanter, 1994) or inter-organisational rents (Dyer and Singh, 1998).

This is an important consideration and should arguably become an integral part of a mainstream framework for explaining the formation of strategic alliances. The main motivation of this research is, therefore, to combine both mechanisms, namely (1) the strategic selection of alliance partners and (2) the configuration of alliance relations, and to jointly integrate these mechanisms into a single framework which can also be applied in future research to analyse the alliance formations decisions of companies.

In spite of the growing recognition of the role of strategic networks by scholars across the broader field of strategy (Powell and Brantley, 1992; Powell et al., 1996; Gulati, 1998, 2000; Gadde et al., 2003; Chetty and Stangl, 2009; Cloodt et al., 2010; Martínez-Noya and Narula, 2018), there is still a noticeable absence of a dominant and empirically established framework in neither strategy nor international business (IB) offering a systematic way of (1) analysing the formation of alliance networks across value chains and (2) explaining variance in network strategies and resultant R&D outcomes and internationalisation advantages achieved by different firms through a combination of insights from established theories in strategy and IB on the one hand, and concepts and methodological tools from social network analysis (SNA) on the other hand.

This is not to say that scholars have not made any contributions in this respect. On the contrary, the current research is built on the valuable efforts made by scholars thus far to introduce the network view into the wider field of strategy (e.g. Madhavan et al., 2004; Verspagen and Duysters, 2004; Powell et al., 2005; Robinson and Stuart, 2002; Rosenkopf and Schilling, 2007; Rowley and Baum, 2008; Skilton and Bernardes, 2015; Davis, 2016; Kim et al., 2016; Tatarynowicz et al., 2016) and more recently – albeit to a lesser extent – the field of IB (e.g. Cantwell and Santangelo, 1999; Blankenburg Holm et al., 2015; Cano-Kollmann et al., 2016; Forsgren, 2016; Cantwell, 2017).

The established strategy literature as a whole, however, is limited in that it does not provide sufficient guidance on how alliance network strategies can actually be constructed and utilised by business managers to facilitate their long-term innovation and internationalisation strategies. On the one hand, much of the extant investigations into the wider topic of alliance networks in strategy and IB, whether the formation of alliance networks (Colombo et al., 2006; Lavie and Rosenkopf, 2006; Cabral and Pacheco-de-Almeida, 2019) or their implications for performance (Baum et al., 2000; Lavie, 2007) or internationalisation (Alcácer et al., 2016; Forsgren, 2016), typically use the notion of alliance 'networks' or 'network ties' in a metaphorical fashion without analysing networks as a strategy for innovation or internationalisation – which suggests that there is still a wide lack of understanding of the strategic role of networks. These studies typically analyse alliance networks in light of their composition, measured by the size or diversity of the firm's alliance portfolio (Nieto and Santamaría, 2007), and consequently give no consideration to the strategic implications of the structural configuration of networks and network tactics, and the way in which these can be measured.

On the other hand, work which did incorporate concepts and methodologies from network science often focused on demonstrating the importance of network positions, primarily measured in terms of network density following Coleman's (1988) concept of network closure (Reagans and McEvily, 2003; Gilsing and Nooteboom, 2005) or using Burt's (1992) 'structural hole' concept (Ahuja, 2000a; Zaheer and Bell, 2005; Soda, 2011), in relation to performance indicators at the firm level. These studies have shown that network positions are important to explain performance differences among firms. What they have not explained, however, is how firms can utilise networks as a strategy. As such, it is still not well understood (1) how network positions and their structural features might facilitate inter-organisational collaboration in terms of the collaborative processes and routines established in alliances; (2) how structural network effects influence the strategic partner selection process which underlies the firm's ultimate alliance network position; and (3) how the selection of a particular strategic partner contributes to the long-term network strategy of the firm.

Importantly, a lack of understanding of these relationships might lead to misleading research results and myopic strategy formulations. Moreover, by combining the relational composition and structural configuration of alliance networks into a single framework, we can improve our understanding of the strategic and internationalisation decisions made by modern businesses. Namely, although the field of IB has long acknowledged the importance of hybrid internationalisation strategies, extant IB models cannot explain how firms can configure their hybrid strategies to enter into foreign markets and develop internationalisation advantage.

1.2. Research goal and setting

The research presented in this thesis bridges these gaps between network science and strategy, and advances the integration of SNA into the field of IB. This research is accomplished over three separate but connected studies (Chapters 3, 4 and 5) with the overarching goal to explain how companies can construct alliance network strategies to facilitate achieving their desired outcomes from cross-industry and international collaboration in the semiconductor industry. A primary interest in this respect is to uncover how firms can construct distinct network tactics based on the partner composition and the relation configuration of the alliance relations within their ego networks, and utilise these network tactics to orchestrate the exchange of knowledge and the creation of value through R&D collaboration.

To achieve this, a novel conceptual framework is created to evaluate the strategic utility of network tactics, by combining theories from the fields of strategy and IB with theoretical concepts, models and methodological tools from network science. This approach demonstrates how the SNA methodology can improve our understanding of the strategic and internationalisation decisions made by modern businesses.

The empirical focus of this research is on the semiconductor industry, because this industry has one of the most complex and networked value chain ecosystems in the world (SIA, 2016) – making it a particularly suitable empirical context for testing the developed framework. Inter-organisational collaboration resembles a widely used strategy by semiconductor companies for conducting business activities across the industry's value chain (Hagedoorn, 1993; Stuart, 2000; Kapoor, 2010; Gloger et al., 2017) and, notably in R&D, is often undertaken within networks of strategic partners based within and outside the semiconductor industry as well as within and outside geographical borders (Cusumano and Gawer, 2002). The diverse population of organisations within this industry network enables investigating how the network strategies of semiconductor companies might differ according to the type of value chain activity that is conducted in collaboration and the types of partners which are involved. A detailed background on inter-organisational collaboration in the semiconductor industry is provided in Chapter 2.

The empirical analyses are performed on a network sample of 1,192 semiconductor companies, using a SNA methodology. One of the methodological contributions of the research is in the creation of a unique dataset by connecting two separate data sources: OSIRIS and Factiva. Overall, this dataset contains 5,465 alliance agreements formed by the semiconductor companies with intra- and inter-industry partners as well as domestic and international partners during the period 2004-2014. A more detailed discussion on the data collection process and the construction of the dataset is provided as part of the first study, in Chapter 3[1].

1.3. Research objectives

A number of research objectives are addressed over three independent but connected studies. Starting from the premise that the overall structure of a network influences the collective behaviour and business outcomes of the organisations within it (Gulati et al., 2000; Tatarynowicz et al., 2016), the first study in this thesis (Chapter 3) is focused on examining and disentangling the complexity of the entire semiconductor industry network. Specifically, the objectives are to highlight differences in the motives of collaboration and inter-organisational routines and processes between consecutive stages of the semiconductor value

[1] The second and third studies presented in Chapter 4 and Chapter 5, respectively, rely on the same network sample and will refer to the overview provided in Chapter 3, rather than repeating the same discussion.

chain, namely R&D, manufacturing, marketing and distribution, and supply; and to explain how these differences are linked to distinct network architectures characterised by varying degrees of network connectedness, concentration and clustering.

This will help to understand (1) the distinct collective outcomes that different types of network architectures produce, such as the proliferation of mutual trust and cooperation, the exchange of knowledge, and power asymmetries; and consequently (2) how these distinct collective outcomes (a) facilitate the inter-organisational routines and processes at particular value chain stages, and (b) lead to a collective preference by firms for distinct types of network architectures at different stages of the semiconductor value chain. In addition, this analysis enables uncovering the existence of dyadic relationships vis-à-vis alternative microstructures like triads (Madhavan et al., 2004), through which organisations and alliances are interconnected within the distinct networks. These microstructures are reflections of the strategic partner selections made by semiconductor companies at the level of their ego networks and offer some insight into the existence of distinct types of network strategies pursued by them within a given network.

Deeper analysis of these ego networks is needed, however, in order to adequately explain the strategic decision of organising strategic alliances within alternative microstructures as opposed to purely dyads. This constitutes the wider objective of both the second (Chapter 4) and third (Chapter 5) studies, albeit in the contexts of cross-industry collaboration and international collaboration, respectively. The focus in both of these studies is on the semiconductor R&D network, which is the most value-adding activity in the semiconductor industry (Yinug, 2016), which requires closer collaboration across industries, the exchange of knowledge and technologies and the joint application of technical skill and capabilities, beyond simply pooling resources, in order to create novelty. Moreover, the R&D ecosystem of the semiconductor industry also stands out as a particularly complex network built on both dyadic and triadic microstructures with alliances extending beyond the semiconductor industry. The choice of network tactic is therefore key for successful innovation and R&D internationalisation.

Specifically, the second study (Chapter 4) introduces and applies the concept of strategic utility of triads to evaluate whether, why and how chipmakers construct, through (1) structural configuration and (2) relational composition, triadic R&D alliances with intra- and cross-industry partners as a means of reducing uncertainty projected upon them by the increasing cost of R&D, increasing technological complexity, highly volatile product demand and intense competition. As such, an alternative approach to analyse the formation of R&D alliances is demonstrated to show how the configuration of R&D alliances within triads can enable companies to achieve long-term network advantages. Hypotheses are formulated and tested regarding a range of distinct R&D network strategies, using stochastic actor-oriented modelling (SAOM). SAOM allows explicitly capturing the interdependencies between the organisations in the semiconductor industry network through tests of structural network effects, such as the formation of triadic structures.

Finally, the third study (Chapter 5) builds on the concept of strategic utility and explores how chipmakers can achieve internationalisation advantage by utilising triadic tactics, notably, to build cross-industry bridges between strategically selected foreign technology and end-market partners in cross-regional R&D collaboration. This study advances research in the field of IB by offering a framework for analysing the internationalisation of R&D networks, and applying this framework through hypothesis testing using SAOM. Specifically, based on this framework, the study improves our understanding of how triadic tactics might facilitate (1) the enhancement of value and the novelty of value created through international R&D and (2) the acceleration of R&D internationalisation.

Overall, the three studies presented in this thesis enrich the fields of strategy and IB and improve our understanding of the innovation and international strategies of modern companies. Moreover, they offer recommendations on how firms can utilise their position within the industry network strategically to achieve strategic advantage and develop cross-industry network strategies for internationalisation.

2. Industry background: Collaboration in the semiconductor industry

With total global sales of US$335 billion in 2015 (Semiconductor Industry Alliance, 2016) and its role as core technology enabler for sectors ranging from consumer electronics to medical and automotive, the semiconductor industry plays a pivotal role in the growth direction of today's digital economy. Used in anything that is computerised or uses radio waves, such as the first transistor radio in the 1950's, semiconductors – or integrated circuits, microchips or just 'chips' – now function as the heart of smart phones, laptops, flat-screen displays, medical devices, airplanes and military defence systems (see Figure 2.1 for an illustration). The 2 to 2½ years that it takes to develop a new generation of chips (Global Semiconductor Alliance, 2016), as dictated by Moore's Law, is so financially and technologically intensive that this industry has evolved around one of the most complex, geographically dispersed and intertwined value chain ecosystems in the world (Semiconductor Industry Alliance, 2016).

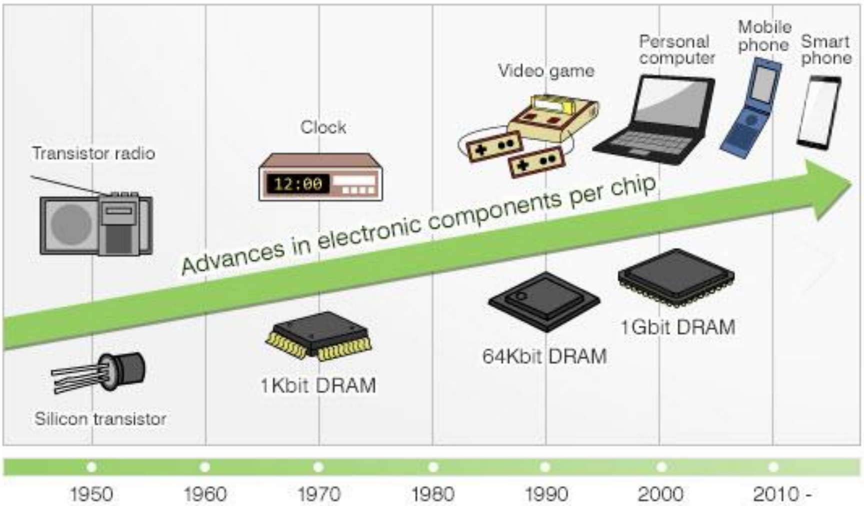


Figure 2.1: Evolution in semiconductor technology (source: Hitachi, 2019)

To fully comprehend the role of cooperation and the importance of networks to firms in the semiconductor industry, a first essential step is to understand the inherent complexities that are involved in developing semiconductors, how the semiconductor value chain is structured, and how it has evolved over the past decades. This will be explored in the next sections.

2.1. Characteristics of the contemporary semiconductor industry

2.1.1. Industry pressures

There are various unique characteristics that set the semiconductor industry and its ecosystem apart from other high-technology industries studied in the strategy literature. Rapid technological advancements, the ongoing emergence of new technological markets, and the ever-changing customer demand for specialty products impose short product lifecycles (as short as under one year), making the semiconductor industry highly volatile (Figure 2.2) and competitive (Katircioglu and Gallego, 2011; Bauer et al., 2011). The development of new semiconductor products is therefore best described as a technological race for the quickest time-to-market and the best product functionality and performance at minimal cost (Collet and Pyle, 2013).

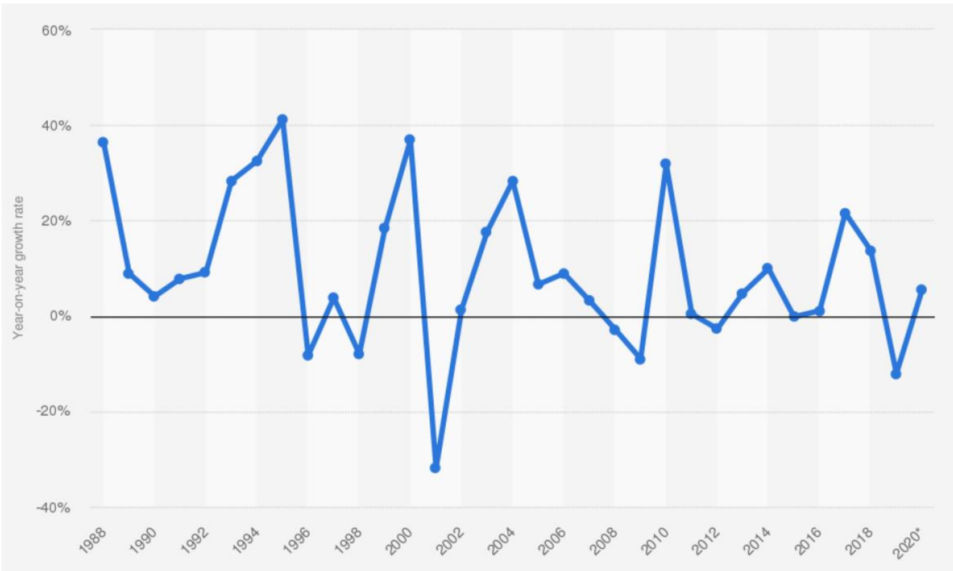


Figure 2.2: Global semiconductor industry revenue growth from 1988 to 2020 (source: Statista, 2019)

Achieving these objectives, however, coincides with rising costs in R&D, design and manufacturing, due to the ever increasing complexity of chips and the costly need to upgrade existing fabrication plants ('fabs') in order to keep up with technological change (Semiconductor Industry Alliance, 2016). To illustrate: between 1994 and 2014, total R&D spending by US semiconductor firms grew at an average annual rate of roughly 33% (Semiconductor Industry Alliance, 2015). In 2015, total global R&D investments in the semiconductor industry amounted to US$56.4 billion, which equated to industry-wide investment rates of between 15-20% – making the industry one of the most R&D intensive in the world. By comparison, automakers generally maintain rates of 3% (Heck et al., 2011).

The cost of a chip design project can reach up to US$200 million, depending on the complexity of the chip development and the nature of its end market (Tamme et al., 2013; Global Semiconductor Alliance, 2016). Furthermore, the costs involved with constructing a state-of-the-art fab generally range between US$1.6 billion and US$4 billion[2], and developing the

[2] In 2010, Taiwan Semiconductor Manufacturing Corporation started construction of a new *US$9.3 billion* foundry (TSMC, 2010).

necessary process technologies for the fab can amount up to another US$600 million (Heck et al., 2011; Nenni and McLellan, 2013). If we also take into account the short chip generation cycles, depreciation costs of a fab can consequently reach up to US$1 billion a year. Accordingly, in order to keep unit costs low and protect profit margins, fab owners must strive to maximise utilisation of capacity (Katircioglu and Gallego, 2011) or, as described by industry participants, 'fill the fab' (Nenni and McLellan, 2013). This illustrates well the high levels of risk and financial commitment which are associated with the semiconductor industry, as well as the resultant high barriers to entry that have made it increasingly expensive and hugely difficult for start-ups to establish a presence in the industry.

In order to mitigate these high investments in R&D, design and fixed capital assets, and to overcome the uncertainty of constant technological change, semiconductor firms have long readjusted the basis of their competitive advantages. By developing business models centred on inter-organisational collaboration and spanning beyond regional borders, notably across the Americas, Europe and Asia (Figure 2.3), these firms have been able to achieve operational efficiencies and respond effectively to changes inside the industry. China, in particular, has been growing rapidly over the last decades (Figure 2.3) – as a market for complementary technologies and R&D expertise as well as for the commercialisation of new chip technologies (Ernst, 2005). As will become clear from the next sections, the semiconductor industry is uniquely structured to enable firms to generate maximum strategic advantage from the wide diversity of skills, know-how, human resources, and location-specific assets of strategic partners based elsewhere across the globe.

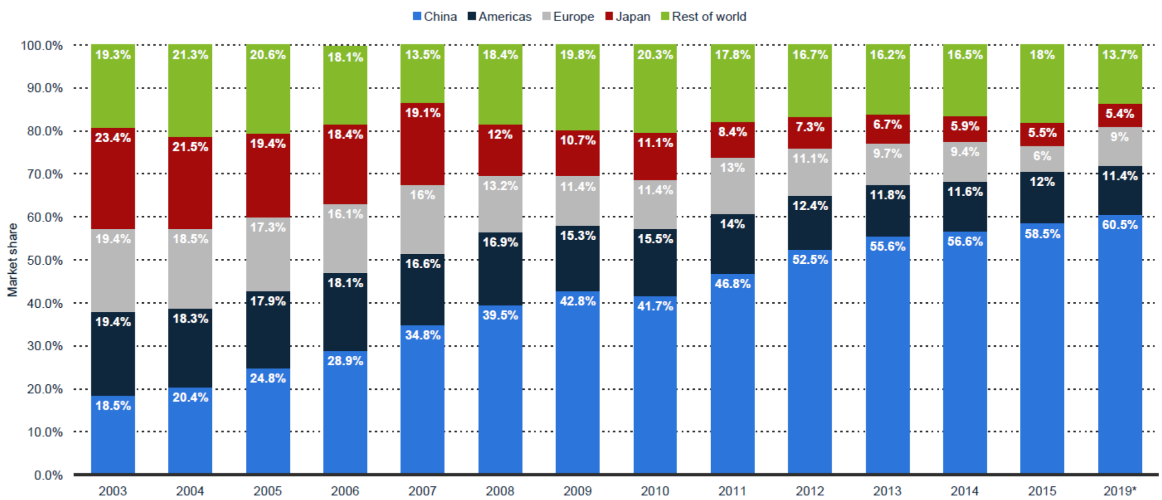


Figure 2.3: Global semiconductor market share by geographical region (source: Statista, 2019)

2.1.2. The semiconductor innovation cycle

Since the late 2000's, increased demand for customisation and the growing popularity of the System on Chip (SoC) platform have been shaping the strategies of companies in the semiconductor industry. The semiconductor industry has since the 1980's gradually gone through an evolution of disintegrating the semiconductor value chain, whereby building networks of strategic alliances between chip designers and companies operating at other stages of the value chain became essential for success (see Section 2.4 for a detailed overview of the evolution of the semiconductor industry). Competing chipmakers eventually ended up having access to broadly the same components and manufacturing processes based on the same standards. Hence, during the 2000's, the industry arrived to a phase whereby hardware products became commoditised as a result of standardisation, and chipmakers began struggling to maintain their profit margins and to differentiate their products in terms of performance or cost.

The industry's cycle between phases of standardisation and customisation was initially described by Tsugio Makimoto in 1987, dubbed 'Makimoto's Wave', who predicted that each phase should endure for about 10 years; with the basis of competition swinging as a pendulum between (1) innovation in functionality, performance and reliability; and (2) innovation in speed, convenience and customisation (see Figure 2.4). In 2010, following a prolonged period of standardisation and chipmakers' failing economic models[3] (Wingard, 2014), a new phase of customisation was partially set off by the decision of the large system companies Apple and Samsung to begin developing their own suite of cell phone application processor chips, respectively starting with the 'Apple A4' and 'Exynos 3 Single' SoCs, as standard SoCs offered by the semiconductor industry were not meeting their demands for speed, convenience and customisation, thus forcing out major chipmakers from the market (McLellan, 2014).

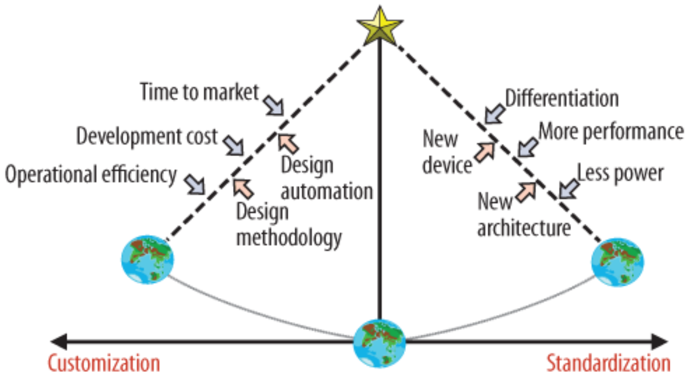


Figure 2.4: Semiconductor Pendulum (Makimoto, 2002)

[3] For example, in the cell phone and digital TV markets, semiconductor companies attempted to build increasingly larger SoC platforms targeting an ever broader set of applications in order to generate the consumer volumes necessary to turn a profit. The economies of scale promised by standardized semiconductor platforms fell apart as the designs became too monolithic and the cost for a single development program reached upwards of $200 million.

Aside from smart phones, SoCs are increasingly embedded in devices of a wide variety of systems, including wearables, cars and sensors; and an essential enabler of the Internet of Things (IoT), with the rise of cloud computing, machine to machine (M2M), big data and artificial intelligence in particular. A single SoC can integrate multiple core processing units (CPUs), a graphics processing unit (GPU), a wireless modem as well as other software and hardware to support functions such as a global positioning system (GPS), camera, gesture recognition, audio and video. SoCs are highly efficient in the use of space and power in the devices into which they are embedded, enabling systems companies in the end-industries to design increasingly smaller and thinner devices. Accordingly, the shift towards customisation and the integration of hardware, software and systems is being driven by a growing demand for application-specific packaging and ever more miniaturised computing power requirements for end-systems (Wingard, 2014; McLellan, 2014).

The complementary technologies which are integrated into SoCs may be developed by the same chipmaker, but they are typically sourced from or jointly developed with specialised partners within and outside of the semiconductor industry. Consequently, the growth in the deployment of IoT devices vis-à-vis traditional devices, such as PCs (see Figure 2.5), implies a shift in the R&D activities and processes of chipmakers, with greater emphasis on the collaboration between chipmakers and cross-industry partners to integrate an increasingly complex technologies into chips.

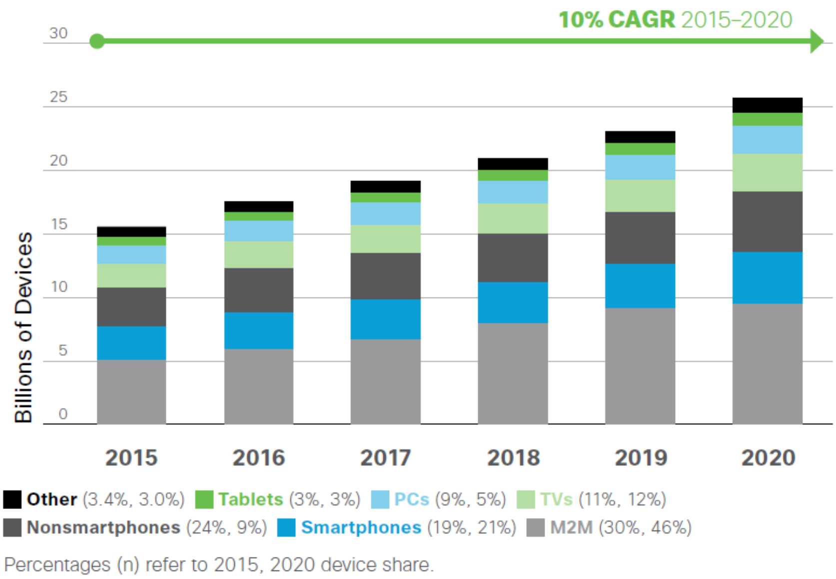


Figure 2.5: Growth of global devices and connections (source: Cisco, 2016)

2.2. The semiconductor value chain and ecosystem

From conception to completion, the creation of a new generation of chips starts with R&D, followed by design, foundry fabrication services (manufacturing), assembly, testing and packaging, and finally distribution to the end market (see Figure 2.6). Each of these core stages of production is highly specialised, and participants compete on the basis of cost advantages or R&D excellence and technological competence. The R&D function of the value chain, however, need not necessarily be competitive by definition. In light of promoting technological innovations, while also sharing the enormous costs of developing new technologies, semiconductor companies may forge joint development projects with rivals, universities, national governments, and research institutes.

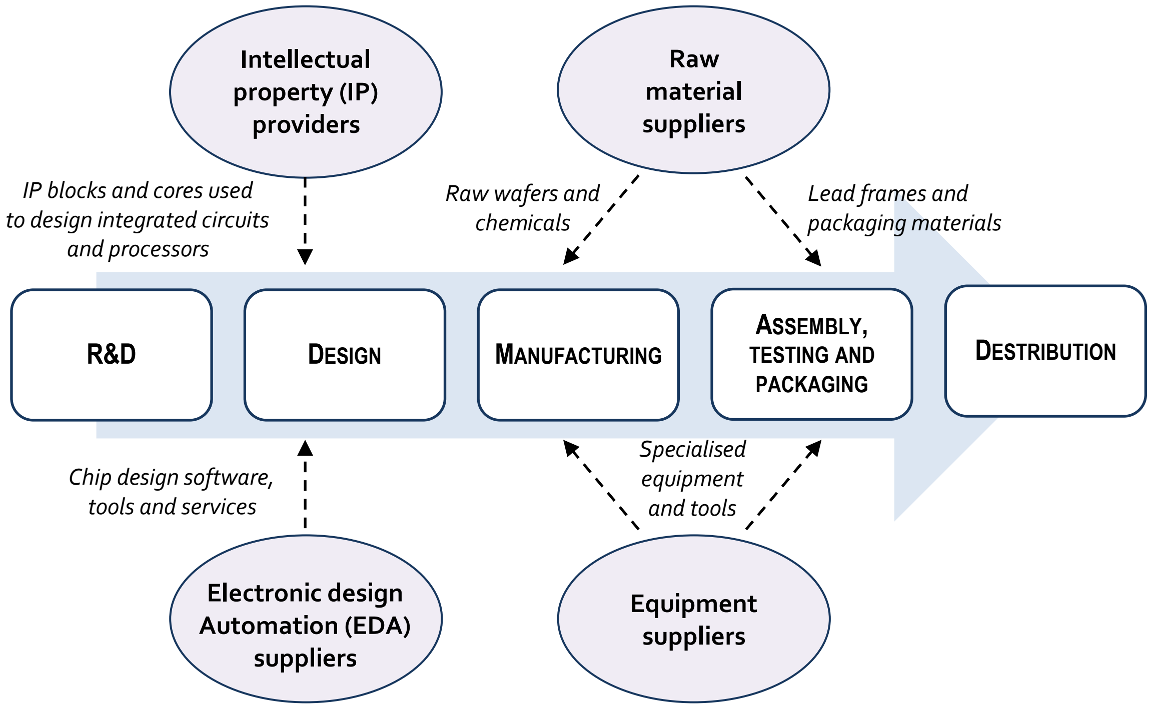


Figure 2.6: The value chain and ecosystem of the semiconductor industry (source: Semiconductor Industry Alliance, 2016)

Accordingly, over the years, various technology consortia have been established with the objective of researching and developing new semiconductor materials, process technologies, and manufacturing equipment. Some of the most well-established consortia include *SEMATECH* (Semiconductor Manufacturing Technology) in the US, the *Centre for Semiconductor Research* at the State University of New York, the *Industrial Technology Research Institute* (ITRI) in Taiwan, the *Interuniversity MicroElectronics Center* (IMEC) in Belgium, and the *Institute of Microelectronics* in Singapore.

The core of the semiconductor value chain is supported by a number of specialised types of suppliers, which complete the ecosystem of the semiconductor industry. Providers of semiconductor IP, such as *ARM Holdings*, *CEVA* and *Imagination Technologies*, specialise in developing and licensing so-called IP 'blocks' or 'cores' of integrated circuits to chip designers, which integrate these blocks into their chip designs. Electronic design automation (EDA) companies, such as *Cadence Design Systems*, *Mentor Graphics* and *Synopsys*, provide computer-aided design (CAD) services and develop software for designing chips, circuits, and various semiconductor IPs, which they license to chip design companies (typically through a 3-year time-based license). Raw material suppliers produce and supply raw chemicals, wafers (such as crystalline silicon) to foundry players and packaging materials to the assembly, testing and packaging segment. Finally, semiconductor equipment manufacturers, such as *ASML Holding*, *Applied Materials* and *Aixtron*, produce and supply specialised machines and equipment for the manufacturing, assembly, testing and packaging of integrated circuits.

2.3. Chipmaker operating models

2.3.1. In-house versus outsourcing chip manufacturing

Starting in the early 1980's, the customer-driven demands for speed, convenience and customisation along with the rising costs of R&D and manufacturing, sent various waves of disruption through the semiconductor industry. The enormous investments required to construct a state-of-the-art fabrication facility meant that only the largest and best established companies with the ability and necessary resources to afford the immense sunk costs and the scale to consistently run the fab at capitalisation rates of at least 90% (Wong et al., 2014), could maintain efficiency and survive. This growing importance of specialisation and scale (Naeher et al., 2011) led to a series of collaborative revolutions, ultimately vertically disintegrating the semiconductor value chain and shifting the basis of competitive advantage away from manufacturing to product-development capabilities – placing collaborative networks at centre stage.

Today, the industry is dominated by two key chipmaker types which are based on distinct operating models (Figure 2.7): (1) the integrated device manufacturer (IDM), which performs all stages of production in-house; and (2) the fabless-foundry model. 'Fabless' companies are those firms that do not own fabs and concentrate solely on the design stage of the semiconductor production process. Running fabs is not efficient for these companies because they lack the scale needed for high-volume fabrication (Ladendorf, 2004). However, by forging long-term partnerships to outsource the fabrication of their designs to dedicated foundries, and the assembly, testing and packaging of their chips to outsourced assembly and test companies (or OSATs), they spread the risk and financial costs associated with the short product cycles and slumps in chip demand to these manufacturing service providers (Harlin, 2010). Larger fabless companies may have a larger portfolio of partnerships with various manufacturing partners, enabling them to constrain potential opportunism of the supplier, reduce the risk of losing supply, introducing price competition, and achieve faster time-to-market.

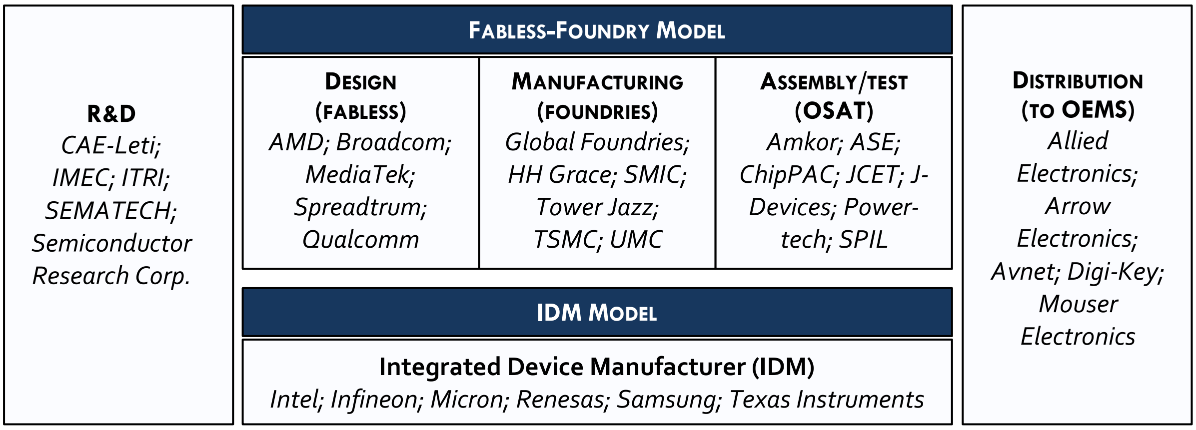


Figure 2.7: The operating models in the semiconductor industry (source: Semiconductor Industry Alliance, 2016)

In the early stages of this industry transformation, the fabless model was infamously dismissed with the phrase "Real men have fabs", as initially introduced by Jerry Sanders, a founder and former CEO of US-based *Advanced Micro Devices* (AMD). Today, however, some of the most successful semiconductor companies are in fact fabless, such as *Broadcom* and *Qualcomm*, and about 40% (Clarke, 2014) of total global semiconductor sales are generated by the fabless segment.

The IDM business recognised the benefits of collaborative ecosystems. Due to the immense and increasing costs and risks of setting up, maintaining and upgrading fabrication facilities, as well as the increasing competitiveness of the foundry segment, many traditional IDMs have resorted to a hybrid model, or 'fab-lite' strategies, whereby they perform in-house production for specialty devices while outsourcing a share of their process capacity needs to dedicated third-party foundry players (Tamme et al., 2013; Semiconductor Industry Alliance, 2016). Retaining a share of the production in-house through fab-lite strategies also allows these IDMs to hedge against potential opportunistic behaviour of the foundry company and the risk of increasing foundry fees.

Once considered as technology laggards, these specialised foundry companies, such as Taiwan's *TSMC* and *UMC* and Singapore's *Chartered Semiconductor Manufacturing Ltd*, are now among merely a handful of firms that are able to afford the increasing cost of owning fabs and that have a large enough network of customers to maximise capitalisation and efficiency (Ladendorf, 2004). This gives them a cost advantage over traditional IDMs, in turn making them an attractive strategic partner enabling IDMs to avoid excessive capacity investment risk (Wu, 2014). Accordingly, only a few huge (in terms of capacity) IDMs are able to win in the industry's fierce drive toward efficiency, such as *Intel Corp* of the US or *Samsung Electronics* of South Korea. For others, full vertical integration has become a competitive disadvantage (Christensen and Raynor, 2003). Accordingly, estimations from 2009 show that relatively smaller IDMs are outsourcing varying shares of their production to foundries: *Texas Instruments* (55%), *Freescale Semiconductor* (23%), *STMicroelectronics* (20%) and *Renesas Electronics* (10%) (Wu et al., 2014). In a similar vein, in early 2009, the once fully integrated *AMD* spun off its complete chip fabrication facilities due to the climbing costs of maintaining and upgrading these plants.

Table 2.1: Preliminary market shares for the top 10 chipmakers in 2015 (source: IHS Technology, 2015)

Rank	Company	Operating model	Revenue (*in billions*)	Market share
1	Intel Corp	IDM	US$49.3	14.0%
2	Samsung Electronics	IDM	US$40.7	11.6%
3	SK Hynix	IDM (fab-lite)	US$16.9	4.8%
4	Qualcomm	Fabless	US$16.2	4.6%
5	Micron Technology	IDM (fab-lite)	US$14.8	4.2%
6	Texas Instruments	IDM (fab-lite)	US$12.3	3.5%
7	NXP	IDM (fab-lite)	US$10.1	2.9%
8	Toshiba	IDM (fab-lite)	US$9.2	2.6%
9	Broadcom	Fabless	US$8.4	2.4%
10	Avago Technologies	IDM (fab-lite)	US$7.0	2.0%

Increasingly more fabless and IDMs pursuing fab-lite strategies have joined the top ten chipmakers (see Table 2.1). Beyond this group of top-performing companies, the core of the semiconductor industry is essentially populated by fabless chipmakers, IDMs with fab-lite strategies that use foundries for leading-edge fabrication processes, or IDMs who manufacture all of their chips in-house (Nenni and McLellan, 2013). By outsourcing the fabrication of their semiconductor devices, fabless and fab-lite IDMs can compete much more effectively with the industry leaders. These chipmakers are advantaged in that they can generate a substantial amount of revenue per employee. To illustrate this: in 2015, fabless player *Xilinx* achieved roughly US$2.38 billion in revenues with 3,451 employees, or nearly US$690,000 per employee (Xilinx, 2015). By contrast, *Cypress Semiconductor Corp*, a fab-lite IDM, reached US$256,000 per head (Cypress Semiconductor, 2015) and *NXP Semiconductors*' much larger fab-lite chip business generated only US$136,000 per employee (NXP, 2015). In result, growth in global sales by fabless chipmakers has been outpacing that of IDMs over the past decades (see Figure 2.8); although IDMs are still leading the industry.

However, relying on foundry partners for the production of all or a fair share of chips is not entirely risk-free. It places a huge dependence on chip makers, and shifting between foundries is known as an onerous process due to the various qualifications and extensive tests that products must pass in a new factory before they are ready to be sold in their respective end-markets. This inefficient process would impose a high level of transaction costs, making it imperative to develop mutual trust. It is therefore essential that chip makers build deep relationships with their foundry partners and develop strict routines for the exchange of information and knowledge. Accordingly, US-based *Silicon Labs* has been reported to exchange information with its Taiwanese foundry partner every week and its chief executive would visit the foundry on a quarterly basis to reinforce the strength of their inter-firm ties and to maintain a detailed flow of communication (Ladendorf, 2004).

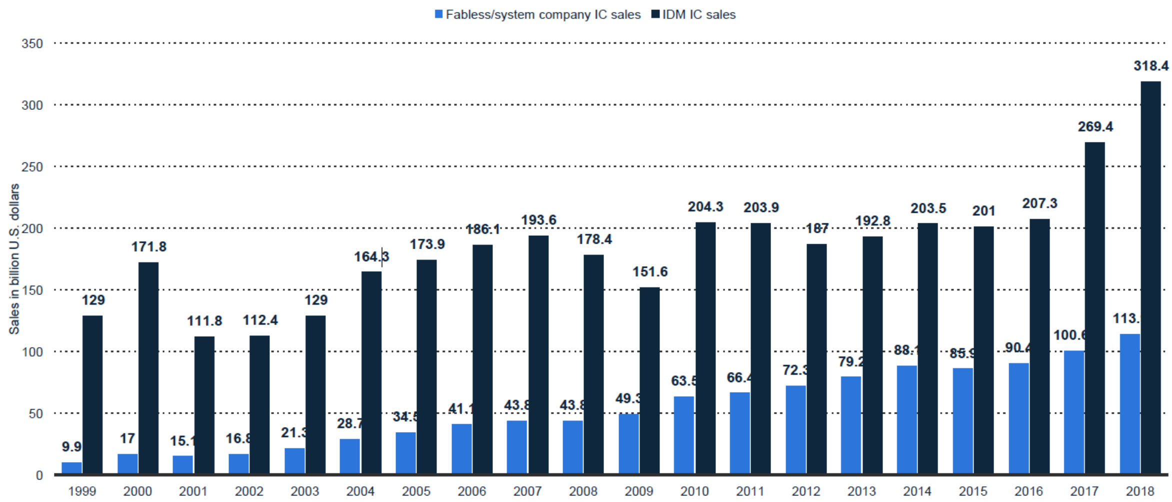


Figure 2.8: Worldwide chip sales by fabless chipmakers and IDMs (source: Statista, 2019)

However, relying on foundry partners for the production of all or a fair share of chips is not entirely risk-free. It places a huge dependence on chip makers, and shifting between foundries is known as an onerous process due to the various qualifications and extensive tests that products must pass in a new factory before they are ready to be sold in their respective end-markets. This inefficient process would impose a high level of transaction costs, making it imperative to develop mutual trust. It is therefore essential that chip makers build deep relationships with their foundry partners and develop strict routines for the exchange of information and knowledge. Accordingly, US-based *Silicon Labs* has been reported to exchange information with its Taiwanese foundry partner every week and its chief executive would visit the foundry on a quarterly basis to reinforce the strength of their inter-firm ties and to maintain a detailed flow of communication (Ladendorf, 2004).

2.3.2. R&D collaboration by chipmakers

Since the dominant share of chipmakers have adopted either the fabless or fab-lite model, competitive advantage across the semiconductor industry is no longer derived from manufacturing differentiation, but predominantly from R&D excellence and technological leadership (Cusumano and Gawer, 2002); the ability to design the most functional and best performing products in the shortest amount of time (Collett and Pyle, 2013). Accordingly, every year chipmakers increase their investments into their R&D activities (Figure 2.9) in order to meet the changing demands of customers and to stay ahead of competition. Figure 2.9 suggests that this is especially important to IDMs, such as Intel and Samsung, as their R&D investments determine their ability to remain at the forefront of the industry's technological frontier and, consequently, maintain their leading market positions needed to offset their large operating costs. Conversely, for those chipmakers who do not have the same amounts of resources which they can invest into R&D to advance their value creation capabilities, R&D collaboration with strategic partners both within and outside the semiconductor industry is *especially* critical – which enables sharing the increasing cost of R&D, overcoming the increasing complexity of chip technologies, meet the changing demands of customers, and keep up with competition.

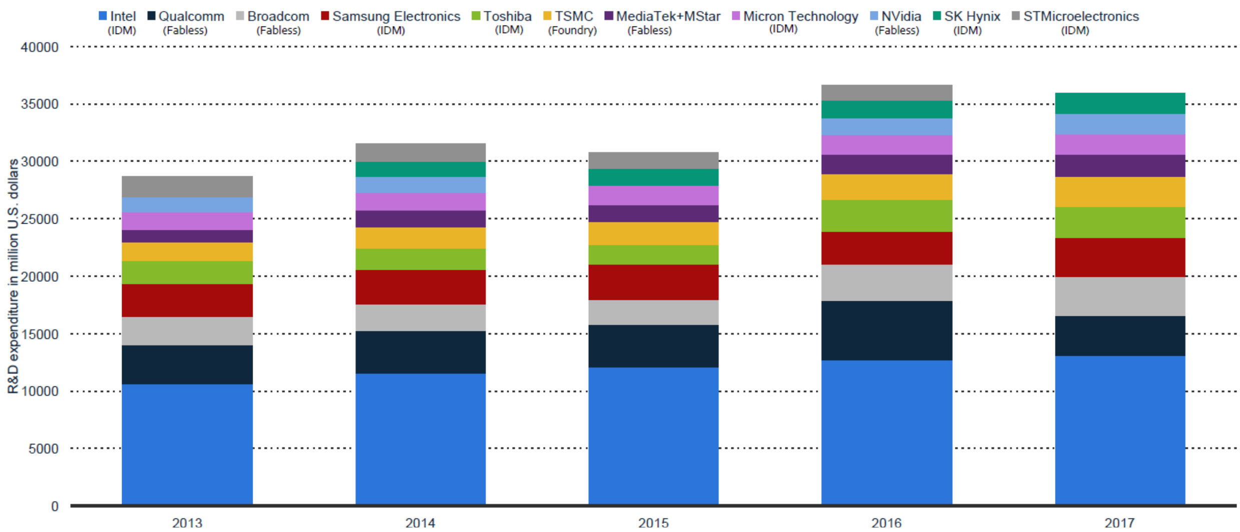


Figure 2.9: Top semiconductor vendors by worldwide R&D expenditure (source: Statista, 2019)

Consequently, one of the key factors determining who wins in the race for technological leadership is the strategic advantage that firms accumulate from establishing superior innovation networks of deep and sticky inter-organisational relationships with R&D partners in various industries and locking in external resources that enable them to sustain technological differentiability. According to research done by Heck et al. (2011), top performing semiconductor companies typically have closer relationships with key partners and customer. This enables them to enhance their value creation capabilities by leveraging the R&D skills and capabilities of strategic partners, as well as accessing deep insights regarding ongoing and future market developments and evolving customer requirements. Strong networks of strategic partners can also enable access to new IP, capital investments from leading foundries which are seeking to provide integrated solutions, or advanced-packaging technologies, among other resources.

Each operating model has its own way of using R&D collaboration to combat the intense competition. Beyond the outsourcing of production, technology licensing has had a long tradition in the semiconductor industry. IDMs and fabless firms generally build strong licensing relationships with specialised IP developers and EDA software providers. Developing the increasingly complex chips which the markets demand has become so costly and slow, that even or those firms that have the necessary in-house capabilities it is more efficient to license IP from specialised suppliers (Tamme et al., 2013). The strategic rationale of building networks of strategic ties to IP suppliers revolves around securing the latest advancements in logical and circuit blocks, processor cores and chip design tools, while concentrating internal R&D resources on developing more value-added IP. Ultimately, this enables accelerating time-to-market. Similar collaborative responses to competitive pressures are also manifest on a horizontal basis, between rivals. For example, in 2005, chipmakers *Cree Inc* (USA) and *Nichia Corp* (Japan) signed a long-term cross-licensing agreement in order to battle competition by sharing new production technologies to lower fabrication costs (Nichia, 2005). Configuring networks of both vertical and horizontal alliance partners may thus carry important strategic implications for the firm.

Even the modern foundry business has recognised the importance of building superior alliance networks. Foundry players now compete by collaborating with and licensing various types of semiconductor IP from IP suppliers and fab-lite players and by building large networks of third-party EDA centres in order to optimally support fabless/fab-lite customers with designing and producing their new generations of chips. As a case in point, through a network of partnerships with various IP providers, South Korean foundry firm *MagnaChip* provides its customers with direct access to proven IP which would otherwise be costly for them to develop in-house (MagnaChip, 2019). Accordingly, foundries are able to attract new customers by developing a network of strategic IP partners; enabling them to leverage the status of their partners, offer new and sophisticated products and services, and to expedite the process of reaching high volume production of new chip designs (Naeher et al., 2011). This illustrates well the importance of strategic alliances and the transfer of IP to the competitive advantage of firms across the semiconductor industry.

Chipmakers may also outsource chip development in addition to chip fabrication. Consider the example of Fujitsu, which used to fabricate system chips in-house, making it a natural competitor to other companies in the foundry segment – until 2010. Fujitsu conceded to the increasing competitive strength of the foundry segment and resorted to outsourcing a share of its production to rival TSMC – a strategic relationship which soon thereafter was deepened by including the joint development of new advanced products (Nikkei, 2010). Nowadays, Fujitsu assumes the role as *broker* between chip users in the end-markets and its partner TSMC; observing new customer requirements and assigning production and development responsibilities.

The joint development of new technologies and products, however, is not confined to only the core of the semiconductor industry. Suppliers of semiconductor manufacturing machines and equipment, also, are using a combination of horizontal and vertical alliances as a means of pooling R&D resources and spreading the increasing cost of developing new manufacturing tools, which can reach up to tens of millions of dollars (Baldwin, 2005). Accordingly, the use of joint development pacts, contract-manufacturing and sourcing agreements has become a common trend in this segment of the industry.

Furthermore, universities and research centres play a critical role in semiconductor R&D, particularly at the pre-competitive stage of fundamental R&D (Rea et al., 1997; Bruynseraede, 2009; Logar et al., 2014). These partners possess specialised fundamental research expertise and may provide chipmakers with early access to technological breakthroughs or knowledge about new fields of semiconductor technology, and can facilitate chipmakers in identifying or redirecting new innovation opportunities. Hence, many chipmakers invest heavily in forging R&D partnerships with universities and research centres. As a recent example, in 2013 TSMC established multiple research centres at four universities in Taiwan, and the company also partners with top universities in the USA, both to cultivate new talent and to collaborate on the development of new semiconductor technologies (TSMC, 2020). The *Interuniversity Microelectronics Centre* and the *Fraunhofer Society*, as well as the more recently established *nanoelectronic Computing Research (nCoRE)* and the *Joint University Microelectronics Program (JUMP)* in the USA, are other examples of long-term partnerships where chipmakers and universities/research centres collaborate pre-competitively to advance chip architectures and system designs while spreading the rapidly increasing cost of R&D (Semiconductor Industry Alliance, 2019).

In this race for technological leadership and the search for external resources, current partners can be crucial sources of information regarding new partnering opportunities. For instance, mutual distributing partner *China Electronic Appliance Shenzhen Co., Ltd.* played a pivotal role in connecting US-based *Freescale Semiconductor* and *Zhuzhou CSR Times Electric* (a Chinese rail transportation company), whom subsequently established a joint R&D laboratory for microelectronics applications (Business Wire, 2007). Similarly, the association with industry leaders also bears other clear strategic benefits to the semiconductor firm. In 2006, *Agilent Technologies* jointly developed a new test solution in cooperation with *Freescale Semiconductor*. The then vice president of *Agilent* stated that the close association with an industry leader such as *Freescale* is essential to its strategic position in the industry (Agilent Technologies, 2006), which is due to the obtained access to *Freescale's* widely-adopted chipset platform, as well as its established distribution channels and customer relations with (influential) end-users (Stuart, 2000).

While these examples of strategic partnerships provide a good indication of the types and the extent of alliance activities in the semiconductor industry, they only scratch the surface of the true complexity and dispersion of the global semiconductor industry network. In fact, many chipmakers collaborate with the same partners, serve the same customers, and use the same suppliers. This overlap of relationships adds further complexity to the partnering decisions of firms and the way in which they structure their alliance networks.

Furthermore, the growing demand for SoCs to enable an increasing range of new product innovations has been calling for a change in the way chipmakers operate and compete. This is especially true for fabless chipmakers, as they dominate the SoC segment (Saito, 2009). Whereas the collaborative strategies of chipmakers were traditionally focused on developing better performing chips at a lower cost, the emergence of the IoT and wearables has been increasing the value of embedded systems and associated application software in products, requiring chipmakers to shift their strategic focus to developing highly integrated solutions with dedicated functions aimed at enabling actual applications. Accordingly, opportunities for new chip development projects are closely linked to end-user industries (Zhang and Roosmalen, 2009) and have been calling for the transition to a 'silicon to services' business model (Global Semiconductor Alliance, 2018).

To capture value and avoid becoming obsolescent, Bauer et al. (2015) concluded that chipmakers should deliver fully integrated solutions, covering multiple layers of the technology stack – if they are to extract full value from the IoT. This implies that chipmakers need to complement their traditional capabilities in chip design with capabilities in software development and system integration. Closing the gap between these capabilities is critical as it determines the difference between the ability to develop a high- or low-end product.

2.4. Evolution of collaborative activities in the semiconductor industry

Since its emergence in Silicon Valley in the 1950's, the semiconductor industry has gone through a number of disruptive revolutions which transformed the industry's production process and innovative efforts and placed the importance of strategic partnerships centre stage. As a further contextual supplement to the main analyses performed in this thesis, below follows a description of the various stages through which the semiconductor industry has evolved over the past decades (Figure 2.10 provides a visual illustration). Where it is not explicitly stated, information has been adopted from Nenni and McLellan (2013).

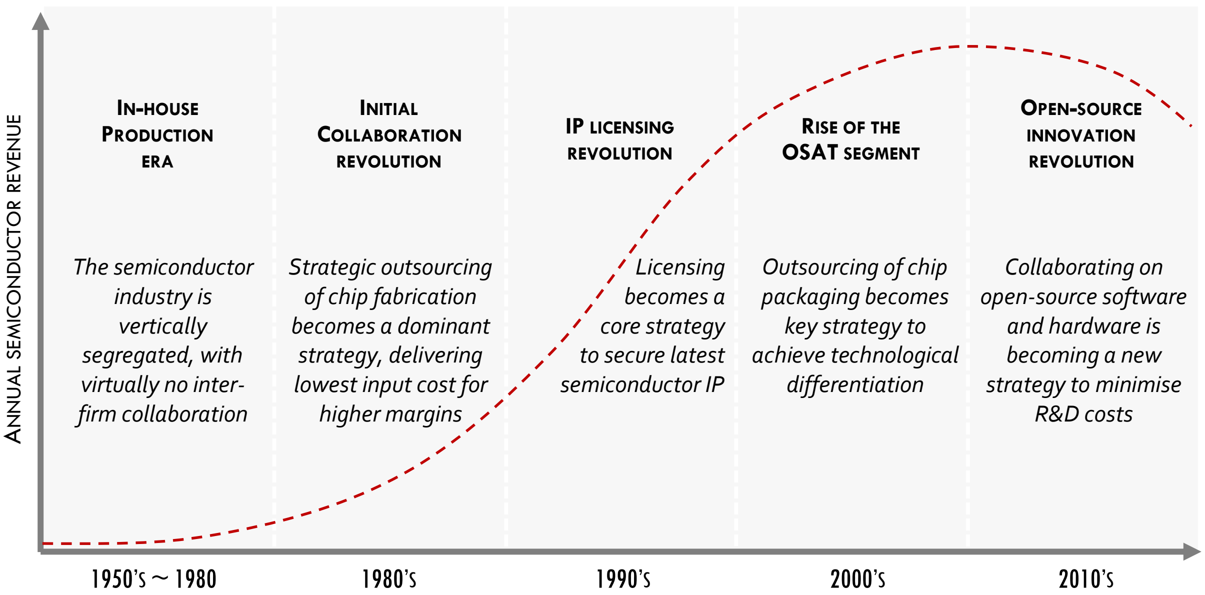


Figure 2.10: Evolution of collaborative activities along the semiconductor industry life cycle (source: created by the author)

1950's ~1980 – In-house production era

Over the first 30 years leading to the early 1980's, the semiconductor industry was vertically segregated, following the integrated manufacturing model. Companies that owned manufacturing facilities researched, developed, manufactured and marketed their own products. During this period, there was virtually no collaboration between these firms. Inter-organisational interaction primarily revolved around the supply of semiconductor devices for military and mainframe applications.

1980's – Initial collaboration revolution

Initial collaborative activities between semiconductor firms began to develop in the wake of the emergence of the personal computers market during the 1980's. In order to manage excess capacity and increase the ROI of the capital intensive semiconductor manufacturing process, IDMs started offering smaller firms design, manufacturing, and packaging services. The first fabless semiconductor companies, such as *Xilinx* (est. 1984) and *Chips & Technologies* (est. 1985), operated a business model based on strategic partnerships with these IDMs in order to tap into their excess manufacturing capacity. This marked the earliest stage of the outsourcing revolution which led to what we now call the fabless semiconductor industry.

In 1987, the establishment of the *Taiwan Semiconductor Manufacturing Corporation* (TSMC) gave birth to the foundry segment which consequently enabled the emergence of the fabless operating model. Initially started as a provider of semiconductor manufacturing services to IDMs who were suffering a deficit in their own fabs, TSMC's focus shifted towards the fabless and fab-lite ecosystem after increasing numbers of these players entered the industry. Essentially, TSMC made it possible for fabless chipmakers to have their products manufactured on a contractual basis. This meant that they no longer had to rely on in-house fabrication facilities, enabling them to focus their internal resources on the design stage of the semiconductor production process.

The year 1987 also saw the development of *SEMATECH*, one of the first consortia between the US government and US-based semiconductor manufacturers – as a response to Japanese competitors and as a means of jointly conducting R&D concerning semiconductor manufacturing techniques (Hof, 2011). From 1996 onwards, however, *SEMATECH* abandoned the initial US government-driven initiatives and shifted its focus towards joining broader industry participation from across sub-sectors and becoming a unified global consortium (Sematech, 2013). This is also when the wider semiconductor industry saw increased activity in R&D collaboration between semiconductor organisations within and across national borders.

The period of the 1980's also marked the emergence of Electronic Design Automation (EDA) as an industry. Large electronics/semiconductor companies, such as *Intel* and *Hewlett Packard*, had traditionally performed EDA in-house. In 1981, however, these companies spun off their EDA groups, enabling them to emerge as a specialised business and offer their design products and services to the electronics companies through 3-year time-based licensing agreements (as it was initially introduced by *Avant!*). Nowadays, this is still the predominant means of collaboration between EDA providers and chip makers.

1990's – The semiconductor IP licensing revolution

Economic downturn during the 1990's led semiconductor companies to also spin off their internal IP groups to cut costs, leading to the rise of a new segment of dedicated IP providers. Subsequently, with the establishment of *ARM Holdings* in 1990, the new IP segment witnessed the rise of the microprocessor IP business model, which revolved solely around developing and licensing IP 'blocks' to chip makers for incorporation into their chip designs. These licenses involve upfront fees and the payment of royalties for each chip sold.

The IP business model was further changed as it became clear that the timely availability of high quality IP libraries was an important enabler of the foundry business – to attract and optimally support customers. The explosive growth of the Internet and rising demand for more advanced mobile communications products inflated the importance of a rapid time-to-market and increasingly drove the basis of competitive advantage towards technological excellence. This further reinforced the importance of inter-organisational collaboration. In the late 1990's, *Artisan* forged a partnership with TSMC that gave chip designers free access to Artisan IP libraries if they used TSMC as their foundry partner. This changes the IP model from an upfront licensing model to a royalty-based model backed by the foundries. Today TSMC has the largest commercial IP catalogue, its *IP Alliance Program* (TSMC, 2019), which is part of its *Open Innovation Platform*, which encompasses hundreds of millions of dollars invested in the fabless enablement ecosystem.

The increased availability of various kinds of IP through licensing agreements to chip makers considerably lowered barriers to market entry and eased the process of designing more complex chips.

2000's – Rise of the outsourced semiconductor assembly and test (OSAT) segment

Although outsourced semiconductor assembly and test (OSAT) companies had been in operation since the late 1960's (as pioneered by *Amkor Technology* in 1968), it was only from the early 2000's onwards that part of the segment made the transition from low-end, commoditized service businesses to technological differentiators. As a result of the slowing pace of radical innovation in the front-end segment of the semiconductor industry, pressure on the industry to deliver more complex and technically differentiated semiconductor devices meant that the OSAT players had to offer innovative and sophisticated packaging solutions with an eye to improving chip performance (Naeher et al., 2011). The increasing demand for technological differentiation led to the separation of a group of high-end OSAT players from the commoditised mainstream companies.

In the high-end segment, the development of close collaborative relations with partners across the semiconductor industry became essential to achieving technical differentiation. Accordingly, OSAT companies have become actively involved in the joint development with (1) system design companies, to develop new and better performing packaging solutions; (2) IDMs, to combine front-end and back-end manufacturing capabilities and technologies; (3) foundries, to develop new technologies for advanced processes and leverage both partners' respective strengths in semiconductor manufacturing under a 'total' integrated manufacturing service. (Cross-)licensing agreements, with a rivalling OSAT player or a foundry partner, have also become a more popular strategy to secure new packaging technologies as well as lowering manufacturing costs.

2010's – Open-source innovation revolution

After half a century of continued growth and technological advancements, the modern semiconductor industry is characterised by shrinking revenues and tightening profit margins amid shifts in chip demand and the ever-increasing R&D and manufacturing costs (Global Semiconductor Alliance, 2016). According to industry experts, the emergence of the Internet of Things (IoT), which encapsulates 'smart' technologies such as smart wearables, smart cars, smart homes and smart cities, is likely going to be the key growth driver for the semiconductor industry over at least the next decade (Simon, 2015). The rising cost of chip development, however, is hampering the IoT market from achieving its full potential. This has encouraged semiconductor companies to explore new ways of collaborating for innovation; most notably through open-source innovation.

By collaborating with open-source software developers, chip makers have begun to bring innovative chips to market while achieving a cost advantage by avoiding multi-million dollar licensing fees which are usually paid for the incorporation of software stacks. Moreover, this minimises contractual risks associated with intellectual property. As a case in point, in 2015, *IBM* and fabless chip maker *Xilinx* forged an alliance to address emerging applications like machine learning and big data analytics by integrating *IBM*'s open POWER architecture with *Xilinx*' chips (IBM, 2015).

Another recent trend in light of reducing development costs has been the concept of open-source *hardware* (rather than software). In a pioneering move, researchers at the University of California, Berkeley have developed an open-source 'instruction set architecture' named *RISC-V*[4], allowing anyone to design and fabricate *RISC-V* chips without the need to purchase an expensive license. This open-source alternative has been gaining increased industry support from the likes of *Google*, *Hewlett Packard*, *IBM*, *NVIDIA*, *AMD*, *Qualcomm*, *Lattice Semiconductor*, *Oracle* and many others. However, industry experts believe that it will likely take a few more years before this open-source hardware movement will receive full support from the wider semiconductor ecosystem (Hemsoth, 2016).

[4] https://riscv.org/

3. THE ARCHITECTURE OF INTER-ORGANISATIONAL COLLABORATION: A NETWORK VIEW ON ALLIANCE FORMATIONS IN THE SEMICONDUCTOR INDUSTRY

3.1. Introduction

Over the past decades, inter-organisational collaboration through alliances has become an integral part of the competitive strategies of many companies. This is especially true in highly competitive and volatile environments, such as high technology industries with disintegrated value chains (Lorenzoni and Baden-Fuller, 1995), characterised by falling profit margins due to increasing fixed costs (notably R&D) and investments in fixed capital assets (Sahlman and Stevenson, 1985; Klepper and Graddy, 1990). This threatens firm survival and amplifies the importance of coping effectively with uncertainties around rapid technological advancements, the ongoing emergence of new technological markets, and short product lifecycles that result from the non-stop, changing customer-driven demand for specialty products.

Competitive advantage, in this kind of business environment, is derived from the ability to develop functional and reliable products at the speed, convenience and customisability demanded by customers (Christensen and Raynor, 2003). Responding to these demands effectively requires the firm to design and manage an efficient value creating system that permits for the flexible and rapid commercialisation of products. Arm's-length agreements between the innovator and other actors, in this situation, are typically not efficient as partners may be required to make investments that are relation-specific (Teece, 1986). Vertical internalisation without scale economies is also inefficient as this requires the firm to upgrade and redesign the complete chain of value-added activities following the development of every new product generation. Instead, with the *basis of competition* resting on speed, responsiveness and convenience, and the complexity and cost of developing new technologies often stretching beyond the internal capabilities and financial resources of the firm (Hagedoorn and Duysters, 2002), interdependency between organisations and their resources becomes the industry standard. As a consequence, the extent to which the firm can gain a competitive edge over its rivals is heavily dependent on the access that it has to, and influence over, critical resources located outside its own boundaries (Gomes-Casseres, 1994, 2003; Dyer and Singh, 1998).

This implies that companies have to collaborate beyond arm's length by forging enduring and strategically significant ties that are governed by specific inter-organisational arrangements, such as licensing agreements, outsourcing agreements, R&D partnerships and joint ventures. Since the 1990s, strategy scholars have shown that the proliferation of these alliances has led to companies becoming increasingly embedded in extensive and complex inter-organisational networks (e.g. Normann and Ramirez, 1993; Gomes-Casseres, 1994; Gulati, 1995b, 1998; Powell et al., 1996; Gulati et al., 2000). These inter-organisational networks have been termed variously as "trading networks" (von Hippel, 1988), "innovation networks" (Freeman, 1991), "value constellations" (Normann and Ramirez, 1993), "alliance constellations" (Gomes-Casseres, 2003), "alliance networks" (Gulati, 1998) and "strategic networks" (Gulati et al., 2000). They are viewed, in general, as a form of market and organisation which connects different organisations with different resources and competencies to jointly create and capture value and achieve competitive success.

The modularised structure of many high tech industries dictates that innovating companies design networks of alliances at the interface of different stages of their value chain, connecting to strategic partners such as competitors, complementors, suppliers and customers. These alliance networks provide firms with access to complementary assets that are essential for the rapid commercialisation of new innovations, including R&D capabilities, intellectual property, manufacturing processes, logistics and distribution channels. The importance of establishing networks of inter-organisational relationships with various kinds of external partners to the innovation process has been well-documented in the literature on open innovation (e.g. Chesbrough, 2003; Gassmann, 2006; Gassmann et al., 2010; Huizingh, 2011). Within such a relational structure of organisational interdependence lies the inherent strategic challenge for firms to effectively configure and manage their alliance networks in order to generate the desired strategic outcomes.

Over the past 20 years, an increasing number of studies have shifted the level of their analyses from the individual alliance towards the of the alliance network, in order to explain organisational outcomes such as growth (e.g. Powell et al., 1996), innovation output (e.g. Ahuja, 2000; Zaheer and Bell, 2005; Nooteboom et al., 2006; Boschma and Ter Wal, 2007; Capaldo, 2007; Shiri, 2015) and access to venture capital (Sorenson and Stuart, 2001). Others have underscored that the ability of the firm to accomplish its desired strategic outcomes and achieve competitive success depends on the way in which it *orchestrates* its network activities (Hacki and Lighton, 2001; Dhanasai and Parkhe, 2006). This implies that rather than solely by complementing ones internal resources with the critical resources of an individual strategic partner, it is also the way in which resources from multiple network partners are assembled, structured and managed within the firm's network or value creating system that determines the magnitude of strategic benefits that it may derive from a collaboration (Vanhaverbeke and Cloodt, 2006).

Research has also highlighted that the patterns of "connectivity and cleavage" (Wellman, 1988: 26) which define the overall structure or *architecture* of industry-wide, inter-organisational networks can also help to explain various *collective* business outcomes, such as disseminating knowledge and other resources, transmitting signals of partner reliability, constraining opportunism, or establishing norms of cooperation and trust through shared third-party ties (Granovetter, 1973; Gulati, 1995a; Rowley, 1997; Uzzi, 1997; Walker et al., 1997; Gulati and Gargiulo, 1999; Ahuja, 2000; Stuart, 2000; Owen-Smith and Powell, 2004; Schilling and Phelps, 2007). An industry-wide network encapsulates all organisations and their alliance ties in a given industry. It is the aggregate of all, potentially interlinked, ego network structures (i.e. the alliances between the focal firm and its partners, plus the alliances among its partners), and its architecture represents the overall pattern that describes how all industry network participants are connected to one another. While the benefits associated with particular network architectures have been relatively well-documented, there has been a noticeable shortage of research explaining the causes of variation between the distinct architectural properties of inter-organisational networks in different industrial environments.

Only a small number of more recent studies have compared large-scale, inter-organisational networks across different industries to identify the sources of variation between the architectural properties of these networks. For instance, Verspagen and Duysters (2004) compared the technology alliance networks of the chemicals and food and electricals industries for small-world properties. Rosenkopf and Schilling (2007) suggested that the architecture of networks is associated with the technology dynamism, product modularity and architectural control that characterise the industries which they represent. Finally, Tatarynowicz et al. (2016) showed that, among six industries, differences in technological dynamism and demands for value creation lead to distinct architectural network properties.

These studies, although valuable in themselves, have left an important area unexplored. The concept of product modularity in particular, resulting from the rapid and ever-changing customer demands for value creation, has been used in well-known work to understand the disintegration of value chains as seen in many of today's high tech industries (Christensen and Raynor, 2003). Modularity, within this logic, forces companies to collaborate, through multiple types of strategic relations, with specialised partners in several or all of the distinct activities of an industry's value chain. It is therefore important to distinguish between different types of sub-networks *within* a single industry-wide network, and to understand how these different sub-networks are built in the first place. Interestingly, quantitative research on the organisation of inter-organisational activities at different stages of an industry's value chain is still in its infancy. Such investigation calls for an understanding of how the drivers of collaboration and the inter-organisational routines and processes that characterise alliances in different value chain activities lead to distinct network architectures. This is necessary if we are to adequately link the different network configurations that firms pursue to the collective outcomes that they seek at different stages of the value-added chain.

With the aim of shedding light on this matter, this chapter examines networks of inter-organisational alliances, at distinct stages of the value chain of the semiconductor industry, and explores why their architectural properties differ across value-added activities. Although the architecture of a network can be measured in various ways, this chapter will focus specifically on the indications of network connectedness, centralisation and clustering. Understanding the variation in these architectural properties of distinct sub-networks requires shifting the focus from the role of the individual alliance towards the role of the alliance network, which implies linking the collective outcomes related to particular network configurations to the value-added activities for which these networks are used. Concurrently, with alliances constituting the foundational building-blocks of a network, it is important to also consider the wide range of arrangements that firms can use to govern their alliances as well as the associated inter-organisational routines and processes, upon with a given alliance network is built in the first place.

Following this line of reasoning, the relational properties that characterise an alliance relation between a pair of organisations should ultimately dictate the collective outcomes, as provided by particular network configurations, which are needed to effectively manage the strategic interdependence between them and to carry out the value-added activity for which their alliance was initiated. For instance, one could argue that the establishment of norms of cooperation and trust, as induced through shared third-party ties, is crucial to alliances that require a higher degree of relational commitment and investment for the value-added activity at hand to bear fruit – but less to others. The relational properties of alliance relations can, accordingly, be expected to indirectly influence the architectures of distinct alliance networks at different value chain stages. Due to the widespread modularisation across high tech industries, the appropriateness of a given network architecture, as will be argued, can therefore not be sufficiently understood without considering the value-added activity for which the network is used alongside the nature of the inter-organisational relations upon which it is founded.

This implies that the differences in the architectures of alliance networks cannot be adequately captured by one-dimensional conceptual frameworks. Accordingly, we must integrate different lessons that past studies have taught in the light of (I) the drivers of collaboration, (II) inter-organisational routines and processes, (III) value chain analysis and (IV) social network analysis into a single comprehensive conceptual framework. The need for combining theoretical views has previously been stressed by Madhok and Tallman (1998), Amit and Zott (2001), Gomes-Casseres (2003), and Vanhaverbeke and Cloodt (2006). Accomplishing this was beyond the scope of these past studies, and no attempts have been made since then. The present chapter will thus seek to advance existing theory by developing a multi-dimensional conceptual framework and applying this to analyse variation in the architectural properties of alliance networks at distinct value chain stages, in the global semiconductor industry.

With this objective in mind, the remainder of this chapter is structured as follows. The next section explores in greater depth the role of strategic alliances and the importance of inter-organisational routines and processes in determining strategic outcomes. The third section examines how semiconductor companies use the routines and processes to conduct distinct value-added activities in collaboration. The fourth section reviews the social network literature and discusses the benefits associated with particular network configurations. Finally, the fifth section explores how the particular patterns of relation-building that firms use can help to predict differences in the architectural properties of alliance networks at different stages of the (semiconductor) value chain. Several hypotheses are formulated and tested in the subsequent sections.

3.2. The nature of strategic alliances

3.2.1. The drivers and benefits of inter-organisational collaboration

To adequately comprehend the sources of variations in the architectures of alliance networks, it is essential to first understand the fundamental motivations that drive firms to enter into the alliances that make up different kinds of networks. In general, alliances entail long-term arrangements through which at least two independent partners work together to carry out particular business activities and gain access to specific strategic benefits (Duysters and Hagedoorn, 1993; Tsang, 1998). Over the past decades, studies have found that firms collaborate with other organisations for various explicitly formulated reasons which can mostly be linked to the content of the activities at the various phases of the innovation process; from R&D and product development to marketing and distribution (Hagedoorn, 1993).

To explain the roles of alliances in the light of these activities, scholars have drawn upon various fields of theorising, including transaction cost analysis (Williamson, 1981), resource dependence (Pfeffer and Nowak, 1976), social exchange (Levine and White, 1961), organisational learning (Kogut, 1988), the resource-based view (Eisenhardt and Schoonhoven, 1996; Das and Teng, 2000) and competitive strategy (Porter, 1980). Narula and Hagedoorn (1999) have organised the motives for inter-organisational collaboration along strategic and cost-economising lines. Broadly speaking, the strategic motives revolve around the need to enhance the long-term value of the assets of the firm, which firms can achieve by (1) accessing complementary resources and capabilities, (2) learning, (3) sharing risk or uncertainty, and (4) accessing markets, and tend to be reflected more in horizontal and cross-industry alliance agreements (Martínez-Noya and Narula, 2018). By contrast, the cost-economising motives relate to the need to improve efficiency or reduce costs, and are more often inherent to vertical alliance agreements (Narula and Hagedoorn, 1999), such as in manufacturing, marketing and supply activities. Other studies have also identified motivational elements which are not necessarily related to a single particular business activity, such as necessity, asymmetry, reciprocity, stability, legitimacy, reduced competition or revenue enhancement (Oliver, 1990; Glaister and Buckley, 1996).

Access to knowledge, complementary resources and learning

Contrary to traditional views, research has shown that firms do not solely seek to achieve competitive advantage using their internal resource. Instead, firms often seek to leverage the critical resources and capabilities which are located outside of their boundaries by forging collaborative relations with other organisations (Dyer, 1996, 1997; Dyer and Singh, 1998). The formation of alliances can thus be driven by the need for access to strategic resources (Eisenhardt and Schoonhoven, 1996) or, as Tsang (1998) theorised, the need to create rents, expand resource usage, diversify resource usage, imitate resources and dispose of resources.

Specifically, the role of alliances often revolves around the need to share and advance research and transfer basic scientific and/or technological knowledge (Hagedoorn, 1993). Some motives are related to sharing the state-of-the-art or other knowledge-based resources such as manufacturing or customer-related information (Teece, 1986; Shan, 1990). Accordingly, some scholars have conceptualised the role of inter-organisational alliance ties as "pipelines", or closed conduits, through which knowledge and technology flow from one organisation to another (Owen-Smith and Powell, 2004). However, alliances typically involve more than merely the transfer of knowledge or other resources (Glaister and Buckley, 1996). They often entail the development of longer-term relations, based on reciprocity, balance and mutual support (Oliver, 1990) through which organisations actively work together to join their complementary skills and talents with the aim of conducting concrete research activities or overcoming the increasing complexity and interdisciplinary nature of new technological areas. The overarching purpose of these relations is to pursue common or mutually beneficial objectives. This can also be related to monitoring the evolution of technologies to identify new strategically valuable complementarities (Hagedoorn, 1993). Alliances can therefore provide great potential for generating new innovations (Contractor and Lorange, 1988), achieving economies of scope (Hagedoorn, 1993), and accelerating the R&D process in those industries where rapid time-to-market is essential (Gilsing et al., 2008) – which firms on their own would have otherwise been unable to achieve. While such collaborations are usually done in good faith, it has been reported that firms may also be driven by the potential opportunity of secretly capturing some of their partners' resources or capabilities (Hagedoorn, 1993).

Shared risk or uncertainty

The role of alliances has also been commonly described by scholars as a strategic tool for overcoming technological complexity and hedging against risk and uncertainty (Porter and Fuller, 1986; Eisenhardt and Schoonhoven, 1996; Lavie and Rosenkopf, 2006), especially in the areas of R&D, production and marketing (Eisenhardt and Schoonhoven, 1996; Das and Teng, 2000). Alliances which are driven by this motive can help to reduce risk and uncertainty in a number of ways. Generally, alliances are often formed when the cost of the partnership is less than the cost of the investment undertaken by an individual firm alone (Contractor and Lorange, 1988). More specifically, alliances can involve collaborating organisations aligning their supplementary or complementary resources (Das and Teng, 2000). In the former situation, partners join a comparable amount of similar resources to their collaboration. For example, by contributing a more or less similar amount of financial resources, firms can spread the risk of large projects or particularly capital intensive activities among multiple firms. By complementing dissimilar resources, however, firms can achieve economies of scale and/or scope which enable them to more easily diversify into new product markets and expand into new end markets (Hagedoorn, 1993). Ultimately, this can reduce the market risk associated with relying on a single type of product and increase the speed of attaining a return on investment (Contractor and Lorange, 1988).

Access to markets

A rich literature has also highlighted the role of alliances in entering foreign markets and creating new markets and products. The wider field of international business, in particular, has shown that alliances are not bound by national boundaries and they can enable firms to overcome their liability of foreignness (Zaheer, 1995) by combining certain of their business activities with those of a partner based in another country or geographic region, in order to enter a particular foreign market (Contractor and Lorange, 1988). Although a firm may possess the capability and resources to produce products, a lack of international experience and knowledge of foreign markets may imply that it is unable to efficiently expand into foreign markets independently. Alliance partners located in the local market can therefore help to reduce the costs and risk associated with international expansion. Furthermore, organisations collaborating on the development of new products and processes can leverage their alliance relationship to jointly monitor new market opportunities and environmental changes within and outside of their core industry (Hagedoorn, 1993).

Improved efficiency or reduced costs

The formation of alliances can be driven by an organisation's attempt to achieve economies of scale when insufficient product demand and increased unit costs and downtime in the case of internal production would otherwise impact negatively on its long-term competitiveness (Oliver, 1990; Glaister and Buckley, 1996). This need for cost efficiency as a driver of collaboration has been famously emphasised by the transaction cost perspective (Williamson, 1981, 1985). This perspective holds that alliances can be used to economise on the costs of transactions, specifically, in the light of vertical linkages and the transfer of technology, such as costs associated with negotiating and re-negotiating contracts, and the need to monitor partners (Dyer, 1997). These transaction costs arise fundamentally from a fear of opportunism on the part of the contract partner, and they grow as firms make larger relation-specific investments and as uncertainty and the frequency of recurring transactions increase (Oliver, 1990). Firms may thus find that the intermediate governance structures of longer term alliances mediate their transactions more efficiently than arm's-length agreements, as they reduce the costs of bargaining over profits from relation-specific assets (Williamson, 1985). Inter-firm specialisation, by leveraging the comparative advantage of each alliance partner, can then enable collaborating organisations to achieve economies of scale (Contractor and Lorange, 1988). Concurrently, this allows firms to avoid the uncertainties and difficulties associated with a possible merger (Mariti and Smiley, 1983).

Other motives and benefits

Scholars have identified various other motives to explain the formation of alliances between organisations. For instance, firms have long used alliances to strategically alter the competitive landscape by allying with potential or existing rivals (Porter and Fuller, 1986); in order to reduce competition through collaboration or to put pressure on the profits of a common rival (Contractor and Lorange, 1988). By forging ties with the partners of existing competitors, firms can also reduce the value that the competitor appropriates from these partners (Madhavan et al., 2004). Similarly, allying with rivals, e.g. through licensing, can also be done with the purpose of enhancing revenues, to avoid complacency and to create 'second sources' to encourage the market to adopt one's product or technology (Nalebuff and Brandenburger, 1996).

Furthermore, in her review, Oliver (1990) puts forth that inter-organisational relationships are driven by necessity, stability, asymmetry and legitimacy, in addition to the earlier discussed need for reciprocal relations and cost efficiency. The need to conform to host government policy or particular legal or regulatory requirements, as a necessity, for example, has long been a key factor explaining firms' decision to enter into alliances (Glaister and Buckley, 1996). The formation of alliances therefore need not be voluntary. For instance, governments in many of the developing countries allow foreign companies to enter their markets under the condition that they collaborate with a local partner. Similarly, collaborative activities in certain strategic sectors of a country's economy are often subject to government requirements which are aimed to protect it.

More commonly, alliances have been considered to constitute voluntary actions, which are often reflective of strategic responses to environmental uncertainty. Uncertainty around the availability of critical resources within the firm's business environment along with a lack of knowledge on environmental changes and the availability of potential partners implies that alliances provide a means to gain access to resource flows, knowledge and exchanges which are required for it to carry out its strategy (Paulson, 1976; Pennings, 1981). This provides stability to a company's business (Oliver, 1990).

Conversely, however, the scarce nature of particular critical resources has also been argued to prompt firms to enter into alliances in an attempt to gain power or control over the organisations possessing the critical resources (Provan et al., 1980; Oliver, 1990); in particular those operating upward and downwards along the supply chain (Harrigan, 1985). This has been a central premise of the resource dependency perspective (Pfeffer and Salancik, 1978). Access to critical resources in general would arguably enable firms to reduce the lifecycle of their products and increase their time-to-market, which are consequently also believed to constitute motives for collaboration (Hagedoorn, 1993). In a similar fashion, a firm may also use an alliance as a means to improve its legitimacy by connecting with a particular high-status partner (Baum and Oliver, 1991). This enhances its own organisational status and improves the external perception of its ability to create a valuable product (Oliver, 1990).

3.2.2. Modes for collaboration and inter-organisational routines and processes

An alliance is not a discrete event. Each alliance is embedded in a broader network of other inter-organisational relationships. Concurrently, alliances are not homogenous and can encompass various relational properties and be driven by various motives – as discussed previously. Understanding the variation in the architectures of alliance networks that were created for distinct value-added activities requires comprehending the roles of alliances within these broader networks and their fundamental inter-organisational routines and processes, upon which these networks are built.

Inter-organisational networks, at their very core, are social fabrics of strategic interdependencies between organisations. Organisations are interdependent to the extent that they may own strategically critical resources or capabilities which are beneficial to, but not possessed by, another (Gulati, 1995b). Organisations perceive this interdependence when resources are scarce (i.e. critical) and they are unable to internally generate the necessary resources, such as materials, information, specialised skills, technologies, and market access (Aiken and Hage, 1968; Oliver, 1990). Past research around the subject of resource dependence has long shown that organisations use alliances to manage, at least partially, their interdependencies and generate strategic advantage (Whetten, 1977; Pfeffer, 1978; Barringer and Harrison, 2000). Accordingly, the ability to achieve organisational success increasingly hinges on the firm's access to and control over scarce resources beyond its own boundaries; or the power that it has over other organisations that own the required resources, relative to other industry players (Ulrich and Barney, 1984; Pfeffer, 1987).

Alliances, within this logic, constitute the social building-blocks of networks. Selecting the most appropriate organisational mode to shape a strategic relation and achieve a specific strategic outcome, such as the development of a new technology, is at the centre of a company's commercialisation strategy (Pisano, 1990; Chesbrough and Teece, 1996; Chesbrough, 2003). Various studies have been dedicated to describing the different inter-organisational modes from which companies can choose to shape their relations with partners beyond arm's length (e.g. Pisano, 1990; Hagedoorn, 1993; Chesbrough and Teece, 1996; Chesbrough, 2003; Dyer et al., 2004; Contractor and Reuer, 2014; Choi and Contractor, 2016). However, limited work has been done thus far to connect the logic underpinning this tactical decision to the structures of alliance networks.

Organisational modes vary in the level of control needed to manage uncertainty in the light of appropriation concerns, as advocated by transaction cost economists (Williamson, 1985, 1991), and otherwise reduce the costs of coordinating[5] activities across organisational boundaries through "superior information-processing mechanisms" (Gulati and Singh, 1998), as emphasised by organisational sociologists – to efficiently deliver the quality and technological and product specifications demanded by customers. The relative need for control and coordination will differ depending on the type of arrangement and the nature of the relation (Lumineau and Malhotra, 2011). The continuum of hybrid inter-organisational arrangements stretches from non-equity modes that involve low levels of hierarchical control, such as licensing agreements or joint R&D agreements; to joint ventures in which partners are tied through equity shares and which offer greater hierarchical control (see Figure 3.1). These types of alliance are necessarily aimed towards different missions or tasks, embody different degrees of partner interaction, involve different financial and managerial investments, and entail varying levels of risk (Contractor and Reuer, 2014).

Figure 3.1: The traditional continuum of organisational modes (Source: created by the author)

Concurrently, any alliance is formed voluntarily by organisations who seek to create value that is greater than each of the collaborating organisations would be able to create individually (Dyer and Singh, 1998). Importantly, value can be generated in different ways depending on the purpose of the alliance, and partners' estimated value of their alliance may differ depending on their own subjective valuation of the anticipated alliance outcome. The pursuit of certain outcomes requires different levels of coordination between the collaborating organisations and thus involves varying degrees of interdependence. For example, the transaction value approach (Zajac and Olson, 1993; Dyer, 1997) stresses that the choice of organisational mode may be aimed towards maximising the joint value created by the

[5] Gulati and Singh (1998) define coordination costs as "the anticipated organisational complexity of decomposing tasks among partners along with ongoing coordination of activities to be completed jointly or individually across organisational boundaries and the related extent of communication and decisions that would be necessary".

collaborating organisations, at the cost of sacrificing transaction cost efficiency, such as when organisations collaborate to learn from one another or to develop a new product. By contrast, the logic of created value will be inherently different when an organisation outsources the manufacturing of its product to a specialised partner in order to achieve greater cost efficiency, and this is likely to demand a different level of coordination.

The extent of interdependence therefore depends on the motive of the alliance. While some alliances which are aimed at joint value creation may involve high levels of interdependence, resulting from a complex and overlapping division of resources that require ongoing coordination and alignment of tasks and joint decision making between partners; other alliances, aimed at improving cost efficiency, may entail a simpler division of resources with minimal coordination and inter-organisational interaction (Gulati and Singh, 1998). Accordingly, depending on the logic for value creation, the choice of organisational mode has to ensure a particular level of *operational* coordination of tasks and flows of complementary assets, information, technologies and materials between the collaborating organisations; and *strategic* coordination of the distribution of returns to the created value (Teece, 1992).

Striking the right balance between cost efficiency and value creation, and coordinating accordingly the interface of labour, tasks, products and economic returns, is essential if a company is to develop and profitably commercialise new technologies. Regardless of the precise motive, as Vanhaverbeke and Cloodt (2006) noted, the choice of the organisational mode of an alliance tie should be examined from the tie's role in the firm's network. In other words, the choice depends on the need for cost efficiency versus value creation; the answer to which naturally resides in the nature of the value chain activity that is to be conducted under the collaborative arrangement.

In the first place, however, it is crucial to understand precisely *how* the organisation of any alliance can provide firms with the necessary control and coordination needed to accomplish the anticipated cost- or value-driven benefits which they have set at the initialising stage of their alliances. As discussed previously, past studies that have investigated how companies collaborate for competitive advantage have underscored improving cost efficiency, learning and the pooling of complementary resources as important motives for collaboration. Naturally, deriving strategic benefits from inter-organisational relations does not happen spontaneously; firms must be sufficiently committed to and invested in building idiosyncratic relationships that are mutually beneficial, rare and difficult to imitate (Gulati et al., 2000).

As partners perceive gradually higher levels of interdependence, they must interact more intensively to coordinate the disentanglement of an increasingly more complex array of tasks and to ensure ongoing mutual adjustment and adaptation. More integrated collaborative arrangements are generally capable of providing greater coordination needed to ultimately achieve competitive advantage (Gulati and Singh, 1998). In order to understand how organisations accomplish this, Dyer and Singh (1998) put forward the *relational view*.

The firm's ability to generate competitive advantage from an alliance, they argue, is conditioned on the extent to which the relationship is idiosyncratic and increases as the relationship moves away from the attributes of basic arm's-length agreements. This implies that inter-organisational relationships vary in the intensity of the fundamental routines and processes through which the collaborating partners organise their joint activities. The relational view thus holds that, fundamentally, organisations can create the control and coordination needed to generate their desired strategic benefits by (1) making relation-specific investments; (2) developing knowledge-sharing routines; (3) combining complementary resources and capabilities; and (4) employing effective governance mechanisms to lower transaction costs.

Committing to relation-specific investments

The successful and profitable commercialisation of an innovation requires the firm to create strategic assets that can be utilised in *conjunction* with the complementary assets of a strategic partner which can only be accessed beyond arm's length, through arrangements such as joint R&D, licensing, manufacturing, marketing and distribution agreements (Teece, 1988). The strategic nature of these assets dictates that they are either *specialised* to the innovation at hand or *co-specialised* to induce a mutual dependence upon the collaborating organisations (Teece, 1992; Amit and Schoemaker, 1993). This implies a certain degree of *inter-organisational specialisation*, which companies can achieve by making significant investments that are specific to a particular relation and thereby less or non-redeployable in other relations (Williamson, 1985; Oliver, 1990). The willingness to make such relation-specific investments, again, stems from the need for coordination and is hence expected to increase as higher degrees of task interdependence demand more specialised assets to be dedicated to coordination (Scott, 1981). Arguably, designing a tightly integrated production network with high degrees of inter-organisational specialisation allows the firm to create competitive advantage (Asanuma, 1989; Dyer, 1996).

In theorising about the concept of relation-specific investments, the relational-view builds on the work done by Williamson (1979, 1985), who identified site, physical and human asset-specific investments as the main types of relation-specific investments made by firms. Investments are site-specific when they are made to locate successive, immobile production stages in the same vicinity to enhance coordination and lower inventory and transportation costs. Physical asset-specific investments are capital investments which are made to tailor a production process to a particular transaction partner (e.g. by purchasing machinery, tools or other equipment). Finally, investments are human asset-specific when firms gain experience working together and accumulate specialised information, language and know-how necessary for efficient and effective communication. Human co-specialisation is hence essential for improving time-to-market (Dyer, 1996).

The downside of making any of the above relation-specific investments is that they expose the firm to a greater risk of opportunism (Klein et al., 1978). This situation requires a governance structure that is able to enhance partners' confidence in one another that they will accomplish their respective obligations as agreed upon signing the alliance agreement, and act predictably and with goodwill instead of opportunistically (Dyer and Singh, 1998; Davis, 2016). Accordingly, many studies have underscored the importance of trust as a foundation for alliances as this enables partners to more efficiently commit to relation-specific investments (e.g., Morgan and Hunt, 1994; Gulati, 1995a; Uzzi, 1997; Das and Teng, 1998; Gulati and Sytch, 2008), as well as reputational sanctions as a means of imposing high social costs on opportunistic behaviour (Gulati et al., 2000).

Developing knowledge-sharing routines

Learning from and with partner organisations is essential for efficiently coordinating activities across organisational boundaries. Indeed, a large body of literature has emphasised the benefits of learning and knowledge transfer associated with inter-organisational collaboration (e.g. Von Hippel, 1988; Levinson and Asahi, 1996; Powell et al., 1996; Dyer and Nobeoka, 2000; Zhang et al., 2007; Buckley et al., 2009). Ultimately, translating inter-organisational learning into competitive advantage requires that the firm systematically develops, stores and applies the new knowledge that it acquired from a partner organisation (Nelson and Winter, 1982; Grant, 1996).

This implies that collaborating organisations should strive to develop inter-organisational knowledge-sharing routines. In their relational-view, Dyer and Singh (1998) define such a routine as "a regular pattern of interfirm interactions that permits the transfer, recombination, or creation of specialised knowledge". This follows the similar logic of informal know-how trading as described by Von Hippel (1988), which entails the routine and informal trading of proprietary information between technical personnel of partner organisations. The knowledge-sharing routines that exist in multiple collaborative relationships may, collectively, be an indication of the firm's capability of managing knowledge flows in alliance networks (Lorenzoni and Lipparini, 1999).

It is further argued that knowledge-sharing routines can only be effectively created in the presence of two main sub-processes. Firstly, partner-specific absorptive capacity, or the firm's ability to recognise and integrate valuable knowledge from a specific alliance partner (Cohen and Levinthal, 1990; Dyer and Singh, 1998), is essential. Secondly, the arrangements employed to govern the alliance should incentivise knowledge sharing and discourage free-riding, such as through equity stakes or informal norms of reciprocity.

Complementing resources and capabilities

The modularisation of product architectures dictates that distinct value-added functions are tightly integrated and in close and continuous communication, in order to ensure a successful innovation process – from initial technology development to final commercialisation (Teece, 2000). This implies that developing new technology, manufacturing designs and distributing end products often necessitates organisations to combine their existing resources (Teece, 1986, 1992). In theory, complementary resources could be generic in nature and thus be procured in the market on competitive terms. In this case, however, they would be valuable yet bear relatively little strategic importance to innovation (Rothaermel and Hill, 2005). Complementary resources, such as technological know-how, high-end manufacturing processes or reputation, rather tend to be specialised to specific innovations, meaning that they cannot be accessed through basic market-based contracts (Teece, 1992; Oliver, 1997; Chetty and Wilson, 2003).

Dyer and Singh (1998), therefore, suggest that the process of innovation requires the firm to collaborate with organisations who are active or specialised in particular value-added activities and who possess distinctive resources which, in combination with the firm's existing internal resources, would create greater value than when these resources would be used in isolation. This value-creation potential, however, depends on the extent to which the resource combination is indivisible and inimitable resulting from the co-evolution of capabilities and the establishment of a long-term relationship. Consequently, unique combinations of distinctive resources can generate significant competitive advantage.

As argued by Teece (1992), the interdependence between distinctive resources can, naturally, vary considerably. Some resources are more generic and widely possessed than others, and they may also differ in terms of their relative strategic importance to the generation and commercialisation of an innovation. This should largely depend on the nature of the value-added activity and the structural characteristics of the sub-sector (value chain stage) from which complementary resources are to be sourced.

Employing effective governance mechanisms

The way in which a collaborative relationship is governed defines the processes by which organisations interact and perform joint decision-making, and thus bears implications for the strategic outcome that alliance partners may realise. Governance influences the costs of transacting and coordinating activities across organisational boundaries, as well as the risks of opportunism and thereby the willingness of collaborating organisations to make relation-specific investments, to share knowledge, and to pool specific complementary resources (Dyer and Singh, 1998). Effective governance should, therefore, provide the structure for an efficient collaborative relationship and incentivise mutual cooperation and joint value-creation.

From a relational view (Dyer and Singh, 1998), alliances can be governed through third-party enforcement and self-enforcement of agreements. Proponents of the transaction cost perspective would argue that dispute resolution requires access to a third-party enforcer, such as the state (i.e. legal contracts) or a legitimate organisation authority (Williamson, 1991). However, in those cases where the anticipated outcome of a transaction does not exist at the time of signing, such as the development of a new technology or product, ex ante contractual agreements are ineffective as they cannot be accurately written to specify or enforce the division of returns (Teece, 1992).

Self-enforcing governance mechanisms are more effective in such situations. *Formal* safeguards, or economic hostages, such as equity stakes or symmetric investments in specialised or co-specialised resources, can be used to control opportunism by increasing the financial commitment of the partners (Klein, 1980; Williamson, 1983). Moreover, equity holdings may also provide access to the board of directors and potentially some control in the strategic coordination of the partner organisation (Teece, 1992).

On the other hand, informal (social) safeguards, such as trust or embeddedness (Powell, 1990; Gulati, 1995a; Uzzi, 1997) and reputation (Larson, 1992), can supplement or replace formal safeguards (Granovetter, 1985). Indeed, trust is widely considered as imperative to the success of any strategic alliance (e.g., Sherman, 1992; Gulati, 1995a; Lavie et al., 2012), as it typically leads to loyalty and commitment to the partnership at hand (Schurr and Ozanne, 1985). When both trust and commitment exist in a partnership, as posited by Morgan and Hunt's (1994) commitment-trust theory, then partners are encouraged to (a) make and work at preserving relation-specific investments through close collaboration; (b) resist the lure of reaping short-term benefits in favour of the longer-term benefits of remaining with existing partners; and (c) consider potentially high-risk, high-reward actions because of the belief that the partners will act in the interest of the partnership rather than opportunistically. Accordingly, past research has argued that informal safeguards provide a more efficient and effective means of safeguarding relation-specific investments and facilitating the sharing of knowledge (Hill, 1995; Uzzi, 1997) through reductions in the costs of bargaining and monitoring (Sako, 1991).

Taken together, these inter-organisational routines and processes suggest that the competitiveness of the firm is determined, to a large extent, by the scope of its alliance network and the way in which it organises its alliance relations. These relational concepts provide a necessary theoretical foundation for understanding the strategic role of *networks*. Before connecting the relational concepts offered by the relational view to the literature on network configurations, the next section will first examine the inter-organisational routines and processes of collaborating organisations in the semiconductor industry, at distinct stages of the value chain.

3.3. Inter-organisational collaboration across distinct value chain activities in the semiconductor industry

At its very core, the firm constitutes a chain of activities that are performed to design, produce, market, deliver and support its product. Each activity is intended to add value to the output of the preceding stage. This is encapsulated by the concept of the value chain, as put forth by Porter (1985). This implies that competitive advantage is realised when the output produced by the sum of the individual value-added activities performed by the firm is perceived by customers as more valuable than the output of a competitor. However, each activity is distinct and may yield advantage to a different degree, depending on how it is executed.

With alliances being an essential part in many of the modularised high tech industries, distinct value-added activities are often jointly performed. Consequently, the competitive advantage that firms derive is naturally linked to the inter-organisational routines and processes that describe how distinct value-added activities are conducted in collaboration. It is therefore important to distinguish between distinctive value chain activities while assessing the differences in inter-organisation routines and processes, in order to understand the role of alliances and networks in generating competitive advantage in a particular industry.

This section connects the first two theoretical dimensions of the comprehensive conceptual framework developed in this chapter: the relational view (Dyer and Singh, 1998) and value chain analysis (Porter, 1985). The case of the semiconductor industry is introduced, which is known for having one of the most complex and networked value chain ecosystems in the world. First, a general understanding is offered regarding the roles that alliances play in the value-creation process of this high tech environment. It is essential to understand which kinds of arrangements chipmakers use and for which specific reasons. This is followed by an examination of the inter-organisational routines and processes that define the strategic relationships developed by semiconductor companies in different value chain activities.

3.3.1. Modes of collaboration in the semiconductor industry

Starting from the early 1980's, the customer-driven demands for speed, convenience and customisation along with the rising costs of R&D and manufacturing, sent various waves of disruption through the semiconductor industry. The growing importance of specialisation to achieve higher performance speed and lower cost in line with *Moore's Law* (Heck et al., 2011; Gloger et al., 2017) – due to the growing role of chips serving an increasingly wider variety of applications across industries – needed to meet the ever-changing customer demands, had long driven semiconductor innovation and led to the vertical disintegration of the semiconductor value chain. Specialisation also implied that product architectures, which were once fully integrated, became modular – giving space for specialised chipmakers and suppliers to enter chain of value-added activities.

With the rise of the Internet of Things (IoT) in the 2010's, the basis of competitive advantage, or the value of chips, is no longer measured solely in terms of performance and price, but to a greater extent in terms of power consumption, miniaturization, software, configurability and durability (Gloger et al., 2017). Namely, in the IoT, chips function as the heart of a myriad of industries, including medical, automobiles, consumer electronics, military defence, aerospace, manufacturing, telecommunications, logistics, utilities and so forth. This means that semiconductor companies now compete on their ability to make the best functioning chips for very specific purposes, within the shortest amount of time.

Among the strategies that semiconductor companies can adopt to distinguish themselves in the technological race, the ability to develop and leverage "access relationships" (Stuart, 2000) with strategic partners at the interface of different value-added activities has been one of the core tactical elements. Collaboration plays a crucial role in the ability of semiconductor companies to operate efficiently and effectively, as it allows accessing critical knowledge, resources and capabilities from which they can learn and which they can recombine to produce chips in line with customer demand. This involves creating and managing technology and service ecosystems by collaborating with universities, governments, research institutes, downstream players, suppliers, end-customers as well as rivals; conducting cross-industry technological innovation; and efficiently managing various sales channels (Gloger et al., 2017). Strategic relationships are organised through different modes across the value-added activities of the semiconductor value chain. The semiconductor value chain, along with the dominant organisational modes at each stage, is depicted in Figure 3.2.

The creation and commercialisation of a new generation of semiconductor chips starts with R&D and design. These comprise the stages where innovation is conducted. The designing of chips, in particular, is where the most significant amount of value-added is generated. A substantial amount of intellectual property is contained in the designs created by skilled engineers using highly sophisticated computer software and equipment (Semiconductor Industry Association, 2016). Digital chip designs are subsequently manufactured by foundries, assembled, tested and packaged, and finally distributed to the end market (see Figure 3.2). These core stages of production are populated by chipmakers, manufacturers and distributors, who are supported by material and equipment suppliers and IP and software vendor. Correspondingly, strategic relationships within these distinct production stages are organised through different organisational modes and essentially revolve around three core activities: technological innovation, manufacturing and distribution/marketing; and supply. The next section discusses how the value chain activities in the semiconductor industry are organised through inter-organisational routines and processes with the aim to achieve particular strategic benefits.

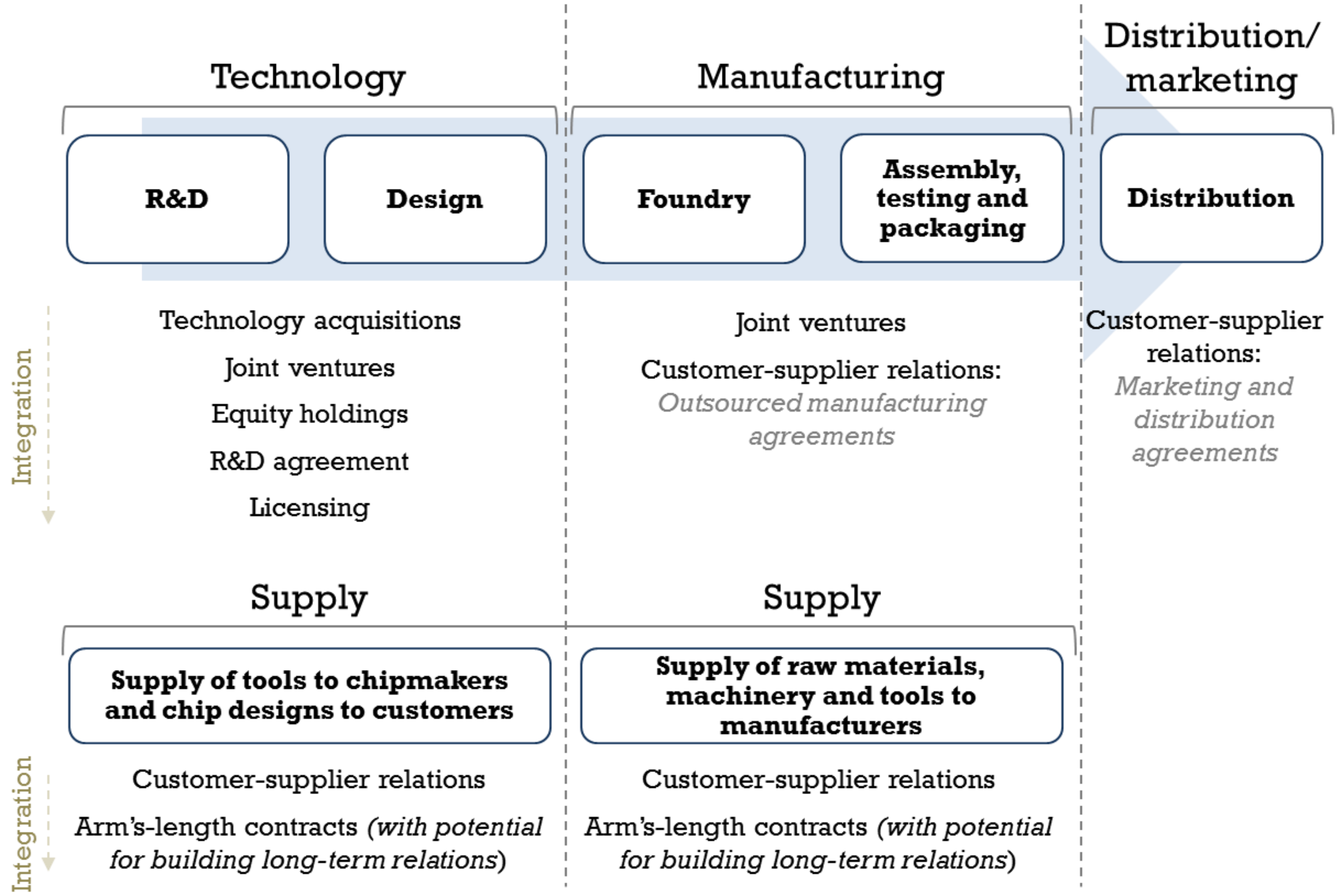


Figure 3.2: Organisational modes depicted along the semiconductor value chain (partially adopted from Semiconductor Industry Association, 2016)

3.3.2. *Inter-organisational routines and processes in the semiconductor industry*

Over the past decades, the semiconductor industry has evolved into a set of networks of collaborating organisations, each specialised in a particular value-added activity to collectively form a complex innovation system (Dibiaggio, 2006). Naturally, creating and capturing value from inter-organisational collaboration does not happen spontaneously. Each value-added activity is inherently different in terms of its purpose, is driven by different motivations, and requires a distinct pattern of interaction and coordination of tasks when conducted in collaboration (Okada, 2000). Even among semiconductor companies, according to a survey published by Kapoor (2010), joint activities with partners are coordinated by varying internal departments, such as marketing, engineering or different. Relationship building is therefore a matter which concerns not just executives but also different organisational disciplines. The inter-organisational routines and processes which are used by semiconductor companies to coordinate different value-added activities are discussed below.

Technology partnering

In order to meet stringent customer demands while maintaining profit margins, the development process of a new generation of semiconductor chips must be highly productive to efficiently translate ideas, investments and engineering efforts into the best functioning and valuable chips. Developing a new chip can cost up to US$200 million, depending on the complexity of the chip and the nature of its end market, and cane require over two years (Tamme et al., 2013; Global Semiconductor Alliance, 2016). In this process, quality and speed are paramount.

The high costs and risks associated with these projects, along with the diverse technological competences which are required, have made partnerships increasingly important over the past decades – even for the well-established chipmakers. To illustrate, Okada (2000) indicated that inter-firm R&D accounted for an average of 91.8% of the total R&D budget of semiconductor companies in Japan. This can involve simply providing technical support, licensing technology, joining a development project, membership to a technology consortia, or more significant commitments like minority equity investments (Chesnais and Thomas, 2017). Some of the most well-known consortia include *SEMATECH* (Semiconductor Manufacturing Technology) in the US, the *Centre for Semiconductor Research* at the State University of New York, the *Industrial Technology Research Institute* (ITRI) in Taiwan, the *Interuniversity MicroElectronics Center* (IMEC) in Belgium, and the *Institute of Microelectronics* in Singapore.

To develop a highly functional chip, joint development projects must be coordinated to bring together specialists from a multiplicity of technical disciplines into various activities and facilitate a process of joint decision-making between the partners involved. Specifically, these projects must provide opportunities for *learning* through the exchange of state-of-the-art knowledge, and resource pooling, in order to share the immense costs associated with the development of increasingly complex chips while leveraging the complementary expertise of a partner.

Especially with the current rise of the IoT, the capability to integrate different hardware and software components into a functional product is increasingly becoming a distinctive element of chipmakers' technology strategies (Dibiaggio, 2006; Global Semiconductor Alliance, 2016; Patel et al., 2017). In particular, as Bauer et al. (2015) and Bauer et al. (2017) have noted, the ability of chipmakers to successfully create and capture value nowadays depends heavily on their software capabilities – which they are still developing –, making licensing and joint development agreements efficient tactics through which they can rapidly learn from other organisations and strengthen their capabilities.

The increasing importance of complementary technologies and skills while mitigating development costs implies that semiconductor companies are *reciprocally interdependent* and that inter-organisational specialisation is critical in order to develop a well-functioning chip; and therefore, to keep up in the race for technological leadership. Moreover, semiconductor companies collaborate closely with suppliers of materials and equipment to coordinate the ongoing development and compatibility of advancements in materials, design tools and manufacturing equipment and processes (Semiconductor Industry Association, 2014).

Furthermore, some chief executives, for instance, have noted that it has become increasingly difficult for integrated device manufacturers to differentiate their products purely on the basis of core manufacturing process technologies (Clarke, 2008). The rising development costs has made these semiconductor companies mutually dependent on one another, to the extent that they are better off sharing the costs of developing a *common* process technology. Moreover, innovations in chips designs are, in fact, highly dependent on developments in manufacturing process technology and leading chipmakers and foundries therefore often seek one another's complementary skills and technologies in order to advance towards a new manufacturing standard (Dibiaggio, 2006). Furthermore, licensing agreements are a critically important tactic for leveraging the IP from other chipmakers or specialised suppliers which is required to develop a new chip without boosting development costs (Bauer et al., 2015). As modern chip designs are becoming increasingly more complex, integrating various IP blocks for distinct functions (Fangaria, 2014), it has become impossible for any chipmaker to develop every technological component in-house. Some fabless semiconductor companies have made it their core business to cater to this group of chipmakers by designing and selling innovative solutions and IP through licenses or patents (Dibiaggio, 2006). As it turns out, some research indicates that chipmakers obtain on average 34% of their IP from their strategic partners (Kapoor, 2010).

Needless to say, mutual trust and reliability between partners are essential in such high-risk projects. The penalty of any late product introduction is significant (Appleyard, 1996), such as a considerable loss in market share, making any opportunistic behaviour highly disruptive. Moreover, the costly and risky nature of chip development projects therefore requires chipmakers to carefully identify areas of complementarity, potential partners and the appropriate type of partnership, and they must ultimately be fully committed to their collaboration by making the necessary relation-specific investments (Chesnais and Thomas, 2017).

Core IP blocks, for example, are often licensed from existing suppliers, including pure-play IP vendors, Electronic Design Automation solution suppliers, and specialised design-services providers (Poltronetti, 2007). Co-specialisation with an existing licensing partner is often necessary as it is not always the case nowadays that IP blocks can be instantly incorporated into a chip design; moreover, specialised software tools must also often be developed jointly with the IP provider (Dibiaggio, 2006). This is due to the increasing constraints being placed on the design of chips. When partners share prior experience working together, however, they are able to establish a strong team dynamic, which is critical to reduce communication errors and improve the quality of feedback, allowing engineering teams to be highly productive (McKinsey, 2017).

Such team dynamics are even more essential during collaborations of a more exploratory nature, as they inherently bear the lion's share of the cost and risk involved in the chip development process. This is why semiconductor companies, in this case, typically opt for more integrated joint development agreements or even equity-based joint ventures or joint research centres. By making larger relation-specific investments in physical facilities, new equipment, tools and/or software, semiconductor companies are able to substantially increase stability in their partnership and reduce the uncertainty associated with exploring new technologies and markets – as had long been suggested by Pfeffer and Salancik (1978). Moreover, equity-based joint ventures/research centres in particular provide a platform where partners can physically bring together their engineering teams and stimulate the exchange of knowledge and information through face-to-face contact.

While physical proximity is not an equally predominant occurrence in non-equity joint development agreements, although this could arguably enhance the innovation process, semiconductor companies have developed particular knowledge-sharing routines to overcome the constraints of geographic distance. For example, globally dispersed chip designers are able to collaborate with engineers at TSMC of Taiwan in real time using an internet-based platform (EE-Times, 2000). This facilitates the accuracy and speed of communications between different teams of engineers, while mitigating the costs of setting up an equity joint venture. Moreover, it is in general not uncommon for chipmakers to invest in their long-standing relationships with particular past partners to leverage pre-established trust and working routines; either by extending an existing collaboration or by initiating a new partnership through a similar or different type of collaboration agreement.

In principle, however, this does not in isolation guarantee a company's willingness to commit to a partnership and to share knowledge. In collaborations between competing chipmakers, for instance, higher degrees of secrecy and a reluctance to share specific technical information generally tend to prevail (Appleyard, 1996). Some research even refers to extreme cases in which collaborating semiconductor companies pursued portions of their own R&D agendas independently, while still sharing technology and R&D costs (Okada, 2000). To incentivise their partners to commit fully to their collaborations, semiconductor companies have been reported to use various governance mechanisms. Especially in high-profile projects, minority stock ownership can be used to enable semiconductor companies to join a development process, which signals long-term commitment while enabling the partners to shorten the development cycle (SMIC, 2015). Such more complex governance mechanisms help to drastically reduce the cost of bargaining over profits from relation-specific investments (Williamson, 1985). In addition, certain semiconductor equipment developers have forged partnerships with customers (i.e. chipmakers), who provide sales guarantees or co-fund the development of new semiconductor manufacturing equipment, in order to reduce risks and generate a return on their development investments (Mahindroo and Santhanam, 2015). Overall, the technology partnering strategies of semiconductor companies can be considered to be characterised by high degrees of interdependence and cooperation (Okada, 2000).

Manufacturing partnerships

The process of manufacturing semiconductor chips consists of two sub-processes: front-end manufacturing, i.e. the fabrication of an integrated circuit on a wafer; and back-end manufacturing, i.e. the testing, packaging and assembly of the fabricated chips. The chip fabrication process, in particular, is a highly restrictive activity due to the enormous capital risks associated with setting up, maintaining and upgrading fabrication facilities. Generally speaking, the costs involved with constructing a state-of-the-art fab can easily range up to US$10 billion (Mokhoff, 2012), and developing the necessary process technologies for the fab can amount up to another US$600 million (Heck et al., 2011). By contrast, the costs of setting up a new, leading-edge chip packaging line generally amounts to between US$100 million and US$200 million (Lapedus, 2016). In manufacturing, the name of the game is achieving the scale needed to generate a return on the significant investments in fixed capital assets and the development of manufacturing technologies.

While a limited number of semiconductor companies have been successful in setting up efficient and profitable fabrication operations, the fast majority of chipmakers have either partially or completely spun off or outsourced the fabrication and packaging of their chips to specialised manufacturing service providers. This allows most chipmakers, notably the fabless players, to mitigate the high costs of manufacturing by accessing specialised complementary assets while fully focussing their core business on the designing of chips.

However, this strategy typically coincides with extreme dependency on a few or, in some cases, a single manufacturing partner. As one operations executive noted in an interview, a strong relationship between a chipmaker and foundry partner is paramount (Ladendorf, 2004). Semiconductor foundries lay out specific chip design rules and share SPICE (Simulation Package for Integrated Circuit Emulation) models according to which chipmakers must design their chips. While this implies a significant degree of asset specificity, adhering to these rules and models also minimises the need for ongoing coordination and thus keeps overall transaction costs low (AlixPartners, 2013). These relationships must therefore be nurtured over the long term, as shifting between foundries is an onerous process which requires searching for a new manufacturing partner as well as re-qualifying and re-testing products in accordance with their design rules and models (Ladendorf, 2004). However, to hedge against potential opportunistic behaviour of a single partner, the risk of increasing manufacturing fees or losing supply, some larger chipmakers collaborate with multiple foundry partners. Indeed, research by Kapoor (2010) indicates that chipmakers are more dependent on their foundry partners than vice versa, indicating a relatively small extent of mutual adjustment. By contrast, the same study also shows that back-end manufacturing suppliers tend to tailor their operations considerably more to the requirements of chipmakers.

Strong customer relations, from the foundry's perspective, are also crucial as foundries can naturally only invest in a limited range of process technologies with which they can attract customers. In other words, foundries rely on their network of customers to design chips using the manufacturing technology that they have on offer, in order to achieve scale and scope economies and maintain an efficient manufacturing operation (AlixPartners, 2013). In tackling this challenge, TSMC's Open Innovation Platform constitutes a prime example and the industry's largest ecosystem of design partners, technology and manufacturing capabilities (TSMC, 2019). Although the majority of the partnerships encompassed by such ecosystems do not involve any equity investments, the establishment of joint ventures between major manufacturers is not uncommon. For instance, in 2014 the integrated device manufacturer Micron Technology began sourcing specialised assembly and packaging services from Powertech Technology through the formation of an equity joint venture. With estimated investments of over US$200mn in equipment and a physical facility, this partnership involves a significant degree of asset specificity acting as an effective governance mechanism.

Indeed, there is research indicating that back-end manufacturing suppliers tend to considerably tailor their operations to the requirements of semiconductor companies (Kapoor, 2010). The same study also suggests, as illustrated above, that chipmakers are more dependent on their foundry partners than vice versa, signifying a relationship which is not necessarily reciprocal or based on mutual adjustment. Either way, however, inter-organisational partnerships in the area of semiconductor manufacturing do involve considerable relation-specific investments.

High levels of mutual trust, as a governance mechanism, and a smooth transfer of information are essential in these manufacturing partnerships. Both front- and back-end manufacturing suppliers share extensive information with their chipmaker customers; on future plans for technology development and production capacity expansions, as well as proprietary technical information and process monitoring data (Kapoor, 2010). In light of achieving a rapid time-to-market, chipmakers must also have direct access to current, reliable and accurate information on a foundry's design rules and process technologies. Major foundries, such as TSMC and UMC Group, have therefore developed specific internet-based tools which enable chipmakers to access this information from anywhere in the world and which distribute information on planned changes in design rules and manufacturing processes (Macher et al., 2002). In addition, information exchange routines generally also take a more personal form. For example, US-based Silicon Labs has been reported to exchange information with its Taiwanese foundry partner every week and its chief executive would visit the foundry on a quarterly basis to reinforce the strength of their ties and maintaining a detailed flow of communication (Ladendorf, 2004).

Contract manufacturers, both front- and back-end, are clearly considered by chipmakers as strategic partners; not merely sub-contractors who are dealt with at arm's-length. Moreover, these strategic relationships also increasingly include services beyond the manufacturing of chips, such as the procurement of components as well as logistics (Ertel, 2006), and are thus more integrated than otherwise considered by classical scholarly reasoning.

Distribution and marketing partnerships

In the semiconductor industry, technological competence, product performance and functionality, and access to advanced manufacturing technology, while paramount, make up only one side of the equation for success in maintaining a sustainable competitive advantage. The rate of product obsolescence is especially high in the logic chip segment, which is by far the largest segment of the overall chip market (Wong et al., 2014), as inter-generation chips are not substitutable (Dibiaggio, 2006). Time-to-market is therefore a crucial competitive factor, which ultimately determines whether or not a chip becomes a new standard (Gruber, 2000).

The semiconductor industry is one of the most globalised in the world and chipmakers maintain vast networks of foreign customers, in various end-markets. To rapidly and efficiently market and sell their new generations of products, most chipmakers maintain close, long-term partnerships with one or multiple distributors who push sales through direct contact with customers (Batra et al., 2016) and they occasionally engage with other chipmakers to jointly market their products. Leading fabless chipmaker Xilinx, for instance, has reported that its dedicated distributing partner, Avnet, accounted for 75% and 59% of total net accounts receivable in 2016 and 2017 respectively (Xilinx, 2017). Similarly, Texas Instruments, a major fab-lite chipmaker, reported that roughly 60% of their semiconductor sales to their 100,000 customers are concluded by distribution partners (Texas Instruments, 2016). To avoid becoming overly dependent on a few dedicated partners, larger chipmakers tend to diversify their distribution partnerships across multiple distributors within each major geographical region and product area, allowing them to increase their market access and exposure to a wider range of business customers, such as those in the SME segment (e.g. Maxim Integrated, 2017).

Importantly, these relationships involve more than just a traditional contractual arrangement and typically involve the establishment of a certain degree of co-specialisation. By collaborating with dedicated distributors, chipmakers are primarily able to reach a broader range of customers in a cost-effective way by leveraging the complementary assets of logistics partners, such as local market expertise, established distribution channels and logistical networks. Reaping the benefits of complementarity, however, requires that chipmakers are committed to share information on production forecasts and replenishment plans with their logistics partners, in order to optimise transportation costs and ultimately ensure on-time delivery to customers (Ertel, 2006). As is the case for graphics chip designer Nvidia, this also involves jointly defining the pricing and timing of new products in close collaboration with retailers and distributors (Nvidia, 2016).

Furthermore, distribution partners in particular also often provide timely customer service and support on behalf of the chipmaker. As an example, in addition to warehousing and inventory management, Xilinx' distributors also provide customers with engineering support in designing Xilinx chips into their end-products (Brown et al., 2000). In fact, Xilinx built a global network of over 250 qualified strategic partners through the Xilinx Alliance Program (Xilinx, 2019) whose engineers have been trained and certified to assist customers with integrating Xilinx devices into their end-products. In order to qualify for membership to the alliance program, however, potential strategic partners must have collaborated with at least one of Xilinx' sales representatives or dedicated distributors; and they must have at least one complementary product and/or service which can be re-combined with Xilinx' products in order to penetrate new applications and product/geographical markets (D&R, 2010). Such alliance programs are not rare occurrences. Other examples include Intel's Global Distribution

Network (Intel, 2019); NXP Semiconductor's Partner Program (NXP, 2019); and Renesas' Alliance Partner Program (Renesas, 2019). Similarly, chipmakers occasionally also collaborate with one another in the marketing of combinations of complementary products, with the aim of catering to customers' need for flexibility, high performance and quicker time-to-market (e.g. Business Wire, 2005; Lattice Semiconductor, 2007).

Such a networked, multi-market approach is increasingly important in the current era of the IoT (Bauer et al., 2015) and signifies a considerable degree of product customisation towards the specific needs and applications of customers. However, as Batra et al. (2016) note, to achieve an effective logistics approach through collaboration, chipmakers must sufficiently incentivise their partners to focus on those products, customers and geographical markets which complement in-house sales efforts and which are in line with the chipmaker's strategic objectives. This can be done through economic incentives, such as the payment of a financial compensation for increasing sales of a particular product. In addition, according to one distribution agreement signed by chipmaker Altera and Arrow Asia Distribution in 2001 (U.S. Securities and Exchange Commission, 2001), chipmakers can also oblige their distributors to maintain a particular value worth of inventory of specific selection of products at a price set by the chipmaker. This creates a safeguard against potential opportunism by forcing the partner to make investments in physical relation-specific assets. This incentivises the partner to engage in value-creation activities in the best interest of the relationship. All in all, the establishment and maintenance of strategic partnerships in the area of marketing and distribution go well beyond signing a basic unilateral contract.

Customer-supplier relationships

The semiconductor industry can be described as a fast-paced environment characterised by a proliferating product variety, resulting from the ongoing introduction of new product generations even before existing products reach a peak in their maturity. As a consequence, product life cycles tend to overlap and demand periods for individual products typically stretch from six months to two years, thereby forcing chipmakers to diversify into multiple product markets (Brown et al., 2000). Keeping up in this product development race is not an easy task as customer demand is notoriously difficult to predict due to the ever-changing demands for specialised products and faster delivery (Ertel, 2006).

However, by establishing extensive networks of suppliers of materials and equipment, product complementors as well as end-customers, semiconductor companies can overcome these challenges and attain significant competitive advantage. Semiconductor companies typically source generic materials and equipment through shorter-term contracts from multiple suppliers in order to reduce the risk of supply disruptions (Semiconductor Industry Association, 2014). Spot markets are less efficient in the case of specialised materials, such as rare earth gases, helium and liquid hydrogen, as these materials are subject to greater price increases and/or shortages (Semiconductor Industry Association, 2014). To hedge against these risks, semiconductor companies engage in long-term partnerships. Although data on the duration of supply contracts have been absent from the extant literature, the Semiconductor Industry Association reports that these long-term agreements typically last for at least two years (Semiconductor Industry Association, 2014).

Aside from the mere supply of goods, these partnerships provide a platform through which semiconductor companies and their suppliers can exchange critical information. While this is important in the light of responding to situations of variable demand (Ertel, 2006), the lack of substitutes for key materials renders the process of replacing existing material inputs highly complex – potentially leading to modifications in existing production processes and tools – and therefore necessitates that finding and qualifying new materials is done in close collaboration with both material and equipment suppliers (Semiconductor Industry Association, 2014).

Ultimately, those semiconductor companies which can leverage their support networks to maintain a consistent input of production resources and price stability are more likely to be perceived as reliable suppliers by their customers (Ertel, 2006). Reliability is the bedrock of a strong customer relationship, which in many cases goes beyond the traditional conception of a basic buyer-seller agreement. In fact, customer relationships in the semiconductor industry are typically highly reciprocal in nature and involve some degree of co-specialisation outside their respective manufacturing operations. This is most notably the case in the market segments for logic chips, including microprocessors, microcontrollers and digital signal processors (DSP), and programmable logic devices (PLD), as both these types of chips can flexibly be programmed to perform a variety of functions and are therefore not commodities which can be sold through spot market agreements (Dibiaggio, 2006). With a 57% share in total chip sales in 2013, these segments account for the majority of value-added activity in the integrated circuit market (Wong et al., 2014), which provides an indication for the importance of close customer relationships within the wider semiconductor industry. By contrast, in other semiconductor markets, such as memory chips and analog semiconductors, arm's-length agreements are more widespread (Kleindorfer and Wu, 2003).

As research by Kapoor (2010) indicates, customers tend to share information particularly on volume projections and product development status, as well as some proprietary technical information, and to a lesser extent on their general business strategy and product costs. In particular, the routinized provision of demand signals is an important enabler of chipmakers to effectively address variability in supply and demand (Ertel, 2006). Concurrently, the willingness of a customer to share information is typically reciprocated by a greater involvement of the chipmaker in the value-creating activities of its customer (Kapoor, 2010). For example, makers of PLDs, like Xilinx and Altera, design their chips in such a way that their customers can configure the logic underlying the chip at the post-manufacturing stage using specialised software (Brown et al., 2000). Assistance with the customisation of integrated systems, optimising performance or otherwise is often provided at the customer's site via dedicated channel partners or highly skilled in-house teams of engineers who are specialised in different applications (Bauer et al., 2015; NVIDIA, 2016; Xilinx, 2017).

In addition to product design, semiconductor companies tend to also be involved in activities surrounding their customers' cost reduction and long-term technology planning (Kapoor, 2010). Moreover, on some occasions semiconductor companies work together with a complementor, such as a communications equipment company, to combine their existing hardware and/or software components into an integrated solution for a specific application of a joint customer, like a manufacturer of cellular handsets. Clearly, these described inter-organisational processes between semiconductor companies and their customers involve a certain degree of coordination in order to align their respective product designs. At the same time, the reciprocally interdependent nature of these supply relationships creates a visible collateral bond in the form of symmetric relation-specific investments and subsequently incentivises both partners to engage in mutually beneficial value-creation initiatives.

3.4. The strategic configuration of alliance networks

3.4.1. Alternative relational network configurations

The structure of an alliance network plays a pivotal role in determining the performance differences among firms (Dyer and Singh, 1998). It can be defined by the number of firms, the relative characteristics of firms, as well as the intensity, the range, the types and the geographical and sectoral openness of inter-firm alliances between the firms (Burt, 2001); and thus the asymmetric access that industry players have to markets, materials, information, knowledge, technology or other requirements crucial to the execution of their strategies (Madhavan et al., 1998).

While the overall structure of a network can represent the competitive landscape of an industry or value chain segment, alliances function as the "network pipelines" allowing knowledge and information to flow from one firm to another (Owen-Smith and Powell, 2004). Moreover, the structure of an ego-level alliance network, i.e. the pattern that describes how the focal firm and its partners are connected, determines the degree to which individual firms can access different resources. Ultimately, it is important for managers to ally with those partners that enable them to secure key positions in the wider industry network.

Amidst the evidence offered by previous studies indicating that the network positions of firms in inter-organisational networks matter to their strategic actions and outcomes (e.g. Powell et al., 1996; Walker et al., 1997; Gulati, 1999; Rowley et al., 2000; Gilsing et al., 2007; Shiri, 2015), there has been a debate about what it means to be 'better connected'. Beyond the fact that relations with other firms in the network can provide the firm with the potential to accumulate strategically important network advantages and benefits, what matters in this equation as well are the identity of the alliance partners and the pattern of ties that exist among them (Gulati, 1998). This pattern of ties is especially important as it is likely to determine the value of the obtained advantages, and therefore firms must carefully configure their networks of alliance ties in order to gain privileged access to various kinds of resource flows (Powell et al., 1996; Uzzi, 1996).

The social network literature has been divided when it comes to examining the association between the configuration of firm-level networks and network advantage. According to some scholars, strategic network advantages arise from densely connected network configurations whereby the firm's partners are also partners (Coleman, 1988; Walker et al., 1997; Uzzi, 1997; Hagedoorn and Duysters, 2002). These configurations are considered advantageous to the extent that they are "integrated" or "closed" (Greve et al., 2014) and firms should thus strive to maximise the interconnectedness among their *direct* alliance partners. By contrast, others advocate that network advantages derive from the *brokerage* opportunities that are generated by an open network configuration (Burt, 1992; Soda, 2011), representing a "hub-and-spoke" structure which consists of disconnected partners (Greve et al., 2014). Accordingly, superior competitive advantage ought to be achieved by being positioned *between* dense networks instead of *within* them. Rather than enhancing interconnectedness, firms should configure their networks to maximise disconnections (or *structural holes*) between their *direct* alliance partners and ally with those firms that have many other partners (i.e. *indirect ties*). Finally, another group holds that these two distinct types of configurations instead provide complementary properties (Baum et al., 2010; Gilsing et al., 2007; Gobbo and Olsson, 2010) which can be combined into a "hybrid" network structure (Greve et al., 2014) that offers a wider variety of network advantages and associated benefits depending on the context.

An important insight from past research has been that the emergence of closed and open network structures ought to be the product of the inherent differences in the strategic motivations of firms, and that either of them are advantageous to the extent that the firm is engaged in exploitation or exploration of know-how (Rowley et al., 2000); is partnered with incumbent industry players or new entrants (Walker et al., 1997); or is situated in a technologically dynamic or stable industry (Tatarynowicz et al., 2016). Likewise, the formation of either of these different network configurations should also depend on the underlying nature and the strategic rationale of the transactions for which particular alliance networks are used (Ahuja, 2000). This means that the feasibility of specific alliance arrangements, the distinctive capabilities of the partners, and the level of mutual trust should play important roles in shaping the advantages and benefits that firms can accumulate through closed or open network configurations (Afuah, 2013).

Ultimately, this should reveal that different alliance networks are not configured by firms in homogenous ways (Shipilov, 2012); but rather that the structural configuration of one type of alliance network may be driven by a need for closure while the structural configuration of another kind of alliance network may reflect a need for access to brokerage opportunities.

3.4.2. Comparing the strategic benefits of alliance network configurations

The degree to which the alliance strategy of a firm is designed to exploit existing technologies, skills and information through, for example, joint production or licensing agreements; to explore emerging innovations through joint development pacts; to constrain potential opportunistic behaviour of partners; or to develop trust, behavioural norms and knowledge sharing routines (Uzzi, 1997; Walker et al., 1997; Gulati and Singh, 1998; Dyer and Noboeka, 2000), among other strategic outcomes, likely dictates the network benefits that the firm needs as well as the appropriateness of particular structural network configurations.

In particular, the firm's ability to derive strategic benefits from their alliance networks, according to past research, depends on the pattern of interconnectedness (or disconnectedness) among their alliance partners (Coleman, 1988; Burt, 1992). Two main, contrasting views, as introduced previously, have dominated the literature. According to Coleman's (1988) original work around closed networks, and the various past studies that have adopted his views, firms ought to derive various benefits from being embedded in densely interconnected alliance networks whereby the firm's partners are also partners. This concept revolves around the idea that those firms which are cohesively tied are able to effectively routinize knowledge-sharing practices and joint problem solving (Uzzi, 1997; Dyer and Noboeka, 2000) as well as stabilise their alliance relations by establishing mutually understood norms of cooperation and trust (Granovetter, 1973; Gulati, 1995a; Rowley, 1997; Walker et al., 1997). Increased trust can subsequently facilitate the proliferation of triangulation among alliance partners (Gilsing and Nooteboom, 2005), whereby the richness and reliability of information that the firm obtains from its partners can be assessed through cross verification from multiple sources. This should consequently enhance the absorptive capacity of the focal firm (Gilsing et al., 2008). Accordingly, densely interconnected alliance network structures impose a certain degree of interdependence on the focal firm and its partners (Skilton, 2015), which benefits them to the extent that they are able to share and obtain fine-grained information about each other (Gulati, 1998). Without these structural benefits, sharing and combining resources with strategic partners, and making large relation-specific investments are bound to be unproductive and highly inefficient (Coleman, 1988).

Furthermore, firms can also leverage their densely interconnected alliance networks as mechanisms for constraining opportunism (Coleman, 1988; Gulati, 1995a; Walker et al., 1997; Hagedoorn and Duysters, 2002). Should a certain actor deviate from the established norms of cooperation, whether that concerns poor quality of investments or opportunistic behaviour, information regarding such acts of free-riding will travel rapidly to other firms in the densely interconnected network and the actor will consequently be sanctioned (Walker et al., 1997). This can result in a severe loss of reputation, drastically limiting the actor's ability to find new alliance partners who are willing to collaborate (Ahuja, 2000). This mutual monitoring capability inherent in dense alliance networks therefore provides members with the economic incentive to act honestly and trustworthy (Granovetter, 1985; Coleman, 1988).

Opponents of the high density argument, however, criticise that it creates risks of undesirable spillovers and prevents firms from accessing and utilising diverse resources, and consequently creating novelty value (Gilsing and Nooteboom, 2005). Namely, in dense alliance networks, the densely disseminated nature of information and knowledge means that the novelty benefits of direct and indirect alliance ties are limited because many other firms have equal access to it (Gilsing et al., 2008). Accordingly, Burt's (1992) original theory of structural holes advocates that direct alliance ties provide access to distinct flows of new information, alternative ways of thinking, and entrepreneurial opportunities to the extent that this entails allying with mutually unconnected alliance partners (Ahuja, 2000; Reagans and McEvily, 2003; Soda, 2011). By bridging such 'structural holes' or gaps in the flows of information between network participants which are not connected to each other, firms can gain strategic access to non-redundant resources which can consequently enhance their capacity for novelty creation (Burt, 1992; Ruef, 2002).

Other benefits associated with *brokering* structural holes may be derived from a power advantage which originates from the firm's ability to negotiate, arbitrage and exercise control over the flows of information and knowledge between its disconnected alliance partners (Burt, 1992; Kilduff and Brass, 2010; Soda, 2011). Accordingly, the firm can withhold or distort information to their advantage and leverage its bargaining power by playing off unconnected partners against each other in an attempt to secure favourable transaction terms or discouraging the potential opportunistic behaviour of partners (Gulati, 1998; Afuah, 2013; Greve et al., 2014).

Overall, it can be argued that if the successful execution of a firm's alliance strategy relies on access to rich and reliable information, cohesive, dense network configurations should likely be optimal. Conversely, constructing networks rich in structural holes should be beneficial when the successful execution of the firm's alliance strategy depends on access to novel, non-redundant information and the identification of entrepreneurial opportunities.

3.5. Hypothesis development: the properties of alliance network architectures

The aggregate of all ego networks of alliances surrounding all firms in an entire network defines the overall structure or *architecture* of that entire network – which therefore reflects a specific pattern that represent the collective collaborative behaviour of all the firms within the network at hand. This behaviour can reflect a collective tendency towards forming open or closed networks, depending on the network benefits which firms are seeking to attain. Namely, the architecture of a network greatly influences the way in which information, knowledge and other resources are diffused among organisations within it. The cohesiveness of networks can lead to particular collective outcomes, as past studies have indicated (Gulati, 1995b; Rowley et al., 1997; Gulati and Gargiulo, 1999; Ahuja, 2000; Stuart, 2000; Reagans and McEvily, 2003; Owen-Smith and Powell, 2004), and this can subsequently shape the performance of firms (Bell, 2005; Schilling and Phelps, 2007; Gilsing et al., 2008).

Given the role of network architectures in shaping the nature of the collective outcomes which firms can reap as a result of their positions in a network, the following will be argued: which collective outcomes firms seek depends on the (a) value-added activity that they are performing in collaboration with a partner organisation and (b) the rationale and collaborative nature of their partnership; and variation in the architectural properties of networks can therefore be explained through these factors. Network connectedness, clustering and centralisation are important architectural properties which can be used to understand how patterns of inter-organisational collaboration differ between value chain activities.

Table 3.1 integrates the various theoretical concepts discussed previously into a comprehensive framework and offers a structured overview illustrating which network architectural properties are expected to be observed in the distinct value chain modules as well as why.

3.5.1. Network connectedness

The connectedness of a network indicates how integrated or fractured the overall network is. Highly interconnected networks are a reflection of firms' collective tendency towards forming dense networks of alliance relationships. As previously discussed, this tendency is especially said to come forth from the ability of dense networks of relationships to promote the establishment of mutual norms of cooperation and trust between organisations (Granovetter, 1973; Gulati, 1995b; Rowley, 1997; Walker et al., 1997; Hagedoorn and Duysters, 2002) and facilitate the routinisation of knowledge-sharing practises (Uzzi, 1997; Dyer and Noboeka, 2000), by functioning as coalitions against potential opportunism and mechanisms to inflict considerable reputational damage (Coleman, 1988; Gulati, 1995a).

Accordingly, intense connectivity among organisations in a network ought to be found in environments where the build-up of trust prevails as an essential part of the inter-organisational processes established by collaborating organisations. Trust is particularly critical in situations where firms face extensive uncertainty and risk, such as in activities which are exploratory in nature, where the effectiveness of formal contracts as a governance mechanism is limited (Nooteboom, 1999, 2002). Without trust induced by an interconnected network structure, as Coleman (1988) suggested, the sharing and combining of resources with inter-organisational partners, and making large relation-specific investments are likely to be unproductive and inefficient.

In the production of a new generation of semiconductor chips, the development stage of a new chip most closely resembles such a context, as it is known as a notoriously expensive and sophisticated value-added activity which is subject to extensive uncertainty and risk. Chipmakers therefore collaborate to share the costs and risks associated with these uncertain development projects. This is predominantly done through non-equity joint development agreements, and to a lesser extent through equity joint ventures, as flexibility to rapidly move into new technological areas and product markets is essential. Although substantial amounts of value and IP are created at this stage, the anticipated outcome of any given joint chip development project does not exist at the time of signing. This comprises a major difference with other, downstream value-added activities in the semiconductor industry, where outcomes can be more easily specified ex ante. Moreover, the risk of any form of opportunism in the development of a new chip could be detrimental to the competitive and financial position of a chipmaker.

Accordingly, a governance structure must be in place which is aimed towards maximising the joint value of the output of a joint development project and minimising the potential for opportunism. Specifically, this structure should incentivise the collaborating chipmakers to share their technical knowledge, combine their complementary technological competences, and make substantial relation-specific investments in the interest of the partnership. Ex ante contractual agreements are ineffective in this case, as they can neither be written to sufficiently safeguard the partners involved against opportunism, nor specify or enforce a division of returns to a product which has not been developed yet (Teece, 1992). Chipmakers therefore occasionally use equity investments as a governance mechanism, for instance through participation in setting up an equity joint venture or acquiring a minority equity stake in a partner's business as part of a non-equity joint development agreement.

Self-enforcing agreements or trust, by contrast, enable organisations to overcome the limited effectiveness of formal contracts on the one hand and the inefficiency of equity stake investments on the other hand (Granovetter, 1985; Dyer and Singh, 1998). Importantly, mutual

Table 3.1: Multi-dimensional conceptual framework, presenting a systematic overview of expected sub-network architectures at distinct semiconductor value chain stages (source: created by the author)

Value chain module	**R&D**	**Design**	**Foundry**	**Assembly, testing and packaging**	**Distribution**	**Production inputs and outputs**
Type of network	**Technology**		**Manufacturing**		**Distribution/marketing**	**Supply**
Characteristics of value chain activity	Highly specialised and increasingly complex and expensive. Aimed at generating innovative technological breakthroughs and creating significant value-added. Exploitative and exploratory in nature and subject to high levels of uncertainty and risk.		Predominantly highly restricted due to immense fixed capital requirements. Achieving economies of scale and scope is essential to long-term survival.		Segment populated with a large number of distributors and potential joint marketing partners across all geographical regions and major product markets. Rapid time-to-market through efficient and effective channel strategies is imperative to chipmakers' competitive advantage.	Supply chains are increasingly seen as strategic differentiators as customer demand is becoming more difficult to predict. Supply does mostly not involve high levels of specialisation.
Drivers of collaboration	Accessing specialised complementary resources and capabilities; learning; and sharing the costs and risks entailed with the development of semiconductor chips.		Mitigating the substantial costs of manufacturing by leveraging assets specialised to fabricating and packaging new generations of chips.		Improve cost efficiency while rapidly maximising market access and customer reach, including smaller customers which might otherwise be overlooked.	Improving cost efficiency, achieving price stability and reducing the risk of supply disruptions.
Dominant type of organisational mode	A variety of alliances based predominantly on non-equity ties, such as R&D partnerships and licensing agreements to retain strategic flexibility while rapidly accessing diverse critical resources. Equity-based ties, such as JVs, technology acquisitions and minority equity investments, occur less frequently.		Predominantly customer-supplier relations based on non-equity ties, with most chipmakers completely outsourcing the manufacturing of their chips to dedicated foundries and/or back-end manufacturers. Costly JVs occur less frequently.		Non-equity based customer-supplier relations, linking chipmakers to a wide range of distributors and marketing partners across the globe.	Predominantly customer-supplier relations based on non-equity ties, with some collaborative activity organised through arm's-length contracts with the potential for longer-term relationship building.
Integration and interdependence of joint activities	**Low to high integration.** Collaboration is long-term and aimed at joint value creation; involving a complex and overlapping division of technical resources and capabilities which requires ongoing coordination and joint decision-making. Partners perceive high degrees of reciprocal interdependence.		**Medium integration.** Deep and sticky relationships aimed at enhancing transaction cost efficiency. Cost of ongoing coordination of collaborative activities is minimised due to predetermined design rules and SPICE models. Mutual adjustment is more prevalent with respect to back-end manufacturing.		**Medium integration.** Close and long-term relationships with a single or multiple dedicated channel partners to improve cost efficiency; extending beyond arm's-length to include qualified customer service and engineering support on behalf of chipmakers.	**Low to medium integration.** A variety of short- and longer-term agreements with multiple suppliers of generic and specialised materials and equipment, and customers of generic and programmable chips. Relations often involve some degree of mutual adjustment.
Relation-specific investments	Extensive specialised investments in physical and site-specific assets and human co-specialisation, to facilitate the coordination of joint decision-making and task execution, and stimulate the exchange of knowledge.		Significant asset specificity, as chipmakers must design their chips in line with the design rules and SPICE models defined by foundries. Co-specialisation is more prevalent in relations between chipmakers and back-end manufacturers. Switching foundry partners is also highly costly.		Overall relatively low degree of co-specialisation. Some co-specialisation resulting from technical and sales training provided by chipmakers to channel partners. Distribution partners may also be obliged to invest in maintaining large stock of specific products.	Non-asset specific investments in arm's-length agreements; with some degree of co-specialisation to the extent that chipmakers are closely involved in the value-creation activities of customers.

Table 3.1 Continued

Inter-firm knowledge-sharing routines	Highly reciprocal, with partners actively transferring, recombining or creating specialised knowledge. Overlapping knowledge bases are essential.	Extensive sharing of technical and operational information between chipmakers and manufacturing partners, with occasional visits to the manufacturers' sites.	Two-way flow of production- and market-related information, also involving training routines, to align company goals with distributors' strategies and ensure on-time delivery to customers.	Longer-term supply partnerships involve information sharing routines to combat periods of variable demand. Customers share a variety of information, enabling chipmakers to address demand variability.
Complementary resources and capabilities	Exploitation of licensable IP, technology and software and joint exploration of new technologies by combining complementary development skills and capabilities of redundant and non-redundant partners, to develop novel and functional chips.	Front- and back-end chip manufacturing is often outsourced to exploit the specialised assets and capacity of dedicated manufacturers.	Chipmakers exploit the existing market knowledge and distribution network of the partner. These are typically not specialised to a particular chip generation; however, specialised investments in technical and sales training enhance the indivisibility of resources.	Materials and equipment are sourced from secondary markets and are mostly not specialised to specific chip generations; however, triadic supply agreements involving complementors often entail more specialised resource combinations and greater indivisibility.
Effective governance	Stabilised relationships created primarily through trust relations and reputation, as development outcomes cannot be specified ex-ante. Equity stakes are also used, although relatively less frequently.	Manufacturing relations require high degrees of trust as a means of ensuring the continuous sharing of information and safeguarding relation-specific investments, due to high partner switching costs.	Economic incentives to encourage sales growth of particular products; or economic hostages in the form of relation-specific investments in physical assets (i.e. stock) as a means of safeguarding against potential opportunism.	Supply agreements are mainly enforced through legal contracts, with some agreements involving economic hostages.
Expected properties of overall network architecture				
Connectedness	**High connectedness** functioning as effective governance structure to promote mutual trust and norms of cooperation while safeguarding substantial specialised investments through a social reputation mechanism.	**Low connectedness** resulting largely from chipmakers' commitments made to partner-specific design rules and SPICE models.	**Low connectedness** resulting from the largely generic nature of relationships and low switching costs, which mitigates the need for reputation-induced governance.	**Low connectedness** resulting from the largely generic nature of relationships and low switching costs, which mitigates the need for reputation-induced governance.
Clustering	**High clustering** to enhance the diversity of technical resources and capabilities needed to generate novel product innovations.	**Low clustering** due to the vertical nature of manufacturing relationships	**Low clustering** due to the vertical nature of distribution/marketing relationships.	**Low clustering** due to the vertical nature of customer-supplier relationships
Centralisation	**Low centralisation** with privileged access to diverse knowledge and technologies concentrated among a number of central technological leaders.	**High centralisation** due to highly specialised and nature of assets and inter-firm relationships and capital-intensive value chain activity, enabling a select few manufacturers to establish a high degree of centrality.	**Low centralisation** due to generic nature of value chain activity and relatively low degree of co-specialisation, which lead to lower costs of switching to other partners and little space for concentration of network power.	**Low centralisation** due to generic nature of value chain activity and relatively low degree of co-specialisation, which lead to lower costs of switching to other partners and little space for concentration of network power.

trust can effectively be established by firms within networks characterised by high degrees of connectedness. Highly interconnected networks thus function as governance structures enabling semiconductor companies to effectively and efficiently safeguard their enormous specialised investments into chip development projects, while also facilitating the exchange of sensitive and highly tacit technical knowledge.

Accordingly, it is reasonable to expect to identify architectural patterns of higher network connectedness among strategic technology alliances at the R&D and design stage of the semiconductor value chain, in comparison to the sub-networks of alliances at other value chain stages. The following is hypothesised:

Hypothesis 1 | *Network connectedness is the highest in the network of technology alliances, as compared to other alliance networks.*

3.5.2. Network clustering

The downside of excessive network connectedness is that it can lead to the homogenisation of knowledge and information available within a network (Uzzi and Spiro, 2005). Knowledge and information diffuse rapidly between densely interconnected organisations and this is likely to render conventional rather than novel. Moreover, with high connectivity comes an increased risk of unwanted spillovers, constraining the firm's ability to appropriate significant value from particular knowledge or information (Gilsing et al., 2008). Concurrently, high degrees of interconnectedness may cause established incumbents to collectively resist adopting a new or innovative way of thinking; thus creating a barrier for newcomers to introduce technological innovations that could potentially disrupt existing markets and production processes (Uzzi, 1997; Kraatz, 1998). The main argument against network connectedness has therefore been that it limits the possibilities for novelty creation (Lazer and Friedman, 2007; Gilsing et al., 2008; Tatarynowicz et al., 2016).

By contrast, research pioneered by Burt (1992) has shown that less interconnected networks rich in structural holes are better at preserving diversity. Organisations within these networks are able to reap efficiency and brokerage advantages by forging non-redundant ties. Concurrently, Burt (2001) suggests that the need for network closure or openness is not necessarily an 'either/or' matter, as both structures provide different benefits which are valuable for different activities or purposes. The structure of a network sets the stage for a firm's ability to innovate (Tolstoy and Henrik, 2010).

We may find that networks in which organisations require some degree of connectedness to induce trust as well as a sufficient extent of openness to access complementary, novel information and knowledge will have an architecture that exhibits a high degree of network clustering. Accordingly, clustered networks are populated by interconnected groups or clusters of organisations that are linked on the basis of similarity or complementary, which induce a common identity, trust and reciprocity norms (Grannovetter, 1973; Coleman, 1988); which can stimulate joint problem solving by increasing the diffusion of alternative interpretations of and solutions to problems (Powell and Smith-Doerr, 1994); and which maintain non-redundant bridges to organisations in other clusters to ensure access to novel information and knowledge (Schilling and Phelps, 2007). This combination of structural network properties provides information transmission capacity (Burt, 2001) and ultimately enhances the possibilities for firms to recombine resources into novel solutions (Schilling and Phelps, 2007). In line with this logic, Krugman (1991: 142) described clusters as "dynamic arrangements based on knowledge creation, increasing returns and innovation in a broad sense".

Although access to critical complementary resources is important in relation to all of the value-added activities in the semiconductor industry, such as access to technology, manufacturing capacity, marketing, distribution and after-sales support, it is the need for complementary resources in *combination* with the need for mutual trust which renders high degrees of clustering most probable among strategic technology alliances at the R&D and design stage of the semiconductor value chain. Indeed, a wide range of studies has indicated that clustering enhances the firm's ability to innovate (e.g. Baptista and Swann, 1998; Morosini, 2004; Schilling and Phelps, 2007; Boja, 2011).

As discussed previously, chipmakers which engage in the joint development of new chips or manufacturing processes predominantly arrange this activity non-equity joint development agreements and, although less frequently, through equity joint ventures. These types or alliances involve relatively significant degrees of interdependence between partners in comparison with the customer-supplier relationships seen in relation to the other value chain activities of the semiconductor industry. This is due to the more integrated nature of joint development agreements, which is the result of the substantially greater specialised investments made under these agreements along with the active sharing of knowledge and complementary technological resources and capabilities. This requires collaborating chipmakers to interact more intensively on joint development projects, in order to coordinate the division of a complex array of technical tasks and investments and ensure high levels of ongoing cooperation and joint problem solving.

Complementary IP is typically also licensed from, mainly, several leading IP developers and integrated into newly developed chip designs. Licensing is a relatively uncomplicated means of accessing complementary technology which requires relatively little coordination. Although this type of agreement does not account for the majority of collaborative activities at the chip development stage, it does contribute to the architectural representation of the overall network.

All in all, however, chipmakers collaborating on joint development projects require a network structure which not only offers a self-enforcing governance mechanism that safeguards their specialised investments and preserves their critical resources, but which also provides access to non-redundant resources and capabilities necessary for advancing the existing technological standards. It is therefore reasonable to argue that patterns of high network clustering ought to be exhibited among strategic technology alliances at the R&D and design stage of the semiconductor value chain. Accordingly, the following is hypothesised:

Hypothesis 2 | *Network clustering is the highest in the network of technology alliances, as compared to other alliance networks.*

3.5.3. Network centralisation

One of the principal concepts of network structure is *centrality*, which indicates the position of an organisation relatively to other organisations within a network (Borgatti, 2005). In other words, centrality indicators capture the patterns of alliance relations maintained by a given organisation, along with the processes by which information and knowledge are potentially mobilised within the overall network and the firm's ability of accessing these flows (Borgatti, 2005). Network centrality has been long linked by network researchers to effects such as power (Krackhardt, 1990; Alderson and Beckfield, 2004), influence and prestige (Wasserman and Faust, 1994), reputation (Gulati, 1998; Gulati et al., 2000) and status (Podolny, 1993), and can therefore be viewed as an indication of an organisation's level of network dominance over other organisations in the network.

Network power, in this respect, is therefore inherently relational and results directly from the connectedness of a given individual organisation. With each relation being a potential source of relevant information, resources or influence, firms have power to the extent that they are well-connected and function as central hubs of knowledge and information. Powerful firms thus derive strategic advantage from their ability to control the mobilisation of resources through their various alliance partner networks (Galaskiewicz, 1979; Burt, 2004), coordinating action and withholding or distorting information to their advantage; their extensive bargaining power (Crook and Combs, 2007); and their ability to become better informed about trends, developments and new business opportunities within the overall network (Gilsing et al., 2008). In addition, high levels of power have been shown to strengthen customer-supplier relationships (Maloni and Benton, 2000; Benton and Maloni, 2005), enable economies of scale (Cox, 2001) and enhance the ability to design and coordinate distribution channels (Kähkönen and Virolainen, 2011).

The distribution of network centrality among all the organisations in a network gives rise to the architectural property of *centralisation* (Wasserman and Faust, 1994). This indicator captures the connectivity among all organisations in a network by measuring the degree to which the overall network is clustered around one single firm (Freeman, 1978). In other words, network centralisation provides an indication of the extent to which flows of information, knowledge and other resources are controlled by a single dominant organisation.

While network power, to a certain degree, can arguably be important across all value-added activities within the semiconductor industry, whether in the light of curtailing opportunism, improving cost efficiency, or increasing access to technical skills, technology, or new product or geographical markets; the strategic benefits associated with network power ought to be particularly essential in the manufacturing of semiconductor chips. The key to explaining variation in the degree of network centralisation between the manufacturing network and the other alliance networks along the semiconductor value chain is economies of scale.

The competitiveness of semiconductor companies hinges on their ability to generate innovations for new markets as well as their ability to achieve the productivity required to compete in mature markets. Whereas innovativeness, as discussed, should require high degrees of network connectedness and clustering, productivity requires high degrees of network centralisation. To maintain a semiconductor manufacturing operation, a semiconductor company must be able to make substantial capital investments in manufacturing facilities and technology development. As most chipmakers are unable to accomplish this, they mitigate these extreme costs by outsourcing the fabrication of their chips to specialised foundries. Due to the enormous cost of manufacturing, there are only a handful of foundries that offer their services, whereas in other value-added activities, such as semiconductor distribution, specialised channel partners are plentiful as they are not bound by substantial capital investments. While the availability of potential partners should help to explain some of the variation in the centralisation of distinct alliance networks, this is fundamentally due to high capital requirements as well as the ability to maintain a productive operation.

The foundry's ability to sustain productive, however, relies to a large extent on economies of scale generated by consistently high foundry capitalisation rates, which naturally requires sufficient demand from a network of customers. By aggregating the business of multiple fabless chipmakers, foundries can achieve the scale required for the enormous capital investments and risks that they take on (Wong et al., 2014) and consequently achieve competitive advantage over less productive foundries. The name of the game is, therefore, building large, centralised networks of customers.

By laying out their specific chip design rules and SPICE models to which new chip designs must conform, and which drastically increase the cost of switching foundry partners, foundries can 'lock' their chipmaker customers on to their process technologies. While this implies a certain degree of asset specificity which minimises the need for ongoing coordination, it also reduces the foundry's risk of losing customers to rival foundries and consequently enables it to maintain high levels of productivity. All in all, the following is hypothesised:

Hypothesis 3 | *Network centralisation is the highest in the network of manufacturing alliances, as compared to other alliance networks.*

3.5.4. Network properties in other value chain modules

The nature of collaborations in the areas of distribution/marketing and supply should not demand the same extent of strategic network benefits as do chip development alliances and manufacturing partnerships. The main reason ought to revolve around variation in the need for specialised versus generic complementary resources along with the vertical nature of customer-supplier relationships. Whereas the joint development of new semiconductor chips demands combining highly specialised technological resources and capabilities, and the fabrication of chips through outsourcing requires access to specialised process technology, with any chip design needing to conform to specific design rules and models; the distribution/marketing of chips and the supply of materials, resources and end-products generally requires access to resources which are more generic to the innovation at hand. In turn, this allows predicting how the architectural properties of these alliance networks should vary in comparison to the networks of technology and manufacturing alliances.

Both distribution/marketing and supply relations are largely driven by the need for cost efficiency and access to complementary resources, whether that is established local distribution channels or production materials and equipment. For the most part, unlike is the case in especially the area of semiconductor manufacturing, these complementary resources are generic to the extent that they are exploitable and have many available providers. With time-to-market being critical to the competitive advantage of any chipmaker due to the high rate of product obsolescence in the majority of the chip market, chipmakers require rapid access to markets and customers. While some chipmakers (e.g. Xilinx) have reported to rely mainly on a single dedicated distribution partner, many others (such as Maxim Integrated) diversify the distribution of their chips across multiple partners within every major geographical region and product area in order to increase market access and exposure while mitigating excessive dependence on a single partner and reducing potential opportunism.

With the exception of specialised materials and equipment which have relatively few potential suppliers, semiconductor companies mostly source generic materials and equipment, from multiple suppliers in order to maintain a consistent input of production resources and price stability. Demand for semiconductor chips is notoriously variable and thus the general tactic is to maintain a large network of partners in order to lower the risk of supply disruptions, reduce the cost of switching suppliers and curb potential opportunism in general; without requiring the mutual trust and inflow of innovative resources provided by high degrees of partner interconnectedness and network clustering needed in highly specialised joint chip development projects.

Accordingly, some degree of network power ought to be necessary to improve the chipmaker's competitive position within the network, while also strengthening its relationships with suppliers and customers and enhancing its ability to design and coordinate distribution channels, as suggested by Maloni and Benton (2000) and Kähkönen and Virolainen (2011) respectively. Concurrently, in both the distribution/marketing and supply of semiconductor chips, the need for access to a wide range of strategic partners should outweigh the importance of having a densely interconnected network of partners that can function as a reputation mechanism to safeguard relation-specific investments and the sharing of operational, logistical and market-related information and knowledge. Taken together, the following is hypothesised:

Hypothesis 4	*Network connectedness, clustering and centralisation are low in the networks of (i) distribution/marketing alliances and (ii) supply relations.*

3.6. Research methodology

3.6.1. Data collection

The data collection process for this research is comprised of two main stages, with the aim of creating a new dataset by connecting two separate data sources: OSIRIS and Factiva. As a first step, an initial sample of semiconductor firms was collected from the OSIRIS database. These firms were classified as being active at the core of the semiconductor industry as indicated by their primary US SIC codes (code 3674: "Semiconductors and related devices"). The sample was selected randomly, without the imposition of any selection criteria besides firms' primary US SIC codes and their 'active' status; and therefore no selection bias based on their country of origin, firm size or otherwise was introduced into the sample. The selection in OSIRIS resulted in an initial sample of 483 publicly traded semiconductor firms who were either active or established during the 11-year period of 2004-2014.

The present research focuses on the collaborative activities of firms in the global semiconductor industry for a few reasons. Semiconductor companies have conventionally been engaging in large numbers of horizontal, vertical and cross-industry partnerships (Hagedoorn, 1993). This provides a suitable context that permits studying the development of networks of alliances over time. Moreover, the semiconductor industry is home to heterogeneous players, ranging from smaller, specialised chip producers to large and integrated manufacturers (Stuart, 2000; Wong et al., 2014).

The second stage of data collection revolved around the collection of data on alliance formations announced by the 483 semiconductor firms selected during the first stage. Factiva was used as the primary data source during this stage. Factiva provides an aggregation of content from various news sources, including newspapers, magazines, journals and newswires. In constructing the dataset for this study, searches for alliance announcements during the period 2004-2014 were made in Factiva using the names of the 483 semiconductor companies as well as key words relevant to alliance announcements, such as "alliance", "partnership", "agreement", "joint venture", "cooperation" and "collaboration". Searches in Factiva were made on a company-by-company basis.

A number of important considerations were made during the process of collecting the data on the formation of alliance agreements by the 483 semiconductor companies, in line with Duysters and Hagedoorn (1993) who created the MERIT-CATI alliance databank using Factiva. First of all, the boundary of the network was determined on the basis of the industry affiliation of the focal firms in the sample as indicated by OSIRIS, namely the semiconductor industry. Searching Factiva within the boundaries of this semiconductor industry network resulted in the identification of both intra-industry alliances and intra-industry alliances, as cross-industry collaboration constitutes an essential part of the innovation activities of semiconductor companies (Andén et al., 2015; Global Semiconductor Alliance, 2018). Therefore, alliance formations between semiconductor companies and partners located outside the semiconductor industry were also recorded in the dataset. Importantly, the network boundary did not extend to cover all alliance ties formed by all the partners of the focal semiconductor firms; therefore, alliance ties formed between the non-focal partner organisations were not collected and recorded when these ties did not form part of a multi-partner alliance (i.e., three or more partners) with at least one focal semiconductor firm, as it would be practically impossible to gather alliance data on a network of potentially thousands of organisations. Moreover, since the current research is focused specifically on the collaborative strategies of semiconductor companies, if alliance ties formed by non-focal partner organisations are not formed with at least one focal semiconductor firm, either within a dyadic or multi-partner alliance, then these 'missing' ties would fall outside of the network boundary and would therefore not be of interest to this research.

Secondly, a copy of the main points raised in each of the alliance announcements was saved in the database. This covered the names of the companies participating in the alliance, the year of formation, and a description of the overall goal or objectives of the alliance. Importantly, this also enabled recording (1) the names of partners beyond the focal firms, (2) whether a given alliance is dyadic or multi-partner (e.g., triadic) in nature, and (3) any alliance ties between non-focal partners in order to capture cross-industry triadic alliances within the boundary of the network. Often, the announcement specified the type of alliance agreement on which it reported, such as a joint development agreement, licensing agreement or a supply contract; however, when this was not specified, the description of the alliance agreement would enable to derive the type of alliance which had been formed. The types of alliance agreements specified in the dataset were determined in line with the types recorded in the MERIT-CATI databank (Duysters and Hagedoorn, 1993).

Thirdly, the company names mentioned in any alliance announcement found in Factiva were checked against the actual names of the focal companies recorded in the sample created in OSIRIS. Namely, it could occur that some companies, based in entirely different industries, carry similar names; therefore, it was important to ensure that alliance data were collected for the semiconductor companies actually recorded in the sample. In addition, all alliance announcements were read through in case references were made to the semiconductor industry or any other industry; and in the rare case of doubt these companies' websites were visited to ensure they were indeed affiliated to the semiconductor industry. This helped to further ensure that the correct alliance data were collected for the companies in the sample.

Fourthly, foreign subsidiaries of multinational enterprises were recorded as individual companies and any alliance formations formed by these companies were registered against their own names in the dataset, rather than against their parent organisations. This consideration was made in line with research demonstrating that foreign subsidiaries do often operate and make strategic decisions, such as the formation of alliance network relations, autonomously (Boehe, 2009; Gammelgaard et al., 2012).

Finally, although there are a number of limitations to the data collection approach used for this research, such as that companies generally do not publicly announce every single collaborative relationship they establish; smaller and less-known firms might be more likely to appear less often in the media; and our coverage of reported alliance announcements was limited to English-language press journals, Factiva has been deemed a reliable source as it also constituted the primary data source for the MERIT-CATI alliance databank (Duysters and Hagedoorn, 1993), which has yielded numerous articles in the alliance literature (e.g. Hagedoorn and Narula, 1996; Hagedoorn et al., 2005; Dittrich and Duysters, 2007). The MERIT-CATI databank has, however, not been updated since the early 2000s and therefore it has been decided to establish a new dataset reflecting more recent alliance trends.

3.6.2. Sample composition

During the second stage of the data collection process, data on alliance formations were found for 285 out of the 483 semiconductor firms in the initial sample. This sample of 285 firms forms the basis for this research and is composed of companies located in a total of 22 countries (see Table 3.2), creating an international context for the research.

Table 3.2: Composition of initial sample by country of origin, in terms of firm counts and alliance agreements formed throughout the sample period of 2004-2014.

Country of origin	Firms		Alliances		Country of origin	Firms		Alliances	
	Count	%	Count	%		Count	%	Count	%
USA	95	33.3%	3,528	58.2%	France	2	0.7%	93	1.5%
Taiwan	87	30.5%	796	13.1%	Canada	2	0.7%	92	1.5%
South Korea	29	10.2%	166	2.7%	Australia	2	0.7%	27	0.4%
Japan	24	8.4%	304	5.0%	India	2	0.7%	8	0.1%
China	14	4.9%	184	3.0%	Switzerland	1	0.4%	145	2.4%
Netherlands	4	1.4%	181	3.0%	Hong Kong	1	0.4%	14	0.2%
Singapore	4	1.4%	61	1.0%	Belgium	1	0.4%	12	0.2%
United Kingdom	4	1.4%	29	0.5%	Denmark	1	0.4%	6	0.1%
Germany	3	1.1%	263	4.3%	Finland	1	0.4%	5	0.1%
Israel	3	1.1%	131	2.2%	Italy	1	0.4%	4	0.1%
Malaysia	3	1.1%	16	0.3%	Philippines	1	0.4%	2	0.0%
					Total	**285**	**100.0%**	**6,067**	**100%**

These sample firms are largely, but not exclusively, based in the US, Taiwan and other parts of Asia; and these firms are consequently also involved in the vast majority of all alliance agreements, with US semiconductor firms accounting for roughly 58% of all alliances. This is reflective of the nature of the semiconductor industry (Ernst, 2005; Semiconductor Industry Association, 2016). The sample also highlights the highly diverse cross-industry nature of the industry's partner ecosystem (see Table 3.3), with the vast majority of inter-organisational alliance partners based not within the semiconductor industry itself, but rather in other public and private sectors.

Table 3.3: Full sample composition by industry affiliation

Industry affiliation	# firms	Proportion
Semiconductor core industry	635	19.3%
Semiconductor satellite industry	557	17.0%
University research centre	102	3.1%
Research institute	66	2.0%
Government	90	2.7%
Other industries*	1,832	55.8%
Total	**3,282**	**100.0%**

**See Appendix A for an overview of the top 50 of 'other' industries*

Furthermore, the majority of alliance agreements were formed by fabless chipmakers and IDMs, which are the two main types of chipmakers (see Table 3.4). On average, these chipmakers types tend to differ considerably in overall size, both in terms of annual revenues and the size of their labour force. Although fabless chipmakers proportionally invest more in R&D, their overall smaller size ought to constrain them in terms of their absolute investments which they can commit to R&D on their own. R&D collaboration should therefore be particularly critical to their ability to drive semiconductor innovation in competition with the larger and less constrained IDMs.

Table 3.4: Descriptive statistics broken down by semiconductor company type

	Firms		Alliances		Years of operating*	Firm size		R&D intensity* (R&D expenses/revenues)
	Count	%	Count	%		Revenues*	Number of employees*	
Fabless chipmakers	141	49%	2,639	43%	24	512,186	1,156	22.7
Manufacturing equipment makers	44	15%	731	12%	33	740,565	1,445	15.1
Assembling, testing & packaging	28	10%	245	4%	28	826,589	2,152	2.5
IDM	17	6%	1,406	23%	30	7,303,674	20,222	17.1
Materials	16	6%	144	2%	30	758,255	2,222	4.4
Other electronic components	12	4%	76	1%	25	130,701	232	26.0
Foundry	11	4%	481	8%	23	3,315,695	2,322	5.9
Distributors	8	3%	57	1%	32	588,611	263	0.1
IP core design	8	3%	288	5%	22	85,997	132	38.1
Total	**285**	**100%**	**6,067**	**100%**				

**Measures of firm size, innovativeness and years of operating are averaged across all firms with the same industry affiliation, taking the most recent data available for each firm*

Broadly speaking, we define alliances in line with Duysters and Hagedoorn (1993), namely as collaborative agreements which serve the common interests of independent partners who are not tied through majority ownership. While most of the alliances in the dataset can be related to technology collaboration where joint innovative activity or the exchange of technology forms at least part of the agreement, such as R&D, licensing and joint ventures; the dataset also includes alliance agreements where manufacturing, marketing and distribution or supply activities form a core part of the agreement (see Table 3.5 for an overview of all the types of alliance agreements covered in the dataset). In addition, data was collected on the year of alliance formation and the names, locations and industry affiliations of the alliance partners. Partners' industry affiliations were verified using OSIRIS and the Capital IQ database.

Overall, the dataset covers 5,465 alliance agreements, equating to a total of 7,581 alliance ties, formed between the 285 focal semiconductor firms and their partners. While the number of *alliances* refer to the actual agreements signed between a pair or group of partners, the notion of alliance *ties* captures the number of dyads and the direction of the dyadic alliance relationship; i.e. a single alliance based on a reciprocal dyadic relationship contains two ties (from partner A→B and B→A).

In total, the sample contains 3,282 organisations based across 59 countries (see Appendix B), which can be split into 1,192 semiconductor companies (as classified either by primary or secondary semiconductor activities) and 2,090 other types of cross-industry partner organisations, including satellite semiconductor firms[6], universities, research centres, government bodies as well as a firms active in neighbouring industries and end-industries.

Table 3.5: Overview of alliance types included in the dataset

Alliance type	Relations	Description	# alliances	# ties
R&D partnership	Joint development agreement Technology consortium Joint research pact Interoperability alliance Joint reference design R&D contract State intervention R&D Joint development kit Technology sharing	Development or (re)-engineering of new products or patentable technology for later commercialization	1,340 (24.5%)	2,772 (36.6%)
Customer-supplier partnership	Customer-supplier partnership	Contract to sell or receive materials or products	1,931 (35.3%)	2,075 (27.4%)
Technology licensing agreement	Licensing Cross-licensing Porting agreement	Acquisition or sale of a license or rights to technology/IP/software/ codecs	1,050 (19.2%)	1,228 (16.2%)
Distribution/ marketing partnership	Distribution agreement Marketing partnership	Agreement to jointly distribute and/or market products, or to act as distributor	493 (9.0%)	521 (6.9%)
Manufacturing/ production partnership	Outsourcing agreement Co-production contract Second sourcing Mutual second sourcing	Agreement to manufacture products in joint partnership or as a contractor or second source	282 (5.2%)	430 (5.7%)
Technology joint venture	Technology joint venture	Agreement to set up a joint entity for the development of new technology	121 (2.2%)	234 (3.1%)
Technology acquisition	Technology acquisition	Acquisition or sale of a technological product line or IP	138 (2.5%)	182 (2.4%)
Technology-related strategic investment	Strategic investment Minority holding Cross-holding Government funding	Technology-related capital investments, funding or minority equity holdings	110 (2.0%)	139 (1.8%)
		Total number of alliances	**5,465**	**7,581**

[6] Satellite semiconductor firms are companies whose primary US SIC code does not classify their primary business as being in the semiconductor industry, but who do have secondary activities in the semiconductor industry.

3.6.3. *Construction of final network sample*

On the basis of the conceptual framework developed in this chapter, Table 3.6 below provides an overview illustrating how the different types of alliances included in the dataset are divided to make up the relational building-blocks of distinct sub-networks representing collaboration in relation to the different value-added activities within the semiconductor industry. Variation in network architectures will be analysed based on these four types of sub-networks.

Table 3.6: Definitions and compositions of sub-networks representing distinct semiconductor value chain activities

Technology network	Manufacturing/production network	Distribution/marketing network	Supply network
- *R&D partnerships* - *Technology licensing agreements* - *Technology acquisitions* - *Technology joint ventures* - *Technology-related strategic investments*	- *Manufacturing/production partnerships*	- *Distribution/marketing partnerships*	- *Customer-supplier partnerships*

More specifically, variation in network architectures between these distinct sub-networks will be analysed through a cross-sectional comparison. The primary interest of this study is not in analysing and comparing the sources driving the annual structural evolution of distinct sub-networks, but rather in understanding and explaining the variation in the architectural characteristics of sub-networks resulting from alliances formed over a longer period of time. The cross-sectional approach is appropriate in the context of this study, because strategic alliances generally do not last only for a single year.

In fact, although data on the exact duration of the alliances in the sample were unavailable, during the data collection process press reports announcing the formation of alliances by semiconductor companies were often found to state that these were of a 'multi-year' nature. Moreover, an average alliance duration of five years has been a conventional assumption adopted by past studies on the formation of alliances (e.g. Stuart, 2000; Robinson and Stuart, 2002; Lavie and Rosenkopf, 2006; Gulati et al., 2012; Tatarynowicz et al., 2016).

For the purpose of this study we therefore follow past research in assuming that strategic alliances in the semiconductor industry last for five years. Therefore, the sample of alliance formations is split into two consecutive five-year periods (2005-2009 and 2010-2014), to ensure that the architectural properties of the sub-networks can be compared for consistency between the two periods, while allowing to make a cross-sectional comparison between two periods of equal length. Concurrently, alliances formed during the year 2004 are excluded in this study, leaving a total network sample of 3,051 organisations and 4,915 alliance agreements, equating to 6,888 alliance ties, formed during the period 2005-2014.

In line with the formulated hypotheses, the alliance network data are converted into one-mode adjacency matrices, with semiconductor firms and their partners representing both the rows and columns of each matrix. Two matrices, one for each five-year period, are created for each sub-network using data on the relevant types of alliance ties which define each of the networks along the semiconductor value chain (see Table 3.6).

3.6.3. *Network analysis method*

The created network matrices are visualised using Gephi, a comprehensive tool for visualising network data, and analysed for different measures of network structure, namely network connectedness, clustering and centralisation using UCINET 6 (Borgatti et al., 2002). UCINET is a software package used for analysing network data and it has been one of the most widely used tools for analysing the structural properties of networks of inter-organisational relationships (e.g. Gulati, 1995b, 1999; Baum et al., 2005; Ahuja et al., 2009).

Although UCINET does provide functionality for visualising network data, Gephi provides considerably more layout algorithms which can be used to visually highlight important structural features of networks. In particular, this study will employ the Fruchterman-Reingold algorithm (Fruchterman and Reingold, 1991) to visualise the distinct alliance networks. This is a force-directed layout algorithm, which means that it considers a force between any two nodes in a network, with the basic idea to enable the researcher to move nodes within the network and change the forces between every pair of nodes. This provides an easy way to visually identify structural differences between distinct network graphs.

Although network graphs cannot provide any statistical proof with regards to the specific hypotheses under investigation, they do offer important suggestive evidence. To reinforce this evidence, the network representations are accompanied with overall network metrics of connectedness, clustering and centralisation, in order to quantify the structural configurations of distinct alliance networks.

The connectedness of a network indicates how integrated or fractured the overall network is; or the extent to which any organisation in a network is linked to another organisation, whether directly through an alliance relationship or indirectly through other organisations in the network. The connectedness of a network is defined by Krackhardt (1994) as the proportion of pairs of nodes that can reach each other by a path of any length; i.e., the proportion of pairs of nodes that are located in the same network component. Thus, a network can have a maximal connectedness of 1.0 when any given organisation can reach every other organisation within the network. Accordingly, network connectedness indicates whether all organisations in a network belong to a certain common system.

Conversely, *disconnectedness* of a network is defined by the number of 'violations' (i.e. those cases where a pair of network actors cannot reach each other) of the connectedness condition. Dividing the number of actual violations by the theoretical maximum of this function, then, gives rise to a degree to which a network is disconnected. In turn, a network connectedness score is obtained by subtracting the degree of disconnectedness from 1.0. This is formally defined as follows:

$$Connectedness = 1 - \left(\frac{V}{N(N-1)/2}\right)$$

where Krackhardt (1994: 8) defines V as the "number of pairs of points which are not mutually reachable, and the maximum number of violations is the total number of pairs of organisations = $N(N-1)/2$".

To measure the extent of clustering in each alliance network during each five-year period, we calculate the network average clustering coefficient. The clustering coefficient of an *individual* organisation in a network can be measured as the proportion of its partners who are themselves directly connected to one another. In turn, the clustering coefficient of a *complete* network is obtained by calculating the mean of this measure across all organisations in the network. This can be formalised as follows:

$$Average\ clustering\ coefficient = \frac{1}{N}\sum_{i} C_i$$

where C_i captures the local clustering coefficient of an individual organisation i in a given network; or the proportion of strategic partners of i that are connected. In other words, C_i is the probability that two partners of c are also partners of each other. The clustering coefficient $\bar{C}$ for the overall network, then, is calculated by dividing the sum of C_i by N organisations in the network. Whereas network connectedness captures the connectedness of the whole network, the clustering coefficient captures the extent to which the overall network contains localised knots of dense connectivity (Schilling and Phelps, 2007). The network average clustering coefficient hits its maximum score of 1.0 when, across the whole network, all partners of i are connected to each other.

Network centralisation, on the other hand, indicates the degree to which a network's core is composed of a small number of highly central organisations through which all alliance ties run. This decreases the distance between any two network actors (Wasserman and Faust, 1994) and thus influences the transmission capacity of the network. Specifically, network degree centralisation is used in this study, which measures the extent to which one organisation in a holds *all* alliance ties (i.e. incoming as well as outgoing ties) in a network

(Borgatti et al., 2013). Degree centralisation is based on the variation in degree centrality (i.e. the total number of immediate alliance ties) of all individual organisations within a network divided by the theoretical maximum variation (Freeman, 1978). The centralisation score is formally expressed as follows:

$$Centralisation = \frac{\sum C_D max - C_D(n_i)}{max \sum C_D max - C_D(n_i)}$$

where $C_D max$ is the largest degree centrality score across all of the organisations in a given network; $C_D(n_i)$ is degree centrality of organisation n_i; and $max \sum C_D max$ is the maximum possible variation in the degree centrality of organisations within a network. Network degree centrality has a maximum score of 1.0, which is reached when all alliance ties are centred around one single organisation.

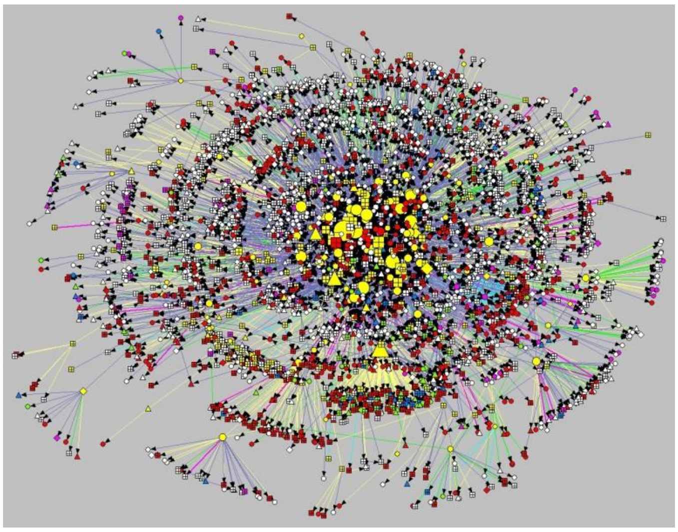
3.7. Results: Analysis of network architectures across distinct alliance networks

3.7.1. Visual patterns within the overall industry network

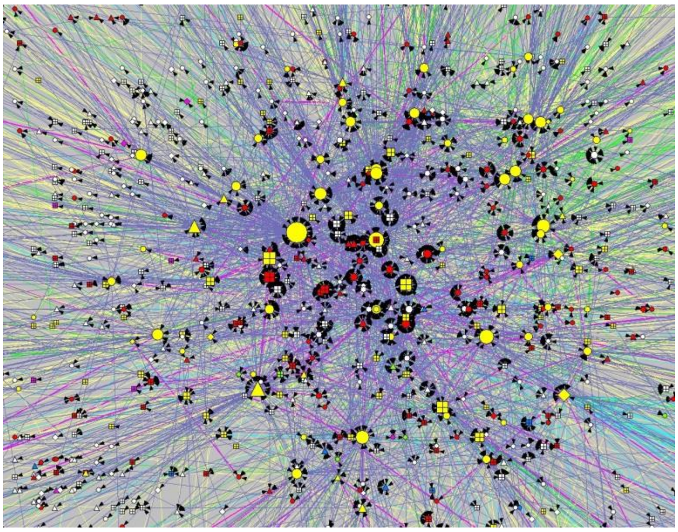
To offer an initial glance at the size and complexity of the network of alliance ties created by semiconductor firms, a visual representation of all alliance ties formed from 2005 through to the end of 2014 is provided in Figure 3.3. The size of the nodes is based on degree centrality (i.e. the total number of alliances formed by the node over the period); their colour reflects their sectoral affiliation[7] to either (a) the core of the semiconductor industry, (b) satellite semiconductor industries, (c) university research centres, (d) public research institutes, (e) government or (f) other industries; and their shape represents their regional origin, namely North America, Europe, Asia or 'Other'. These regional affiliations reflect the regional concentration of semiconductor value chain activities (Semiconductor Industry Association, 2016). The colour of alliance ties indicates their functional activity: technology (purple), manufacturing/production (blue), distribution/marketing (green) or supply (yellow).

A number of features stand out from the graph. Technology alliances (purple) are mainly clustered at the centre of the network, which is a clear indication that organisations with strong R&D capabilities and rich intellectual property are highly sought for collaboration. Judging by their central presence, these partners are often affiliated to satellite semiconductor industries (e.g. suppliers of IP and software, or diversified firms with secondary activities in the semiconductor field) – aside of other core semiconductor firms (yellow) – and are located across the range of geographical regions.

[7] These industry affiliations reflect the diversity of the collaborative landscape of the semiconductor industry.



Overall view



Close-up of the core of the network

Legend

Node colour (industry affiliation)

- Core semiconductor firm
- Satellite semiconductor firm
- University research centre
- Public research institute
- Government
- Other industry firm (*white*)

Node shape (region of origin)

- ● North America
- ■ Asia
- ▲ Europe
- ◆ Other

Node size

- Based on degree centrality (i.e. the total number of alliances formed by the node over the period.

Alliance types

- Technology alliance
- Manufacturing/production partnership
- Distribution/marketing partnership
- Customer-supplier partnership
- Multiplex alliance

Figure 3.3: The industry network comprised of all alliance ties formed over the 2005-2014 period

In addition, few university research centres (green), such as *IMEC* in Belgium, and public research institutes (blue), like the *Institute for Microelectronics* in Singapore, also appear as core technology partners. These organisations are allied with the likes of *Intel*, *AMD*, *STMicroelectronics*, *Freescale* and *TSMC* – who are among the largest and most active participants in the network, and are positioned at the core of the network.

Overall, the network is comprised of a wide diversity of participants from various geographical regions and sectoral fields. Both white ('other' industries) and red (satellite semiconductor industries) nodes are predominant partners in the network, which suggests that inter-industry partnerships are a crucial part of the collaborative strategies of semiconductor firms. American organisations (circled nodes) are particularly active in the semiconductor network – which is reflective of the overall industry. However, the large presence of organisations from the range of other geographical regions both at the core and towards the periphery of the network, who are important partners also to the American firms, underscores the true global nature of the semiconductor industry network.

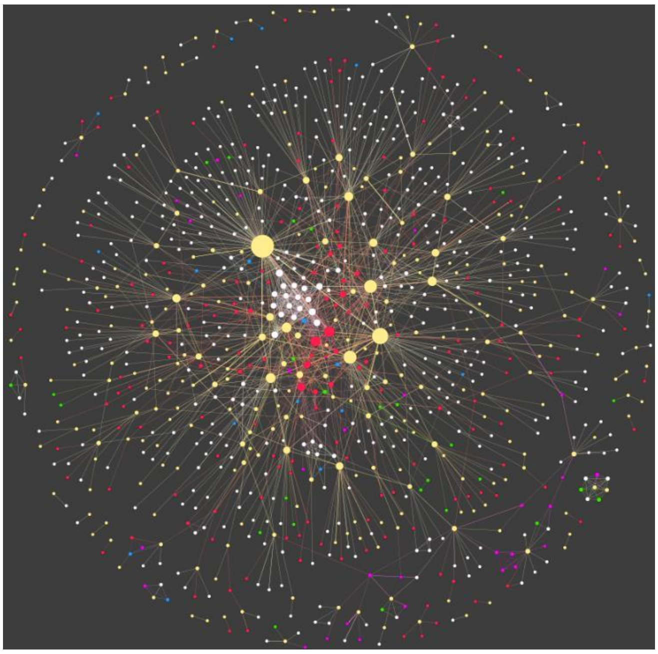
3.7.2. *Cross-sectional analysis of variance in the architectural properties of distinct alliance networks*

Visualisations of the four different alliance networks are shown in Figure 3.4 and Figure 3.5 on the next pages; each network representing the operation of distinct industrial activities, with alliance ties depicting the flow of knowledge, technology, goods, services or equity between organisations. The size of the nodes in the networks is based on the number of incoming ties. Specifically, these network graphs allow identifying the architectural patterns that describe how semiconductor companies, collectively, build networks of alliances as well as how and why the architectures of these networks vary across distinct value chain activities. A cross-sectional comparison between two 5-year periods then allows examining the consistency of the obtained results. The graphical network representations are accompanied by overall network indicators of network connectedness, clustering and centralisation (also summarised in Table 3.7), which allow describing the architectural configurations of distinct alliance networks. These network measures are relative indications of network structure and thus allow directly comparing the architectures of distinct alliance networks.

Table 3.7: Overview of cross-sectional results (highest scores are underlined)

Network properties	**Technology**	**Manufacturing**	**Distribution/ marketing**	**Supply**
Connectedness				
2005-2009	<u>0.77</u>	0.02	0.00	0.01
2010-2014	<u>0.75</u>	0.02	0.01	0.00
Clustering				
2005-2009	<u>0.25</u>	0.02	0.02	0.07
2010-2014	<u>0.27</u>	0.00	0.00	0.08
Centralisation				
2005-2009	0.11	<u>0.25</u>	0.05	0.07
2010-2014	0.07	<u>0.21</u>	0.03	0.15

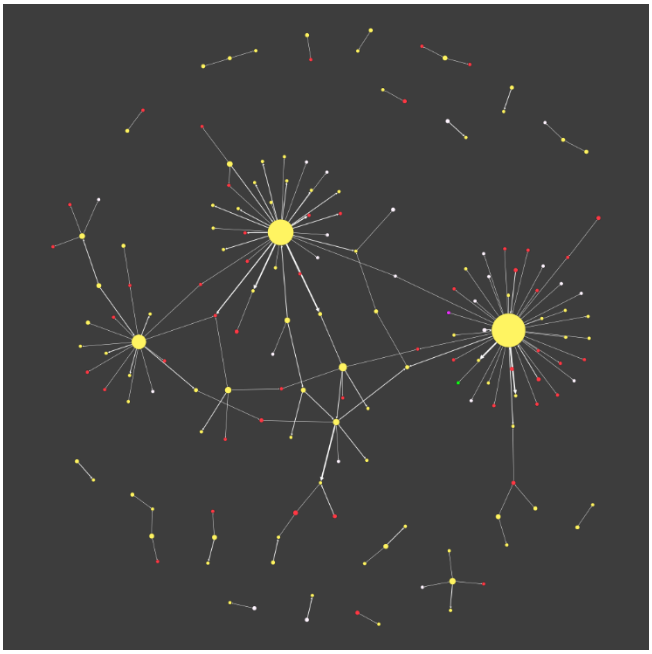
At first sight, the distinct alliance networks clearly depict very different architectures. By measures of network connectedness (0.77 during 2005-2009 and 0.75 during 2010-2014) and clustering (0.25 during 2005-2009 and 0.27 during 2010-2014), the network of technology alliances is substantially more cohesive than the other networks, all of which exhibit a greater extent of dispersion of organisations – thereby providing support for both Hypothesis 1 and Hypothesis 2.



Network of technology alliances
2005-2009

Tie colour indicates alliance type *(1.892 ties; 2,130 incl. repetitive ties)*
Size of nodes is based on in-degree centrality *(1.026 nodes)*

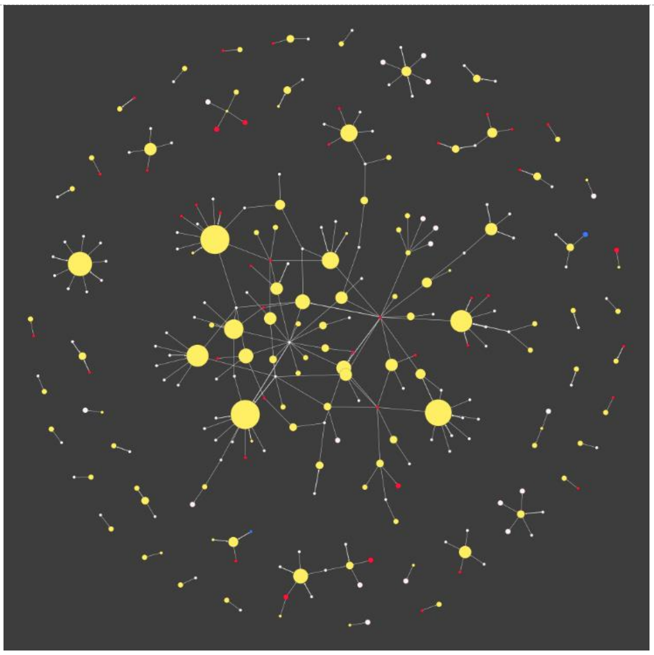
Density: 0.003
Connectedness: 0.766
Centralisation: 0.109
Clustering coefficient: 0.247



Network of manufacturing alliances
2005-2009

Number of network ties: *157 ties; 235 incl. repetitive ties*
Size of nodes is based on out-degree centrality *(166 nodes)*

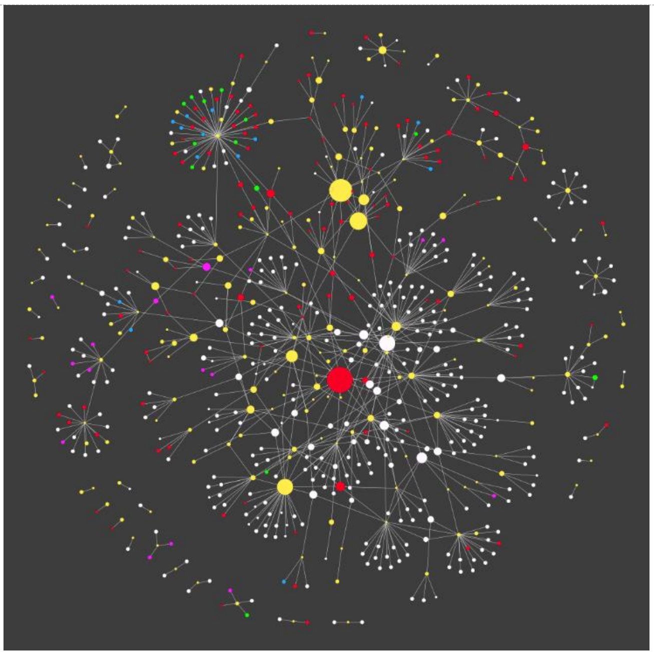
Density: 0.006
Connectedness: 0.019
Centralisation: 0.246
Clustering coefficient: 0.017



Network of marketing alliances
2005-2009

Number of network ties: *255 ties; 264 incl. repetitive ties*
Size of nodes is based on in-degree centrality *(277 nodes)*

Density: 0.004
Connectedness: 0.004
Centralisation: 0.047
Clustering coefficient: 0.016

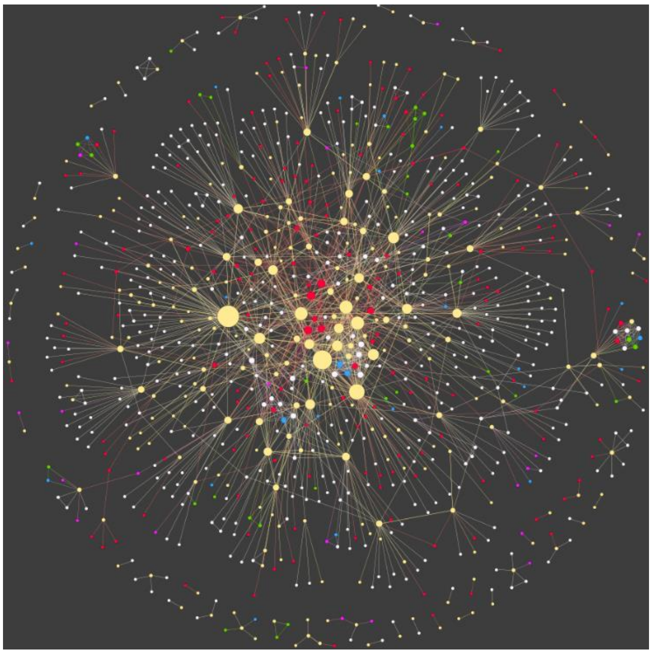


Network of customer-supplier partnerships
2005-2009

Number of network ties: *795 ties; 959 incl. repetitive ties*
Size of nodes is based on in-degree centrality *(734 nodes)*

Density: 0.002
Connectedness: 0.006
Centralisation: 0.068
Clustering coefficient: 0.065

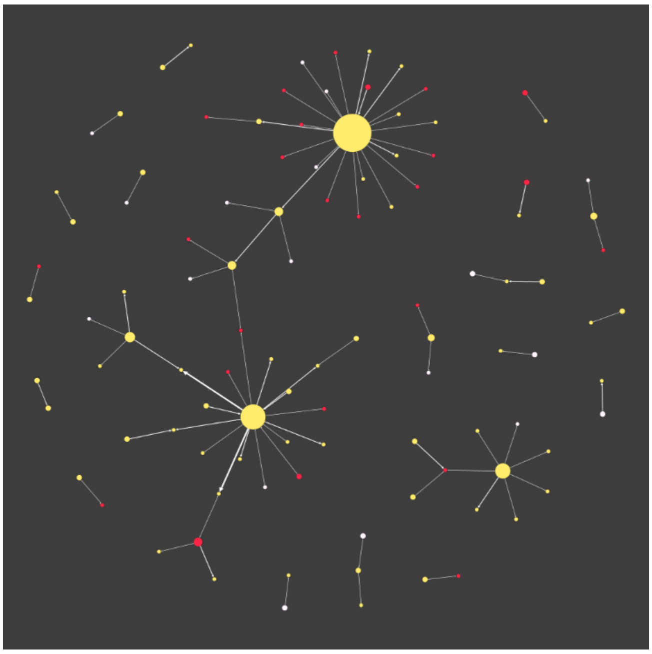
Figure 3.4: Visualisations of distinct alliance networks, displaying ties formed over the 5-year period 2005-2009



Network of technology alliances
2010-2014

Tie colour indicates alliance type *(1.864 ties; 2,045 incl. repetitive ties)*
Size of nodes is based on in-degree centrality *(990 nodes)*

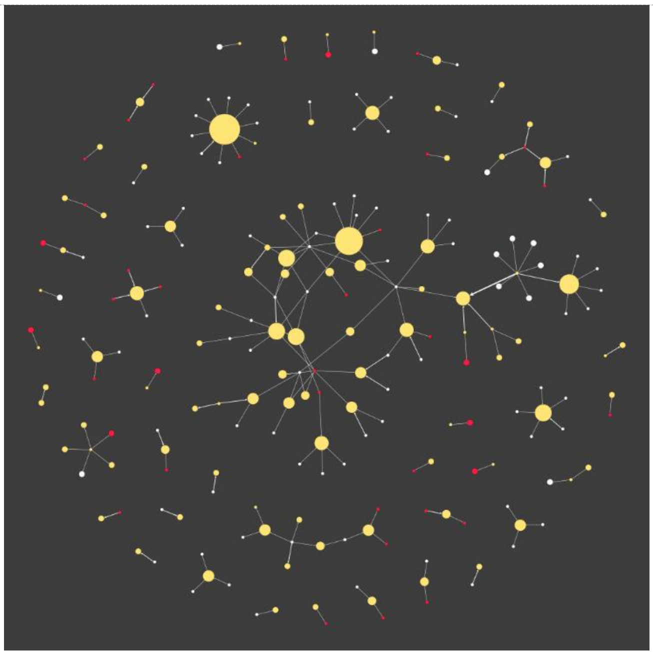
Density: 0.003
Connectedness: 0.753
Centralisation: 0.072
Clustering coefficient: 0.272



Network of manufacturing alliances
2010-2014

Number of network ties*: 86 ties; 149 incl. repetitive ties*
Size of nodes is based on out-degree centrality *(105 nodes)*

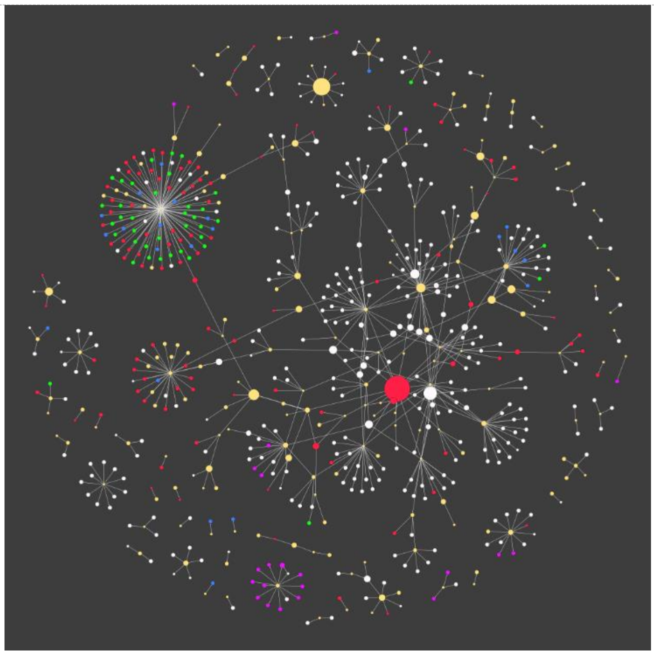
Density: 0.008
Connectedness: 0.015
Centralisation: 0.208
Clustering coefficient: 0.000



Network of marketing alliances
2010-2014

Number of network ties*: 191 ties; 203 incl. repetitive ties*
Size of nodes is based on in-degree centrality *(226 nodes)*

Density: 0.004
Connectedness: 0.005
Centralisation: 0.032
Clustering coefficient: 0.000



Network of customer-supplier partnerships
2010-2014

Number of network ties*: 716 ties; 903 incl. repetitive ties*
Size of nodes is based on in-degree centrality *(722 nodes)*

Density: 0.001
Connectedness: 0.004
Centralisation: 0.146
Clustering coefficient: 0.078

Figure 3.5: Visualisations of distinct alliance networks, displaying ties formed over the 5-year period 2010-2014

In turn, the network of manufacturing alliances is most highly centralised (0.25 during 2004-2009 and 0.21 during 2010-2014), thus confirming Hypothesis 3; while both the networks of distribution/marketing agreements and supply relations score consistently lower on the three network metrics, thereby confirming Hypothesis 4. The following paragraphs will examine these results in more detail.

The network of technology alliances consistently exhibits substantially higher degrees of network connectedness and clustering across both periods in comparison to the other alliance networks. A number of collaborative patterns become particularly clear from the visual representations of this particular network, which should help to comprehend why this network is relatively highly interconnected and clustered. These structural patterns correspond strongly to the importance of mutual trust and norms of cooperation in, particularly, joint development agreements, which make up the majority of alliances in this network.

The technology network resembles a complex system of interconnected and clustered organisations densely tied through a number of different types of technology alliance ties. Clustered at the core of this network are mainly organisations which are interconnected through highly technical R&D partnerships (red ties) and joint ventures (light blue). Organisations engaged in these types of alliances, as argued previously, require trust as a self-enforcing governance mechanism, or a 'mutual monitoring device', to safeguard their specialised investments and to ensure that all parties involved conform to agreements concerning the routinised sharing of knowledge within their partnerships. Highly interconnected alliance networks can function as effective governance structures which facilitate establishing such a collaborative environment.

Concurrently, we can observe equity investments (dark blue ties), technology acquisitions (green) and particularly licensing agreements (yellow) connecting central actors with unconnected partners at the network's periphery. As indicated by the patterns that describe how these particular ties connect organisations within the network, these ties are not primarily used to construct a network as a means to promote mutual trust and norms of cooperation, but rather to source non-redundant knowledge and technology from unconnected partners at the periphery in order to advance existing technological standards. In line with Burt's (1992) concept of structural holes, this is a crucial network tactic of firms to enhance their innovative capacity.

Taken together, this architectural pattern is referred to by network scholars as a core/periphery structure (Borgatti and Everett, 1999), which implies a certain degree of asymmetry in organisations' access to information and technical knowledge flowing through the wider network. This gives central network actors the ability to build up trust among one another while also gaining an advantage over their less central counterparts when it comes to accessing specialised complementary technologies and skills and learning about new business and partnering opportunities, new technological developments, and other trends within the semiconductor industry. Moreover, this architectural structure enables central actors to leverage their dominant network positions to improve their competitive position within the wider semiconductor industry, by controlling the distribution of technical information and knowledge within the network. As previously hypothesised, these are the key network benefits that describe the strategic foundations upon which the network of technology alliances is built. The evidence obtained from the network analysis supports this.

Indeed, as is the case in the network of technology alliances, a network architecture approaching a core/periphery structure can consequently also give rise to a high degree of centralisation. However, the dominance of a few central network actors in this case is not nearly as clear in the network of manufacturing alliances, where a considerably higher degree of centralisation can consistently be observed in both time periods.

The ability to fabricate semiconductor chips is a relatively scarce skill and an activity which has been highly restricted to only a hand-full of specialised organisations, in large part due to the immense fixed capital requirements, as is clearly reflected by the few large nodes that dominate the manufacturing network; specifically the *Taiwain Semiconductor Manufacturing Corporation* (TSMC), *Semiconductor Manufacturing International Corporation* of China, and *Tower Semiconductor Ltd* of Israel. The visualisation of this network is indicative of a completely different collaborative and competitive landscape in comparison to that in the other alliance networks; with chipmakers being collectively driven to cut costs and enhance efficiency by outsourcing the front- and back-end fabrication of their semiconductor devices to a few specialised manufacturers.

The competitiveness of semiconductor manufacturers in general and foundries in particular depends on their ability to achieve high levels of productivity, in order to maintain a state-of-the-art manufacturing operation with sufficient profit margins to survive over the long-term. As can be drawn from the network graph, this operational challenge limits the availability of manufacturing partners. However, the graph also shows that the majority of chipmakers are invested in a relationship with a single long-term manufacturing partner, while fewer, mainly large chipmakers, outsource their business to multiple foundries and/or back-end manufacturers. For most chipmakers, the size of their business does likely not justify going through the onerous process of passing various qualifications and tests in line with specific chip design rules and SPICE models defined by foundries, and coordinating multiple of these long-term relationships. In turn, this provides foundries in particular with guaranteed markets and lower risk of losing customers, enabling them to maximise capacity utilisation and productivity. Importantly, as opposed to the highly interconnected and clustered technology network, the main collective network benefit sought by participants within the manufacturing network is scale economies.

This does not imply, however, that partnerships between chipmakers and their manufacturing partners do not need to be governed by trust. On the contrary, although the outcome of a manufacturing partnership can be specified ex-ante in a contract, trust is essential in these relationships due to the high cost of switching foundry partners as well as the negative impact of losing a customer on a foundry's productivity. Chipmakers and foundries in particular are therefore reciprocally interdependent. Chipmakers can, however, leverage their immediate networks of strategic technology partners, who may outsource to the same manufacturers, as a means of imposing reputational sanctions on those manufacturing partners that deviate from the established norms of cooperation.

As further hypothesised, the visualisations of the networks of marketing alliances and supply contracts, along with the accompanied network indicators, illustrate that neither network stands out as especially interconnected, clustered or centralised. For the most part, both networks exhibit higher degrees of centralisation than connectedness and clustering, which is indicative of semiconductor companies' collective tendency towards constructing alliance networks which enable achieving cost efficiency through access to complementary resources and capabilities, and increasing bargaining power through brokerage as a means of minimising the potential opportunistic behaviour of strategic partners and playing off partners against each other.

This finding is in line with the previously discussed motivations underlying the formations of distribution/marketing agreements and supply contracts. Both kinds of alliances mostly involve the exchange of generic, rather than specialised, complementary resources and capabilities, such as access to geographic and product markets, local market knowledge and the supply of raw materials and equipment, in order to achieve cost efficiency. This should imply a greater availability of potential partners possessing these assets, as can be seen by the relatively large populations of actors in both networks and the groups of multiple partners circling around many of the semiconductor companies. Such large networks of unconnected alliance partners not only enable semiconductor companies to source complementary materials from a diversity of sources, but also provide an effective mechanism to avoid becoming over-reliant on a single partner and reduce the risk and cost of potential opportunism. This is not to say that distribution/marketing and supply alliances do not involve any degree of co-specialisation, as chipmakers do need to be committed to sharing information with their partners in order to reap the benefits of complementing their in-house resources and capabilities with those of partners. Rather, having multiple partners to collaborate with on distinct value-added activities lowers the cost of terminating one relationship and shifting business to another. This collective network strategy is evidently reflected by the network graphs and network indicators and corresponds to the inter-organisational processes and routines described earlier in this chapter.

3.8. Discussion & conclusions

In view of improving our understanding of the strategic role of networks in inter-organisational collaboration, the central premise of this study has been that variation in the overarching structures of networks are due to fundamental differences in the collective collaborative arrangements of firms in relation to distinct value chain activities. As such, it is argued that variation in the architectural configurations of different alliance networks comes forth not solely from the nature of the value chain activity for which a network is used, but more fundamentally from the drivers of collaboration and the inter-organisational routines and processes which define why and how a value chain activity is jointly conducted and upon which a given alliance network is founded.

To disentangle the complexity of the entire semiconductor industry network, a distinction was made between different types of sub-networks *within* the overarching industry network, as defined by distinct semiconductor value chain activities, in order to understand how these different sub-networks are built in the first place. Specifically, we distinguished between networks of alliances related to technology and product development, manufacturing, distribution/marketing, and the supply of materials, equipment and end-products. Variation in the architectural properties of these networks was analysed in terms of network connectedness, clustering and centralisation.

Different network configurations are associated with distinct collective network benefits. Whereas densely interconnected networks function as effective self-enforcing governance mechanisms that can be leveraged by firms to constrain opportunism and facilitate the establishment of mutual norms of cooperation and trust through shared third-party ties; high degrees of clustering can further enhance a network's information transmission capacity (Burt, 2001) while also increasing the diversity of knowledge within a network and improving the innovativeness of firms. Finally, high degrees of network centralisation provide a single or a few dominant firms with privileged access to knowledge flowing through the network along with the ability to control the dissemination of resources among other organisations in the network.

Thus, in order to explain the variation in the architectural properties of distinct sub-networks, the collective outcomes related to particular network configurations were linked to the value-added activities for which these networks are used as well as to the inter-organisational routines and processes describing how these activities are conducted in collaboration. Accordingly, we argued that the differences in the architectures of alliance networks cannot be adequately captured by a one-dimensional conceptual framework, and hence different lessons that past studies have taught in the light of (1) the drivers of collaboration, (2) inter-organisational routines and processes, (3) value chain analysis and (4) network analysis were integrated into a single comprehensive conceptual framework.

On the basis of this framework, it was specifically hypothesised that the highest degrees of network connectedness and clustering should both be found in the network of technology alliances and that the highest degree of network centralisation should be found in the network of manufacturing alliances. Finally, relatively low degrees of these properties should be exhibited by the networks of distribution/marketing alliances and supply contracts.

These hypotheses were examined using data on the formations of eight different types of alliances by semiconductor firms during the periods 2005-2009 and 2010-2014. The obtained results provide evidence suggesting that differences in the motivations for collaboration and inter-organisational routines and processes, at different value chain stages, result in distinct network architectures characterised by different degrees of connectedness, clustering and centralisation. Specifically, the results indicate that joint value-added activities that are driven primarily by the need to access highly specialised and technical complementary resources and capabilities, and which are characterised by high levels of uncertainty and risk; which require partners to commit to significant relation-specific investments and the sharing of critical knowledge; and in which outcomes cannot be specified ex-ante, are associated with high degrees of network connectedness and clustering.

In contrast, those joint value chain activities which are driven mainly by the need to access and exploit complementary resources and capabilities in order to improve cost efficiency, such as in manufacturing, are associated with relatively centralised network structures. In particular, the extent of network centralisation is amplified when the availability of potential strategic partners is low, as is the case among specialised semiconductor manufacturers due to the highly specialised nature of semiconductor manufacturing as well as the extreme fixed capital costs associated with this.

These findings have several important implications to future research and the advancement of theories to explain the alliance decisions of firms. First and foremost, to the researcher's knowledge, this study is the first to have put forward a multi-dimensional conceptual framework to advance our understanding of the sources of variation in the architectural characteristics of sub-networks of joint value chain activities within a single industry. An important distinction from past studies is that this framework enables accounting for several different types of alliance relationships and their associated inter-organisational routines and process as the fundamental network building-blocks. The absence of these relational aspects has previously been acknowledged as a research limitation by Schilling and Phelps (2007).

Future research may adopt this framework to as a basis for better explaining the collaborative decisions made by companies.

Using this framework, the study has highlighted that the semiconductor industry resembles a highly complex network of interdependent collaborative relationships interconnecting organisations from within and outside of the semiconductor industry, (1) built on structurally distinct sub-networks of alliances formed in different value chain segments, which are in turn (2) defined by alternative open and closed micro-level network structures in addition to dyadic structures. This resembles an important empirical contribution because it illustrates that the formation of inter-organisational alliances takes place within relational structures which are more complex than the dyadic relational structures upon which most extant alliance research has been built.

Furthermore, the study demonstrates that variance in the architectural characteristics of distinct sub-networks of value-added activities is unlikely to emerge due to chance and rather points at underlying strategic reasons linked to the fundamental nature of companies' alliance strategies upon which these networks are built. The technology alliance sub-network, for instance, reflects a collective preference of semiconductor companies for closure and building a relatively interconnected network which can function as a governance structure and facilitate the establishment of mutual trust and cooperation as well as the flow of knowledge and resources necessary for joint R&D between the organisations within the network. By contrast, the other sub-networks, such as the manufacturing sub-network, are more concentrated and less interconnected and consequently reflects an inherently different collective preference of semiconductor companies for particular relational structures. Accordingly, this suggests that alliance networks might not only provide firms with access to external resources, as commonly assumed in research on alliance formations; but that they function as mechanisms that can enable the achievement of distinct network advantages.

However, a few limitations to this study should also be acknowledged. Firstly, this study is industry-based, which implies that the obtained results cannot likely be used to generalise about the differences in network architectures within other, especially low-tech, industries. This does not mean, however, that this study does not contribute to advancing our understanding of the strategic importance of alliance networks. In fact, the framework introduced in this study is not limited to the semiconductor industry and can therefore be applied to explain variation in the architectures of sub-networks in other industries.

Furthermore, the study is subject to the unavailability of data indicating the duration of alliance agreements. We built on limited insights provided by previous studies and assumed that alliance last for five years on average; however, the incorrect specification of the duration of different types of alliances could potentially change the obtained results. Future research could investigate in depth the duration, along with other contract terms, of different types of alliance agreements across various industries.

Future research could advance this study by examining inherent multiplex nature of industry networks. Different sub-networks of alliance relationships might not emerge and evolve in isolation from each other when they are built by the same set of organisations. Past research (e.g. Shipilov, 2012) has thus underscored the importance of also examining how a firm's embeddedness in multiple types of alliance relationships could simultaneously influence the outcomes that firms attain through their network strategies. This consequently constitutes a fruitful avenue for future research.

Ultimately, the present study offers important insight into the organisation of alliance networks and the collective strategic benefits which can be obtained from distinct network architectures. From a managerial perspective, it suggest that managers should recognise and understand the different collective network benefits which their firm can derive from particular network positions. Understanding its position within the wider industry network will help to shape its competitive advantage through the accumulation of network benefits. As such, this study not only contributes to the academic field but also to managers' understanding of the impacts that network structures may have on business outcomes. Deeper analyses of firms' ego networks performed in the next two chapters will offer further insight and advice regarding the strategic implications of network positions and network strategies.

4. EXPLORING THE FORMATION AND STRATEGIC CONSTRUCTS OF TRIADIC CROSS-INDUSTRY R&D ALLIANCE STRATEGIES

4.1. Introduction

The previous chapters demonstrated that the semiconductor industry has evolved into a large and highly complex network, which spans across multiple value chain activities. More specifically, this network possesses characteristics of a partner ecosystem which (a) interconnects not only chipmakers but also a vast majority of other types of organisation; (b) is built on different microstructures, including not only dyads but also triads and multi-partner alliances; and (c) in which these microstructures are formed beyond the core semiconductor industry to connect organisations from adjacent industries, such as manufacturers, various types of technology complementors, suppliers and systems companies.

The semiconductor R&D network, in particular, is highly complex due to the diverse population of organisations from the core semiconductor and adjacent industries. Moreover, R&D is of particular strategic importance to chipmakers because the wide range of intellectual property and technologies that are developed and combined at this stage of the semiconductor value chain add the most value into the final product (Semiconductor Industry Alliance, 2016). Therefore, adequately understanding the essence of strategies in R&D networks is essential for both strategists and the advancement of the strategy literature. Hence R&D comprises the empirical context for both the current and the next chapter.

The goal of the current chapter is to investigate and explain how chipmakers can utilise network tactics to maximise the R&D outcomes of their strategic alliances. This investigation is conducted by (1) developing a conceptual framework for evaluating the *strategic utility* of triadic tactics for R&D collaboration and (2) developing hypotheses to test chipmakers' tendency to configure their R&D alliance relations within triads in response to industry pressures. Concurrently, this chapter advances the common dyadic approach to analysing the formation of R&D alliances (e.g. Anand and Khanna, 2000; Colombo et al., 2006; Sampson, 2007; Rothaermel and Boeker, 2008; Mukherjee et al., 2013) and reveals the essence of R&D collaboration in the semiconductor industry through a triadic framework.

The importance of triads stems from past research emphasising that the formation of R&D alliances resembles an interdependent process whereby the chipmaker's strategic partner choice is, in fact, influenced by not only the firm-level attributes of potential R&D partners, but also by the existing R&D alliance relations between potential R&D partners and other organisations within the industry network (Contractor et al., 2006; Ahuja et al., 2012; Kim et al., 2016). Triads constitute the smallest microstructure in a network within which dyadic alliance relations interconnect (Madhavan et al., 2004). A triadic framework, contrary to traditional dyadic frameworks used by the majority of extant research on R&D alliances, therefore enables analysing whether chipmakers configure their R&D alliances within triads, as opposed to dyads, to maximise their R&D outcomes; by explicitly capturing the influence of the characteristics and existing R&D alliance relations of potential alliance partners on the formation of new R&D alliances (Choi and Wu, 2009).

As such, triads also explicitly capture the facts that (a) the R&D strategy of a firm might join several complementary partners together in a development project and that over time the partner portfolios of organisations might evolve to overlap, consequently interconnecting the organisations through separate dyadic relationships with common partners (Khanna and Rivkin, 2006; Davis 2016); and (b) the strategic goal of the R&D project changes depending on the functional specialisation of the partners involved within the triad. This is encapsulated by a company's partner selection decision, which comprises a core mechanism determining the value that a company may capture from triadic R&D strategies.

Importantly, this chapter asserts that the *strategic utility* of R&D alliances is not solely defined by the selection of specific types of partners, but also by the way in which R&D alliance relations are configured within triads. It is important to differentiate triadic forms of R&D collaboration because they are strategically distinct from pure dyadic collaboration and they have lacked attention from the strategy literature. Moreover, better understanding the strategic utility of triads has far reaching management implications. Chipmakers have different strategic options for the configuration of R&D alliances within triads – which are broadly divided into two strategic approaches based on models of network closure (Coleman, 1988; Uzzi, 1997; Hagedoorn and Duysters, 2002) and network brokerage (Burt, 1992; Soda, 2011), in which the presence or absence of dyadic alliance relations either 'closes' (or integrates) a triad or marks it with a 'structural hole'.

Through the formation of integrated triads, chipmakers might enhance mutual trust and establish shared norms of cooperation through the interconnectedness of partners (Coleman, 1988) – by forming three-way R&D alliances; allying with common and potentially redundant partners; or mediating the establishment of interconnecting alliance ties between partners. Such an *inclusive* strategy essentially fosters full open innovation (Chesbrough, 2003), whereby the chipmaker is able to efficiently utilise R&D alliances to both (a) exploit technological assets located beyond its own boundaries in conjunction with its own existing assets, and (b) capitalise on R&D partners' technological assets to jointly explore and develop new technologies; as opposed to closed innovation, whereby the chipmaker rather develops and commercialises new technologies internally (Chesbrough, 2003; Van de Vrande et al., 2009). Moreover, through close collaboration this strategy can reduce environmental uncertainties (Boyd, 1990) which are projected onto chipmakers' R&D

activities from pressures existing in the industry (see Chapter 2), including the exponential increase in the complexity of technological progress and the associated capital requirements; the volatility of product demand and consequently the shortening chip life cycle; and intense competitive pressures. In addition to the benefits associated with collaborating with multiple partners, such as sharing the risks and costs of R&D and shortening the R&D process; network closure enhances the diffusion of information and knowledge among all partners in a triad, enables mutual monitoring and sanctions opportunistic behaviour (Coleman, 1988, 1990), which are strategic benefits that can help to reduce such uncertainties.

In contrast to pursuing the benefits of integrated triads, a chipmaker might aim to arbitrage, and gain control over, the flows of information and knowledge between unconnected parts of the R&D network through the disconnectedness between its partners; by deliberately forming alliances with partners who do not collaborate among themselves and/or by imposing contractual exclusivity upon its partners. Such a *protective* network strategy creates brokerage opportunities that enable chipmakers to protect exclusive access to specialised knowledge or other strategic assets. In result, the benefits of R&D collaboration are not equally shared and are controlled by a *gatekeeper* (Burt, 2010). This strategy consequently embodies open innovation to a lesser degree than inclusive network strategies, as the protective intentions of the chipmaker do not encourage collaboration beyond exploiting the existing technological assets of a strategic partner (Van de Vrande et al., 2009).

In spite of the evidence showing the strategic implications of both of these triadic strategies (see Section 3.4. of Chapter 3 for a review), there has been a lack of attempts by strategy scholars, chipmakers' strategists and industry analysts alike to explain and understand how triads can help chipmakers to maximise the R&D outcomes from their alliances in the face of industry pressures. Strategy scholars' traditional explanation of the formation of R&D alliances has largely been limited to the need of companies to gain access to, and control over, strategic information, knowledge, skills and other complementary assets flowing through the wider network (Hennart, 1988; Kogut, 1988; Williamson, 1991; Powell et al., 1996). However, it is essential to also consider whether or not access to these strategic assets is to be openly shared or deliberately protected as reflected by the structural patterns of the company's triadic tactics.

The partnering strategies pursued by chipmakers seem to reflect the traditional logic of pursuing short-term benefits from gaining access to partners' assets, as no past research or documentation could be identified during this study to indicate that chipmakers' strategists utilise a systematic approach to understand the scope of the available network strategies and to assess and derive the strategic benefits of their network strategies. As such, this chapter contributes to the traditional strategy literature by enhancing our conceptual understanding, as well as develop strategic implications for chipmakers, of how a partner selection based on partner-specific interests might fit into a company's long-term network strategy.

The assumption that the formation of triads by chipmakers is merely the by-product of its pursuit for partner-specific assets has thus left an important and relatively unexplored gap in the strategy literature. Such a one-sided conceptualisation is deficient and, if followed by chipmakers, will result in a myopic strategic position in the industry. To develop a comprehensive conceptual approach and managerial implications, however, it is imperative to consider (1) partner selection and (2) network configuration as two complementary elements of strategic utility.

This chapter makes conceptual contributions to the field of strategy by exploring and introducing the concept of strategic utility as a twofold construct. Firstly, the strategic and network approaches to analysing the formation of R&D alliances are merged into a framework of strategic utility. Secondly, this framework is used to evaluate the strategic utility of alternative microstructures; specifically, how triadic alliance structures can enable firms to reap long-term network benefits from their R&D collaborations, such as improved trust and norms of collaboration among partners, more efficient integration of complementary resources and superior project outcomes.

Empirically, this evaluation is aimed at addressing a number of strategic research questions, such as (1) whether inclusive or protective triadic strategies are pursued by different types of chipmakers to mitigate external uncertainties and industry pressures; (2) whether there is similarity or dissimilarity in preferences for these two triadic strategies between the two major types of chipmakers; (3) whether the establishment of cross-industry bridges between adjacent industries through triads encompasses a strategy that is more distinctly pursued by a single type of chipmaker; (4) whether triadic R&D strategies are driven by (a) knowledge sharing and deep collaboration in the light of open innovation or (b) countering or mirroring the strategic moves of rivals.

Building on the conceptual framework, eight hypotheses are developed to test the tendencies of chipmakers to configure their R&D alliance relations, with strategically selected partners who differ in their functional specialisation, within triads. The hypotheses are therefore not merely designed to test whether or not chipmakers do form triads vis-à-vis dyads, but more specifically to test whether chipmakers utilise these triadic tactics to conduct fundamental R&D, to link and collaborate with partners across technological sectors and end-markets, and to develop co-opetitive relations for R&D collaboration as a means of responding to industry pressures. These hypotheses are tested on a new dataset containing a network sample of chipmakers and their partners covering R&D alliance formations during the 11 year period 2004-2014, using stochastic actor-oriented modelling (SAOM). Such an approach, combining the configuration of R&D alliance relations and partner choices of companies as core elements of triad formations, is important for understanding and developing implications of triadic tactics for R&D collaboration and has, to our knowledge, not been applied in past alliance research.

The remainder of this chapter is structured as follows. In Section 4.2, we develop the conceptual framework and explore the concept of strategic utility and the mechanisms by which chipmakers are able to utilise triadic tactics to maximise the R&D outcomes of their strategic alliances. The hypotheses are then formulated in Section 4.3 on the basis of this conceptual framework, followed by a discussion of the research methodology and SAOM specifications in Section 4.4. The statistical results are presented in Section 4.5 and interpreted in Section 4.6. Finally, conclusions and implications are discussed in Section 4.7.

4.2. Development of the conceptual framework

4.2.1. Alliances as a strategic response to reduce industry pressures on semiconductor R&D outcomes

The successfulness of semiconductor R&D strategies rests on the ability of the semiconductor company to optimise its R&D outcomes, both process- and output-related, of its R&D activities; whether in terms of the speed and cost efficiency of the R&D process or the innovativeness and time-to-market of the R&D output. As highlighted in Chapter 2, however, high levels of industry pressures due to the increasing cost and complexity of semiconductor R&D, the ever-changing customer demand for speciality products and intense competition amplify the uncertainty around the ability of individual semiconductor companies to achieve their desired R&D outcomes. Mitigating this uncertainty and adapting to these industry pressures requires semiconductor companies to organise and reconfigure their R&D activities *strategically*, in ways which build on their existing resources and capabilities (Teece et al., 1997; King and Tucci, 2001).

There is a consensus among alliance scholars that strategic alliances provide governance mechanisms enabling companies to share and reduce uncertainty and costs in such high pressure environments (Pfeffer and Nowak, 1976; Pfeffer and Salancik, 1978; Porter and Fuller, 1986; Dyer and Singh, 1998; Gomes-Casseres, 2003; Mahnke and Overby, 2005; Lavie and Rosenkopf, 2006; Contractor and Reuer, 2014). However, in spite of the notable contributions of several scholars (e.g. Powell, 1990; Gulati, 1998; Gomes-Casseres, 2003; Madhavan et al., 2004; Afuah, 2013; Kim et al., 2016), the wider literature has largely refrained from building on these studies to explain *how* companies can (1) actually utilise alliances strategically to maximise the outcome of R&D in the face of industry pressures and (2) configure their alliance relations as well as how these configurations affect the outcome of their joint R&D activities. Such explanations are essential to more adequately understand the actual role of alliances in enhancing R&D outcomes because – as demonstrated in Chapter 3 – joint R&D activities in high pressure environments like the semiconductor industry form a highly complex network of interdependent alliance relations, and the configuration of the alliance relations in this network may influence the governance of joint R&D activities as suggested by Powell (1990). Moreover, this also helps to better understand how companies' strategic assets are created (Afuah, 2013). Ignoring the configuration of alliance relations can consequently lead to inaccurate research insights and myopic strategy formulations.

This chapter therefore focuses on explaining how individual chipmakers respond to industry pressures and maximise their R&D outcomes by configuring their R&D alliance relations within complex ego networks. Disentangling the complexity of ego networks requires a triadic framework in order to capture the inherent interdependence that exists among the R&D alliance formation decisions of chipmakers (Contractor et al., 2006; Choi and Wu, 2009). In addition, as the strategic objective of any R&D alliance is not merely concerned with the formation of an inter-organisational relationship but more importantly with the optimisation of a chipmaker's R&D outcomes in the face of external uncertainties, it is essential to introduce a new construct which is able to characterise and capture (1) the effect of alliance relations on R&D outcomes and (2) the strategic intent of the chipmakers to optimise their R&D outcomes through alliances.

4.2.2. The strategic utility of alliance networks for optimising semiconductor R&D outcomes

To develop this construct, we leverage the concepts of expected utility (Bernoulli, 1954) and social utility (Camerer, 1997) from the field of behavioural economics and apply these in a strategic context. These concepts are both directly relevant to analysing how companies can optimise their R&D activities through strategic alliances, because they explain, respectively, how companies make alliance decisions with uncertain R&D outcomes and develop governance structures in alliances based on social mechanisms such as mutual trust (Das and Teng, 1998) (see Chapter 3, Section 3.2.2 for a discussion on the importance of trust as a governance mechanism in alliances). To capture (1) the expected utility of alliance partner choices and (2) the social utility of relation building as two complementary core aspects of a single view on explaining how companies utilise R&D alliances strategically to minimise the uncertainty of R&D resulting from industry pressures and maximise the outcomes of their R&D activities, we put forward the concept of *strategic* utility.

Thus, the maximisation of strategic utility (i.e. R&D outcomes) through alliance networks, in essence, encapsulates the value generated following the initiation of an R&D alliance. Specifically, it is the outcome of a dual decision made by the company, which has roots in two strands of literature. On the one hand, the field of strategy has long built on the resource-based view (Eisenhardt and Schoonhoven, 1996; Das and Teng, 2000), the relational view (Dyer and Singh, 1998) and the dynamic capabilities perspective (Teece et al., 1997) to underscore the strategic motivations underpinning alliance formations (Hagedoorn, 1993) and, more specifically, the importance of *partner-specific interests* as the main driving force of R&D partner choices in the company's pursuit to enhance the value of their R&D outputs (Zajac and Olsen, 1993) while overcoming environmental uncertainties owing to incomplete knowledge (Sydow et al., 2013); largely from a dyadic point of view.

The social network literature, on the other hand, offers a complementary, triadic view (Caplow, 1959, 1968; Siltaloppi and Vargo, 2017) stressing that it is not solely the access to partner-specific resources which shapes the strategic utility of an R&D alliance, but also the way in which the access to and exchange of these resources is governed via the strategic *configuration* of the company's alliance relationships within its wider ego network as reflected by the degree of interconnectedness of the company's R&D alliances (Coleman, 1988, 1990; Burt, 1992, 2010). Concurrently, companies' alliance partner selections might also be driven by a pursuit for network benefits resulting from the interconnectedness or disconnectedness of their partners (Rowley and Baum, 2008; Greve et al., 2014).

Triadic alliance configurations have, however, not been fully recognised in the strategy literature, in spite of the growing evidence underscoring the strategic benefits that a clear network strategy could unlock (Coleman, 1990; Burt, 1992; Uzzi, 1997; Ahuja, 2000; Uzzi and Gillespie, 2002; Bell, 2005; Zaheer and Bell, 2005; Greve, 2009; Afuah, 2013; Shiri et al., 2014; Kim et al., 2016). Notwithstanding this growing body of evidence, the strategy field as a whole has given insufficient consideration to the question of how, then, an R&D partner selected for its partner-specific benefits might fit into a company's long-term R&D network strategy.

The concept of triads came forth from the social network literature, where they are essentially defined as groups comprised of three alliance partners with any possible configuration of alliance relations among them (Simmel, 1950; Davis, 2016), with closed triads (Coleman, 1988) and open triads marked by a structural hole (Burt, 1992) as the most famous examples. Triads are fundamental to any ego network as they form the microstructures within which dyadic alliance partnerships are formed and interconnect to shape the company's ego network (Madhavan et al., 2004). In essence, the concept of triads enables conceptualising and investigating the relational dynamics between chipmakers and their partners and the strategic implications of alliance strategies within a network by explicitly taking into account how one alliance relation is affected by the presence or absence of other alliance relations (Choi and Wu, 2009). This can naturally not be achieved by studying dyadic alliance relations in isolation.

Past research has shown that different forms of alliances can be conceptualised and analysed empirically within a triadic framework. Alliance relations within triads can be built through different organisational forms whereby the three partners in a triad may be connected through a single three-way alliance agreement or through independent parallel dyadic alliances (Davis, 2016). Moreover, the relational dynamics which can be conceptualised and observed within triads are not only applicable to those within groups of three alliance partners, but also to those within larger multi-partner alliances, such as technology consortiums (Davis, 2016) or large alliance constellations (Gomes-Casseres, 1994; Das and Teng, 2002). Importantly, however, the current research does not distinguish between these types of triadic alliances as the main interest is in investigating how triadic alliance network strategies might provide chipmakers with strategic outcomes beyond those achievable through dyadic alliances; not in examining how triads emerge or are built-up. This approach follows past research on triadic alliances, such as Madhavan et al. (2004).

Accordingly, the configuration of companies' R&D alliance partners and relationships should therefore be analysed through a triadic framework. As such, the (1) combination of the company's network partners resulting from its strategic partner choices as well as (2) the configuration of its alliance relationships within its wider ego network, together, constitute the two core mechanisms which determine how strategic utility can be derived within R&D alliance networks and maximised through triads. Both mechanisms are illustrated in Figure 4.1.

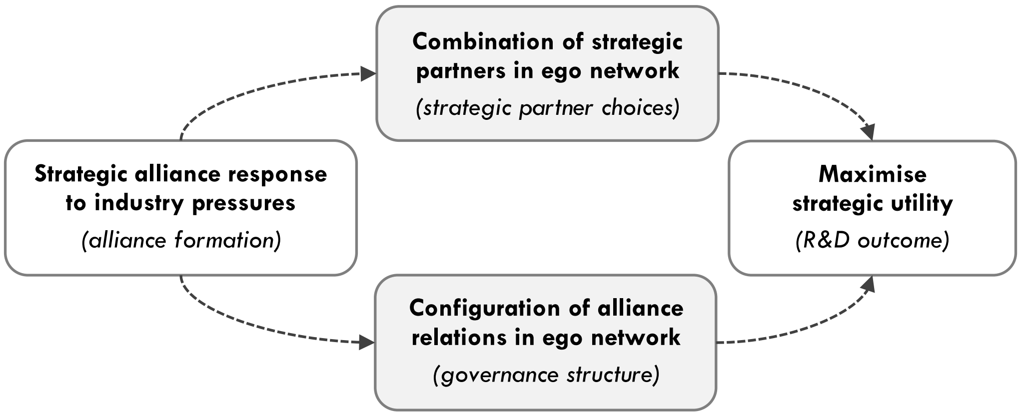


Figure 4.1: The concept of strategic utility (source: created by the author)

The notion that companies' approach to building R&D alliance networks is driven by a pursuit to maximise the strategic utility through the strategic configuration of their R&D alliances within triads is especially relevant to the strategic context of semiconductor R&D – as will be discussed next. This discussion is guided by a review of the mechanisms determining how the configuration of R&D alliance partners and relations within triads might shape the strategic utility attainable from R&D alliances. Figure 4.2 provides a schematic overview of these mechanisms, all of which have been associated with important strategic outcomes in past research.

Figure 4.2: The mechanisms underpinning the maximisation of the strategic utility of R&D alliances configured within triads

Strategic partner choices within triads in the face of uncertainty

Although semiconductor R&D, like any R&D process, is inherently uncertain (Narula and Hagedoorn, 1999) because R&D outcomes are difficult to predict, this uncertainty is amplified as the development of semiconductor devices becomes increasingly more complex and the risk of not meeting the intended R&D outcomes rises as a result of the rapidly increasing capital requirements for semiconductor R&D, volatile demand and intensive rivalry. These uncertainties challenge chipmakers to select those R&D alliance partners who can contribute the most value in view of achieving their desired R&D outcomes with the least amount of uncertainty.

The configuration of strategic partners in the chipmaker's ego network thus constitutes a core mechanism which, via the enhancement of the value of R&D outcomes, shapes the strategic utility which the chipmaker may derive from its network of R&D alliances. In view of enhancing the value of R&D outcomes through strategic alliances, past studies have emphasised the strategic motives underlying R&D alliances (Narula and Hagedoorn, 1999) and have thus most notably linked R&D alliance formations and partner choices to the need for certain or timely access to scarce, complementary resources and capabilities (Hennart, 1988; Williamson, 1991; Narula and Dunning, 1998; Colombo et al., 2006), opportunities for learning through access to non-redundant knowledge (Powell et al., 1996; Anand and Khanna, 2000; Baum et al., 2010; Shiri et al., 2014; Martínez-Noya and Narula, 2018), access to commercially viable ideas (Laursen and Salter, 2006), as well as access to new markets (Hagedoorn, 1993). Concurrently, strategic partner choices aimed at capitalising on complementary financial and strategic assets naturally also enable chipmakers to economise on costs (Narula and Hagedoorn, 1999), such as by sharing the total investments required for an R&D project.

Importantly, these partner-specific benefits are not merely sourced from a single type of partner but rather from a diverse network of R&D partners specialised in different functional areas within the innovation ecosystem, such as competitors, cross-industry partners, customers, suppliers, universities, research centres and government organisations

(Teece, 1992; Narula, 2001; Chetty and Wilson, 2003; Cassiman and Veugelers, 2006; Kedia and Mooty, 2013; KPMG, 2018). As such, we consider partner diversity in light of the differences among partners' strategic assets, which define their functional specialisations and complementary roles in relation to the chipmaker (Parkhe, 1991; Duysters et al., 2009). The network analysis results presented in Chapter 3 demonstrated a high degree of partner diversity within the semiconductor R&D network.

The diversity of strategic partners may be reflective of (1) chipmakers' pursuit for different kinds of R&D outcomes (Lavie and Singh, 2012; de Leeuw et al., 2014), such as (re)combining their existing resources with (non-)redundant partner-specific assets to advance technological progress in line with customer demand or overcome technological complexities (Duysters and Lokshin, 2011; Wassmer and Dussauge, 2011; Oerlemans et al., 2013; Cobeña et al, 2017; Garcia Martinez et al., 2017; Subramanian and Soh, 2017), or mitigating technological, capability and market risks (Wassmer and Dussauge, 2011); as well as (2) changes in their R&D objectives as reflected by changes in the complementarities of the partners involved in the their ego networks (Rothaermel and Deeds, 2004). For example, a chipmaker might select an R&D partner for its technological complementarity and to reduce its exposure to risks of technological obsolescence; or for its expertise regarding the commercial exploitation of technology and to mitigate uncertainties arising from market pressures like volatile demand (Wassmer and Dussauge, 2011).

This logic suggests that the strategic utility that chipmakers may derive from their R&D alliances in response to industry pressures can be better understood when we consider that the type of industry pressure a chipmaker is responding to with an R&D alliance may be reflected in its choice for a functionally distinct type of R&D partner to gain access to a set of specialised complementary assets. Importantly, chipmakers might search for and select those R&D partners who can complement one another (Vanhaverbeke and Cloodt, 2006; Sarkar et al., 2009) within triads as a means of *maximising* the strategic utility attainable through an R&D alliance as a result of triadic partner synergies. This resembles a key strategic benefit which sets triadic alliance relationships apart from dyadic alliance relationships, as these types of partner synergies cannot be achieved within dyads. Moreover, these partner synergies are maximised when integration within alliances promotes not only pooling resources, but importantly also creating new technological assets and knowledge as an outcome of this triadic collaboration. This creation of new value and novelty, however, depends on whether partners are able to establish effective governance structures as will be discussed next.

Effective governance through the configuration of alliance relations within triads

The mere signing of an alliance agreement with a selected R&D partner does not, however, automatically guarantee that this partner will commit to cooperate in line with the terms of the agreement (Williamson, 1975, 1985; Gulati, 1995a). Effective governance is imperative to ensuring that R&D collaborations run efficiently and requires that chipmakers configure their alliance network relationships in ways which encourage cooperation in view of efficiently (re)combining resources, exchanging knowledge, creating new value and developing new technologies and knowledge within triads.

There is not a single universal approach toward establishing effective governance; it depends on several factors, including the strategic purpose of the alliance, the assets which are committed to the alliance by the partners (Contractor and Reuer, 2014) and the type of knowledge which is shared (Contractor and Ra, 2002). Although practically all alliances have legally drawn up contracts at the base of their governance structures (Das and Teng, 1998; Reuer and Ariño, 2007), legal contracts alone are not necessarily sufficient to ensure efficient collaboration and minimise relational risk (Das and Teng, 1996) in terms of opportunism.

The configuration of alliance relations within triadic network structures can, instead, function as a more effective governance mechanism, because they might foster trust and commitment, control, and change the balance of power. To determine how chipmakers can actually configure their R&D alliances in triads to develop effective governance structures as a means of *maximising* strategic utility, we leverage the prominent models of network closure (Coleman, 1988; Uzzi, 1997; Hagedoorn and Duysters, 2002) and network brokerage (Burt, 1992, 2010; Soda, 2011) and conceptualise two major triadic network tactics: integrated triads and protective triads.

Integrated triads are formed when R&D alliance partners are configured in three-way alliance relationships. These integrated triads function as 'relational' types of alliance governance structures which can reduce power asymmetry among partners, due to shared access to the same partner-specific assets, and encourage partners' commitment to the partnership as well as improve enhance the equality of benefit sharing as each partner is likely to participate more actively in the joint activities. Namely, the high level of closure (Coleman, 1988) among R&D partners in integrated triads creates an opportunity to develop mutual trust effectively (Uzzi 1996; Ahuja, 2000; Rowley et al., 2000). The presence of densely connected relations among the partners within the triad can create reputational hostages (Gilsing and Nooteboom, 2005) based on the collective monitoring and sanctioning of R&D partners (Granovetter, 1985; Rowley et al., 2000). In result, this can instil a sense of trust among R&D partners that each will act in the interest of the partnership. Partners are thus encouraged to remain loyal to the partnership and engage in relation-specific investments, as opposed to potentially acting opportunistically, as suggested by Morgan and Hunt's (1994) commitment-trust theory (see Chapter 3, Section 3.2.2). In addition, the development of trust within integrated triads can enhance the transaction cost efficiency of negotiating, monitoring and enforcing legal contracts, and facilitate contractual flexibility (Dyer and Singh, 1998; Poppo and Zenger, 2002; Lavie et al., 2012; Kranenburg et al., 2014).

The high level of density in integrated triads has often been associated with the presence of redundant ties, such as strong ties which developed over a longer term through repeated interactions (Granovetter, 1973; Gulati, 1995a; Hagedoorn and Frankort, 2008) and ties between partners who are cognitively similar in terms of their knowledge bases and functional specialisation (Shiri et al., 2014), and consequently with higher levels of redundancy of information and knowledge as partners share their R&D alliance relations (Burt, 1992; Rowley et al., 2000). Arguably, however, as mutual trust improves the predictability of the partner's cooperative behaviour and its factual cooperation and commitment (Gulati, 1995b; Das and Teng, 1998), the relational governance enabled in integrated triads ought to consequently enhance collaboration with non-redundant R&D partners who are cognitively different as it facilitates communication and the exchange of tacit and fine-grained knowledge (Uzzi, 1996, 1997; Gereffi et al., 2005; Afuah, 2013) in line with the *common* objectives of R&D alliances and with greater certainty that partners will not misappropriate any of the R&D outcomes. Integrated triads do not, however help to build up control over flows of knowledge and the transfer of technology.

Protective triads, on the other hand, are formed when R&D alliance relationships are configured to create a 'captive' type of alliance governance structure (Gereffi et al., 2005) on the basis of stronger social control mechanism induced by the broker position (Burt, 1992, 2001) of a *leading* chipmaker between its R&D partners. This type of governance structure may enable chipmakers to minimise relational risk by locking in (capturing) the R&D partner through transactional dependence or contractual exclusivity – ultimately to maximise their *own* desired R&D outcomes. This triadic tactic, however, increases power asymmetry and thus it does not induce mutual trust as a governance mechanism which could facilitate the efficient exchange of tacit knowledge, and as such it is arguably particularly suitable for R&D alliances intended to govern the transfer codified knowledge from the R&D partner to the chipmaker (Uzzi, 1997) – owing to its relatively easy transferability as compared to tacit knowledge.

Ultimately, both integrated and protective triads do help to increase the strategic utility which chipmakers can derive from their R&D alliances, albeit through different governance mechanisms. Moreover, whether or not the chipmaker may increase strategic utility through either of these triad types depends also on their strategic goals, such as whether they aim to achieve technological leadership through market dominance or enhance their access to novel technologies and knowledge.

4.2.3. Maximising strategic utility through triadic network tactics

Chipmakers derive strategic utility from their R&D alliances to the extent that the configuration of their R&D partners and alliance relationships in triads contribute toward (1) alleviating the increasing cost of semiconductor R&D by enhancing the speed and cost efficiency of the R&D process; (2) overcoming the increasing complexity of semiconductor technologies through efficient knowledge exchange and learning; and (3) adapting to changing customer demand and intense competition by enhancing the innovativeness and time-to-market of R&D outputs through more efficient and effective (re)combining of resources and capabilities.

Thus, the way toward maximising strategic utility through triadic network tactics is not a straight one. To understand, then, under what condition which triadic network tactic would yield most strategic utility, it is important to consider (1) the types of distinct strategic outcomes that either triadic network tactic create via distinct governance structures; (2) the types of industry pressures in response to which chipmakers are best off capitalising on these distinct strategic outcomes; as well as (3) the types of R&D alliance partners who, based on their functional specialisation, would contribute the most value to (a) maximising the desired R&D outcomes and (b) reducing the uncertainty created by these industry pressures. These elements are illustrated in Figure 4.3.

The configuration of alliance relations within the ego network is an important strategic choice for managers, and can arguably influence the scope and nature of the chipmaker's internal R&D activities in different ways in view of shaping the openness of semiconductor innovation. Namely, network position and network density, i.e. the extent to which the chipmaker's alliance partners are interlinked, which result from managers' decisions about alliance network configurations, have previously been connected to the extent of open innovation (Boschma and Ter Wal, 2007; Gilsing et al., 2008; Lyu et al., 2019). In view of forming and configuring a new R&D alliance, chipmaker managers thus have to decide whether (1) to strengthen their ego networks to create an open innovation environment based on close cooperation to potentially both exploit existing technologies and jointly create new technological assets; or (2) to expand their ego networks in search for exclusive access to new, exploitable knowledge and resources within a relatively more closed innovation environment. While extant research on alliance networks has associated triadic alliance configurations with the achievement of important strategic outcomes, scholars remain divided about the relative strategic utility which chipmakers may attain within protective and integrated triads.

While some might argue that the choice to broker R&D alliance relations or to integrate R&D alliances within triads would not constitute a universal strategic response to all strategic challenges (Gilsing et al., 2007; Baum et al., 2010; Gobbo and Olsson, 2010), the scope of distinct strategic outcomes attainable through either of the triadic tactics (see Figure 4.3) might arguably render one of them a relatively superior means to maximising strategic utility. The question is: which strategic outcomes are likely most beneficial to maximising strategic utility in the semiconductor industry?

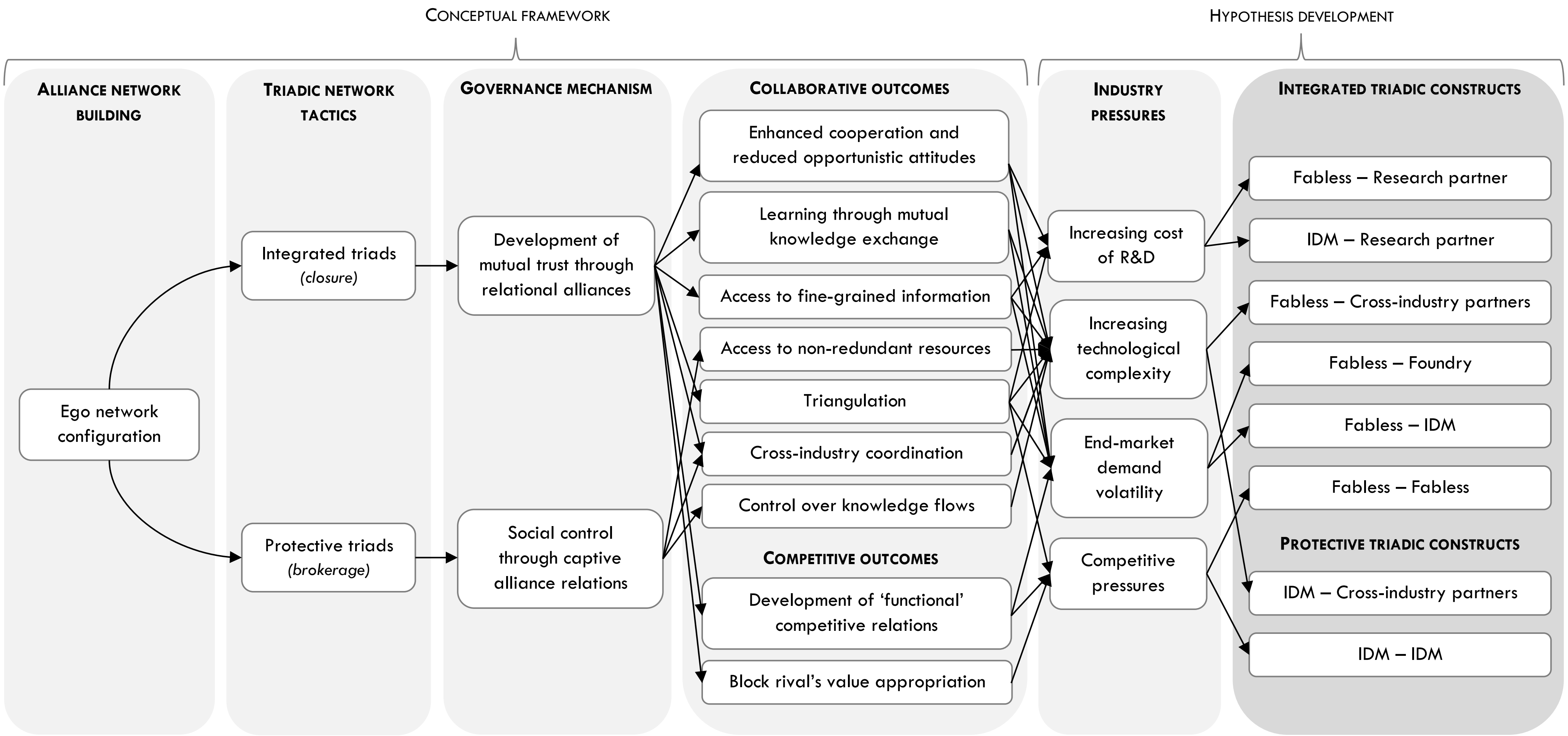


Figure 4.3: Relationship between triadic alliance network tactics and (1) the maximisation of strategic utility in terms of collaborative and competitive network benefits; and (2) the formation of distinct R&D strategies as reflected by chipmakers' partner choices

In view of maximising R&D outcomes, scholars have generally linked the sources of novelty value to brokerage opportunities within protective triads (Hargadon and Sutton, 1997; Burt, 2001), while closure among R&D partners within integrated is often associated with the development of a chipmaker's capacity to effectively recognise and capitalise on the value in these opportunities (Burt, 2001; Gilsing and Nooteboom, 2005; Gilsing et al., 2008).

Configuring R&D alliances within protective triads yields strategic utility to the extent that it enables chipmakers to, first of all, secure and maintain exclusive access to new, heterogenous knowledge possessed by non-redundant R&D partners at the opposite end of a structural hole – often via 'weak' ties (Granovetter, 1973; Perry-Smith and Shalley, 2003) – in view of exploring opportunities for novel resource combinations (Gilsing and Nooteboom, 2005; Soda, 2011). Chipmakers can consequently reduce the risk of becoming locked-in or overembedded within their networks as a result of closure (Uzzi, 1997; Rowley et al., 2000). Furthermore, brokerage can uniquely enable a chipmaker to lead the collaborative development process for a new chip by strategically configuring notably captive R&D alliance relationships as a means to (a) maintain control over the mobilisation of resources between 'captured' network partners (Galaskiewicz, 1979; Burt, 1992, 2004; Rowley and Baum, 2008); (b) to coordinate action and withhold or distort information flowing between R&D partners who are indirectly connected via the chipmaker, to maximise the strategic value of its sources (Alderson and Beckfield, 2004); and (c) to play off disconnected partners against each other (Gulati, 1998). The brokerage opportunities created with this triadic tactic consequently enable chipmakers to maximise their own returns on innovation, while limiting the appropriation of R&D outcomes by their partners. Consequently, the choice to broker alliance relations is made at the expense of the power symmetry and mutual trust among R&D partners.

Concurrently, however, some research suggests there is a threshold beyond which the strategic utility derivable from protective triads declines. Firstly, there is a limit to the chipmaker's capacity to actually capitalise on and integrate and recombine new knowledge and resources (Perry-Smith and Shalley, 2003), in terms managerial capacity as well as absorptive capacity (Cohen and Levinthal, 1990). Secondly, the re-negotiating of new alliance agreements may, especially with 'weak' connections, increase transaction cost inefficiencies (Shiri et al., 2014). Moreover, in spite of the access to non-redundant, novel opportunities, the maximisation of strategic utility via protective triads might arguably be constrained in the context of the semiconductor industry, where efficient, reliable and close cooperation are required to effectively integrate various complementary technological assets and meet the desired R&D outcomes with minimal exposure to opportunism and industry pressures (Ahuja, 2000; Gilsing and Nooteboom, 2005).

This is not to say that protective triads do not yield strategic utility in view of maximising the R&D outcomes of chipmakers. However, these constraints do suggest that the development of the chipmakers' capacity to actually capitalise on novel opportunities in R&D alliances in order to *maximise* strategic utility, needs to be supported by an effective relational governance structure which facilitates learning through knowledge exchanges and the creation of *new* knowledge through the joint application of technical skills and capabilities, in addition to complementing existing technologies and knowledge, within, essentially, an open innovation environment (Ahuja, 2000; Chesbrough, 2003, 2006; Gilsing et al., 2008; Chiaroni et al., 2010; Huizingh, 2011).

Centred on close cooperation, such an environment can be created by configuring R&D alliance relations within integrated triads; where, (1) on the one hand, collective monitoring and sanctioning foster mutual trust and commitment among the R&D partners in the triad, establish a balance of power relations through equal access to knowledge (Cook and Emerson, 1978), and reduce chipmakers' exposure to the risks of opportunism and knowledge appropriation; and (2) on the other hand, three-way communication can facilitate the mitigation of intra-triad issues of conflict, interference and influence during the joint R&D process (Davis, 2016).

Integrating R&D alliance relations with strategically selected R&D partners within triads consequently creates a fundamental basis for networks of learning (Powell et al., 1996) and, indeed, effective open innovation (Chesbrough, 2003, 2006), and enables developing new technologies and knowledge in addition to complementing existing resources. The integrated triadic tactic, namely, first of all enables chipmakers to leverage mutual trust to enhance the ease and efficiency with which fine-grained information and tacit know-how are exchanged with its R&D partners, and subsequently to capitalise on partners' tacit knowledge to develop and enhance their internal absorptive capacity to search, explore and find external resources, new ideas, technological opportunities and routes to market needed to create and commercialise novel R&D outcomes (Nelson and Winter, 1982; Chesbrough, 2003). Secondly, closer cooperation through three-way communication among the chipmaker and its R&D partners in the triad may improve the coordination and division of tasks between multiple R&D partners (Davis, 2016), and enable the chipmaker to efficiently capitalise on the (re)combination potential of cross-partner resource complementarities to accelerate the R&D cycle and enhance time-to-market.

The open innovation process may be accelerated as a result of 'triangulation' among the R&D partners (Rowley et al., 2000; Gilsing and Nooteboom, 2005; Gilsing et al., 2008). This is a distinctive feature inherent to integrated triads whereby the chipmaker can leverage the absorptive capacity of a third partner to better understand, evaluate and integrate more diverse knowledge. Consequently, close R&D collaboration within integrated triads may enable chipmakers to effectively bridge larger cognitive distances to potential R&D partners, notably cross-industry partners based outside of the core semiconductor industry, who possess a distinct variety of knowledge and technological resources; and, contrary to traditional conceptions (Gilsing et al., 2008), facilitate chipmakers in avoiding technological lock-in by efficiently expanding the scope and depth of their external search for complementary assets and information possessed by diverse sources – and, in result, enhance the novelty value of their R&D outcomes (Katila and Ahuja, 2002; Rowley et al., 2004; Laursen and Salter, 2006; De Leeuw et al., 2014). Similarly, chipmakers might, through a process of 'network transitivity' (Uzzi and Gillespie, 2002), leverage specific complementary assets of one R&D partner to enhance the value obtainable from another R&D alliance relationship within the same integrated triad.

The pursuit for these cooperative outcomes of integrated triads reflect what Madhavan et al. (2004) describe as a 'clustering' motive, whereby chipmakers aim to maximise strategic utility by bundling the value creation capabilities of a cluster or close group of R&D partners. Importantly, this triadic tactic is not restricted to maximising the strategic utility of cooperative R&D alliance relations, as it has long been known that rivals, too, collaborate for R&D (Madhavan et al., 2004; Quintana-García and Benavides-Velasco, 2004). Yet, how companies actually utilise network tactics for competitive purposes in R&D remains relatively under researched (Contractor and Reuer, 2014). By exception, several studies do highlight important strategic outcomes attainable through integrated triads in view of changing the nature of competition through co-opetition (Brandenburg and Nalebuff, 1996); which may or may not reflect joint value creation intentions.

Past research suggests that integrating R&D alliance relations with rivals within triads can facilitate in symmetrising market power balance, in order to reduce intra-triad competitive conflict and to stimulate mutual cooperation and the pursuit of shared interests (Morgan and Hunt, 1994). Integrated triads can, thus, render competitive relations 'functional', or co-opetitive (Brandenburg and Nalebuff, 1996), to the extent that rival chipmakers may cooperate in the exploration of new knowledge and research into new technologies and product applications, and compete in the exploitation of the jointly created R&D outcomes. Furthermore, both Gimeno (2004) and Madhavan et al. (2004) suggest that configuring co-opetitive R&D alliance relations within integrated triads may also function as a way for a chipmaker to *counter* the alliance decision of a rival R&D partner by forging an alliance with the same partner, thus cancelling the rival's brokerage advantage and reducing the value which it can appropriate from this partner.

Ultimately, the maximisation of strategic utility within triads is the result of a joint decision by chipmakers concerning (1) their strategic partner choices, in view of creating novel resource combinations; and (2) the configuration of their ego networks of R&D alliance relations, in view of developing effective governance. In the next section we will develop distinct triadic 'constructs' to explore and hypothesise how, by combining effective governance within triads with strategic partner choices, chipmakers might maximise the strategic utility of their R&D alliances in response to several industry pressures.

4.3. Hypothesis development

4.3.1. Constructing R&D strategies through triadic alliances

Semiconductor companies face pressures to organise their joint R&D activities within triadic structures to mitigate the risks and uncertainties that arise during the R&D and commercialisation process as a result of the (1) growing financial capital requirements of chip development projects paired with shrinking profit margins; (2) increasing complexity of semiconductor technologies; (3) high volatility of product demand in end-industries; and (4) intense competition within and beyond the core semiconductor industry, in technology and end-markets.

Table 4.1 provides an overview of these industry pressures along with the risks and uncertainty that these project upon the two major types of chipmakers, IDMs and fabless chipmakers, which the hypotheses will focus on.

The aim of this chapter is to develop hypotheses to demonstrate how chipmakers achieve their R&D alliance strategies through constructing distinct *triadic constructs*. These hypotheses are formulated to test the formation of network strategies defined by (1) the configuration of R&D alliance relations within triads, as illustrated in Figure 4.3 and discussed in Section 4.2, and (2) the strategic partner choices made by the chipmaker (see Table 4.2 for an overview of the key R&D partner types), in response to the industry pressures shown in Table 4.1.

The hypotheses are developed as follows. Each of the industry pressures are addressed separately, starting with the formation of triads as a network tactic for enhancing the efficiency of fundamental R&D, followed by triadic tactics for enhancing cross-industry R&D collaboration, reducing the uncertainty caused by demand volatility, and developing co-opetitive R&D alliance relations. The strategic advantages of distinct triadic configurations are discussed in line with the links identified in Figure 4.3, between the strategic outcomes of distinct triadic tactics and the industry pressures. Descriptions of the strategic challenges posed by industry pressures are subsequently linked to choices for specific types of R&D partners typically combined within chipmakers' ego networks (see Table 4.2). This is done by identifying the alliance-specific assets of these R&D partners, the nature of relations characterising these alliances, and characterising their partner-specific complementarities to semiconductor R&D.

Table 4.1: Main industry pressures and risks faced by chipmakers (source: created by the author)

Impact of industry pressures and strategic risks			**Extent of uncertainty**	
Industry pressure	**Risk**	**Impact**	**IDM**	**Fabless**
Increasing cost of R&D	• Failing to achieve a return on R&D investment.	• Loss of profits. • Bankruptcy.	High	High
Increasing technological complexity	• Failing to keep up with advancement of fundamental and complementary cross-industry technologies. • Becoming technologically locked-in. • Failing to develop highly integrated and functional semiconductor devices which systems companies will want to integrate into their systems. • Failing to achieve a return on R&D investment.	• Reduction in demand for R&D output. • Loss of long-term market position.	High *(pressure at both chip design and fabrication stages)*	Moderate *(nimble model; specialised in chip design and system-specific applications)*
Highly volatile product demand	• Failure to keep up with changing customer requirements. • Failure to introduce a new, enhanced and valuable product generation at the start of new demand cycle relative to rivals. • Failure to reach, compete and diversify in end-industries.	• Loss of profits. • Loss of long-term market position.	Moderate *(shorter go-to-market cycle due to close integration of design and fabrication)*	High *(dependent on foundry for advancement and alignment of fabrication technologies)*
Intense competition	• Falling behind competitors' time-to-market. • Falling behind technological advancements of competition. • Intense price competition.	• Loss of revenue, profit margins and total profits. • Loss of long-term market position.	Moderate *(highly concentrated; focus on domination in large product markets)*	High (*fragmented system-level chip segment*)

Table 4.2: Specification of partner types in the semiconductor R&D ecosystem and partner-specific complementarities (source: created by the author, using industry reports and alliance announcements)

	Partner type	R&D output	Alliance-specific assets/processes	Asset types	Nature of alliance relations	Complementarity of assets to R&D process/output
Core function	**Integrated chipmaker**	• Chip design • Materials • Manufacturing process	• Core technology	• Chip design • Manufacturing process	• Co-development (direct R&D involvement)	• Integrated design lifecycle.
	Fabless chipmaker	• Chip design	• Core technology	• Chip design	• Co-development (direct R&D involvement)	• Flexibility to change chip architecture and design implementation and productization.
	Foundry/OSAT	• Manufacturing process	• Production capital	• Manufacturing process	• Co-development (direct R&D involvement) • Licensing / co-development	• Alignment of chip design process with manufacturing technologies and advancement of process development. • Advancement of process development. • Proprietary process technology.
	Distributor	• Chip design	• Commercialisation of R&D output	• Market access	• Co-production	• Alignment of development process with end-markets and established distribution systems.
Support function	**Complementor**	• Chip design • Materials • Manufacturing process	• Complementary technology *(increases value of end product)*	• Software • Electronic components • Applications technology • Material technology • Fabrication technology • Semiconductor IP • Applications IP • Chip design skills	• Licensing of patented technology • Co-production • Co-development (direct R&D involvement) • Promotion of technology	• Capability to customise complementary technology. • Capability to align development process with application-specific expertise. • Capability to contribute to process of chip architecture design and design implementation. • Advancement of process development. • Specialised know-how of materials development for semiconductor devices. • Technology adoption for application development.
	Supplier	• Chip design • Manufacturing process and equipment	• Support technology *(standardised technologies)*	• Chip design tools • Semiconductor IP • Applications IP • Manufacturing equipment	• Licensing of patented technology • Integration of standardised components • Co-development (direct R&D involvement)	• Proprietary semiconductor technology. • Methodologies and tools for IP integration and virtual design collaboration. • Proprietary applications technology. • Alignment of process development with advancement of manufacturing equipment.
	Research centre University	• Chip design • Manufacturing process	• Fundamental technology	• Fundamental R&D	• Co-development (direct R&D involvement) • Joint research	• Specialised research expertise and facilitation in identifying or redirecting industrial innovation opportunities.
	Investor	• Chip design • Manufacturing process	• Financial support	• R&D funding	• Provision of funding	• Financial funding for R&D.
	End-industry	• Chip design	• Project initiation	• Systems specifications	• Initiation of project	• Alignment of systems specifications and end-user feedback with development process.
	Government	• Chip design • Manufacturing process	• Project initiation with/without R&D grant	• Systems and/or fundamental R&D specifications • R&D grant	• Initiation of application-specific or fundamental project • Provision of R&D grant	• Alignment of development process with requirements of large-scale, national technology projects. • Grants for fundamental and application-specific R&D.

4.3.2. Increasing R&D costs: Enhancing efficiency of fundamental R&D through triads

The rising cost of semiconductor R&D is one of the primary drivers for chipmakers' decisions to form R&D alliances as a means of sharing the cost of R&D and reducing exposure to risk and uncertainty around their ability to generate a return on R&D investments; especially in terms of fundamental R&D. According to the Global Semiconductor Alliance (2016), capital investment requirements for research into and the development of semiconductor technologies have been on an exponential growth trajectory tracking the pace of technological progress as predicted by Moore's Law.

With traditional R&D strategies, such as in-house R&D or dyadic forms of R&D alliances, it would be very challenging for chipmakers to commercialise fundamental innovations with a return on their R&D investments and maintain long-term innovativeness. The risks and uncertainties, namely, weigh on chipmakers' profit margins (AlixPartners, 2013) due to the increasing difficulty of quickly capitalising on opportunities to commercialise new fundamental innovations. This may subsequently inhibit them to invest in new R&D projects and generate future revenue growth, which may, eventually, result in a loss of market share. These pressures consequently add to chipmakers' perception of uncertainty in relation to their long-term competitiveness and survival, and shift their priority away from fundamental R&D toward application-specific R&D, the outputs of which can be commercialised faster; both domestically and abroad in line with chipmakers' internationalisation ambitions.

In the face of pressure to increase R&D investments to remain technological leadership, it is imperative for chipmakers to enhance R&D efficiency to reduce uncertainty. Especially at the stage of fundamental R&D, the strategic configuration of R&D alliance relations within triads is important as this can improve the efficiency of the R&D process by effectively governing the alignment and coordination of chipmakers' R&D investments with those of multiple other organisations within the semiconductor ecosystem (Miller et al., 2012; KPMG, 2016), while also sharing the cost of R&D and increasing the speed of the R&D process.

To examine the utilisation of triadic alliances in response to the rising costs and risks of R&D, we focus on the configuration of chipmakers' alliances for fundamental R&D, where these risks are particularly acute. Fundamental R&D activities often involve a high degree of interdependence among the R&D programs of partners within and outside the core semiconductor industry, and longer-term investments targeted at industry-wide or network-wide R&D objectives. As such, joint fundamental R&D is essential to ensure alignment of the pace of technological advancement across the semiconductor industry's value chain modules (Miller et al., 2012) and often involves collaborations with universities and research centres at the technological frontier of the industry.

Universities and research centres provide open access to specialised expertise and know-how regarding the latest and most advanced fundamental technological breakthroughs. Consequently, they often function as (international) R&D hubs at the centre of the industry's innovation network where chipmakers are joined with – often multiple – other actors from the industry and the scientific research community on R&D projects within an open innovation model that is based on the sharing of cost, risk and IP (Bruynseraede, 2009).

Universities and research centres, as fundamental R&D partners to chipmakers, fulfil an important role in directing innovative activities, as they can provide chipmakers with updates on, and access to the latest technological advancements, and they can leverage their informational network advantage to link chipmakers with new opportunities to develop and/or commercialise innovations that could result from combining their complementary specialised assets with those of a third partner (Bruynseraede, 2009), such as other universities/research centres, other chipmakers, technological complementors, suppliers or end-market companies (see Table 4.2).

In this context, the *integration* of fundamental R&D alliance relations within triads is likely to fulfil a critical role in enhancing the efficiency of fundamental R&D. Integrated triads, namely, function as 'bridges' connecting technological 'think tanks' like universities and research centres to strategic partners in, for example, complementary technology and end-markets, while effectively stimulating these organisations to cooperate closely and share their knowledge and expertise in line with a common strategic goal. Chipmakers can thus capitalise on this bridging tactic as a means of efficiently combining fundamental breakthrough technologies with core semiconductor and application-specific complementary technologies developed at other stages of the semiconductor value chain, as well as integrating these into end-systems or products for rapid commercialisation.

By bridging the disconnect between these think tanks and technology and end-markets within integrated triads, chipmakers can thus accelerate the fundamental R&D cycle, enhance time-to-market and consequently increase R&D efficiency and reduce the pressure of rising R&D costs. Figure 4.4 provides a schematic view of the triadic form of R&D collaboration that can be manifested and which will be used in the empirical analysis. The following is hypothesised:

Hypothesis 1a	*Chipmakers have a significant tendency to conduct fundamental R&D through integrated triadic alliances.*

Importantly, between chipmakers, IDMs and specialised fabless companies operate inherently different business models (see Chapter 2) and even though they are both exposed to pressure coming from the rising cost of fundamental R&D, the strategic utility of configuring fundamental R&D alliances within integrated triads as a means of adapting to this pressure might be different for IDMs and fabless chipmakers due to the efficiency of fundamental R&D which is achievable on the basis of their business models.

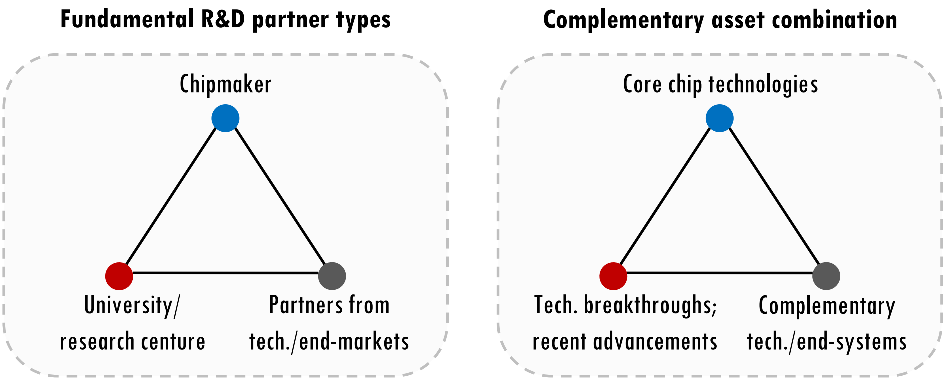


Figure 4.4: Triadic construct for fundamental R&D

IDMs compete with fabless chipmakers in chip design and with foundries in manufacturing, which requires a highly efficient division and allocation of resources for the advancement of semiconductor technologies as well as fabrication processes. In contrast to fabless chipmakers, which enjoy a shorter cycle time from chip development to fabrication as they outsource fabrication to specialised foundries (Hung et al., 2017), IDMs thus take on greater risk resulting from a wider scope of fundamental R&D investments. Moreover, the costly consequences of failing to optimise the utilisation of their fabrication capacity following a lengthy R&D process puts greater pressure on IDMs to ensure they are able to rapidly commercialise their fundamental R&D outcomes. The rapid and efficient integration of new fundamental breakthroughs with complementary technologies and end-systems via bridges between think tanks and R&D partners based at other stages of the semiconductor value chain is therefore essential, and ought to render integrated triads an advantageous triadic tactic for IDMs in particular. It is therefore hypothesised that:

Hypothesis 1b	*IDMs have a greater tendency than fabless chipmakers to conduct fundamental R&D through integrated triadic alliances.*

4.3.3. Increasing technological complexity: Cross-industry R&D collaboration through triads

Chipmakers are challenged to invest heavily in the development of increasingly complex chip designs and to rapidly adapt these designs to the system or product-specific requirements of end-market customers. The complexity of chips is determined by the amount of functionality (in terms of modular IP components) that is integrated into the chip.

System-level designs, such as SoCs, are the most complex (Ernst, 2005) and are usually tailored for integration into specific end-products. Consequently, the development of highly complex chips requires a wider range of specialised knowledge and skills to be mobilised across technological and end-markets. How can chipmakers configure their R&D alliance relations to effectively coordinate the cross-industry integration of these technologies, components, knowledge bases and technical skills at the lowest cost?

The risk of not accomplishing this efficiently is logically amplified by the size of the costs of R&D and operations as well as failure to achieve rapid time-to-market or a first mover advantage – which boosts sales and enables the temporary maximisation of profit margins through premium, monopolistic prices. Accordingly, chipmakers experience uncertainty to the extent that they are unable to foresee their advantage vis-à-vis competition to more rapidly and efficiently achieve and commercialise innovative chip designs.

To reduce this uncertainty, chipmakers collaborate closely with complementary technology partners, i.e. strategic partners which operate in 'satellite' industries outside of the core semiconductor industry (see Table 4.2), as well as systems partners operating in end-markets. The integration of software, in particular, has been essential to the enablement of multi-functionality in chips (Global Semiconductor Alliance, 2012; Andén et al., 2015); used by end-industry partners to enable the Internet of Things. Importantly, the strategic utility of these partnerships resides not merely in their function to establish access to different fields of knowledge and complementary resources as a means of driving the advancement of new chip developments, and to share the increasing cost and risks of semiconductor R&D; but also in their potential to accelerate the commercialisation of new chip innovations (Kapoor, 2012) by tactically *linking* access to complementary technologies with access to down-stream revenue streams and commercial opportunities in end-industries within triads. As such, configuring their R&D alliance relations with technological complementors and end-industry partners within triads can enable chipmakers to achieve strategic advantages beyond those of cost and risk sharing, by accelerating overall time-to-market.

Prior research supports the utilisation of triadic tactics by chipmakers as a means of developing cross-industry linkages. Namely, Kapoor (2010) shows that chipmakers with strong collaborative relationships with technological complementors, with whom they exchange information on market-specific applications and technology roadmaps, also tend to have strong collaborative relationships with end-industry customers in light of, as indicated by chipmakers' involvement in customers' long-term technology road mapping and cost reduction planning. As such, by strategically coordinating the triadic flow of knowledge between themselves and their technological complementors and end-industry partners in view of maximising their desired R&D outcomes, chipmakers can direct the creation and extraction of value from their collaborative R&D activities (Dhanaraj and Parkhe, 2006). Chipmakers can establish cross-industry linkages to overcome the aforementioned challenges and maximise strategic utility either by (1) *bridging* the gap between technological complementors and systems companies through integrated triadic alliances or (2) *brokering* cross-industry relations through separate dyadic alliances.

A *bridging tactic*, formed through integrated triads, can be utilised by chipmakers to more effectively resolve the challenge of integrating a variety of complementary technologies and IPs within systems and achieving rapid commercialisation, by directly aligning the development of (customisable) chip technologies with end-user feedback and systems specifications. Integrated triads, namely, function as effective governance structures based on mutual trust, which foster cooperation and a mutual sense of reliability among the R&D partners, and enable coordinating cross-industry knowledge exchanges and triangulation among R&D partners. By integrating their R&D alliance relations within triads, chipmakers can consequently enhance their ability to bridge cognitive distances between R&D partners based in different industries and who might have different views on management practices, R&D routines, strategic visions, goals and views on competition. These differences are more challenging to overcome through traditional dyadic alliances. Furthermore, effective governance in integrated triads helps to establish a balance of power relations through equal access to knowledge (Cook and Emerson, 1978; Molm, 2014) and will, if the complementary technologies are successfully integrated and commercialised, equalise partners' shares in the returns on innovation. This is an important outcome because it helps to avoid failure of R&D alliances due to conflicts over the distribution of returns on innovation.

By contrast, a *brokering tactic*, formed through protective triads, results in very different configuration of R&D alliance relations within triads. Brokerage does not stimulate cross-fertilisation among cross-industry R&D partners, but rather helps to protect a chipmaker's exclusive access to complementary technologies and end-market knowledge and end-user feedback through a different governance structure, which tactically isolates R&D partners from other parts of the networks. This tactic can, therefore, be utilised by chipmakers to separate the development of (novel) technology combinations from their integration into market-specific systems, and consequently enables chipmakers to control the process of developing and commercialising new chip technologies. Concurrently, this gives chipmakers an unequal power advantage over their triadic R&D partners, which they can leverage to marginalise these partners through the appropriation of R&D outcomes, such as property rights and profits from innovation.

The decision to pursue either of these two triadic tactics is not straightforward and is likely to be different for IDMs and fabless chipmakers operating on the basis of inherently different business models. Between IDMs and their fabless counterparts, IDMs are inherently exposed to relatively greater risk of not accomplishing a return on innovation; first of all, due to the large (capital) expenditures of operating and maintaining their fabrication facilities; and secondly, as even a small drop in sales will have a detrimental impact on the IDM's operational efficiency. These operational pressures challenge IDMs to dominate a single or few large, select markets in order to offset their overall operating costs (Kapoor, 2012).

Fabless chipmakers, by contrast, do not face these operational pressures and therefore enjoy greater flexibility to focus their R&D strategies on the development of novel customised and application-specific innovations for small end-markets with limited sales prospects (Saito, 2009). The development of complex, integrated SoCs has therefore been a key focus of fabless chipmakers; predicated on the their ability to effectively recombine an increasingly wider variety of complementary technologies and knowledge from R&D partners based in both technology and ends-markets, in view of developing chip technologies tailored to the system requirements set by end-market partners (Ernst, 2005).

IDMs, therefore, ought to be more likely than fabless chipmakers to pursue brokerage tactics through protective triads; as it would enable them to maintain their technological leadership and protect exclusive access to downstream revenue channels by controlling the process of developing and commercialising new chip innovations through comparatively monopolistic network positions (see Figure 4.5). These brokerage tactics can give IDMs a power

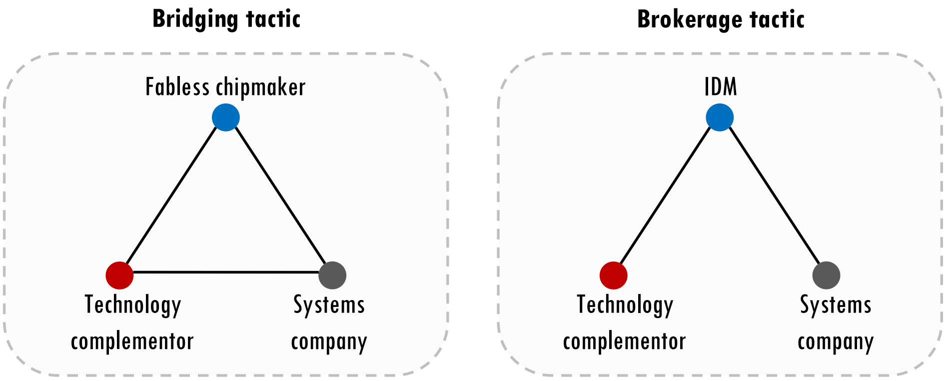


Figure 4.5: Triadic constructs for cross-industry R&D collaboration

advantage over their R&D partners and consequently enable maximising their R&D outcomes by cutting off technological complementors from participating in the further development and/or commercialisation of new chip technologies as well as appropriating their partners' shares in the profits from innovation. In fact, there have been reports of accusations towards Intel, one of the leading IDMs, regarding the expropriation of firms possessing critical complementary technologies (Gawer and Cusumano, 2002).

By contrast, fabless chipmakers ought to derive more strategic utility, than IDMs, from their cross-industry R&D alliances through bridging tactics. This triadic tactic, namely, would facilitate fabless chipmakers in integrating the development and commercialisation of application-specific SoC technologies tailored to specific systems requirements; first of all, by linking the process of recombining complementary resources with the end-market experience and access to end-user feedback possessed by end-industry R&D partners within triads; and, secondly, by creating an effective governance structure to stimulate close cross-industry cooperation, coordinate the three-way exchange of knowledge, and subsequently to overcome cognitive barriers between R&D partners from technology and end-markets. Therefore, the following hypotheses are formulated:

Hypothesis 2a	*Fabless chipmakers are more likely than IDMs to form triads that bridge the gap/disconnect between technology complementors and systems companies in cross-industry R&D collaboration.*
Hypothesis 2b	*IDMs are more likely than fabless chipmakers to broker relations between technological complementors and systems companies.*

4.3.4. Product demand volatility: Market-driven R&D through triadic alliances

Particularly in the space of customisable and system-level chips are chipmakers faced with rapidly changing demand from end-markets for chips which integrate greater functionality, enabled by combinations of a growing range of complementary technologies, and performance (in terms of a chip's processing speed). The demand volatility means that chipmakers are pressured by short chip life cycles and, subsequently, limited time to yield a return on R&D investments; which, in combination with competitive threats, challenges chipmakers to construct R&D alliance strategies which enable both accelerating the chip development cycle and enhancing the novelty of R&D outcomes in response to external market forces.

It is particularly interesting to analyse how fabless chipmakers might respond to this pressure, because they are relatively more exposed to demand volatilities than IDMs, owing to their focus on developing customisable and system-level chips. This challenges fabless chipmakers to decide between (a) reinforcing their application-specific R&D network strategy within their current product markets or (b) expanding their R&D network into new product markets. While there are various reasons for firms to expand into different product markets (Skilton and Bernardes, 2015), here we focus on the potential R&D partner choices of fabless chipmakers within triadic R&D alliance structures and the product market decisions that are reflected by these choices.

Past research suggests that the competitive pressures present in the fragmented fabless segment should encourage chipmakers to expand into other product markets (Baum and Korn, 1999; Skilton and Bernardes, 2015). In real business settings, however, fabless chipmakers are also confronted with the challenge to overcome cognitive distance to their R&D partners (Boschma, 2005), as well as a lack of market experience and an established base of application-specific resources and capabilities relevant to a new market. This renders the decision of a fabless chipmaker to expand into new product market uncertain and prone to risk of failure.

Fabless chipmakers can, however, tactically configure their R&D alliance relations within integrated triads to enable effectively utilising their R&D alliances to learn from and leverage partners' complementary resources and market experience. This can enhance their capacity to bridge and derive novelty value from cognitive distances (Saviotti, 1996; Gilsing and Nooteboom, 2005) and, subsequently, to pursue entry into different product markets; or strengthen their existing market-specific development capabilities. Moreover, if the alliance governance structure is built on mutual trust and commitment within an integrated triad, then the fabless chipmaker may also be able to enhance cooperation among its R&D partners, communication and consequently time-to-market, as well as reduce uncertainty and the risks of conflict and opportunism as emphasised by commitment-trust theory (Morgan and Hunt, 1994).

These integrated triadic tactics may be observed as at least two triadic constructs, aimed at leveraging the partner-specific resource complementarities of either specialised foundries or IDMs. These are the two types of R&D partners which possess the dynamic manufacturing capabilities needed by a fabless chipmaker to either accelerate its chip development cycle in a current product market or to leverage the established development cycle of a strategic partner.

The first triadic tactic (see Figure 4.6-a) involves expanding an established long-term foundry partnership into R&D to reinforce its market position, coined the 'virtual IDM model' (Sperling, 2012), in order to (a) enhance cross-industry coordination, (b) achieve tighter integration between the development and integration of complementary IP or system components and advancements in manufacturing technology, and (c) enhance joint competitiveness against IDMs. The second triadic tactic (see Figure 4.6-b) entails seeking cooperation for R&D from a potentially competing IDM in order to (a) leverage the IDM's dominant market position and its access to complementary technologies and downstream revenue streams to gain a foothold in a new product market, while (b) sharing the cost of R&D by leveraging the IDM's large financial assets and (c) combining the IDM's core technological assets and manufacturing process capabilities with its own technical assets.

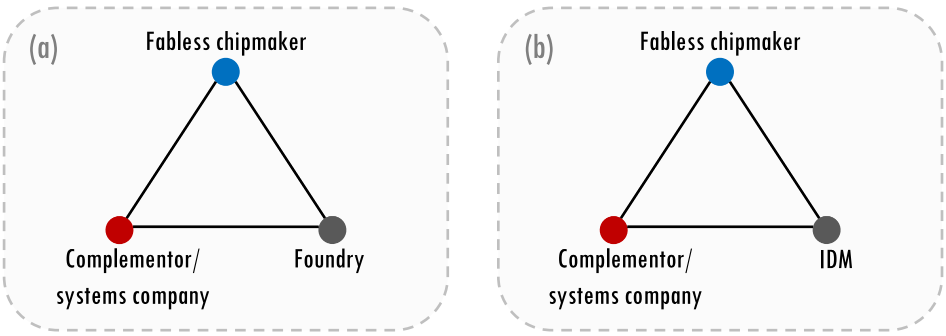


Figure 4.6: Triadic constructs for application-specific and market-expanding R&D alliances

Which triadic R&D alliance strategy has the potential to yield greater strategic utility? The fact that established, interdependent fabless-foundry partnerships are based on a history of collaboration and thus provide a basis of mutual trust, reliability and norms of cooperation upon which cross-industry R&D collaborations can efficiently be built and coordinated to respond swiftly to volatility in the demand cycle, creates a strong case for arguing that fabless chipmakers ought to derive strategic utility from involving their foundry partner in triadic cross-industry R&D alliances. This also follows the consensus among past studies that past collaborations strengthen future, longer-term partnerships (Nohria and Garcia-Pont, 1991; Gulati, 1995a; Rowley et al., 2004) and increase their success rate (Browning et al., 1995; Khanna and Rivkin, 2006). Moreover, Okada (2000) offers research evidence suggesting that fabless chipmakers can shorten the design cycle, and thus reduce uncertainty, by closely integrating manufacturing capabilities into the chip R&D process.

Between fabless chipmakers and IDMs, similarity in their skills and capabilities reduces cognitive distance and should, subsequently, enhance the potential for cooperation (Gilsing et al., 2008). Past research provides strong indications that fabless chipmakers and IDMs are, however, likely to experience competitive conflicts within their alliance, and this might consequently undermine the potential for joint value-creation (Gomes-Casseres, 1994; Rowley et al., 2004). Although integrated triads may improve the conditions for collaboration by preventing competitive conflict and reducing the risks of opportunistic behaviour and the appropriation of R&D outcomes by the IDM, they may not incentivise competing fabless chipmakers and IDMs to engage in long-term collaboration based on mutual trust and commitment, because any overlap in their competitive goals can lead competition to overshadow cooperation (Kogut, 1989; Hamel, 1991). The lack of trust between fabless chipmakers and IDMs might therefore lead this triadic tactic to yield greater strategic utility for short-term rather than long-term collaborative goals, such as entering a new product market, where certainty about the R&D outcomes of fabless chipmakers remains clouded by rivalry. Taken together, these arguments suggest that, when collaborating with either technology complementors or systems companies:

Hypothesis 3a	*Fabless chipmakers are more likely to form integrated triadic R&D alliances with Foundries than with IDMs.*

The ability of a fabless chipmaker to keep up with the demand cycle does not only depend on the speed of its development cycle, but – as discussed previously – also on its ability to keep up with the increasing technological complexity of chips demanded by customers. As such, fabless chipmakers have the strategic options (1) to tighten the alignment of chip design and advancements in manufacturing technology with the integration of complementary technology, IPs and systems components within integrated triads; or (2) to enhance the alignment of chip design and manufacturing processes independently from cross-industry R&D collaborations across technology and end-markets.

Would fabless chipmakers derive greater strategic utility from closely integrating its R&D alliance relations with foundries and other technology partners within triads or from segregating their ego network of R&D alliances to these partners? Fabless chipmakers would arguably prefer to integrate the development and commercialisation of new chip technologies, through cross-industry R&D collaboration with technology complementors and end-industry partners, separately from their R&D alliances with foundries. Close triadic cooperation with a foundry would, namely, be necessary only to stimulate closer communication and cooperation in view of coordinating the alignment of the development of chip technologies with a foundry's upgraded, next generation process technology (Saito, 2009); or to coordinate the validation of IPs integrated into new chip technologies, targeted at a new application or product market, for manufacturing with existing process technologies.

These validation procedures are, however, lengthy in nature and consequently increase the chip development cycle and, thereby, the uncertainty surrounding the fabless chipmaker's ability to keep up with the demand cycle. Fabless chipmakers would arguably avoid this added uncertainty by focusing their R&D strategy within its current product market(s). Moreover, the life cycle of manufacturing process technologies is typically longer than that of chip technologies, so process technology upgrades do not happen frequently enough to justify integrating R&D alliance relations with foundries within triads. It is therefore hypothesised that:

Hypothesis 3b	*Fabless chipmakers are more likely to form integrated triadic cross-industry R&D alliances without Foundries than with Foundries.*

4.3.5. Competitive pressures: Cross-industry co-opetition through triadic R&D alliances

The constant race to efficiently yet swiftly develop better performing and highly integrated chips results in competition between chipmakers for access to technology and end-markets. The nature of competition among chipmakers is, however, not based on purely competitive relations, but often on co-opetitive relations whereby rival chipmakers, similar in technological skills, capabilities and strategic and operating routines (Gimeno, 2004; Madhavan et al., 2004; Rowley et al., 2004; Skilton and Bernardes, 2015), are part of one another's R&D ego networks in result of competitive interdependencies among them. This relational pattern is known as homophily in the network literature (McPherson et al., 2001).

Rival chipmakers can leverage competitive interdependencies in triadic R&D alliances to reduce risk and uncertainty by (1) complementing one another's technological skills and resources (a) to capitalise on new end-market opportunities or accomplish new product innovations and technology advancements, and (b) to gain greater control over the uncertain environment and shortcomings in the internal resource base; or (2) chipmakers can benefit from imitating or countering rivals' partnering moves as a means of undermining the rival's competitive advantage and reduce the relational rents appropriated by the rival. Partner choices within triadic network structures can thus be driven by a pursuit for both cooperative and competitive outcomes (as illustrated in Figure 4.3) and can lead to the maximisation of strategic utility in different ways, such as by integrating co-opetitive relations within the chipmaker's ego network.

Importantly, however, the extent to which competitive interdependencies exist as well as whether chipmakers may derive any strategic utility from integrating co-opetitive R&D alliance relations to rivals within triads, depends on the degrees of fragmentation and concentration of the competitive network structures of the semiconductor industry segments within which chipmakers operate. In which competitive landscape would configuring co-opetitive R&D relations within integrated triads yield more strategic utility?

Chipmakers operating in fragmented segments of the industry network should experience greater competitive pressure to expand into more product markets in order to remain competitive (Li and Greenwood, 2004; Skilton and Bernardes, 2015). This suggests that in industry network segments characterised with a greater diversity of rivals, such as in the segment for SoCs aimed at various end-markets, there is (a) greater potential to explore different end-markets by capitalising on the knowledge and expertise of co-opetitive R&D partners in developing market-specific chip technologies; and (b) greater cognitive distance between rivals focused on different, potentially complementary application areas for chips, which can be leveraged to create novel innovations by recombining rivals' complementary knowledge and resource bases within triads; and (c) space to cooperate in accessing and recombining complementary technologies for exploitation in different end-markets. Such a competitive environment renders collaborations with rivals potentially beneficial.

By contrast, in industry segments where competitive activity is concentrated around a small number of rivals, which would be indicated by a high level of industry network centralisation, it is less critical for chipmakers to differentiate by expanding into different product markets (Skilton and Bernardes, 2015); moreover, there is less scope for resource complementarity with rivals and less environmental uncertainty. This arguably makes it more likely for rivals to ally within fragmented than concentrated product markets, as reflected in the previous paragraph.

This provides an important basis for comprehending the strategic utility that fabless chipmakers and IDMs may derive from forming triadic R&D alliances with rivals – because IDMs operate in highly concentrated industry segments (e.g. memory chips and high-end microprocessors) and fabless chipmakers mainly in fragmented segments (e.g. system-level chips). The triadic constructs for these competitive R&D alliances are shown in Figure 4.7.

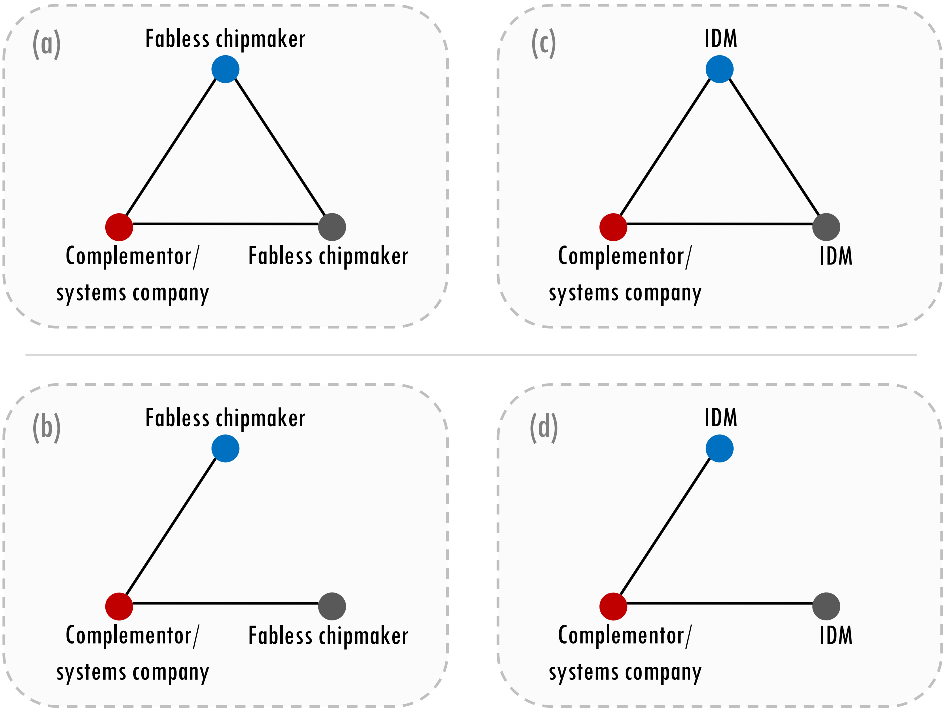


Figure 4.7: Triadic constructs for co-opetitive cross-industry R&D alliances

Chipmakers within the fragmented fabless segment are specialised to develop chips for relatively small end-markets (Saito, 2009), often requiring the integration of a wide range of complementary technologies onto a chip designed specifically for a single system. As such, the greater diversity of rivals, along with all of their ongoing technological advancements aimed at various application-specific technologies and product markets, expose fabless chipmakers to greater environmental uncertainty as well as internal uncertainty, owing to the presence of some degree of cognitive distance as well as the lack of core technological resources and experience needed to enter other product markets (Pfeffer and Salancik, 1978).

Yet, the smaller degree of overlap between rivals' resource and knowledge bases increases the cognitive distance between them and consequently creates opportunities for these rivals to (1) enhance the novelty of value created through R&D collaboration, by recombining their complementary their technical knowledge, skills and IPs; (2) share access to technology and end-markets and enhance joint competitiveness; and (3) reduce the risk of becoming locked-in within similar knowledge basis in less-diverse networks. Although cognitive similarity between rivals provides an important basis upon which R&D alliances can be formed, some cognitive distance is arguably necessary to enable the creation of novel innovations through resource complementarities – thus providing scope for competing fabless chipmakers to cooperate with one another (Nooteboom et al., 2007; Gilsing et al., 2008). Moreover, the fabless model, owing to foundries' standardised fabrication technologies, provides flexibility through dynamic manufacturing capabilities which might be utilised into different product markets – as suggested by studies on dynamic capabilities (Teece et al., 1997; King and Tucci, 2001).

There are clear strategic benefits to be gained by chipmakers in the fabless segment by organising and governing joint R&D within integrated triads. While the development of mutual trust and commitment between rivals is arguably a long process, this triadic tactic can be utilised to establish an effective governance structure with reputational hostages to minimise the lure of opportunism, which arguably creates greater uncertainty when strategic partners share the same competitive goals (Hamel, 1991; Kogut, 1989). Consequently, integrated triads can help to avoid 'unfunctional' competitive conflicts and develop co-opetitive relations characterised with enhanced mutual cooperation and improved coordination of R&D tasks, to ensure the seamless integration of critical complementary semiconductor technologies, IPs and system components (Figure 4.7-a). Still, however, as there is no single chipmaker that dominates the fabless segment, there are also opportunities for fabless chipmakers to enhance their long-term market positions through the appropriation of relational rents and capabilities via co-opetitive triadic R&D alliances. Specifically, by allying with the technology and systems partners of a rival, who may (Figure 4.7-a) or may not (Figure 4.7-b) be a partner as well, fabless chipmakers can minimise the value of the relational rents appropriated by its rival as well as attempt to expand into new product markets.

By contrast, IDMs should be less likely to gain benefits from collaborating with their rivals. Namely, IDMs are the technological leaders within their concentrated markets and thus determine the pace of technological progress and, through their dominant market positions, largely define competition. Moreover, competing IDMs possess similar resource and knowledge bases as well as technological capabilities which are similarly advanced. Within this industry environment, IDMs consequently face relatively little uncertainty and scope for resource complementarity, which suggests that there is little strategic utility to be gained by IDMs from forming integrated triadic R&D alliances with their rivals. Similarly, as IDMs cannot sustain an efficient operation in small markets, there is likely also little strategic utility to be gained from mimicking rivals' partnering decisions by allying with common technology or end-industry partners (see Figure 4.7-c and Figure 4.7-d). Accordingly, when competing in technology and systems markets:

Hypothesis 4a	*Fabless chipmakers are more likely to form integrated triadic R&D alliances with other fabless chipmakers, than IDMs with other IDMs.*
Hypothesis 4b	*Fabless chipmakers are more likely to have common technology and systems partners than IDMs (both in triads and at a distance of two).*

4.4. Research methodology

4.4.1. Construction of the network sample and data collection

The analysis conducted in this chapter relied on the alliance dataset used in Chapter 3. For details on the sources and the method of collection of the data used in the current chapter, please see Section 3.6.

The current analysis was conducted on a network sample of 1,827 organisations, out of which 425 are chipmakers (38 IDMs and 387 fabless chipmakers), with a total of 4,559 intra- and cross-industry R&D alliance formations across the period 2004-2014[8]. To set up the investigation into R&D collaboration for this study, we utilise the network of R&D alliances formed by chipmakers with partners based in various industries and research sectors. We define an R&D alliance as an agreement between at least two organisations with the aim of conducting research and/or development of a fundamental semiconductor technology or a new chip design using existing or novel technologies and IPs. The network sample thus involves joint development agreements, licensing agreements, equity joint ventures, technology acquisitions and technology-related strategic investments. These types of strategic alliances form an integral part of the R&D strategies of chipmakers, and are thus considered in the light of chipmakers' triadic R&D alliance strategies.

Another advantage of such a rich network sample comprised of R&D alliances between chipmakers and various types of alliance partners is that it also allows creating specific sub-networks suitable for testing the individual hypotheses formulated in this study. Six sub-networks are created to reflect distinct R&D alliance tactics as captured in the hypotheses. This sub-network approach, as opposed to analysing overall networks, helps to investigate whether chipmakers may derive strategic utility from specific triadic R&D alliance tactics. The sub-networks, within which these collaborative interactions between chipmakers and their R&D partners are captured, are based on one-mode matrices in which the direction of resource flows is also captured; as the network dataset captures both relatively unilateral licensing and investment agreements as well as bilateral R&D alliances.

By creating sub-networks which are based on relevant triadic tactics and R&D alliance ties with specific partner types, it is possible to reduce the complexity of the network of interest and to more easily analyse whether and to what extend distinct R&D strategies are executed through the formation of specific triadic constructs within the sub-network. This follows a method of network construction utilised in other fields of research (e.g. Zhao et al., 2016; Hepburn, 2017). The specific definitions for each of the distinct sub-networks created in this study are provided together with the SAOM specifications in Section 4.4.3.

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[8] Data on the duration of R&D alliances, as indicated by dates of alliance termination, were unavailable to this study.

4.4.2. Network analysis method: the stochastic actor-oriented model (SAOM)

This study adopts stochastic actor-oriented modelling (Snijders, 1996, 2011) shortened for SAOM, as a method to examining the dynamic process of triadic R&D alliance formations. This method is advantageous over traditional regression techniques utilised by alliance researchers in a few ways. It is inherently based on the assumption that R&D alliance formations are not only driven by the pursuit for partner-specific assets, but also by the structure of the alliance network. Accordingly, it takes into account the interdependence that naturally exists in the formation of R&D alliances between pairs of organisations vis-à-vis the presence of other R&D ties (i.e. endogenous structural effects) as well as the characteristics of other organisations and distinctive attributes of dyadic and triadic alliance relations (i.e. exogenous structural effects) in the network.

Capturing these structural effects is especially important in the analysis of triadic R&D alliances, as the configuration of triadic alliance structures, in terms of closure and brokerage, may represent different R&D alliance strategies and determine the kinds of strategic benefits that organisations may gain. Traditional regression methods, however, are unable to capture these structural effects.

In contrast to traditional regression methods, the SAOM is an agent-based simulation model for network evolution (Ripley et al., 2019) which uses a different calculation mechanism, based on a combination of random utility models and continuous time Markov models (Van de Bunt and Groenewegen, 2007). This means that the SAOM can be used to test chipmakers' preference for forming integrated and protective triads with different combinations of distinct types of R&D alliance partners, as encompassed by the formulated hypotheses. These R&D alliance choices are modelled through simulation and are based on the core assumption that chipmakers select triadic structures and R&D partners from which they are expected to derive optimal strategic utility.

This model mechanism is defined by a *utility function* (also referred to as *objective function*), which is comparable with the linear predictor in generalised linear models, and which essentially expresses the probability that a chipmaker may change the structure (e.g. open vs closed triads) and composition (choice of partner type) of its network in a particular way (Snijders et al., 2010). In estimating the formation of integrated and protected triadic constructs, the utility function takes into account the current state of the chipmaker's R&D alliance network as defined by its current partners and their characteristics as well as the presence or absence of ties between its partners.

Accordingly, the utility function works with the assumption that the R&D alliance decisions of chipmakers, in light of the configuration of alliance relations within triads and the selection of strategic partners, can be explained by a linear combination of *effects*. This combination can be defined by tendencies towards particular structural network formations (structural effects), such as transitive closure or brokerage, but also by the attributes of organisations (ego covariates) or pairs of organisations (dyadic covariates):

$$f_i(\beta, x) = \sum_k \beta_k S_{ki}(x)$$

where $f_i(\beta, x)$ is the value of the utility function for chipmaker i depending on the state x of the R&D sub-network, $S_{ki}(x)$ are the effects, and β_k are the statistical parameters (Snijders et al., 2010). The parameters can be interpreted as the 'preference' for, or the 'attractiveness' of a network configuration for a chipmaker. The parameter value $\beta_k = 0$ indicates that the effect does not explain the formation of R&D alliance ties; $\beta_k > 0$ indicates a higher probability that chipmakers have a preference for an R&D alliance network with higher values of the corresponding effect; and $\beta_k < 0$ indicates the opposite.

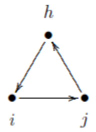
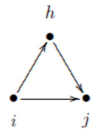
Although data on the duration of R&D alliances were not available to this study, the SAOM is capable of overcoming this limitation by allowing R&D alliances – once formed – to exist during the remainder of the sample period.

The hypotheses tested with the SAOMs are implemented using the program *SIENA* (Simulation Investigation for Empirical Network Analysis) in the statistical tool R, which has been developed and maintained by Ripley et al. (2019). The model specifications and construction of the distinct sub-networks for each hypothesis are presented in the next section.

4.4.3. SAOM and sub-network specifications

To test the hypotheses on the formation of distinct triadic constructs within the R&D alliance network, distinct sub-networks are first created in line with the alliance partner combinations specified in each of the hypotheses. Then, SAOMs are specified for each of the formulated hypotheses, which include different effects as reflected in the hypotheses, to test chipmakers' tendencies toward the formation of triadic R&D alliances vis-à-vis dyadic R&D alliances as well as their preferences for choosing specific types of partners when forming triadic R&D alliances. To capture these R&D alliance formation tendencies, several structural effects and ego and dyadic covariates are included in the models – i.e. observed variables (based on organisational characteristics) which we expect to explain the formation of triadic R&D alliances by chipmakers within distinct sub-networks. Specifications of the SAOMs and the included effects for each of the individual hypotheses are shown in Table 4.3.

Table 4.3: Specification of SAOMs for hypothesis testing and the interpretation of structural, ego and dyadic effects (source: Ripley et al., 2019)

Hypothesis	Effect	Formal expression	Interpretation
	Structural effect		
1a; 1b	3- cycles (*cycle3*)	$\sum_{j,h} x_{ij}x_{jh}x_{hi}$ 	Captures the number of three-cycles (regarded as generalised reciprocity), within a triplet of type $\{i \rightarrow j \rightarrow h \rightarrow i\}$.
2a	Transitive triplets (*transTrip*)	$\sum_{j,h} x_{ih}x_{ij}x_{jh}$ 	Captures number of transitive patterns in *i*'s relationships: where *i* has an alliance with the pair (*j*, *h*) who are also tied to each other. Triplets of type $\{i \rightarrow j \rightarrow h; i \rightarrow h\}$ and $\{i \rightarrow h \rightarrow j; i \rightarrow j\}$.
2b	Betweenness (*between*)	$\sum_{j,h} x_{hi}x_{ij}(1 - x_{hj})$	Effect captures the non-existence of alliance tie $h \rightarrow j$ in a triad with ties $h \rightarrow i$ and $i \rightarrow j$.
	Ego effect		
1b; 2a; 2b; 3a; 3b	*V*-ego (*egoX*)	$v_i x_{i+}$	*i*'s out-degree weighted by its covariate value (*V*).
	Dyadic effect		
4a	Same *V* (*sameX*)	$\sum_{j} x_{ij} l\{ v_i = v_j\}$	The number of alliance ties of *i* to all other actors *j* who have exactly the same covariate value (*V*).
4b	Indegree popularity from the same *V* (*sameXInPop*)	$\sum_j x_{ij} \sum_h x_{hj} I\{v_i = v_h\}$	Number of incoming ties received by those to whom *i* is tied and sent by others who have the same ego covariate value (*V*) as *i*.
	Controls effect		
1a; 1b; 2b; 3a	Reciprocity (*recip*)	$\sum_{j} x_{ij}x_{ji}$	Number of reciprocated ties between *i* and *j*.
2b; 3a	Out-degree (log) (*outRateLog*)	$\exp(\ln(\alpha_h(x_i + 1))) = (x_{i+} + 1)^{\alpha h}$	Log of out-degree effect $x_{i+} = \sum_j x_{ij}$ where x_{ij}= 1 indicates the presence of the tie $i \rightarrow j$.

Preference for the formation of triadic R&D alliances vis-à-vis dyadic R&D alliances, captured with the *3-cycles* and *transitive triplets* effects, is explicitly modelled only in hypotheses 1 and 2 because the sub-networks used for testing these hypotheses include both triadic and dyadic R&D alliances. It is important to note that both of these structural effects capture the tendency toward network closure through the formation of triads; however, they capture different directions of resource flows (see Table 4.3). The remaining hypotheses are tested on sub-networks composed of exclusively triadic R&D alliance structures, thus eliminating the need to include either of these triadic effects in the relevant models. Details on all distinct sub-networks, along with the model specifications for each of the hypotheses, are provided in Table 4.4.

Furthermore, with the goal of modelling the formation of distinct triadic constructs that chipmakers may use to achieve strategic utility from their collaborative R&D strategies, several important ego and dyadic covariates are included across the models. Ego effects were used to determine whether an organisation is an IDM (IDM-$egoX$) (hypotheses 1b, 2a, 2b, 4a, 4b) or a fabless chipmaker ($Fabless$-$egoX$) (hypotheses 1b, 2a, 2b, 3a, 3b, 4a, 4b), as well as whether at least one of the triadic partners to a fabless chipmaker is an IDM ($IDMPartner$-$egoX$) (hypothesis 3a) or a foundry ($FoundryPartner$-$egoX$) (hypotheses 3a and 3b). Dyadic effects are used to evaluate the preference of IDMs and fabless chipmakers to form triadic alliances with direct rivals on the basis of their integrated or fabless operating model (IDM-same$X$ and $Fabless$-same$X$) (hypothesis 4a), and to assess their preference for choosing the same partners as their direct rivals (IDM-same$XInPop$ and $Fabless$-same$XInPop$) (hypothesis 4b). Additionally, two-way structural-ego and ego-ego interactions between some of these effects are included [9].

The choice of control variables is also different from the traditional regression models, because of the focus of the study and the specification of SAOMs. The SAOMs specified will control for chipmaker types as a proxy of firm-level attributes, such as size, age and R&D intensity, which are conventionally used by scholars to analyse the formation of R&D alliances.

It is important to emphasise that the focus of the current study, however, is not on the choice of chipmakers to form or not to form R&D alliances, as all chipmakers in the sample do participate in R&D alliances. This study rather investigates the specific choice of chipmakers for distinct triadic tactics within the R&D alliance network, which are reflected by the configurations of their R&D alliance relations. The 'chipmaker type' proxy is relevant because the chipmaker's choice to configure its R&D alliance relations within integrated or protected triads, as opposed to dyads, ought to be determined by the specific needs of the

[9] Ripley et al. (2019) advise that the individual effects underlying an interaction effect do not need to be included in the same model as well.

Table 4.4: Overview of estimation equations and descriptions of associated sub-networks

Hypothesis	Estimation equation	Sub-network description
1a	$f_i(\beta, x) = \beta_1 cycle3_{ijh} + \beta_2 recip_{ij}$	**Sub-network of fundamental R&D alliances.** • *Focal*: chipmakers (IDM and fabless). • *Partners*: university/research centres; any other type. • *Ties*: both dyads and triads (read: only three-way alliance ties that are part of one and the same multi-partner alliance) in which at least one chipmaker and one university/research centre are participants, and the third partner could be of any type.
1b	$f_i(\beta, x) = \beta_1(cycle3_{ijh} * IDM\text{-}egoX_i) + \beta_2(cycle3_{ijh} * Fabless\text{-}egoX_i) + \beta_3 recip_{ij}$	
2a	$f_i(\beta, x) = \beta_1(transTrip_{ijh} * IDM\text{-}egoX_i) + \beta_2(transTrip_{ijh} * Fabless\text{-}egoX_i)$	**Sub-network of cross-industry R&D alliances between technology and end-markets**. • *Focal*: IDMs and fabless chipmakers. • *Partners*: TC and systems*. • *Ties*: both dyads and triads (of any type), formed between either IDMs-TC-systems or fabless-TC-systems. Ties between IDMs and fabless are not included.
2b	$f_i(\beta, x) = \beta_1(between_{ijh} * IDM\text{-}egoX_i) + \beta_2(between_{ijh} * Fabless\text{-}egoX_i) + \beta_3 recip_{ij} + \beta_4 outRateLog_i$	
3a	$f_i(\beta, x) = \beta_1 \left(Fabless\text{-}egoX_i * IDMPartner\text{-}egoX_i \right) + \beta_2 \left(Fabless\text{-}egoX_i * FoundryPartner\text{-}egoX_i \right) + \beta_3 recip_{ij} + \beta_4 outRateLog_i$	**Sub-network of market-driven cross-industry R&D alliances.** • *Focal*: fabless chipmakers. • *Partners*: TC, systems, IDMs and foundries. • *Ties*: triads only (of any type), formed between a fabless chipmaker and either a TC or systems partner plus either an IDM or foundry partner.
3b	$f_i(\beta, x) = \beta_1(Fabless\text{-}egoX_i * FoundryPartner\text{-}egoX_i)$	**Sub-network of cross-industry and manufacturing bridges.** • *Focal*: fabless chipmakers. • *Partners*: TC, systems, foundries and any other. • *Ties*: triads only (of any type), formed between a fabless chipmaker and either a foundry or TC/systems plus a third partner of any other type.
4a	$f_i(\beta, x) = \beta_1 IDM\text{-}sameX_{ij} + \beta_2 Fabless\text{-}sameX_{ij}$	**Sub-network of co-opetitive cross-industry R&D alliances** • *Focal*: IDMs and fabless chipmakers. • *Partners*: TC and systems. • *Ties*: triads only (of any type), formed between either two rival IDMs and a third TC or systems partner, or two rival fabless chipmakers and a third TC or systems partner.
4b	$f_i(\beta, x) = \beta_1 IDM\text{-}sameXInPop_{ijh} + \beta_2 Fabless\text{-}sameXInPop_{ijh}$	**Sub-network of common alliance ties among rivals.** • *Focal*: IDMs and fabless chipmakers. • *Partners*: TC and systems. • *Ties*: only those dyadic ties between either an IDM or fabless chipmaker and a TC or systems partner which are part of triads between either rival IDMs or rival fabless chipmakers (see direct competitor sub-network).

'TC' is short for 'technological complementor' and 'systems' for 'systems partners'

operating model based on which it conducts business, namely either the IDM or fabless operating model; rather than direct effects of company-level attributes, as conventionally used with traditional regression models, to test the initial decision of companies to form alliances at all. Moreover, the methodology underlying the SAOM does not require conventional company-level attributes to estimate the effects of network closure and brokerage within triadic alliance configurations.

Importantly, the chipmaker types do function as a proxies for the size, age and R&D intensity of chipmakers, because IDMs can only be successfully operated by large, well-established companies with extensive financial resources, owing to the substantial financial constraints inherent to the IDM model; and smaller and younger organisations are therefore only able to efficiently sustain a fabless operation which is inherently centred on inter-organisational collaboration. In addition, a few structural control effects are included in several models to control for skewed out-degree distributions of chipmakers ($outRateLog$) as well as chipmakers' tendency to reciprocate the formation of R&D alliance ties ($recip$) – as advised by Ripley et al. (2019).

4.5. Network analysis results

4.5.1. Patterns of triadic R&D alliance formations across distinct sub-networks

The six sub-networks used to test the hypotheses are visualised in Table 4.5 on the next pages. The network graphs and descriptive statistics are based on alliance formation data recorded across the 2004-2014 sample period. Each network represents an aggregation of a different type of R&D strategy pursued by the chipmakers within it, in response to different kinds of industry pressures, as reflected by the different compositions of strategic partners as well as the presence or absence of alliance ties between them. The alliance ties depict the flows of technical knowledge, know-how and technology between chipmakers and their R&D partners. Important descriptive statistics related to each sub-network and relevant to the corresponding hypothesis are provided next to the network graphs.

Table 4.5 also provides lists of the top 10 chipmakers within the sub-network based on the number of triad memberships, along with their degree and betweenness centralities – as an important indication of chipmakers' R&D network strategy and their potentially privileged access to critical knowledge and information flowing through their sub-network.

The sub-networks are non-valued, which means that any alliance tie between any two organisations is counted only once. As such, the sub-network statistics are based on the presence of a single alliance *relationship* between a given pair of organisations as opposed to potential multiplex alliance *relations*. In the tables, the counts of *R&D dyads* refer to those alliance relationships that may or may not be a part of a triadic alliance structure. Where relevant, a distinction is made between *overall* counts of R&D dyads within the entire sub-network and R&D dyads which are not part of any triadic R&D alliance at all, such as in Table 4.5-a.

R&D triads measure the number of *closed* triads which are formed by the organisations within a given sub-network and is not a measure of closed triad memberships from an organisation's perspective. For example, for an R&D triad formed by two IDMs and one technological complementor, one triadic R&D alliance is counted; not the sum of two triad memberships accounted for by IDMs and one by a technological complementor. The tendency of chipmakers to form these triads can be indicated by the degree of transitivity, which is measured as the proportion of actual closed triads against the number of triads (i.e. structural groups of three organisations) in the network that could potentially be closed (i.e. where all three organisations are connected to one another through a three-way alliance).

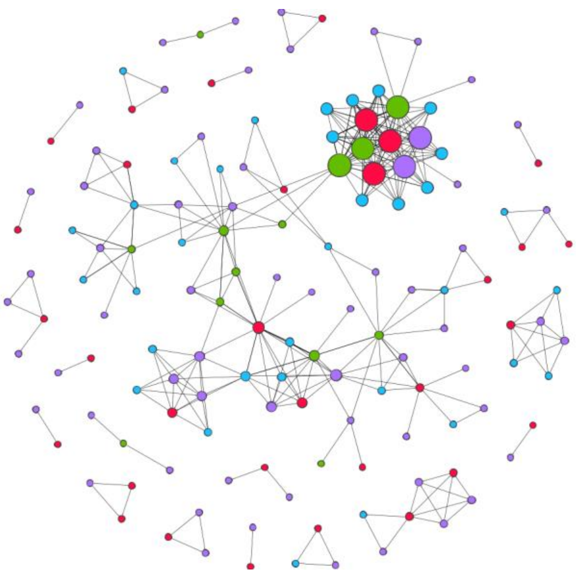
The descriptive results reveal that, across the distinct sub-networks, chipmakers exhibit a general tendency towards forming triadic R&D alliances. These results will be discussed in turn in relation to each sub-network and hypothesis.

The visualisation and descriptive statistics of the sub-network for hypothesis 1a and 1b (Table 4.5-a) show that chipmakers in general seem to have a preference for executing their fundamental R&D strategy through triadic R&D alliances with partner universities and research centres (76%), as opposed to dyadic R&D alliances (24%). This preference seems to be particularly pronounced for IDMs in comparison to fabless chipmakers, as 81% of R&D ties with universities and research centres are formed by IDMs within triads, versus 73% in the case of fabless chipmakers. These statistics suggest that triadic R&D alliances might provide an efficient governance mechanism which is especially beneficial to the fundamental R&D strategies pursued by IDMs.

The sub-network created to test hypothesis 2a and 2b (Table 4.5-c) is at the core of semiconductor innovation and is of particular interest due the growing challenge for chipmakers to integrate the development and commercialisation of new chip technologies. The presence of a total of 193 triads in this sub-network suggests that chipmakers might pursue the benefits of enhanced coordination and cooperation provided by the triadic governance mechanism to achieve this. The cross-industry R&D strategies pursued by fabless chipmakers display a relatively greater degree of transitivity (2.7%) in comparison to IDMs (2.4%). This suggests that although on average IDMs do participate in a greater absolute number of triadic R&D alliances, proportionally speaking fabless chipmakers exhibit a relatively greater tendency to form triadic R&D alliances with their existing technology and systems partners. The descriptive statistics further show that IDMs seem to

Table 4.5: Descriptive statistics for sub-networks using data for 2004-2014 (Note: 'TC' is short for 'technological

Sub-network of fundamental R&D alliances (*hypotheses 1a & 1b*)



Node size based on the firm's number of triad memberships
Node colour: Fabless; IDM; University/Research centre; Other

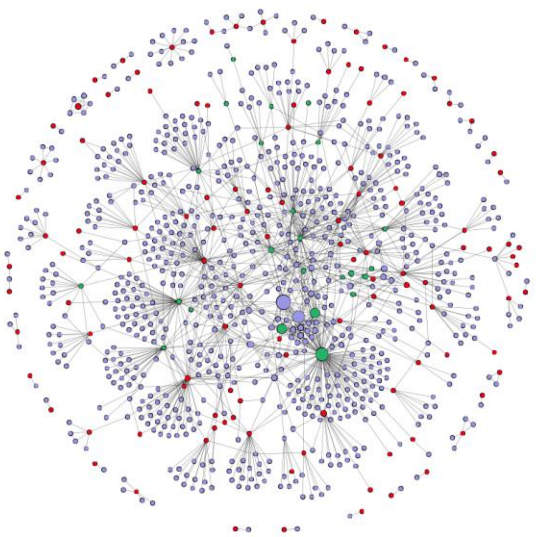
(a)

	Focal	*Partners*		*R&D dyads*				*R&D triads*	
				Overall		*Outside of triads*			
	Chip.	**Uni/ Res.**	**Other**	**Total**	**(a) Uni/Res.**	**(b) Uni/Res.**	**(b/a) %**	**Total**	**Avg per chip.**
Fabless	32	47	28	126	60	16	27%	117	3.7
IDM	13	24	22	132	37	7	19%	108	8.3
Chipmaker	*45*	*63*	*34*	*258*	*97*	*23*	*24%*	*225*	*5.0*
Overall	45	63	34	341	204	23	11%	456	10.1

(b)

Chipmaker name	**No. of triads**	**Degree centrality**	**Betweenness centrality**
Freescale Semiconductor (IDM)	87	26	1,205
Analog Devices (IDM)	85	26	238
Texas Instruments (IDM)	84	23	5
Xilinx (fabless)	84	24	84
Nvidia (fabless)	84	23	5
XMOS (fabless)	84	16	5
AMD (fabless)	26	19	1,578
STMicroelectronics (IDM)	20	14	567
Dolphin Integration (fabless)	18	7	2
IBM (IDM)	16	14	1,712

Sub-network of cross-industry alliances (*hypotheses 2a & 2b*)



Node size based on the firm's number of triad memberships
Node colour: Fabless; IDM; Tech. Compl./Systems

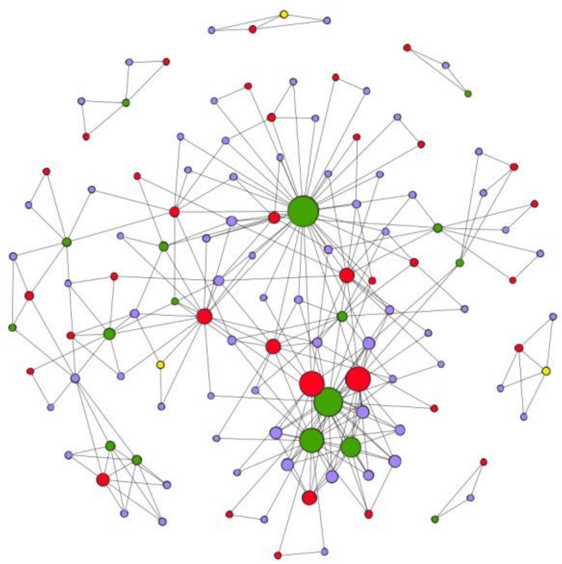
(c)

	Focal	*Partners*		*R&D dyads*	*R&D triads*		**Transitivity**
	Chip.	**TC**	**Systems**	**Total**	**Total**	**Avg per chip.**	
Fabless	116	276	263	668	16	0.1	2.7%
IDM	24	183	186	523	48	2.1	2.4%
Overall	140	410	421	1,312	193	1.4	2.5%

(d)

Chip maker name	**No. of triads**	**Degree centrality**	**Betweenness centrality**
Intel (IDM)	48	124	117,412
Samsung Electronics (IDM)	31	29	7,525
IBM (IDM)	30	23	6,452
AMD (fabless)	7	48	37,831
Renesas Electronics (IDM)	7	31	24,967
Mellanox Technologies (fabless)	7	19	11,525
Sanken Electric (fabless)	6	7	1,784
Toshiba Corporation (IDM)	6	10	3,620
Hitachi (IDM)	6	6	418
Siteco (fabless)	6	5	1

Sub-network of market-driven cross-industry R&D alliances (*hypothesis 3a*)



Node size based on the firm's number of triad memberships
Node colour: Fabless; IDM; Foundry; Tech. Compl./Systems

(e)

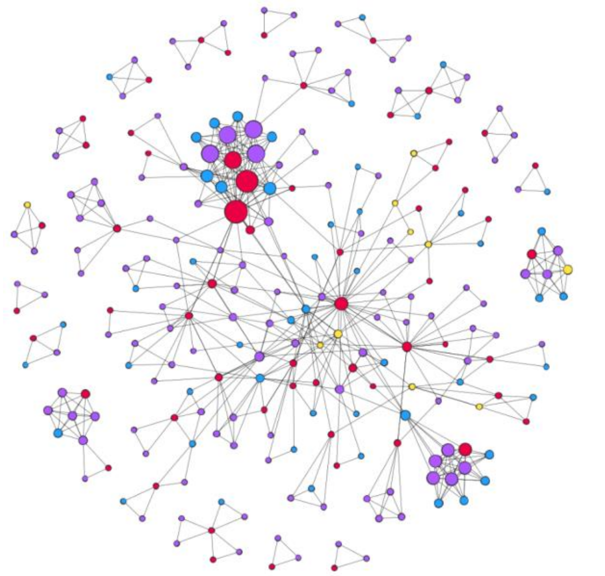
	Focal	*Partners*				*R&D dyads*			*R&D triads*		
	Chip.	**TC**	**Sys.**	**Fndry**	**IDM**	**Total**	**Fndry**	**IDM**	**Total**	**Fndry**	**IDM**
Fabless	35	39	31	3	17	170	3	61	174	7	167
Overall	35	39	31	3	17	280	10	164	174	7	167

(f)

Chipmaker name	**No. of triads**	**Degree centrality**	**Betweenness centrality**
Intel (IDM)	37	38	2,950
Freescale Semiconductor (IDM)	34	25	789
Xilinx (fabless)	28	14	404
Nvidia (fabless)	28	15	332
Texas Instruments (IDM)	27	20	446
Analog Devices (IDM)	21	12	18
AMD (fabless)	14	15	851
Broadcom Corp (fabless)	13	14	435
Marvell Technology Group (fabless)	13	12	450
XMOS (fabless)	12	7	6

Table 4.5 continued

Sub-network of cross-industry and manufacturing bridges (*hypothesis 3b*)



Node size based on the firm's number of triad memberships
Node colour: Fabless; Foundry; Tech. Compl./Systems; Others

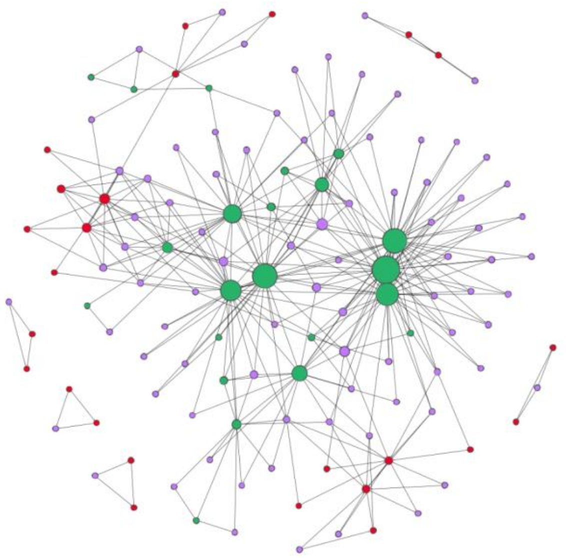
(g)

	Focal	*Partners*				*R&D dyads*	*R&D triads*		
	Chip.	**TC**	**Sys.**	**Fndry**	**Other**	**Total**	**Total**	**Fndry**	**%**
Fabless	59	60	66	10	51	327	526	32	6%
Overall	59	60	66	10	51	576	620	55	11%

(h)

Fabless chipmaker name	**No. of triads**	**Degree centrality**	**Betweenness centrality**
Nvidia	84	30	3,356
Xilinx	80	20	913
XMOS	57	13	12
AMD	37	31	6,770
Siteco	35	10	108
Broadcom Corp	20	23	2,567
Dynex Power	18	7	1
Mellanox Technologies	15	15	1,782
Sanken Electric	15	6	0
Aptina Imaging Corporation	15	7	109

Sub-network of co-opetitive cross-industry R&D alliances (*hypothesis 4a*)



Node size based on the firm's number of triad memberships
Node colour: Fabless; IDM; Tech. Compl./Systems

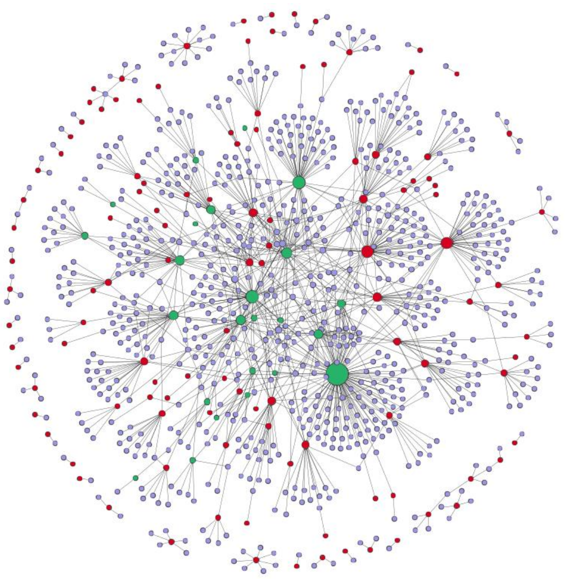
(i)

	Focal	*Partners*		*R&D dyads*			*R&D triads*	
	Chip.	**TC**	**Systems**	**Total**	**To rivals**	**%**	**Total**	**Avg per chip.**
Fab - Fab	25	19	9	83	20	24%	42	1.7
IDM - IDM	22	32	38	255	51	20%	261	11.9
Overall	47	41	42	338	71	21%	303	6.4

(j)

Chipmaker name	**No. of triads**	**Degree centrality**	**Betweenness centrality**
Intel (IDM)	86	45	1,695
Renesas Electronics (IDM)	74	30	914
Samsung Electronics (IDM)	74	35	816
IBM (IDM)	67	29	636
Freescale Semiconductor (IDM)	59	29	1,084
Texas Instruments (IDM)	49	28	1,233
STMicroelectronics (IDM)	39	19	499
Toshiba Corporation (IDM)	32	15	382
Analog Devices (IDM)	20	11	22
Nvidia (fabless)	18	16	763

Sub-network of common ties among rivals (*hypothesis 4b*)



Node size based on the firm's degree centrality
Node colour: Fabless; IDM; Tech. Compl./Systems

(k)

	Focal	*Partners (overall)*		*(a) Common partners*		*(b) Dyads to common*		*(b/a) Avg dyads per common*		**Total R&D dyads**
	Chip.	**TC**	**Sys**	**TC**	**Sys**	**TC**	**Sys**	**TC**	**Sys**	
Fabless	116	276	263	5	36	119	89	23.8	2.5	668
IDM	24	183	186	40	43	100	137	2.5	3.2	523
Overall	140	403	406	93	82	272	285	2.9	3.5	1,191

(l)

Chipmaker name	**Degree centrality**	**Betweenness centrality**
Intel (IDM)	124	116,900
Freescale Semiconductor (IDM)	55	51,284
STMicroelectronics (IDM)	54	45,872
Broadcom Corp (fabless)	52	40,355
AMD (fabless)	48	38,477
Texas Instruments (IDM)	40	29,267
NXP Semiconductors (IDM)	33	30,495
Renesas Electronics (IDM)	31	25,111
Atmel (IDM)	30	24,053
Marvell Technology Group (fabless)	30	19,930

exhibit a tendency to broker structural holes between disconnected industries within the sub-network, as indicated by their relatively high degrees of betweenness centrality (Table 4.5-d).

The descriptive statistics and sub-network visualisation of the sub-network for hypothesis 3a (Table 4.5-e) also highlights the central role of IDMs as brokers and mediators in triadic R&D alliances between fabless chipmakers and their technology and systems partners. Accordingly, triadic cross-industry R&D alliance strategies are not limited to choices of partners based exclusively in different industries. For example, fabless chipmakers may cooperate with (potentially competing) IDMs on cross-industry R&D projects or intensify their partnerships with foundries by involving them in cross-industry R&D alliances. The descriptive statistics highlight that the former is more prevalent (167 R&D triads with IDMs) than the latter (7 R&D triads with foundries), however, according to the descriptive statistics. The preference of IDMs for brokerage tactics is visible from their higher degrees of betweenness centrality (Table 4.5-f), which might indicate that partnering with IDMs resembles a relatively optimal route to accessing complementary technologies or new product markets; and governing this relationship using triadic structures might safeguard the fabless chipmaker against opportunism and enhance cooperation.

Also within a wider sub-network of cross-industry triads, used for testing hypothesis 3b, the involvement of foundries in triads with fabless chipmakers is limited to only 6% of all triadic R&D alliances formed by fabless chipmakers (Table 4.5-g) – thus highlighting a preference by fabless chipmakers to conduct R&D with cross-industry partners within triadic alliances independently from their manufacturing partners.

Furthermore, the descriptive results and sub-network visualisation of the sub-network for hypothesis 4a (Table 4.5-i) also show patterns in the potential competitive use of triadic cross-industry R&D alliances by chipmakers. With 24% of all dyadic R&D alliances formed by fabless chipmakers being to direct rivals, fabless chipmakers – in contrast to IDMs (20%) – appear to have a relatively greater tendency to collaborate with their direct rivals alongside cross-industry partners in triadic cross-industry R&D alliances.

This pattern holds also true in the sub-network created for hypothesis 4b (Table 4.5-k), based on R&D alliances between chipmakers and the partners of their rivals – regardless of whether a direct R&D alliance tie between the rivals exists as well. Between IDMs and fabless chipmakers, there are considerably more fabless chipmakers that form R&D alliances with one and the same technological complementor – 23.8 fabless chipmakers on average. In contrast, on average there are only 2.5 IDMs per common technological complementor. This difference is much less pronounced in relation to common systems partners, in which case there are – on average – actually more IDMs (3.2) than fabless chipmakers (2.5) per common systems partner. Overall, these descriptive results highlight the importance of triadic configurations to R&D collaborations between rival chipmakers.

4.5.2. *Stochastic actor-oriented model results*

The results obtained from the eight SAOMs are presented in Table 4.6. Each model output is focused on a single hypothesis as testing the formulated hypotheses required running the models on distinct sub-networks. Reported in Table 4.6 are only the final models with all structural effects and dyadic and ego covariates added simultaneously. However, robustness checks were performed for each structural, dyadic and ego effect by including these individually in the models. The additional effects improved model fit and were therefore included in the final models.

Table 4.6: Estimated parameters and significance levels for final models

Model	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Hypothesis	**H.1a**	**H.1b**	**H.2a**	**H.2b**	**H.3a**	**H.3b**	**H.4a**	**H.4b**
Utility function								
3-cycles	1.00** (0.46)							
IDM ego * 3-cycles		2221.67*** (434.24)						
Fabless ego * 3-cycles		384.70*** (3.73)						
IDM ego * transitive triplets			1.19 (1.06)					
Fabless ego * transitive triplets			1.77*** (0.44)					
IDM ego * betweenness				74.71 (-7019.02)				
Fabless ego * betweenness				-268.66 (-6988.45)				
Fabless ego * partner (IDM) ego					28.44** (13.37)			
Fabless ego * partner (Foundry) ego					-29.15*** (11.58)	-6.46*** (1.53)		
Same chipmaker (IDM)							-1.06*** (0.14)	
Same chipmaker (Fabless)							0.74*** (0.22)	
Indegree popularity from same IDM								0.03 (0.04)
Indegree popularity from same Fabless								0.10*** (0.04)
Control effects								
Out-degree (log)	Excl.	Excl.	Excl.	Incl.	Incl.	Excl.	Excl.	Excl.
Reciprocity	Incl.	Incl.	Excl.	Incl.	Incl.	Excl.	Excl.	Excl.
Overall maximum convergence ratio	0.17	5.92	0.12	3.66	2.95	0.08	0.14	0.07
Sub-network characteristics								
Number of organisations	159		971		125	217	130	949
Number of alliance ties	326		1,312		280	492	338	1,191
Number of integrated triads	473		193		174	508	303	0

*Main entries represent estimated coefficients (standard errors are shown between brackets). Convergence ratio is a measure of model fit (<0.25 indicates a good fit). Significance indicated as * p<0.10; ** p<0.05; *** p<0.01.*

The control effects $out\text{-}degree$ (log) and $reciprocity$ were not included in the final models 3, 6, 7 and 8, as robustness checks did not indicate an improvement in explanatory power. Overall, no effects were dropped from the models and any insignificant effects were retained as they were of primary interest to the hypothesis tests.

Model fit is indicated by good convergence of the estimation algorithm and measured by the overall maximum convergence ratio reported in Table 4.6. The convergence ratio is calculated as a t-ratio by dividing the average deviation of the simulated values from the observed values by their standard deviation, and should be less than 0.25 as advised by Ripley et al. (2019). Good convergence was obtained for models 1, 3, 6, 7 and 8, with t-ratios of less than 0.25.

To confirm the statistical significance of the structural, dyadic and ego effects, one-sided p-values are used as the hypotheses were tested for either positive or negative relationships. The parameters of all models were tested by referring the t-ratios ($\frac{estimate}{standard\ error}$) of all modelled effects to a standard normal distribution, in line with Snijders et al. (2010).

The results obtained from the model estimations provide statistically significant support for hypotheses 1a, 2a, 3b, 4a and 4b; leaving hypotheses 2b and 3a unsupported. Model 2 also returns significant estimates, for hypothesis 1b; however, the convergence ratio is 5.92, which is greater than the benchmark of 0.25 for good model convergence. As indicated by statistically significant $3\text{-}cycles$ effect (t = 1.00/0.46 = 2.17, one-sided p < 0.05), chipmakers have a preference for conducting fundamental R&D through triadic alliances (*H.1a*), suggesting that triads, in contrast to dyads, may provide a more efficient and effective governance structure to reduce the risk of engaging in increasingly more costly and complex R&D projects. As for hypothesis 1b, the results indicate that the probability that IDMs will engage in triadic fundamental R&D alliances is indicated to be higher than that for fabless chipmakers, by the $IDM\ ego * 3\text{-}cycles$ interaction (t = 2,2221.67/434.24 = 5.12, one-sided p < 0.01) and the $Fabless\ ego * 3\text{-}cycles$ interaction effects (t = 384.70/3.73 = 103.14, one-sided p < 0.01), respectively.

Model 3 provides support for hypothesis 2a, as indicated by the significant $Fabless\ ego * transitive\ triplets$ interaction effect (t = 1.77/0.44 = 4.02, one-sided p < 0.001) and the insignificant $IDM\ ego * transitive\ triplets$ interaction effect (t = 1.19/1.06 = 1.12, one-sided p > 0.10). This suggests that fabless chipmakers, in contrast to IDMs, have a relatively greater preference for forming cross-industry R&D triads by bridging the disconnectedness between technological complementors and systems companies in end-industries. Results obtained for the hypothesis ($H.2b$) indicating that IDMs are more likely than fabless chipmakers to broker the disconnectedness between these cross-industry partners are not supportive due to statistical insignificance of the $Fabless\ ego * betweenness$ (t = 74.71/-7,019.02 = -0.01, one-sided p > 0.10) and $IDM\ ego * betweenness$ effects (t = -268.66/-6,988.45 = 0.04, one-sided p >

0.10), with a convergence ratio of 3.66; which is above the benchmark of 0.25 for good model convergence. The statistical insignificance of both interaction effects is an unexpected yet interesting result in itself as brokerage has commonly been underscored and found in past research to be an important network tactic for collaborative R&D (e.g., Ahuja, 2000; Rowley et al., 2000; Zaheer and Bell, 2005; Shiri et al., 2014). In spite of the statistical insignificance, however, the obtained estimates do suggest a positive preference for brokerage for IDMs and a negative preference for fabless chipmakers.

The results reported under Model 5 are not supportive of the hypothesised (*H.3a*) greater preference of fabless chipmakers to form triadic R&D alliances with foundry partners than with IDMs, alongside either a technology complementor or systems partner. This is indicated by the significant and negative $Fabless\ ego * partner\ (Foundry)\ ego$ effect (t = -29.15/11.58 = -2.52, one-sided p < 0.01) and the significant and positive $Fabless\ ego * partner\ (IDM)\ ego$ (t = 28.44/13.37 = 2.13, one-sided p < 0.05). Moreover, the convergence ratio of 2.95 indicates poor model convergence, as it is above the benchmark of 0.25 for good convergence. The results do, nevertheless, provide an indication that, together with either a technology complementor or systems partner, fabless chipmakers are more likely to form a triadic R&D alliance with IDMs than with foundries. s

Results under Model 6, however, are supportive of the hypothesis (*H.3b*) that fabless chipmakers are more likely to form cross-industry triadic R&D alliances without the involvement of a foundry partner than with a foundry partner – as indicated by a significant and negative $Fabless\ ego * partner\ (Foundry)\ ego$ effect (t = -6.46/1.53 = -4.22, one-sided p < 0.01).

Model 7 provides statistically significant evidence for the hypothesis (*H.4a*) that fabless chipmakers are more likely than IDMs to form triadic R&D alliances with direct rivals within their respective semiconductor industry segments – as indicated by the positive $Same\ chipmaker\ (Fabless)$ effect (t = 0.74/0.22 = 3.36, one-sided p < 0.01) and the negative $Same\ chipmaker\ (IDM)$ effect (t = -1.06/0.14 = -7.57, one-sided p < 0.01). Finally, as hypothesised (*H.4b*) and indicated by the results under Model 8, fabless chipmakers are also more likely than IDMs to form R&D alliances – both within triads and at a distance of 2 – with the partners of their rivals within their respective industry segments. This is indicated by statistically significant and positive $Indegree\ popularity\ from\ same\ Fabless$ effect (t = 0.10/0.04 = 2.5, one-sided p < 0.01) in comparison to the insignificant $Indegree\ popularity\ from\ same\ IDM$ effect (t = 0.03/0.04 = 0.75, one-sided p > 0.10).

Overall, the obtained estimation results indicate that chipmakers – fabless chipmakers in particular – do exhibit a preference for forming triadic vis-à-vis dyadic R&D alliances across distinct sub-networks, in pursuit of achieving various strategic benefits and goals in the face of several industry pressures. Strategic interpretations and discussions of the results are provided in the next section.

4.6. Discussion of findings

The outcome of this study confirms that chipmakers utilise distinct triadic tactics in pursuit of their R&D alliance strategies, which may relate to maximising the R&D outcomes of their strategic alliances in the face of industry pressures. Accordingly, we maintain that the maximisation of the strategic utility of R&D alliances is not only driven by the selection of strategic partners to gain access to short-term partner-specific benefits, as traditionally suggested by strategy scholars, but importantly also by the configuration of the R&D alliance relations with these partners within the chipmaker's ego network.

Overall, the findings suggest that by strategically organising their joint R&D activities within distinct triads, chipmakers may accumulate network benefits beyond the strategic benefits achievable within dyads. Notably, these include (1) bridging sectors for fundamental research, complementary technologies and end-industries to capitalise on cross-partner resource complementarities; (2) developing mutual trust and cooperation among R&D partners to enhance cross-industry R&D collaboration and knowledge exchanges, or controlling the process of (re)combining complementary resources and new knowledge by brokering cross-industry linkages; and (3) mitigating competitive conflicts and developing co-opetitive relations to collaborate with rivals. Triads can therefore help chipmakers to create more efficient and effective responses to the risks associated with the increasing cost of R&D as well as the uncertainties associated with the rapid technological advancements and updates in technology sectors, the successful commercialisation of new chip technologies in end-markets, and the intense competition for access to complementary technologies and end-markets.

The first interesting finding shows that chipmakers evidently utilise distinct triadic tactics for their R&D alliances, which indicates that the concept of R&D alliances is not uniform in nature, but may in fact relate to diverse alliance strategies pursued by companies. Chipmakers, namely, utilise triadic tactics to achieve distinct R&D objectives in view of conducting fundamental R&D, (re)combining technologies through cross-industry linkages between partners within and outside the core semiconductor industry, and joining the development and commercialisation processes of new chip technologies – which lead to the creation of various triadic *constructs*.

Chipmakers thus develop network strategies which might mitigate external risks and uncertainties through *inclusivity* via the integration of R&D alliance relations or through *protection* via network brokerage. Integrated triads enable chipmakers to create an open innovation environment based on mutual trust and close cooperation, while protective triads enable them to gain control over the process of developing and commercialising new chip innovations by brokering the flows of knowledge and resources between distinct technological sectors and end-markets. Importantly, the findings suggest that the strategic utility that inclusive triadic R&D alliances may yield is not valued equally by IDMs and fabless chipmakers, because their inherently distinct operating models induce different perceptions of environmental uncertainties and thus require different network benefits to operate competitively.

The first set of findings reveal different tendencies in the use of triadic tactics for fundamental R&D by IDMs and fabless chipmakers. Specifically, we find that IDMs exhibit a relatively greater preference for organising fundamental R&D within triadic alliance structures than fabless chipmakers, as indicated by a larger positive $IDM\ ego * 3\text{-}cycles$ effect (*H.1b*). IDMs, owing to their capital intensive operating model, experience greater pressure to offset the risks associated with the growing cost of R&D and the uncertainty inherent in conducting fundamental R&D with faster commercialisation. By contrast, the 'openness' of IDMs' network strategies is not equally evident across distinct sub-networks of cross-industry R&D collaboration. The significance level and larger estimate for the formation of triads (*H.2a*) indicate that fabless chipmakers – not IDMs – tend to utilise triadic R&D alliances as mechanisms for establishing cross-industry bridges between technological complementors and systems companies based in adjacent technological industries.

As such, the second set of findings reveal that fabless chipmakers, being the less hierarchical companies disadvantaged by larger resource constraints, are prompted to develop and utilise more effective networking strategies enabling them to encourage cooperation and knowledge exchange between partners from distinct sectors and end-markets in the face of increasing technological complexity and changing demand for the development of application-specific and often customised system-level chips. Specifically, fabless chipmakers seem to derive strategic utility from triadic R&D alliance strategies as they (1) provide a platform that enables capitalising on cross-industry resource complementarities between multiple partners, while simultaneously (2) creating an efficient governance structure based on mutual trust and cooperation which reduces the lure of opportunism and facilitates bridging any cognitive distance that might exist between R&D partners through the coordinated exchange of knowledge and division of tasks. Consequently, specialised fabless chipmakers pursue what we might consider a 'true' open innovation strategy based on inclusivity rather than protection; whereby integrated triads enable, by inducing mutual trust and commitment among R&D partners, effectively governing the open exchange of information and knowledge critical to the efficient and rapid joint integration of complementary technologies and IPs within systems.

By contrast, we find that IDMs implement an opposite triadic tactic, namely by brokering the linkages between R&D partners based in distinct technology sectors and end-market.

This is indicated by the positive vis-à-vis negative $betweenness\ effect$ ($H.2b$) for IDMs and fabless chipmakers, respectively; which suggests that IDMs utilise triadic tactics as a means of protecting exclusive access to key technologies, IPs and non-redundant knowledge, as well as maintaining control over the process of (re)combining complementary technologies and integrating new chip innovations within market-specific systems.

Importantly, however, the statistical insignificance of this result must be re-emphasised because on the surface this result seems to be at odds with common research results, namely that brokerage is a critical network tactic for R&D collaboration as it enables firms to diversify their partner portfolio and gain access to strategically critical non-redundant resources (e.g., McEvily and Zaheer, 1999; Rowley et al., 2000; Zaheer and Bell, 2005; Shiri et al., 2014), particularly in cross-industry collaboration (Hargadon and Sutton, 1997). The statistically insignificant role of brokerage for both IDMs and fabless chipmakers, however, suggests that in the context of the semiconductor industry the benefits of mutual trust, cooperation, the open exchange of knowledge, transaction cost efficiency and reduced opportunism attainable through integrated triadic tactics might be considered relatively more important than the disadvantage of having a lower degree of access to diverse knowledge, expertise and technological assets. This is consistent with the findings of Ahuja (2000) and Schilling and Phelps (2007), namely that a large presence of structural holes in the firm's network has a negative influence on its innovative output, and that integrated and protective triadic tactics may complement each other.

Nevertheless, IDMs might utilise triadic tactics to establish themselves as lead firms in R&D collaborations. This finding can also be derived from the network visualisations (see Table 4.5), which suggests that, across the distinct sub-networks, IDMs systematically utilise brokerage tactics to secure comparatively monopolistic positions within the wider industry network. This enables IDMs to act as a gatekeeper to specialised knowledge, complementary technologies and IP not just within their own ego networks, but within the entire industry network. This reflects a network strategy predicated on exclusionary triadic tactics, rather than on inclusivity, which provides IDMs with a *power* advantage (see Chapter 3.5.3.) over (potential) rivals, which they can leverage to protect their technological leadership and dominance in their respective product markets through exclusive access to information on new technological advancements made in distinct technology sectors as well as to downstream revenues.

The triadic cross-industry alliance strategies of fabless chipmakers might also extend into adjacent segments within the semiconductor industry. Interestingly, the negative $Fabless\ ego * partner\ (Foundry)\ ego$ effect indicates that fabless chipmakers do not derive strategic utility from using triads to govern the coordination between cross-industry chip development and manufacturing by foundries. By contrast, the $Fabless\ ego * partner\ (IDM)\ ego$ effect suggests that fabless chipmakers and IDMs may mutually derive strategic utility from forming triadic R&D alliances with a common technology complementor or systems partner.

We would argue that, in this case, triadic R&D alliances constitute a mutually beneficial network strategy that enables the IDM primarily to leverage the complementary capabilities and technologies of a specialised fabless chipmaker in order to reinforce its technological leadership and reduce the risk of technological lock-in, and the fabless chipmaker to leverage the IDM's dominant market position to expand into a new product market. Concurrently, the presence of a common technology complementor or systems partner may either signify a joint attempt at driving innovation and market reach or an attempt at blocking value appropriation by the other chipmaker by imitating its partnering move.

The third set of findings reveal that IDMs and fabless chipmakers utilise different co-opetitive alliance tactics for R&D. This contrast is revealed both by the visualisation of the sub-network of co-opetitive R&D alliances (see Table 4.5) and the obtained model results (see Table 4.6). Specifically, we find that while IDMs do collaborate with one another across technology and end-markets within triadic R&D alliances, the negative $Same\ chipmaker\ (IDM)$ effect and the positive $Same\ chipmaker\ (Fabless)$ effect indicate that they do so to a lesser extent than fabless chipmakers. IDMs, namely, develop co-opetitive relations with rivals with whom they have a cooperative history, reflecting the utilisation of integrated triadic tactics to develop deep co-opetitive relations while sharing access to specialised knowledge, technologies and IPs within small groups. Fabless chipmakers, by contrast, utilise triadic tactics to establish co-opetitive relations with more diverse portfolio of rivals; which reflects a co-opetitive strategy with a greater focus on driving open innovation spanning across a wider range of fields of knowledge and product-markets.

Overall, important conclusions can be drawn from these findings, with implications for both theory building, future research and managerial decision-making. This will be the topic of discussion in the next section.

4.7. Conclusions and implications

With the introduction of strategic utility of triadic R&D alliances as a two-fold framework predicated on (1) partner selection and (2) the configuration of alliance relations, this industry study makes important contributions which are applicable to research on partner selection and alliance formations.

First and foremost, this study demonstrates that to adequately understand the essence of alliance strategies in R&D networks, it is essential to combine strategic and network analysis approaches within a single analytical framework. The field of strategy, namely, does not offer tools to capture and disentangle the influence of the interdependence of the firm vis-à-vis other organisations within the industry network on the formation of R&D alliances. This is important, however, because the firm's alliance strategy is not merely driven by its pursuit for partner-specific assets and complementary resources, as past strategy research has typically been advocating, but also by the firm's strategic decisions on how it intends to configure its alliance relations within its wider ego network. The field of network analysis offers the tools needed to disentangle the interdependence between organisations, by analysing the structural configuration of alliance relations and explaining the strategic outcomes associated with distinct network configurations. Combining strategic and network analysis approaches therefore enables capturing both the firm's partner choices and its decisions for the configuration of its alliances relations; and, consequently, improving our understanding of the strategic process through which firms form R&D alliances within industry networks. Future empirical alliance research should therefore adopt network analysis in order to explicitly model the endogenous structural processes that exist within R&D networks.

Our findings indicate that when a chipmaker is presented with a choice among multiple potential partners with complementary resources, it is likely to select those partners whose portfolios of alliance ties to R&D partners within and outside of the core semiconductor industry (1) contribute most to the position of the chipmaker within the industry network and (2) fit in with the relational configuration of alliances within the chipmaker's ego network. As such, a chipmaker would select those partners who would not only contribute valuable complementary resources, but who would also enable the chipmaker either to create an open innovation environment or to reinforce and protect its network position as a gatekeeper to specialised knowledge and key technologies. Future research and advancements in theory on the formation of R&D alliances should therefore expand their scope from a narrow focus on the firm's short-term partnering strategy toward its longer-term network strategy.

Concurrently, this study also has implications for research on open innovation. The 'openness' of firm's R&D alliance strategies has typically been measured by the firm's network position or density of the industry network (Boschma and Ter Wal, 2007; Gilsing et al., 2008; Lyu et al., 2019); the characteristics of the firm's partner portfolio, such as the breadth and depth of its external search channels (Laursen and Salter, 2006) or the diversity of its partners (De Leeuw et al., 2014); or the firm's willingness to share previously secret ideas (Henkel, 2006). This study demonstrates, however, that these measures of open innovation are not sufficient to fully comprehend how companies develop open innovation strategies, as it is also important to consider the network tactics at the level of the firm's ego network as a reflection of how 'open' its open innovation strategy is. Network tactics, namely, can be utilised to foster the exchange of knowledge and enhance close cooperation and the coordinated (re)combining of complementary resources by integrating R&D alliance relations within triads; as well as to protect exclusive access to knowledge and resources and to control the availability of these strategic assets to other parts of the industry network, such as to direct rivals or partners based in other technology sectors, through brokerage.

Furthermore, the findings of this study also suggest that triadic tactics do not resemble R&D alliance tactics which are universally suitable for different types of firms. The comparison between IDMs and fabless chipmakers illustrates that different operational strategies contribute to likely dissimilar perceptions of risk and uncertainty arising from the same industry pressures, which may subsequently require different triadic tactics to accumulate long-term network benefits to mitigate these pressures.

Finally, this study also makes methodological contributions by demonstrating the application and advantage of the social network analysis (SNA) approach to analysing R&D alliance network strategies. Firms engaged in R&D alliances are naturally embedded within complex industry networks. By analysing the relational structures within these networks to understand how precisely firms are linked to one another, we can advance our knowledge about how firms develop and utilise network strategies to achieve a long-term competitive advantage. To demonstrate the importance of SNA, this study adopted stochastic actor-oriented modelling. In contrast to traditional regression methods, the SAOM methodology allows explicitly capturing the inherent interdependence of firms in R&D networks through the specification of structural network effects, such as firms' tendency toward triadic closure, in addition to firm-specific attributes. This subsequently allows testing the importance of network configurations in determining the partner choices of firms. Accordingly, future alliance research would benefit from the wider adoption of this method to better comprehend the collaborative behaviour of organisations.

Industry strategists can take lessons from the findings of this study. Business strategists are advised to, first of all, consider the configuration of their alliance network as an integral part of their strategic plan, taking into account the strategic implications of distinct network tactics for the creation of new value and the development of novel innovations. Strategists should thus consider their organisation's position within a wider industry network of R&D alliances and to define a network strategy, *inclusive* or *protective*, in line with their long-term R&D objectives, and to evaluate whether the choice of a potential partner based on partner-specific interests would fit in this network strategy. Please see Section 6.2 of Chapter 6 for a deeper discussion of the managerial implications of this study.

A few limitations to this study should also be acknowledged. Given the industry-specific context of this study, with its focus on semiconductor companies, the findings might not be directly applicable to companies not based in high-technology industries. Importantly, however, a recent study by KPMG (2018) does emphasise on the growing importance of strategic alliances to organisation across 13 different industries; alliances for cross-industry collaboration in particular. As such, we may argue that the outcome of this research on triadic R&D alliances does provide important insights which can be adopted for the analysis of alliance network strategies in other industries. Accordingly, there are opportunities for future research to adopt the framework presented in this study to examine and develop network strategies for organisations in other industries.

Furthermore, one limitation of the empirical methodology applied in this study concerns the unavailability of data on specific contractual terms of the R&D alliances in the sample. This means that the analysis is based on the assumption that the R&D alliances do not fail or dissolve during the sample period. Future research on the formation of triadic R&D alliances should explicitly control for specific contract terms, such as the duration of an alliance.

5. ACHIEVING INTERNATIONALISATION ADVANTAGE THROUGH R&D ALLIANCE NETWORK STRATEGIES

5.1. Introduction

The previous chapter introduced a framework for analysing the strategic utility of R&D alliances, underscoring the importance of triadic tactics to maximising the R&D outcomes of strategic alliances, such as novelty creation, reaping the profits of fundamental R&D, accelerating the commercialisation of new innovations through cross-industry linkages, and mitigating competitive conflicts in R&D collaboration.

We demonstrated first of all that the strategic utility of R&D alliances is determined jointly by (1) the strategic selection of partners possessing complementary assets and (2) the configuration of the chipmaker's alliance relations within triads. The relational configuration of triads can result in two distinct triadic tactics, namely *integrated* triads based on closure among partners and *protective* triads based on relational brokerage. These triadic tactics enable chipmakers to achieve different cross-partner resource complementarities, extend resource complementarities to the joint creation of novelty, and develop distinct governance structures facilitating the development of novel creations. Specifically, while integrated triads function as effective governance mechanisms which enable developing an open innovation environment based on mutual trust and cooperation, protective triads enable chipmakers to gain control over the process of developing and commercialising new innovations by brokering the flows of knowledge and resources between different R&D partners (see Chapter 4, Section 4.2.2 for a detailed discussion). As such, chipmakers utilise these two triadic tactics as responses to industry pressures.

The next important step is to investigate how these triadic tactics might be utilised by chipmakers to internationalise R&D through strategic alliances. R&D alliances are not formed only within or across industries but also internationally and inter-regionally. In fact, the international context adds a layer of complexity to the R&D industry network, which may change the strategic behaviour of chipmakers; first of all, in terms of the selection of partners in foreign industries and markets; and, secondly, in view of shaping the knowledge flows, control and power relations within alliance networks which span across national borders.

The importance of R&D networks has clearly been highlighted in previous research showing that international R&D activities are nowadays increasingly organised through networks of (non-equity) inter-organisational alliances (Tolstoy and Henrik, 2010; Kedia and Mooty, 2013; Kranenburg et al., 2014; Cantwell, 2017) rather than through foreign direct investment (FDI). For example, in line with the RBV of alliances (Das and Teng, 2000), the IB literature has long acknowledged that inter-organisational R&D networks are utilised by firms to exploit their value creation capabilities as well as acquire strategic assets and conduct intra-network learning during the internationalisation process (Andersson et al., 2016; Cano-Kollmann et al., 2016; Sekliuckiene et al., 2016; Cantwell, 2017; Martínez-Noya and Narula, 2018). In addition, networks are utilised by companies to recognise opportunities for and develop strategic business relationships in foreign markets (Blankenburg Holm et al., 2015; Forsgren, 2016). In fact, equity-based alliance arrangements for R&D have been on a decline since the 1970s (Hagedoorn, 2002; Narula and Duysters, 2004). Hybrid arrangements rely on distinct (1) governance mechanisms, such as mutual trust and social control through brokerage, as a means of developing cooperative relations and directing the flows of knowledge and resources among network partners based in different countries; and (2) partner configurations to enable capitalising on different cross-partner resource complementarities.

Especially within high-technology environments, such as the semiconductor industry, flexible non-equity alliance agreements are nowadays at the core of any international R&D strategy to leverage the diverse skills, capabilities and location advantages of foreign cross-industry partners necessary to drive innovation (Semiconductor Industry Association, 2016). In particular, the introduction of the System On Chip (SOC) as a new chip design methodology has increased the complexity of chip design, which has put greater importance on collaborating for R&D with a variety of foreign partners (Ernst, 2005).

Importantly, the configuration of R&D alliance relations within triads enables chipmakers to complement cross-industry bridges with cross-border collaboration, which underscores that the choice to form a non-equity R&D alliance is not based on a uniform decision driven merely by short-term strategic benefits, such as access to complementary resources located in foreign markets, but that it is also about strategically linking different R&D activities performed across the globe through international alliance relations. It is therefore not merely a matter of a choice between non-equity and equity modes of internationalisation, as is conventionally assumed in the IB literature (Pan and Tse, 2000). This traditional view is oversimplified and does not capture the strategic reality of linking different alliances and R&D activities within the industry network.

Internationalising R&D through hybrid modes, however, magnifies the strategic challenges faced by the company within its local market, in terms of risks of opportunism as well as the cognitive, cultural and geographical distance to its foreign partners. With this study, we aim to analyse and explain the internationalisation of joint R&D activities from a network perspective, and explore how international hybrid arrangements can be configured within triads to link different R&D activities within the industry network and overcome the strategic challenges inherent to international R&D collaboration – in view of achieving internationalisation advantage. Specifically, how does network advantage translate into internationalisation advantage? This investigation is conducted by (1) linking concepts from the fields of international business (IB) and network analysis within a single framework for explaining the internationalisation of R&D through hybrid modes; and (2) developing hypotheses to test the tendency of chipmakers to configure to configure their alliance relations within triads as a means to internationalising R&D.

With this aim, this study responds to the call to advance the established IB scholarship by systematically integrating network theory in the field of IB. Building on the concept of the strategic utility introduced in Chapter 4 (see Section 4.2), we develop a network-based framework to analyse and explain the internationalisation of R&D through strategic alliances by integrsating (1) the strategic selection of foreign R&D partners and (2) the configuration of international alliance relations within triads as core mechanisms integral to the R&D internationalisation process. This framework is premised on the idea that the strategic orchestration of the firm's ego network along these two dimensions can help to enhance the value created through international R&D alliances as well as to accelerate the internationalisation of R&D. Triadic tactics, namely, can enable companies to (1) stimulate mutual trust and cooperation through collaboration with relatively redundant partners, and the exchange of knowledge in view of minimising the risks of opportunism and overcoming the cognitive, cultural and geographical distance to selected R&D partners in foreign countries; or (2) secure exclusive access to non-redundant assets in foreign markets and control the flow of knowledge across geographical borders in order to lead the process of developing and commercialising new innovations and to become an attractive R&D partner themselves.

This network framework contributes to the IB literature both conceptually and methodologically. It offers a method of measuring the ambiguous IB concept of 'network ties' and an approach to analyse how firms can configure their strategic networks to develop and advance their value creation capabilities and achieve commercial success in foreign markets. As such, it also provides an alternative way of explaining differences between firms in terms of their internationalisation advantages, based on the different network tactics which they utilise to orchestrate the configuration of their ego networks of international R&D alliance relations.

The traditional conception in the field of IB has long been that internationalisation reflects the exploitation of competitive advantage in foreign markets through FDI (Vernon, 1966; Caves, 1971; Hymer, 1976; Dunning, 1977, 1980; Tan and Meyer, 2010; Narula and Nguyen, 2011). This view is predicated on the idea that firms require firm-specific ownership (O), location (L) and internalisation (I) advantages (Dunning, 1980) in order to be able to internationalise their R&D through FDI. As mentioned, however, the sources of the firm's competitive advantage in foreign markets are increasingly located beyond what has traditionally been considered an ownership advantage. Acknowledging the growing role of network building through hybrid strategies in the internationalisation of R&D, Dunning (1995) has broadened the concept of ownership advantages to also capture the costs and benefits derived from inter-organisational relationships within alliance networks – thus giving rise to the conception that networks belong to the transaction-type ownership advantages of the firm (Collinson and Narula, 2014; Alcácer et al., 2016; Cantwell, 2017).

Importantly, however, this conception arguably neither allows capturing the inherent complexity of networks, nor does it provide a way of measuring precisely how networks facilitate the internationalisation of R&D. Instead, it implies that extant attempts at understanding the strategic utility of networks have been built on the firm as the unit of analysis with its associated firm-level characteristics, consequently relying on the idea that networks are somehow internal to the firm or owned by the firm. Understanding how firms utilise hybrid arrangements to internationalise R&D, however, requires analysing the network-level processes, such as reciprocity and transitivity, by which technology is transferred and knowledge is exchanged between the firm and its foreign network partners. This can only be accomplished by conducting the analysis at the level of the firm's ego network or at the level of even more complex network configurations within and across industries. Namely, the fact of the presence of a given alliance in itself does not automatically equate to internationalisation advantage; rather, it depends on how the firm configures the alliance relation in view of directing the flow of resources and creating an effective governance structure within its wider ego network. Labelling networks as ownership advantages is thus arguably both conceptually and strategically inaccurate, considering that networks actually constitute an alternative entry mode through which hybrid arrangements are realised.

Furthermore, even though Dunning (1995), in line with other studies (e.g. Powell, 1990; Dyer and Singh, 1998; Contractor and Reuer, 2014), acknowledges the importance of mutual commitment and alternative governance structures based on trust – rather than written contracts – in hybrid arrangements, the OLI framework does not capture how these governance mechanisms are linked to the processes of (re)combining complementary resources and creating new knowledge in foreign markets. This is neither achieved in more recent research, such as Alcácer et al. (2016), who link the concept of I advantages to the orchestration of networks as a form of governance of inter-organisational collaborations in foreign markets. Other IB studies have, similarly, emphasised that the firm can act as an 'orchestrating flagship firm' (Cano-Kollmann et al., 2016), 'IB network orchestrator' (Dunning and Lundan, 2008) or 'lead firm' (Narula and Santangelo, 2012) in order to coordinate its collaborative activities with foreign partners. However, while also focusing on dyadic network ties, in spite of the inherent complexities of hybrid arrangements as recognised in the strategy and value chain literatures (Madhavan et al., 2004; Gereffi et al., 2005; Kim et al., 2016), this extant approach does not capture how firms can actually orchestrate their international hybrid arrangements in order to govern the asset flows and knowledge exchanges within their networks in view of maximising value creation and their R&D outcomes.

This framework, therefore, does not hold conceptually and strategically to adequately analyse and explain the mechanisms underpinning the hybrid internationalisation strategies of many modern businesses. Conceptually, it does not help to understand how companies (1) configure their hybrid strategies to enter into foreign markets and (2) develop their internationalisation advantages in dynamic interactions with foreign R&D partners within networks. Strategically, it does not provide any guidance to measure and analyse how companies can utilise network tactics to shape hybrid internationalisation modes to maximise R&D outcomes by (1) creating new value through international resource allocations arising from bridging technology sectors and end-markets; and (2) developing governance mechanisms to improve the cross-border coordination of cross-industry technology transfers, knowledge exchanges and learning.

In result, there is a notable lack of empirical analyses in the field of IB focused explicitly on the actual internationalisation advantages that firms can derive from their *inter-organisational* R&D networks, in terms of resource complementarities, new knowledge creation, cross-industry bridges, control over resource flows and power asymmetries. This study, therefore, develops a new framework based on the network perspective, in order to explore and explain the essence of international R&D alliance networks and how firms can utilise R&D network strategies to develop and advance their internationalisation advantage.

Accordingly, in this chapter we return to the fundamental frameworks of the RBV and TCA underpinning the established methods to analysing the internationalisation of firms, and integrate the premises of the RBV and TCA with the conceptual and methodological tools offered by the network approach (Coleman, 1988; Burt, 1992; Ripley et al., 2019) to analyse the formation of international R&D alliances within a single framework. In line with strategy research done by Dyer and Singh (1998) and Rowley and Baum (2008), we argue that to adequately understand how firms can advance or develop their internationalisation advantages through international R&D alliances, it is necessary to move the unit of analysis from the traditional firm level, and even the dyadic alliance level, toward the ego network level and to explore how firms expand their boundaries across borders to learn, pool complementary resources and develop effective governance structures by strategically configuring their hybrid arrangements within their ego networks.

To overcome the deficiencies of existing frameworks, we build on the concept of the strategic utility (Chapter 4). As such, the central premise of this study is that the firm's ability to achieve internationalisation advantage through R&D alliance networks is influenced by the strategic utility that it may derive from its international network strategy, which is a function of and

(1) the access to location-bound assets gained through the strategic selection of foreign partners and (2) the strategic outcomes associated with the configuration of its international R&D alliance relations within its ego network.

This study makes several conceptual contributions to the field of IB by adopting the construct of strategic utility introduced in Chapter 4 to analyse how network advantage can be converted into internationalisation advantage. Firstly, it demonstrates how the premises of the RBV and TCA are inter-linked with the concepts of closure (Coleman, 1988) and brokerage (Burt, 1992) and the methods offered by the network approach to analysing the formation of international R&D alliances. Secondly, we adopt the concept of strategic utility to develop a framework that enables explaining how modern businesses utilise alliance network strategies to achieve internationalisation advantage. Thirdly, this framework is applied to (1) explain how firms might utilise integrated and protective triadic network tactics to enhance the obtainable value from international R&D via (a) resource complementarities and (b) mutual knowledge exchange; and (2) evaluate how the obtainable network advantages associated with alternative triadic network strategies might influence the ability of firms to develop and advance their internationalisation advantages.

Empirically, we test this network perspective in the context of the global semiconductor industry. This study is aimed at addressing a number of research questions, including (1) whether integrated or protective triadic alliances might be the most efficient network strategy to internationalise R&D; (2) whether the two major types of chipmakers, namely IDMs and fabless chipmakers, show distinct preferences for triadic tactics due to their distinct operating models; (3) whether chipmakers utilise triadic international R&D strategies to enhance their internationalisation advantages by (a) accessing and acquiring the existing complementary assets and knowledge of foreign partners or (b) inter-organisational learning about technologies and foreign markets and commercial opportunities; and, finally, (4) how the interaction between alliance partner choices and the need for location-bound assets might drive the formation of alternative international R&D network strategies.

To address these questions, 10 hypotheses are developed to test the tendencies of chipmakers to configure their international R&D alliance relations, with foreign partners who differ in their functional specialisation, within triads. The hypotheses are, therefore, designed to first of all test whether chipmakers configure their hybrid strategies within triads to enter into foreign markets at all; and, secondly, to also test whether these triadic tactics are utilised by chipmakers in view of achieving specific R&D objectives, such as gaining access to fundamental research expertise, complementary technologies and end-market knowledge, as well as establishing cross-industry bridges between foreign technology sectors and end-markets. These hypotheses are tested on the same dataset used in Chapter 4, containing a network sample of R&D alliances formed between chipmakers and their partners during the 11 year period 2004-2014, using stochastic actor-oriented modelling (SAOM).

The remainder of this chapter is structured as follows. In Section 5.2, we define the concept of strategic utility in view of international R&D; explore the core mechanisms determining the strategic utility of hybrid strategies in the internationalisation of R&D; and link these core mechanisms to the integrated and protective triadic tactics which chipmakers can utilise to internationalise R&D. The hypotheses are formulated in Section 5.3. This is followed by a discussion of the research methodology and SAOM specifications in Section 5.4. Descriptive analyses and the statistical model results are presented in Section 5.5 and strategic interpretations are discussed in Section 5.6. Finally, in Section 5.7, we discuss the conclusions and implications of this study.

5.2. Development of the conceptual framework

5.2.1. The strategic utility of alliance networks for international R&D

To explain the strategic utility of alliance network strategies for the internationalisation of R&D, we first of all need to understand the strategic function of alliance networks in driving the main outcomes in international R&D, namely the process of value creation and the accelerated access to technology sectors and end-markets. The network processes relate to the dynamic capabilities perspective, which suggests that value creation entails a dynamic process in which the chipmaker reconfigures its resource base by acquiring, integrating and recombining resources in response to changes in its industrial environment, in order to sustain a competitive advantage over time (Teece et al., 1997). These dynamic value creation processes entail (1) the development of novel technologies through the joint application of technical skills and capabilities and (2) the creation of new products by complementing existing resources and knowledge; and are best captured with a network perspective, as this can reveal the network processes through which resources and knowledge flow between chipmakers and their foreign network partners.

From a dynamic internationalisation perspective, the ability of the chipmaker to create value through the internationalisation of its R&D activities is determined by its capability to (1) commit and reconfigure resources to conduct R&D in foreign markets (Johanson and Wiedersheim-Paul, 1975; Hitt et al., 1997); and (2) develop a learning advantage by accumulating local market knowledge and developing new routines and processes for conducting R&D based on foreign market experience (Johanson and Wiedersheim-Paul, 1975; Chang, 1995; Barkema et al., 1997).

International networks of R&D alliances fulfil important functions in this regard, as they enable chipmakers to leverage cross-industry resource complementarities, develop effective governance structures, enhance mutual trust and coordination (see Chapter 4, Section 4.2.2 for an in-depth discussion on governance through alternative triadic network tactics) as well as avoid a lock-in situation within the local market through access to the outside world (Boschma and Ter Wal, 2007). The notion that networks enable value creation and, subsequently, enhance competitive advantage, however, not a new one (Gulati, 1998, 2000; Greve et al., 2014). In fact, the position of companies within inter-organisational networks has long been linked by scholars to innovation output and product development (Powell et al., 1996; Rothaermel, 2001; Powell et al., 2005; Capaldo, 2007; Shiri, 2015), and to network advantages derived from access to technological resources (Tolstoy and Henrik, 2010), information and knowledge (Granovetter, 1992; Hadley and Wilson, 2003), as well as to status (Podolny, 1993), reputation (Gulati, 1998; Gulati et al., 2000), influence and prestige (Wasserman and Faust, 1994), and power and control (Krackhardt, 1990; Alderson and Beckfield, 2004).

Studies built on resource-based perspectives of alliances (Eisenhardt and Schoonhoven, 1996; Das and Teng, 2000) suggest that the value generated from resources committed in foreign markets will be greater when they are effectively complemented and recombined with other valuable resources and new knowledge bases possessed by local partners within the chipmaker's R&D network (Teece, 1992; Dyer and Singh, 1998). The premise of this view, originally developed to explain value creation through alliances from a dyadic perspective, can be relaxed and used to also explain that networks of R&D alliances can help chipmakers to create new value in cross-border R&D. Namely, through strategic networking, chipmakers can join *groups* of foreign technology and end-market partners whose existing technologies, IPs as well as heterogeneous technical and market knowledge can be complemented to create unique 'network resource combinations' (Tolstoy and Henrik, 2010), or whose technical skills and capabilities can jointly be applied to develop new chip technologies.

Importantly, however, creating new value by complementing assets or jointly applying technical skills and capabilities through international R&D collaboration requires that chipmakers – besides gaining access to location-bound research expertise, technologies and market knowledge – choose and implement a governance structure, based either on trust in relatively redundant alliance relations or on control in captive relations, which enables them to overcome the risks of opportunism and the geographical, cultural and cognitive distances to their foreign partners which constrain the transfer of technology, the exchange of knowledge and the coordination of joint technology development across borders (Contractor et al., 2011; Kranenburg et al., 2014). The strategic configuration of international R&D alliance relations within the chipmaker's ego network is, therefore, critical to the dynamic value creation process. Moreover, when value creation within networks is combined with access to foreign research expertise, technologies and end-markets, this can enable the chipmaker to also accelerate the internationalisation of R&D in light of the commercialisation of R&D outputs (Johanson and Mattsson, 1988; Criado et al., 2005).

Differences in the capabilities of chipmakers to internationalise R&D are, therefore, increasingly due to differences in the network tactics which they utilise to reconfigure their committed resources and to develop their learning advantages (Dyer and Singh, 1998; Gulati, 1998). Specifically, we argue that chipmakers' utilisation of distinct network tactics, based on the combination of strategically selected partners and the configuration of the R&D alliance relations to these partners within their ego networks, enable generating distinct strategic outcomes (these are discussed in Section 4.2.3 and depicted in Figure 4.3) which they can leverage to (1) enhance the creation of value and the development of new chip technologies as well as (2) accelerate the speed of the internationalisation of R&D and (novelty) value creation. This dynamic process of creation value through network tactics is illustrated by the conceptual model depicted in Figure 5.1, which will be explained in more detail over the following sub-sections.

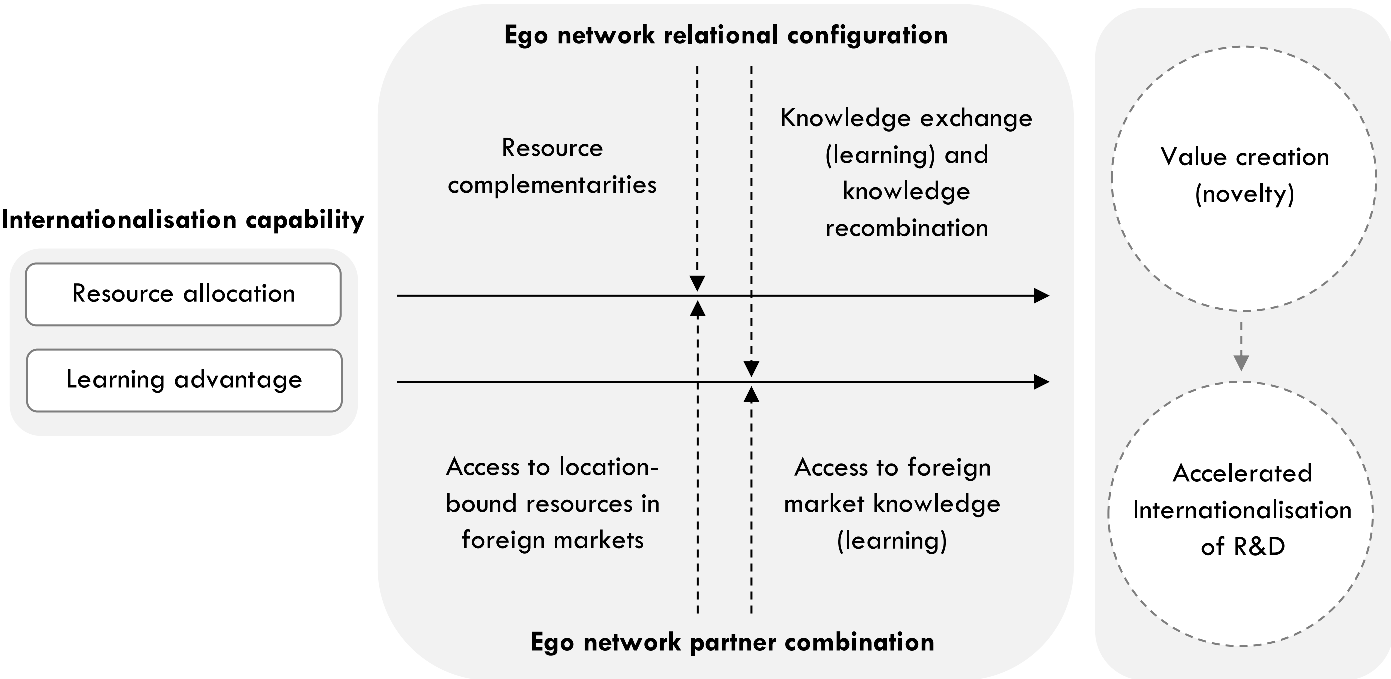


Figure 5.1: Conceptual model of the faciliatory role of strategic networks in the internationalisation of R&D

Utilising network tactics to enhance the value created through international R&D

Chipmakers can utilise network tactics to advance and develop their ability to create value through international R&D by (1) capitalising on foreign resource complementarities and (2) developing their technical skills and know-how and foreign market knowledge through learning. First of all, through strategic networking a chipmaker can gain timely access to and acquire existing complementary proprietary resources and especially codified knowledge from foreign (cross-industry) R&D partners which cannot be readily purchased from competitive markets (Beamish, 1994; Kogut, 1988; Teece, 1992; Madhok, 1997; Oliver, 1997; Stuart, 1998; Chetty and Wilson, 2003), but which are critical to its ability to enhance the value it can create through international R&D by incrementally strengthening its own resource base (Nooteboom et al., 2007).

In the context of the global semiconductor industry, enhancing the value of any chip design demands chipmakers to improve the performance and functionality of their core chip designs by complementing these at least with licensed IPs, electronic design automation tools, supplementary design services, software products and, depending on the type of chip under development, application-specific technologies and systems components (Ernst, 2005). Furthermore, the chipmaker may derive higher status and greater power from its network position within the industry and the utilised network tactics, which it may convert into greater bargaining power and control over the flow of complementary resources and knowledge throughout the network (Burt, 1992).

Accordingly, the chipmaker's position in the industry's R&D network and the strategic configuration of its alliance relations within its ego network enable creating new value based on the complementarities between the existing technologies and knowledge bases of the chipmaker and its foreign network partners (Teece, 1986; March, 1991; Rothaermel, 2001; Owen-Smith and Powell, 2004). Moreover, networks can help chipmakers to enhance close cooperation with R&D partners in regional innovation centres or end-markets to gain access to and leverage complementary resources which are not easily transferrable across national borders, such as technical expertise, R&D facilities and equipment, local market knowledge or partners' reputation (Oliver, 1997) associated with global technological leadership status and prominence in foreign markets. Inherent to the effectiveness of such R&D alliances which are, in essence, aimed at exploiting existing assets, has been the notion that R&D partners should possess similar technological capital (Nooteboom et al., 2007), i.e. tacit knowledge and expertise accumulated through R&D, to enable complementing resources on the basis of the chipmaker's absorptive capacity – to recognise the value of new knowledge and resources, and to assimilate and commercialise them (Cohen and Levinthal, 1990; Fleming and Sorenson, 2001).

Importantly, even prior to evaluating the potential novelty value of joining and combining resources with a given potential foreign partner (as visualised in Figure 4.2 in Chapter 4), firms are challenged to identify the optimal foreign R&D partner. Through networking, chipmakers can also acquire accurate and timely information about potential foreign R&D partners from trusted informants within the global R&D network (Granovetter, 1985; Burt, 1992), as well as to overcome the lack of perfect information and the cost and difficulty of determining the value of complementary resource of potential partners (Dyer and Singh, 1998).

Besides capitalising on resource complementarities with foreign R&D partners, chipmakers can also utilise network tactics to establish and develop global 'networks of learning' (Powell et al., 1996), which enable accelerated learning about new technological discoveries and developments made in foreign innovation centres as well as new commercial opportunities in foreign end-markets to take place on the basis of routines for the exchange and sharing of tacit knowledge and fine-grained information between the chipmaker and its foreign R&D partners (Dyer and Singh, 1998; Das and Teng, 2000; Rothaermel, 2001; Hadley and Wilson, 2003). Chipmakers can, consequently, leverage their network positions not only to establish a presence in foreign markets, but importantly also to develop novelty value in close cooperation with R&D partners in foreign markets by jointly applying their technical know-how, skills and capabilities to explore, discover and experiment with new fundamental chip technologies and technological applications (March, 1991; Teece, 1992; Powell et al., 1996; Nooteboom, 2000). Network tactics for international R&D collaboration can thus help chipmakers to avoid the risk of getting locked in an established technological paradigm, as well as overcome their liability of foreignness by learning about foreign market opportunities and developing awareness of customer problems and technical product specifications required by foreign customers (Fang et al., 2007; Spence et al., 2008).

Research has shown that the presence of cognitive distance between R&D partners, rather than cognitive similarity, is critical to the creation of novelty value in this respect (March, 1991; Nooteboom et al., 2007; Leiponen and Helfat, 2011). Importantly, cognitive distance becomes larger and therefore more challenging to overcome in international R&D collaboration due to the institutional and cultural barriers which a chipmaker may face when collaborating with R&D partners in foreign markets and which render communication and the exchange of knowledge more difficult (Freeman, 1995; Bertrand and Mol, 2013). As such, conducting R&D jointly with foreign network partners enables chipmakers to increase the cognitive distance to their R&D partners to such an extent that it creates potential for accelerating the development of their learning advantages and jointly creating novel chip technologies.

Extant research has, however, highlighted challenges to creating novelty value through international R&D collaboration. The ability to convert cognitive distance into novelty creation, first of all, is constrained by the chipmaker's capacity to comprehend and absorb the knowledge and technologies which are shared by its foreign R&D partners (Nooteboom et al., 2007; Bertrand and Mol, 2013). Furthermore, obstacles in communication, risks of opportunism and differences in culture, tacit knowledge and strategic goals are important challenges which chipmakers are likely to face when collaborating with foreign R&D partners (Heiman and Nickerson, 2004; Forsgren, 2016).

Strategic networking can facilitate in overcoming these challenges by establishing effective governance mechanisms, based on mutual trust and commitment, which foster the exchange of resources and knowledge and, in result, enable realising the creation of novelty value from international R&D collaboration. As discussed in Section 4.2.2, chipmakers can accomplish this by configuring their alliance relations to create a 'relational' type of governance structure (Lavie et al., 2012; Gereffi et al., 2005) which, based on mutual trust and commitment resulting from an increase in the redundancy of the ties in their network, can facilitate the process of exchanging knowledge and transferring technologies in cross-border R&D alliances to enable learning and creating (novelty) value through international R&D. Alternatively, chipmakers can configure their alliance relations to establish a 'captive' type of governance structure (Gereffi et al., 2005) in which the chipmaker orchestrates the process of complementing resources or joining technical skills and capabilities, enabling it to appropriate most of the value created from cross-border collaborations. Maximising the creation of value form international R&D, however, requires integrating mutual knowledge exchange mechanism of networks and this may thus imply shifting the nature of international R&D collaboration from a captive to a more relational style. The chipmaker's choice of network tactic and its position in the global R&D network are therefore directly linked to its ability to learn to create value with new technologies and knowledge, and might consequently also enable it to enhance its absorptive capacity (Gilsing et al, 2008).

Ultimately, chipmakers are thus faced with a triple challenge of (1) maintaining sufficient cognitive distance to foreign R&D partners to enable the creation of novelty value; (2) evaluating the reliability of potential foreign R&D partners as well as the value of their complementary resources, knowledge, technical skills and capabilities; and (3) once these foreign strategic assets are evaluated, choosing the right network tactic to access these assets and to bridge the necessary differences in cognitive focus in comparison with their foreign R&D partners and, subsequently, effectively complementing or jointly applying these strategic assets to create (novelty) value.

Utilising network tactics to accelerate the internationalisation of R&D

Chipmakers can further utilise network tactics to accelerate the process of internationalising R&D and consequently the speed at which firms can enhance the value created through international R&D, via the strategic selection of foreign R&D partners. The acceleration of the R&D internationalisation process implies that the firm transitions to an initial or more advanced state of internationalisation (Johanson & Vahlne, 1977) as a result of the speed at which it (1) gains international market knowledge through learning and (2) commits resources to conducting R&D in foreign markets (Chetty et al., 2014). This process-based conceptualisation goes beyond merely considering the time between the firm's establishment and the formation of its first international R&D alliance (Khavul et al., 2010; Ramos et al., 2011) and can be linked to the network processes through which chipmakers might configure their ego networks of R&D alliance relations.

Knowledge about foreign markets, particularly differences in culture, local formal institutions such as IP rights and product specifications demanded by local customers, is mainly accumulated through experience conducting R&D in different foreign markets (Johanson & Vahlne, 1977) and forms an essential basis for the firm's ability to enhance the value created through international R&D. The firm can consequently learn about foreign markets faster by increasing the amount of experience it can gain within a given (shorter) time frame. By building strategically configured R&D alliance networks, however, firms can accelerate this learning process and time-to-market (Gilsing et al., 2008) by accessing and leveraging the local market experience and tacit knowledge of commercial opportunities possessed by strategically selected foreign R&D partners (Uzzi, 1997; Musteen et al., 2010), such as end-market companies.

Internationalising R&D at a higher speed further demands that the chipmaker allocates more resources and capabilities to conducting R&D in foreign markets (Oviatt and McDougall, 2005; Chetty et al., 2014). Rather than committing to equity investments, such as FDI, however, the chipmaker can also capitalise on its network of strategically selected foreign R&D partners, such as those located in regional innovation centres (Florida, 1997), to gain access to low-cost R&D personnel, fundamental research expertise, facilities and equipment, and complement its own committed resources with the resources and knowledge of these foreign partners as well as jointly apply their technical skills and capabilities as a means of efficiently accelerating the speed and value-creation potential of international R&D. Importantly, by utilising their network tactics to link foreign research expertise, technologies and end-market knowledge, chipmakers can also accelerate the internationalisation of R&D by integrating the creation of new value or the joint development of new technologies with commercial opportunities.

Overall, from this discussion we can derive that being better connected within the industry's R&D network is linked to a greater ability to create (novelty) value and accelerate the speed at which value is created through international R&D. Fully understanding the strategic implications of 'better connectedness' for the novelty creation potential of international R&D alliance strategies, however, requires a deeper analysis of the distinct triadic tactics through which chipmakers can build their networks of international alliance relations. Taking into account the strategic outcomes of alternative triadic tactics as discussed in Section 4.2.3, in the next section we discuss how these triadic tactics might facilitate the hybrid internationalisation strategies of firms and explore what might be the most efficient and effective network strategy to internationalise R&D through alliances.

5.2.2. *The importance of triadic network configurations to the internationalisation of R&D through alliances*

Central to the chipmaker's ability to utilise network tactics to enhance the (novelty) value created through international R&D is its *orchestration capability*. This encapsulates the chipmaker's capability to configure its alliance relations in view of (1) tactically combining cross-industry and cross-regional R&D collaboration to (a) maximise the creation of novelty by complementing or jointly applying resources and knowledge as well as (b) capture its value through accelerated commercialisation in end-markets (see Figure 5.1); (2) and developing effective governance mechanisms based on trust to enhance its absorptive capacity to bridge the cognitive differences vis-à-vis its foreign R&D partners necessary for novelty creation.

We examine the chipmaker's orchestration capabilities in line with the triadic framework introduced in Chapter 4. From a triadic perspective, chipmakers have two strategic options to configure their cross-border R&D alliance relations to enhance value creation via international R&D alliances: either through 'open' (protective) or 'closed' (integrated) triadic network configurations[10].

The standard view has been that protective triads are associated with greater recombination potential than integrated triads and are thus advantageous for novelty creation through international R&D alliances (Burt, 1992; Ahuja, 2000; Rowley and Baum, 2008). This potential stems from the notion that the non-redundant resources and alternative ways of thinking needed to create novelty value are located in relational groups within the network to which the chipmaker and its existing partners and rivals are not a member, on the opposite side of structural holes which – when brokered by the chipmaker – can grant access to new opportunities for creating novel resource combinations (Rowley and Baum, 2008).

This logic is also applicable to international R&D collaboration. By brokering the relations between foreign partners, chipmakers can first of all increase the novelty creation potential of their international R&D strategies through access to foreign technologies, facilities, knowledge, skills and capabilities. The fewer companies, notably rivals, within the chipmaker's immediate network and local market with who it shares access to the same non-redundant resources possessed by foreign cross-industry partners and located in foreign innovation centres, the greater the novelty value the chipmaker can generate through international R&D. It is therefore arguably in the firm's strategic interest to protect its access to these critical resources and to keep searching for new brokerage opportunities across

[10] These distinct triadic tactics were introduced in Section 4.2.3.

geographical borders – not just horizontally within its own industry, but especially between neighbouring industry networks (KPMG, 2018).

As such, the orchestration of international R&D alliance relations within open triadic configurations constitutes a *protective* network tactic based on exclusionary tactics. It can grant the chipmaker a position of power (Greve et al., 2014) or dominance (Gereffi et al., 2005) over foreign R&D partners, enabling it to orchestrate the recombination potential of accessed resources and knowledge by playing off disconnected, dependent partners against each other (Gulati, 1998), controlling the mobilisation of complementary resources and knowledge across geographical borders (Galaskiewicz, 1979; Burt, 2004), and coordinating action and withholding or distorting information in order to maximise the value it can derive from its sources (Alderson and Beckfield, 2004). In result, brokerage within protective triads can also help chipmakers to maintain or reinforce their technological leadership both locally and abroad.

To successfully create value by bridging the relational disconnect between foreign R&D partners, however, the chipmaker must possess a sufficiently large internal resource capacity that can be committed to bridging the cognitive and cultural distance to every additional foreign R&D partner, in order to effectively absorb and complement heterogeneous technical and market knowledge, jointly applying technical skills and capabilities, as well as overcoming a potential liability of foreignness (Zaheer, 1995). In the absence of sufficient absorptive capacity, a predominant focus on this triadic strategy may thus, over time, limit the chipmaker's ability to derive novelty value from its international R&D collaborations (Ahuja and Katila, 2004). Therefore, the long-term effectiveness of protective triadic tactics for novelty creation through international R&D alliances is highly dependent on the chipmaker's available capacity to integrate and recombine the strategic assets, as suggested by Nooteboom et al. (2007); otherwise rendering the creation of value by exploiting complementary resources, while limiting equal access by others, a more achievable strategic objective.

The development of absorptive capacity by the firm can effectively be enhanced through international R&D alliances when these are configured within integrated triads (Gilsing et al., 2008), on the basis of the informational advantages and learning opportunities that it can derive from closure among its network of cross-industry R&D partners in foreign markets (Coleman, 1988). This logic dictates that by establishing a dense global network of R&D partners based on mutually understood norms of cooperation and trust (Grannovetter, 1973; Gulati, 1995a; Rowley, 1997; Walker et al., 1997), allowing for both codified and tacit technical and market knowledge as well as fine-grained information to be exchanged via high bandwidth communication channels across geographical borders (Narula and Santangelo, 2012; Martínez-Noya and Narula, 2018), the firm can utilise its international R&D alliances to co-specialise (Dyer and Singh, 1998) and rapidly build-up its absorptive capacity by learning about new technologies (Powell et al., 1996), foreign cultures (Heiman and Nickerson, 2004) and the reliability of potential foreign R&D partners (Gulati, 1998; Gilsing et al., 2008). Integrated triadic tactics consequently also enable reducing communication errors (Dyer, 1996) and the psychic distance (Johanson and Vahlne, 1977) to other and future foreign R&D partners in view of more effective cross-border R&D collaboration and faster time-to-market.

Integrating international R&D alliance relations within dense global network structures therefore not only advances the chipmaker's resource endowments, but importantly it can also enhance its ability to effectively reconfigure its resource base to coordinate the cross-border integration of complex complementary technologies and heterogenous knowledge to create new value and the joint application of technical skills and capabilities to develop novel technologies. Moreover, by integrating cross-border alliance relations with foreign R&D partners in both technology sectors and end-markets, chipmakers can enhance cross-industry resource flows and align the development and commercialisation of new technologies, as a means of also accelerating the speed at which they can effectively internationalise their R&D activities and derive greater value from these activities

Imperative to understanding the advantage of this triadic tactic is that close integration of international alliance relations stimulates R&D partners to take a long-term rather than a short-term approach to building their international R&D alliances, in view of maximising the long-term strategic benefits for all partners involved, as advocated by Morgan and Hunt's (1994) commitment-trust theory. While partners' mutual agreement to create value jointly is entirely voluntarily, their perception of value might be subject to different estimations of value (Zajac and Olson, 1993) and the signing of an alliance agreement is not a guarantee even for short-term commitment to cooperation (Williamson, 1979, 1981; Gulati, 1995a; Uzzi, 1996). The collective monitoring and sanctioning that is enabled by the rapid diffusion of partner-specific information in dense networks, however, instils a sense of trust and cooperation (Gulati, 1998, 2000; Kogut, 2000; Rowley et al., 2000) beyond what can be established within protective triads or dyadic alliance relationships and which arguably resembles a more efficient means to governing joint R&D than contractual agreements and formal self-enforcing safeguards based on equity stakes (Dyer and Singh, 1998). This creates a powerful stimulus for global R&D partners to focus on the long-term value creation potential of their international R&D alliances rather than deviating from the short-term value creation initiatives that partners agreed to by acting opportunistically or appropriating R&D outcomes as a means of maximising their own short-term returns at the cost of their partners', while also incurring long-term reputational damage and potential isolation from future participation in R&D projects across the wider network (Gulati, 1998; Rowley et al., 2000).

Protective and integrated triadic configurations clearly lead to distinct alliance network tactics for international R&D. The former can arguably enhance the internationalisation capabilities of leading chipmakers through access to and control over the process of integrating the *non-redundant* technologies and knowledge possessed by cross-industry partners in foreign regions into their own proprietary products or technologies. By contrast, integrated triadic tactics can enable chipmakers to develop an international open innovation strategy to capitalise on the benefits of *inclusivity*, rather than exclusivity, among foreign cross-industry R&D partners to establish effective governance mechanisms to closely fuse partners' strategic objectives and values, and overcome the inherent challenges to the creation of new value and the development of novel technologies through international R&D collaboration; such as risks of opportunism, geographical distance, and cognitive and cultural differences between geographically dispersed R&D partners.

Still, the general view has largely been that open collaborative environments, created through integrated triadic tactics, might lead to 'overembeddedness' or technological lock-in and consequently reduce the non-redundancy of knowledge, technologies and other strategic resources (Uzzi, 1997) which chipmakers might find and leverage in foreign markets to create novelty value. This network perspective suggests that, in contrast to what had long been suggested by classical theories on the internationalisation process (Johanson and Vahlne, 1977), there are constraints to the chipmaker's ability to maximise the creation of novelty value from the increasing involvement in foreign markets, and that these constraints can be overcome by strategically configuring international R&D alliance relations within triads. This renders the strategic utility of integrated triads for novelty creation through international R&D alliances, in particular, a matter of adequate network orchestration in line with the chipmaker's long-term strategic vision and objectives, available resources and ongoing developments in the industry – not merely the result of a casual response to a short-term innovation opportunity.

By combining cross-industry and cross-regional R&D collaboration within integrated triads, however, chipmakers can increase the cognitive differences to and among their foreign R&D partners to enhance the novelty creation potential of their international R&D alliances and, in result, reduce the risk of becoming overembedded. The chipmakers foreign R&D partners may, namely, well be specialised in radically different technological areas within the R&D ecosystem or be based in different industries entirely, such as in distinct technology sectors and foreign end-markets (KPMG, 2018). Therefore, rather than deliberately protecting its access to the non-redundant resources of these R&D partners, the chipmaker and its foreign R&D partners may generate greater value by cooperating more closely to complement one another's capacity to recognise the recombination potential of the third partner's technology, overcome cultural barriers, translate and absorb new codified and tacit knowledge, as well as accelerate commercialising the combination of resources as a novel product of joint cross-border and cross-industry innovation (Gilsing and Nooteboom, 2005; Gilsing et al., 2008).

In such a situation, integrated triadic tactics do not merely function as a relational mechanism which enhances the chipmaker's internationalisation capabilities in view of either (1) creating new value by complementing technologies and knowledge or (2) exploring and developing new chip technologies through learning and jointly applying technical skills and capabilities – but potentially both simultaneously due to more effective governance. Similarly, by integrating cross-industry R&D alliances bridging across multiple foreign countries within one triad, the firm can maximise the speed of R&D internationalisation by simultaneously accelerating its speed in committing resources to international R&D and its speed in learning about foreign markets. It is this distinctive function which could enable and accelerate creating and capturing superior novelty value from international R&D, consequently rendering integrating international alliances a more efficient and effective network strategy for internationalising R&D than protective triads and basic dyadic alliance strategies. Identifying and leveraging such coexisting opportunities would consequently represent a distinctive orchestration capability for chipmakers.

5.3. Hypothesis development

5.3.1. Enhancing the achievable value from international R&D through triadic tactics in the global semiconductor industry

The strategic configuration of international R&D alliances within integrated triads may especially prove advantageous in the context of high-tech industries, such as the global semiconductor industry. The fundamental focus of semiconductor R&D is increasingly on the development of fully-integrated, multi-functional and high-performing chips through international collaboration (Semiconductor Industry Association, 2016). While faced with short product life cycles, volatile customer demand and competitive pressures (Section 4.3), this demands chipmakers to utilise their global networks of R&D alliances to (1) combine complementary resources and capabilities as well as (2) enhance their learning advantage through the mutual exchange of knowledge.

The value of semiconductor chips is not merely a function of their speed, but rather their power efficiency, software, durability, functionality and size (Gloger et al., 2017). First of all, chipmakers can enhance the creation of new value through international R&D by utilising network tactics to swiftly and effectively coordinate the efficient integration of its core semiconductor technology with the complementary technologies (e.g. other semiconductor technology, IPs, (customised) software and systems) and capabilities (e.g. expertise in chip design and systems integration) of specialised technological complementors and systems companies (Kapoor, 2010), located in regional innovation centres and end-markets (Semiconductor Industry Association, 2016), into broader platforms or systems via R&D collaboration. Internationalising R&D through networks can thus also help chipmakers to achieve 'platform leadership' (Cusumano and Gawer, 2002) in foreign markets, defining both the chipmaker's ultimate long-term strategic goal and the superiority of its orchestration capability from a strategic network point of view.

Furthermore, to maintain long-term technological leadership in foreign markets, it is equally crucial for chipmakers to incrementally advance their existing resources and capabilities, and to jointly apply their technical skills and capabilities with those of foreign R&D partners to develop radically new knowledge and technologies through explorative innovation. As such, chipmakers might also capitalise on their R&D networks as a means of establishing relational types of R&D alliances which enable enhancing their learning advantages as well as the novelty of the value created through international R&D.

The choice of triadic tactic has clear implications for the internationalisation of R&D. The fact that foreign R&D partners are often based in various industry sectors, both within and outside the semiconductor industry (see Section 4.3), and that collaborating with these partners requires the exchange of tacit knowledge, renders the chip development process both cognitively and organisationally complex (Ernst, 2005). Chipmakers are simultaneously challenged to ensure their alliances bridge the cultural distance to their foreign R&D partners. Together, this requires that complementing resources and capabilities and recombining (new) knowledge bases is supported by efficient and effective task coordination as well as communication and knowledge-sharing practices, which can be more effectively established within integrated triadic R&D alliances than within dyadic or protective triadic R&D alliances.

Importantly, to recombine resources and heterogenous knowledge bases to enhance the novelty of the value created through international R&D, the complexity of partners' knowledge or technologies may easily exceed the absorptive capacity of a chipmaker so that knowledge-sharing practices cannot be effectively established within dyadic and protective triadic alliances. By contrast, complementing its existing resource base with the capabilities of a third R&D partner within an integrated triad may improve the chipmaker's ability to recombine heterogenous knowledge and technologies by enhancing its absorptive capacity, and thereby its ability to effectively enhance the novelty of value created through international R&D.

In sum, the following are hypothesised:

Hypothesis 1a	*Chipmakers are more likely to internationalise R&D through integrated triadic R&D alliances than through dyadic R&D alliances.*

Integrated triadic tactics might, concurrently, enhance the chipmaker's ability to improve its learning advantage through international R&D. Namely, this tactic enables bridging greater cultural and cognitive distances among foreign R&D partners located in geographically different regions, not merely in other countries, as well as searching for and absorbing more valuable, non-local tacit knowledge embedded in these non-local knowledge networks. It is therefore also hypothesised that:

Hypothesis 1b	*Chipmakers pursuing inter-organisation learning (through integrated triads) have a significant tendency to form inter-regional R&D alliances.*

The operational strategy[11] pursued by a chipmaker has implications for its ability to enhance the value created through international R&D by means of complementing its resources or advancing or developing (new) knowledge through learning. This should result in different degrees of strategic utility which chipmakers may derive from integrating their R&D alliances to enhance the value created through international R&D. Namely, accepting the premise that – in the global semiconductor industry – the optimal strategic utility of integrating international R&D alliances within triads stems from two mechanisms, (1) complementing core chip technologies with the technologies of foreign (cross-industry) partners and (2) learning through cross-border knowledge exchanges and the joint application of technical skills and capabilities within triadic structures, then the type of chipmaker likely to create the most value by internationalising R&D utilising integrated triadic tactics is the one best positioned to combine these two mechanisms within one triad.

Both the IDM and fabless models are built on the pooling of complementary resources and capabilities, and this is consequently essential to chipmakers' survival. The innovativeness of IDMs and fabless chipmakers alike is highly dependent on their ability to identify new advancements in complementary technologies and IPs which they can source from regional innovation centres and to combine or recombine these valuable assets with their own core technologies and capabilities (Ladendorf, 2004). Importantly, however, IDMs and chipmakers may have different motivations for integrating R&D alliance relations in foreign markets.

The comparatively capital-intensive nature of the IDM model requires that especially these chipmakers dominate their markets as losing their platform leadership would result in a detrimental impact on the IDM's ability to maintain a cost efficient operation and to survive. Maintaining market dominance in the modern semiconductor industry is, however, not possible by keeping operations and R&D processes within local markets. It is therefore crucial for IDMs to extend their R&D activities into foreign markets to reach complementary

[11] See Section 2.3 for a discussion about the main operational strategies pursued by chipmakers as well as the differences between them.

technologies, knowledge, skills and capabilities which are not accessible within their local markets, in order to maintain their technological leadership and competitive advantage. Forming triads (though captive in nature) with foreign R&D partners is important to their ability to rapidly develop and commercialise new products in their respective foreign markets by advancing the value achievable from integrating resource bases within triads (Saito, 2009).

Fabless chipmakers are free from this pressure for maintaining market dominance in foreign markets (Hung et al., 2017) and consequently enjoy greater flexibility to focus on the development of new knowledge and technologies for integration into market-specific systems and the exploration of new product-specific applications through relational R&D alliances – in addition to complementing existing technologies and knowledge. Increasing the potential for developing novel technologies requires that fabless chipmakers enlarge the cognitive distances to their R&D partners, such as by collaborating with distinct technology and systems partners in foreign markets; as well as that cognitive differences with these foreign R&D partners are effectively bridged within integrated triads, by enhancing the exchange of knowledge for learning, combining skills and capabilities, and improving cross-industry coordination.

Conversely, the IDM's strategic commitment to maintaining dominance and technological leadership in foreign markets rather constrains its flexibility to learn through the exploration of new knowledge and technological areas. Yet, to maintain its technological leadership in foreign markets, the IDM is pressured to enhance its learning advantage in order to advance its capacity to develop and commercialise innovative chip technologies. The advancement of its existing knowledge by learning from foreign R&D partners and the development of new knowledge through joint explorative innovation in foreign markets are, therefore, also of strategic importance to the IDM.

Although the inherent flexibility of the fabless operating model would arguably enable these chipmakers to more effectively integrate both complementing resources and learning within their international R&D triads, the importance of maintaining market dominance and platform leadership in foreign markets for IDMs might constitute a stronger force to form integrated relational alliances to combine reconfiguring its existing resource base and developing or advancing its learning advantage through international R&D. Consequently, we can argue that internationalising R&D through integrated triadic tactics can help especially IDMs to overcome their relative inflexibility by efficiently allocating their resources to the creation of new value and the development of novel technologies. Accordingly, it is hypothesised that:

Hypothesis 2a | *IDMs have a greater tendency than fabless chipmakers to internationalise R&D through integrated triadic R&D alliances than through dyadic R&D alliances.*

Importantly, effectively maintaining long-term technological leadership in foreign markets arguably requires that IDMs, more than their fabless counterparts, protect their access to their foreign sources of value and novelty creation by brokering the alliance relations between their foreign R&D partners, such as those operating in distinct technology sectors and end-markets. This would enable IDMs to act as technological gatekeepers (Boschma and Ter Wal, 2007) between foreign technology and end-markets within the wider semiconductor R&D network. Technological leadership can then be effectively secured through exclusionary tactics aimed at maintaining privileged access to valuable non-redundant resources, knowledge, skills and capabilities in foreign innovation centres as well as controlling which other R&D partners, within their own local markets as well as in foreign markets, can benefit from indirect access to these strategic assets and the extent of the value which they may derive. Accordingly, it is also hypothesised that:

Hypothesis 2b	*IDMs have a greater tendency than fabless chipmakers to broker international R&D alliances with foreign partners.*

5.3.2. Accelerating international R&D through triadic alliance partner selections in the semiconductor industry

Access to fundamental research expertise in foreign innovation centres

Fundamental research expertise is essential to the ability of chipmakers to explore and identify new directions for explorative innovation and to develop new chip technologies, as well as for reinforcing their positions in foreign markets. This expertise is typically located at universities and research centres based in regional innovation centres in the USA, Europe and Asia (Ernst, 2005), and are location-bound (Figure 5.1) owing to their highly tacit nature – consequently 'pulling' the fundamental R&D activities of chipmakers to these foreign partner locations (Granstrand et al., 1993; Cantwell and Iammarino, 2003; Watts, 2014).

Chipmakers can, however, utilise integrated triadic tactics to enhance the transferability of these research skills and capabilities across borders through effective trust-based governance and, in result, accelerate the development as well as commercialisation of new chip technologies in foreign markets. The challenges inherent to jointly conducting fundamental R&D, such as opportunism and cognitive differences between R&D partners, are amplified when these partnerships extend into foreign markets, notably due to cultural differences, language barriers to communicating highly technical and complex information, and differences in R&D management practices (Frost and Zhou, 2005). By closely integrating their alliance relations with foreign fundamental R&D partners within triads, however, chipmakers can (1) enhance mutual trust and commitment, which are necessary conditions for successful cooperation in fundamental R&D, efficient coordination of research tasks, and the exchange of knowledge; as well as (2) facilitating communication among foreign R&D partners, developing their learning advantages and capacity to absorb fundamental knowledge from their foreign partners through the process of triangulation (see Section 4.2.3).

The following is therefore hypothesised:

Hypothesis 3a	*Chipmakers are more likely to form international R&D alliances with fundamental R&D partners, notably universities and research centres, through integrated triads than through dyads.*

Access to complementary location-bound technological assets

Similarly, radical changes in dominant design methodologies of chips, notably the SoC design, to enable the Internet of Things (IoT), have increased the cognitive and organisational complexity of developing new chips (Ernst, 2005; Bauer et al., 2015). The ability of a chipmaker to derive value from internationalising its R&D activities is consequently determined by its position as a platform leader in pooling complementary resources and knowledge from specialised foreign partners based in various distinct technology sectors, and integrating these strategic assets with their own chip technologies and design capabilities as swiftly as possible.

To accelerate the speed of value creation by pooling and complementing these assets through international R&D alliances demands that leading chipmakers coordinate this process most efficiently – by integrating their captive R&D alliances within triadic structures rather than collaborating through dyadic alliances. A third R&D partner (whether local to the other partner or not) might facilitate the exchange of tacit knowledge within the triad by screening and interpreting potentially novel information and the value of this information to the leading chipmaker (Vanhaverbeke et al., 2003), as well as minimising cross-cultural communication errors. Moreover, a collaborative environment in which knowledge exchange and debate are fostered can enhance the leading chipmaker's ability to more rapidly redirect the R&D process among multiple partners who work toward a common goal of enabling a given system (Cusumano and Gawer, 2002). Integrated triads might therefore act as a more effective mechanism for leading chipmakers to govern the process of creating value by complementing technological assets.

Accordingly, the following is hypothesised:

Hypothesis 3b	*Chipmakers are more likely to form international R&D alliances with technological complementors through integrated triads than through dyads.*

Access to foreign end-market knowledge

Enhancing the value created from international R&D further demands that leading chipmakers optimise their R&D network to accelerate commercialisation of product innovations in foreign markets by pooling capacity to design the overall system architectures and specify product applications (Ernst, 2005). It is therefore optimal for chipmakers to conduct R&D in close collaboration with systems partners in foreign end-markets who possess the local market knowledge and direct access to end-user feedback needed to rapidly learn about foreign markets and design improved or novel products integrating the core chip technology of leading chipmakers. Access to this external knowledge is also critical to the chipmaker's ability to achieve global platform leadership (Cusumano and Gawer, 2002).

To effectively increase the speed of learning about foreign markets and systems designs, however, chipmakers need to be able to transfer tacit knowledge efficiently from the foreign systems partner to the leading chipmaker within an integrated triadic alliance structure. Firstly, integrated triads can help chipmakers to establish mutual trust among foreign R&D partners which is critical to the exchange of tacit knowledge (Dyer and Singh, 1998). Secondly, collaborating with multiple foreign partners simultaneously within an integrated triad – whether both are systems companies or only one – who may possess complementary knowledge about the same foreign market or diverse knowledge about different foreign markets, would help to create the most effective learning tactic through which the leading chipmaker could further accelerate the development of its learning advantage and its ability to rapidly commercialise innovations across foreign markets (Figure 5.1).

Accordingly, leading chipmakers might derive strategic utility from integrating systems partners based in foreign end-markets within triadic R&D alliances. The following is therefore hypothesised:

Hypothesis 3c	*Chipmakers are more likely to form international R&D alliances with end-market partners (systems companies) through integrated triads than through dyads.*

5.3.3. Combining cross-industry and international diversification R&D alliance strategies in triads

Notably, the integration of the leading chipmaker's own core chip technologies and design capabilities with both (1) the complementary technologies and technical capabilities of foreign technological complementors and (2) the local market knowledge and system/product-specific expertise of foreign systems partners within triadic R&D alliances, would enable the leading chipmaker to not only (a) enhance the novelty value created from international R&D by complementing resources and jointly applying technical skills and capabilities, but to simultaneously (b) accelerate the *process* of internationalising R&D to create value, by complementing its own committed resources with external assets and via inter-organisational learning.

This would therefore arguably help to create the most efficient and effective alliance strategy to swiftly create superior value through international R&D, and would consequently represent a distinctive network orchestration capacity which would enable the achievement of global platform leadership (Cusumano and Gawer, 2002). Accordingly, it is hypothesised that:

Hypothesis 4a	*Chipmakers have a significant tendency to form international cross-industry R&D alliances within integrated triads.*

With the aim of minimising the cultural and cognitive distance between R&D alliance partners within integrated triads, however, as a means of ensuring greater efficiency in coordinating the integration of pooled complementary resources and capabilities with tacit knowledge about local markets and system or product-specific architectures, we might expect that:

Hypothesis 4b	*In international cross-industry R&D alliances within integrated triads, chipmakers are more likely to source complementary technological assets in proximity to the end-market.*

5.4. Research methodology

5.4.1. Network sample and data

The analysis conducted in this chapter relied on the alliance dataset used in Chapter 3. For details on the sources and the method of collection of the data used in the current chapter, please see Section 3.6. Specifically, the current study relies on the R&D network sample which was used in Chapter 4. This sample is composed of 1,827 organisations, out of which 425 are chipmakers (38 IDMs and 387 fabless chipmakers), with a total of 4,559 domestic and international R&D alliance formations[12] across the period 2004-2014.

In order to analyse whether triadic network tactics might prove more effective for internationalising R&D than dyadic tactics, most hypotheses require that distinct sub-networks are created – as opposed to the overall network – which allow testing distinct international R&D alliance strategies and which are solely composed of R&D alliance ties to the types of strategic partners that chipmakers may specifically select to execute this international R&D alliance strategy within triadic structures. The sub-networks, within which these collaborative interactions between chipmakers and their R&D partners are captured, are based on one-mode matrices in which the direction of resource flows is also captured.

By creating sub-networks which are based on specific triadic tactics and R&D alliance ties with specific foreign partner types, we can reduce the complexity of the network of interest

[12] Please see Section 4.4.1 for the types of R&D alliances included in this sample.

and more easily analyse whether and to what extend distinct R&D strategies are executed through the formation of specific triadic constructs within the sub-network. This follows a method of network construction utilised in other fields of research (e.g. Zhao et al., 2016; Hepburn, 2017). The specific definitions for each of the distinct sub-networks created in this study are provided together with the SAOM specifications in the next section.

5.4.2. Specification of network models & international sub-networks

This study follows Chapter 4 in adopting stochastic actor-oriented modelling[13] (Snijders, 1996, 2011), shortened for SAOM, to analyse the formation of international R&D alliances within triadic network structures over time. This method is advantageous over traditional regression techniques conventionally utilised by alliance researchers in IB. It is inherently based on the assumption that cross-border alliance formations are not only driven by the pursuit for foreign partner-specific and location-bound assets, but also by the structure of the alliance network. The method takes into account the interdependence that is inherent to the formation of international R&D alliances between pairs of organisations vis-à-vis the presence of other R&D alliance relations (i.e. endogenous structural effects) as well as the characteristics of other organisations and distinctive attributes of dyadic and triadic alliance relations (i.e. exogenous structural effects) in the network.

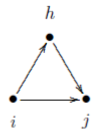
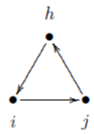
SAOM is an important method to the study of internationalisation of R&D through alliances as it allows capturing endogenous structural effects (the presence of other R&D alliances within the firm's network) and exogenous structural effects (the presence of other actors in the network and their attributes) which can help to explain the importance of network advantages associated with triadic structures to the formation of international R&D alliances. Traditional regression techniques typically utilised by IB scholars are not able to capture these network effects. We implement the SAOMs using the program *SIENA* (Simulation Investigation for Empirical Network Analysis) in the statistical tool R, which has been developed and maintained by Ripley et al. (2019).

In this study, we specify several SAOMs and distinct sub-networks to test chipmakers' tendencies toward the formation of international R&D alliances within triadic structures vis-à-vis dyadic structures as a means of enhancing the value created through international R&D; as well as their preferences for choosing specific types of foreign R&D partners when forming international R&D alliances within triadic structures as a means of accelerating the internationalisation of R&D. To capture chipmakers' tendencies to form international R&D alliances within triads, structural effects and ego and dyadic covariates are included in the models – i.e. observed variables (based on organisational characteristics) which are expected

[13] For a more detailed and technical description of this method, please see Section 4.4.2.

to explain the formation of international R&D alliances within triads by chipmakers, within distinct sub-networks. Table 5.1 provides an overview of all the effects which are included.

Table 5.1: Specification of SAOMs for hypothesis testing and the interpretation of structural, ego and dyadic effects (source: Ripley et al., 2019)

Hypothesis	Effect	Formal expression	Interpretation
	Structural		
1a; 3a; 3b; 3c	Transitive triplets (*transTrip*)	$\sum_{j,h} x_{ih} x_{ij} x_{jh}$ 	Captures number of transitive patterns in *i*'s relationships: where *i* has an alliance with the pair (*j*, *h*) who are also tied to each other. Triplets of type {$i \rightarrow j \rightarrow h$; $i \rightarrow h$} and {$i \rightarrow h \rightarrow j$; $i \rightarrow j$}.
2a	3- cycles (*cycle3*)	$\sum_{j,h} x_{ij} x_{jh} x_{hi}$ 	Captures the number of three-cycles (regarded as generalised reciprocity), within a triplet of type {$i \rightarrow j \rightarrow h \rightarrow i$}.
2b	Betweenness (*between*)	$\sum_{j,h} x_{hi} x_{ij} (1 - x_{hj})$	Effect captures the non-existence of alliance tie $h \rightarrow j$ in a triad with ties $h \rightarrow i$ and $i \rightarrow j$.
	Ego		
1b; 2a; 2b	*V*-ego (*egoX*)	$v_i x_{i+}$	*i*'s out-degree weighted by its covariate value (*V*).
	Dyadic		
4a	Different *V* (*sameX*)	$\sum_{j} x_{ij} (v_j - v_i)$	The alter-minus-ego difference of the covariate over all actors to whom *i* has an alliance tie.
1b; 4b	Same *V* (*sameX*)	$\sum_{j} x_{ij} l\{ v_i = v_j\}$	The number of alliance ties of *i* to all other actors *j* who have exactly the same covariate value (*V*).
	Controls		
1a; 1b; 3a; 3b; 3c; 4a	Reciprocity (*recip*)	$\sum_{j} x_{ij} x_{ji}$	Number of reciprocated ties between *i* and *j*.
2b	Out-degree (log) (*outRateLog*)	$\exp(\ln(\alpha_h (x_i + 1))) = (x_{i+} + 1)^{\alpha h}$	Log of out-degree effect $x_{i+} = \sum_j x_{ij}$ where x_{ij}= 1 indicates the presence of the tie $i \rightarrow j$.

Preference for the formation of international triadic R&D alliances vis-à-vis dyadic R&D alliances, captured with the *3-cycles* and *transitive triplets* effects, is explicitly modelled only in hypotheses 1a, 2a, 3a, 3b and 3c because the sub-networks used for testing these hypotheses include both triadic and dyadic R&D alliances. It is important to note that both of these structural effects capture

Table 5.2: Overview of estimation equations and descriptions of associated sub-networks

Hypothesis	Estimation equation	Sub-network description
1a	$f_i(\beta, x) = \beta_1 transTrip_{ijh} + \beta_2 recip_{ij}$	**Sub-network of cross-country R&D alliances** • *Focal*: chipmakers (IDM and fabless). • *Partners*: any type*. • *Ties*: both dyads and triads in which both R&D partners are foreign to the chipmaker, but both partners can be located in the same foreign country.
1b	$f_i(\beta, x) = \beta_1 (Chipmaker\text{-}egoX_i * Country\text{-}sameX_{ij}) + \beta_2 recip_{ij}$	**Sub-network of triadic R&D alliances** • *Focal*: chipmakers (IDM and fabless). • *Partners*: any type. • *Ties*: triads only, comprised of both domestic and international alliances.
2a	$f_i(\beta, x) = \beta_1 (cycle3_{ijh} * IDM\text{-}egoX_i) + \beta_2 (cycle3_{ijh} * Fabless\text{-}egoX_i)$	**Sub-network of cross-country R&D alliances** • *Focal*: chipmakers (IDM and fabless). • *Partners*: any type. • *Ties*: both dyads and triads in which both R&D partners are foreign to the chipmaker, but both partners can be located in the same foreign country.
2b	$f_i(\beta, x) = \beta_1 (between_{ij} * IDM\text{-}egoX_i) + \beta_2 (between_{ij} * Fabless\text{-}egoX_i) + \beta_3 outRateLog_i$	
3a	$f_i(\beta, x) = \beta_1 transTrip_{ijh} + \beta_2 recip_{ij}$	**Sub-network of cross-country fundamental R&D alliances** • *Focal*: chipmakers (IDM and fabless). • *Partners*: university/research centres; any other type. • *Ties*: both dyads and triads (read: only three-way alliance ties that are part of one and the same multi-partner alliance) in which at least one chipmaker and one university/research centre are participants, and the third partner could be of any type. All partners are foreign to the chipmaker.
3b		**Sub-network of cross-country complementary technology alliances** • *Focal*: chipmakers (IDM and fabless). • *Partners*: technological complementors (TC); any other type. • *Ties*: both dyads and triads in which both R&D partners are foreign to the chipmaker. Dyads only exist between chipmakers and TCs; triads are formed between at least one chipmaker, one TC and any other type of partner.
3c		**Sub-network of cross-country end-market alliances** • *Focal*: chipmakers (IDM and fabless). • *Partners*: end-industry partners (systems companies); any other type. • *Ties*: both dyads and triads in which both R&D partners are foreign to the chipmaker. Dyads only exist between chipmakers and end-industry partners; triads are formed between at least one chipmaker, one end-industry partner and any other type of partner.
4a	$f_i(\beta, x) = \beta_1 Country\text{-}diffX_{ij} + \beta_2 recip_{ij}$	**Sub-network of triadic cross-industry, cross-country R&D alliances** • *Focal*: chipmakers (IDM and fabless). • *Partners*: technological complementors (TC) and end-industry partners (systems companies). • *Ties*: triads only, in which at least one R&D partner is foreign to the chipmaker and, in the case when both partners are foreign, they can be located in the same foreign country.
4b	$f_i(\beta, x) = \beta_1 Country\text{-}sameX_{ij}$	**Sub-network of triadic cross-industry, cross-country R&D alliances** • *Focal*: chipmakers (IDM and fabless). • *Partners*: technological complementors (TC) and end-industry partners (systems companies). • *Ties*: triads only, in which both R&D partners are foreign to the chipmaker, but both partners can be located in the same foreign country.

** Please see Table 4.2 in Section 4.3 for the types of R&D partners in the semiconductor R&D alliance network.*

the tendency toward network closure through the formation of triads; however, they capture different directions of resource flows (see Table 5.1). The remaining hypotheses (1b, 4a, 4b and 4c) are tested on sub-networks composed of exclusively triadic R&D alliance structures, thus eliminating the need to include either of these triadic effects in the relevant models. Details on all distinct sub-networks, along with the model specifications for each of the hypotheses, are provided in Table 5.2.

To model the formation of distinct triadic constructs that chipmakers may use to internationalise R&D through alliances, several important ego and dyadic covariates are included across the models. Ego effects are used to determine whether an organisation is an IDM ($IDM\text{-}egoX$) (hypotheses 2a and 2b) or a fabless chipmaker ($Fabless\text{-}egoX$) (hypotheses 2a and 2b). Dyadic effects are used to evaluate the preference of chipmakers in general to form R&D alliances with R&D partners in countries and regions different from their own. In light of capturing interregional R&D alliance formations, the sample has been split into the regions North America (Canada and the US), Europe, Asia and 'Other'. Notably the former three regions resemble the established and upcoming regional innovation centres within the global semiconductor industry where the majority of collaborative R&D takes place (Ernst, 2005; Semiconductor Industry Association, 2016). Additionally, two-way structural-ego and ego-dyadic interactions between some of the effects are included[14].

The choice of control variables is also different from the traditional regression models conventionally used in IB studies, because of the focus of the study and the specification of SAOMs. The SAOMs specified will control for chipmaker types as a proxy of firm-level attributes, such as size, age and R&D intensity, which are conventionally used in internationalisation studies to analyse the formation of international R&D alliances.

The 'chipmaker type' proxy is relevant because the chipmaker's choice to internationalise its R&D alliances through integrated or protected triadic tactics, as opposed to dyads, ought to be determined by the specific needs of the operating model based on which it conducts business, namely either the IDM or fabless operating model; rather than direct effects of company-level attributes, as conventionally used with traditional regression models. Moreover, the methodology underlying the SAOM does not require conventional company-level attributes to estimate the effects of network closure and brokerage on the formation of international R&D alliances within triadic alliance configurations.

Importantly, the chipmaker types do function as a proxies for the size, age and R&D intensity of chipmakers, because IDMs can only be successfully operated by large, long-established companies with extensive financial resources and market experience, owing to the substantial financial constraints inherent to the IDM model; and smaller and younger organisations with limited internal resources are therefore only able to efficiently sustain a fabless operation

[14] Ripley et al. (2019) advise that the individual effects underlying an interaction effect do not need to be included in the same model as well.

which is inherently centred on inter-organisational collaboration. In addition, a few structural control effects are included in several models to control for skewed out-degree distributions of chipmakers ($outRateLog$) as well as chipmakers' tendency to reciprocate the formation of R&D alliance ties ($recip$) – as advised by Ripley et al. (2019).

5.5. Network analysis results

5.5.1. *Patterns of international and interregional R&D alliance formations*

The importance of international alliances to R&D in the semiconductor industry is underscored by the vast dispersion of joint R&D across countries as well as geographical regions (see Table 5.3). The formation of international R&D alliances[15] consistently accounts for over 50% of all alliance formations across the sample period, and interregional R&D alliances for just short of 50%. It is clear that for chipmakers it is not a matter of whether to collaborate internationally, but rather how to collaborate efficiently and effectively through the utilisation of distinct network tactics in order to maximise their internationalisation advantage.

Table 5.3: International and interregional R&D alliance formations (multiplex alliance relations excluded)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
# international (cumulated)	191	353	604	781	962	1,107	1,277	1,505	1,643	1,779	1,952
*International ratio**	57%	56%	54%	55%	56%	54%	53%	54%	54%	54%	54%
# interregional (cumulated)	164	307	529	684	823	941	1,087	1,277	1,398	1,513	1,648
Interregional ratio	49%	49%	48%	48%	48%	46%	45%	46%	46%	46%	46%

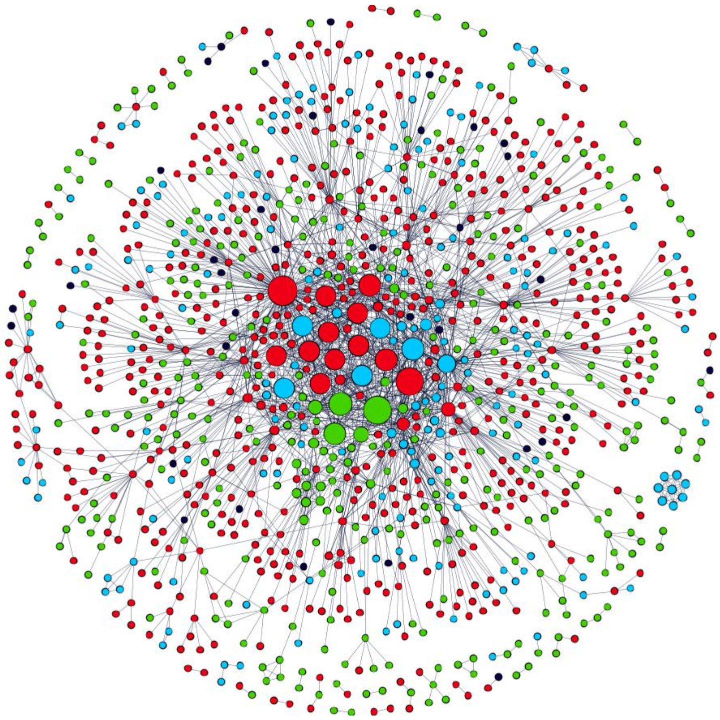
**International/regional ratio shows the number of international/regional alliances against the total (including domestic alliances)*

The process of inter-regionalisation of R&D, in particular, might be accelerated by the formation of strategic alliances within triadic configurations as a means of efficiently and effectively overcoming larger cultural and cognitive distances and outpacing incremental internationalisation processes suggested by traditional IB models (Johanson and Vahlne, 1977). This is illustrated by Figure 5.2, which shows that strategic partners from across the R&D ecosystem and across the industry's most important and upcoming regional innovation centres – i.e. North America (notably the US), Europe and Asia (notably China, South Korea and Japan) – are increasingly pulled into the densely integrated gravitational centre of the semiconductor R&D network where semiconductor companies collaborate inter-regionally within triadic structures. Concurrently, there are no obvious indications that semiconductor

[15] When not specified otherwise, an R&D alliance is defined as a single collaborative relationship which exists between at least two partner organisations. It does not capture multiple agreements that a these alliance partners might potentially have between them.

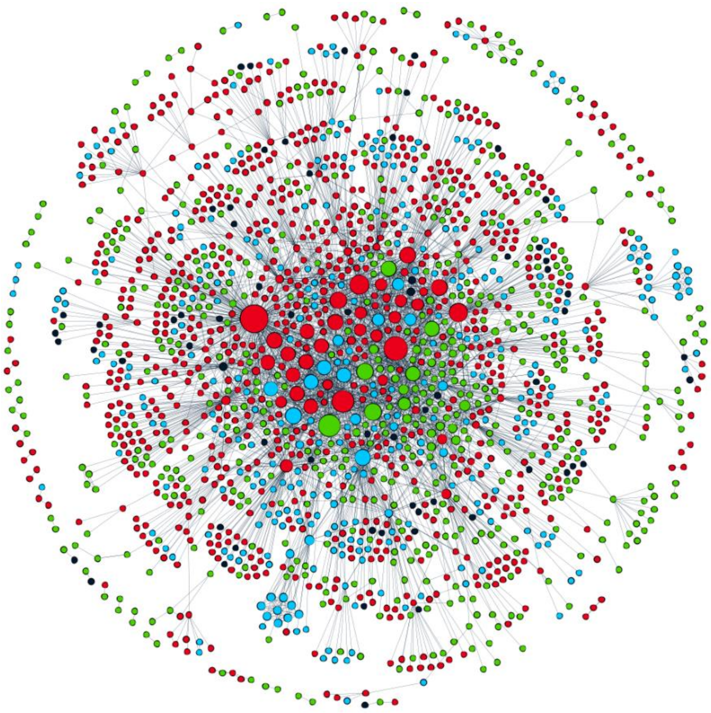
Complete R&D alliance network (period 2004-2009)

1,152 organisations; 2,044 dyads; 2,088 triads



Complete R&D alliance network (period 2004-2014)

1,827 organisations; 3,601 dyads; 4,212 triads



Node size based on the firm's number of triad memberships

Node colour: North America; Europe; Asia; Other

Figure 5.2: Evolution of inter-regional integration of R&D alliance network

companies have a preference for geographical clustering within their home regions – neither in 2009, nor in 2014.

The visuals suggest that this is especially the case for R&D partners based in Asia. While the industry's regional innovation centres had traditionally been concentrated in the US, South Korea, Japan and Europe (Semiconductor Industry Association, 2016), with fabrication largely concentrated in other parts of Asia, Asia's role as an innovation centre for semiconductor R&D has been rapidly growing since the start of the sample period (Ernst, 2005). This is notably due to the increasing population of Asian organisations specialising in the development of chip designs and electronic design automation (EDA) tools, and the growing emergence of Asian systems companies as customers or design partners to chipmakers in the age of the IoT (Ernst, 2005).

This can also be seen from the descriptive statistics in Table 5.4, which show that a majority of the R&D conducted with Asian partners spans across regional borders. This may reflect the relatively new trend in the collaborative behaviour of chipmakers in view of moving their joint R&D activities from traditional innovation centres, such as in the USA, to those in Asia (Ernst, 2005). This trend has been highlighted in Section 2.1.1. The fact that the proportion of interregional alliances with Asian partners has been declining suggests that foreign and Asian semiconductor companies alike have recognised the potential value that they may derive from collaborating with (other) Asian R&D partners and are thus seeking to expand their R&D alliance networks within Asia to explore new opportunities for novelty value creation across technological fields and product applications which potential R&D partners in this region can offer.

Table 5.4: Interregional R&D alliance formations broken down by region (multiplex alliance relations excluded)

Region	Metric	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
N. America	# alliances (cum.)	149	277	463	595	717	815	938	1,112	1,215	1,315	1,427
	Interregional ratio*	52%	52%	52%	53%	54%	53%	54%	54%	54%	54%	54%
Europe	# alliances (cum.)	69	128	251	316	377	446	519	605	655	705	753
	Interregional ratio	79%	86%	79%	80%	77%	77%	71%	72%	72%	73%	73%
Asia	# alliances (cum.)	103	193	312	409	495	549	625	732	798	867	964
	Interregional ratio	86%	80%	78%	76%	75%	69%	68%	70%	70%	70%	68%
Other	# alliances (cum.)	7	16	32	48	57	72	92	105	128	139	152
	Interregional ratio	100%	100%	97%	94%	93%	94%	94%	94%	95%	95%	95%

** Interregional ratio shows the number of interregional alliances against the total (including domestic alliances)*

The data in Table 5.5 show that, indeed, across the board there has been an increase in the R&D alliances formed with partners based in Asia. Notably, the number of intraregional R&D alliances between Asian partners has nearly doubled between 2009 and 2014 – from 244 to 445 – and American-Asian R&D alliances have increased at a similar rate – from 432 to 765.

Proportionally, Asian organisations have also become a more prominent type of R&D partner within the industry's global R&D network, while American organisations' relative prominence has decreased. Accordingly, this suggests that R&D alliances enable semiconductor companies to efficiently and effectively conduct R&D internationally and to enhance the (novelty) value created through international R&D with R&D partners outside of traditional regional innovation centres.

Table 5.5: Regional integration of R&D (two periods compared; multiplex alliance relations excluded)

	Interregional R&D alliance formations (#) and ratios (%)* (2004-2009)							
	N. America	**Europe**	**Asia**	**Other**	**N. America**	**Europe**	**Asia**	**Other**
N. America	717	332	432	51	35.1%	16.2%	21.1%	2.5%
Europe	-	137	105	9	-	6.7%	5.1%	0.4%
Asia	-	-	244	12	-	-	11.9%	0.6%
Other	-	-	-	5	-	-	-	0.2%
	Interregional R&D alliance formations (#) and ratios (%) (2004-2014)							
	N. America	**Europe**	**Asia**	**Other**	**N. America**	**Europe**	**Asia**	**Other**
N. America	1,222	554	765	108	33.9%	15.4%	21.2%	3.0%
Europe	-	278	177	22	-	7.7%	4.9%	0.6%
Asia	-	-	445	22	-	-	12.4%	0.6%
Other	-	-	-	8	-	-	-	0.2%

**Interregional ratio shows the number of Region-to-Region alliances as a proportion of the total number of all intraregional and interregional alliances formed during the period*

The differences in the motives for IDMs and fabless chipmakers to internationalise R&D through alliances are evident from the descriptive statistics in Table 5.6 and Table 5.7. Overall, Table 5.6 shows that 55% of all R&D alliances formed by chipmakers across the entire sample period are formed with foreign partners, which indicates a large overall preference for international R&D collaboration. This tendency appears to be stronger for IDMs than for fabless chipmakers, although there seems to be a shift by IDMs toward expanding their domestic R&D alliance networks, while fabless chipmakers appear to focus increasingly more on expanding their international R&D alliance networks. This is true in both North America and Asia, which points toward increasing integration of R&D between these two regions (as shown in Table 5.5).

Table 5.6: Evolution of international R&D alliance formations, split by region and chipmaker type (multiplex alliance relations excluded)

		2004-2009			2004-2014		
Region	**Metric**	**IDM**	**Fabless**	**Overall**	**IDM**	**Fabless**	**Overall**
N. America	# alliances (cum.)	342	288	630	529	596	1,125
	International ratio*	58%	41%	49%	56%	46%	50%
Europe	# alliances (cum.)	100	63	163	143	147	290
	International ratio	94%	86%	91%	93%	80%	86%
Asia	# alliances (cum.)	54	94	148	59	179	238
	International ratio	53%	56%	55%	46%	57%	54%
Other	# alliances (cum.)	0	10	10	1	17	18
	International ratio	-	100%	100%	100%	94%	95%
Overall	# alliances (cum.)	496	455	951	732	939	1,671
	International ratio	62%	48%	54%	59%	52%	55%

**International ratio shows the number of international alliances against the total (including domestic alliances)*

The differences in internationalisation motives between IDMs and fabless chipmakers are further reflected by their foreign partner choices (see Table 5.7). With an increase from 36% to 47% in the share of international R&D alliances with technology complementors between the end of 2009 and 2014, it is evident that the international R&D alliance strategies of fabless chipmakers are increasingly driven by a motive to access foreign technologies; namely, to complement their core technologies and chip design capabilities with the technologies, IPs and knowledge of foreign technological complementors in order to enhance the value of their chip technologies. By contrast, the international alliance formations of IDMs show an increase from 61% to 63% in the share of international R&D alliances with foreign end-market partners. This indicates a growing focus on linking the development and commercialisation of new chip technologies in foreign markets and may thus reflect IDMs' motive to internationalise R&D to achieve and maintain their technological leadership and dominance in foreign markets.

Table 5.7: Chipmakers' partner choices for international R&D collaboration (multiplex alliance relations excluded)

		2004-2009				2004-2014			
Chipmaker type	**Metric**	**Uni/ research centre**	**Tech. C.**	**End-market**	**Other**	**Uni/ research centre**	**Tech. C.**	**End-market**	**Other**
IDM	*# of intl. alliances*	14	82	123	334	23	139	175	503
	*International ratio**	64%	59%	61%	64%	62%	57%	63%	62%
Fabless	*# of intl. alliances*	14	62	92	263	27	164	177	576
	International ratio	58%	36%	55%	47%	45%	47%	56%	52%

**International ratio shows the number of international alliances against the total (including domestic) alliances formed with a given partner type; **'Tech. C.' is short for 'Technological complementor'.*

Interestingly, while chipmakers' do seem to have a strong focus on accessing fundamental R&D expertise from universities and research centres in foreign markets, chipmakers appear to shift their fundamental R&D networks toward the domestic market – fabless chipmakers in particular, as indicated by the decreasing ratio of international alliances from 58% to 45%. This might suggest that fabless chipmakers, owing to resource constraints, are not yet as advanced as IDMs in their orchestration capability to design triadic network strategies to effectively overcome their cultural and cognitive distances to foreign R&D partners and consequently derive greater value from international R&D alliances.

5.5.2. Stochastic actor-oriented model results

Results were obtained for a total of 11 SAOMs, displayed in Table 5.8 on the next page. These models were run on distinct sub-networks, and results for each hypothesis are provided by a single model – with the exception of hypotheses 4a and 4b, which required a comparison of two models. It is indicated whether a model is focused on cross-country or cross-regional collaboration. Table 5.8 reports only the final model results; however, robustness checks were performed by including relevant structural, dyadic and ego effects individually in the models.

We retained the models with the best model fit – as indicated by good convergence of the estimation algorithm and measured by the overall maximum convergence ratio in line with Ripley et al. (2019). Good convergence was obtained for all models except for model 5.

The control effects $Out\text{-}degree$ (log) and $Reciprocity$ were only included in those models where an improved model fit was obtained, namely in all models except for models 4 and 9.1. No effects were excluded from the models and all insignificant effects were retained as they were of primary interest to the hypothesis tests.

As the hypotheses were tested for positive relationships, one-sided p-values were used to confirm statistical significance of the included effects. We tested the model parameters by referring the t-ratios $(\frac{estimate}{standard\ error})$ of all modelled effects to a standard normal distribution, following the method suggested by Snijders et al. (2010).

Statistically significant support is obtained for all hypotheses, which will be discussed in detail one by one. Model 1 provides a statistically significant $Transitive\ triplets$ effect (t = 6.74/1.52 = 4.43, one-sided p < 0.01), indicating that chipmakers have a greater tendency to internationalise R&D through integrated R&D alliances than through dyadic R&D alliances (*H.1a*). This suggests that configuring international R&D alliances within triadic structures may help chipmakers to overcome cultural and cognitive distance and consequently enhance the value created through international R&D. In addition, model 2 provides a statistically significant $Chipmaker\ ego * Country\text{-}sameX$ interaction effect (t = 0.01/0.004 = 2.5, one-sided p < 0.01), which indicates that chipmakers have a preference to form R&D alliances within triadic configurations when they collaborate with partners in foreign regions (*H.1b*). This suggests that R&D internationalisation is taking more complex network forms through triads.

Table 5.8: Estimated parameters and significance levels for final models

Model	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8.1**	**8.2**	**9.1**	**9.2**
Hypothesis	**H.1a**	**H.1b**	**H.2a**	**H.2b**	**H.3a**	**H.3b**	**H.3c**	**H4a**		**H4b**	
Utility function	*Cross-country*	*Cross-regional*	*Cross-country*	*Cross-country*	*Cross-country*	*Cross-country*	*Cross-country*	*Cross-country*	*Cross-regional*	*Cross-country*	*Cross-regional*
Transitive triplets	6.74*** (1.52)				0.86** (0.40)	1.91*** (0.36)	4.82*** (1.41)				
Chipmaker ego * country-sameX		0.01*** (0.004)									
IDM ego * 3-cycles			0.54*** (0.25)								
Fabless ego * 3-cycles			-1.04*** (0.29)								
IDM ego * betweenness				128.29*** (33.97)							
Fabless ego * betweenness				3.04** (1.67)							
Country-diffX								0.012** (0.006)			
Region-diffX									0.02 (0.11)		
Country-sameX										2.46*** (0.39)	
Region-sameX											1.30*** (0.23)
Control effects											
Out-degree (log)	Excl.	Excl.	Excl.	Incl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.
Reciprocity	Incl.	Incl.	Excl.	Excl.	Incl.	Incl.	Incl.	Incl.	Incl.	Excl.	Incl.
Overall maximum convergence ratio	0.16	0.08	0.12	4.26	0.14	0.09	0.10	0.09	0.12	0.14	0.14
Sub-network characteristics[16]											
Number of organisations	969	572	969		63	367	381	668			
Number of alliance ties	1,886	2,483	1,886		99	501	556	291			
Number of integrated triads	1,640	4,212	1,640		29	155	421	196			

*Main entries represent estimated coefficients (standard errors are shown between brackets). Convergence ratio is a measure of model fit (<0.25 indicates a good fit). Significance indicated as * p<0.10; ** p<0.05; *** p<0.01.*

[16] Please note that the figures indicating the number of integrated triads capture the total number of *triad memberships* of all organisations in the network, rather than the total number of triadic formations in the network. For example, a single triad would be counted as three triad memberships because there are three organisations in the triad.

Model 3 offers support for hypothesis 2a, as indicated by the statistically significant $IDM\ ego *$ 3-$cycles$ (t = 0.54/0.25 = 2.16, one-sided $p < 0.05$) and the $Fabless\ ego *$ 3-$cycles$ (t = -1.04/0.29 = -3.59, one-sided $p < 0.01$) interaction effects. Both of these effects were consistently obtained with, respectively, positive and negative estimates in models where the 3-$cycles$ effect was replaced with the $Transitive\ triplets$ effect; however, the model with the 3-$cycles$ effect provided better model fit. This result indicates that IDMs have a greater tendency than fabless chipmakers to internationalise R&D through integrated triadic R&D alliances.

Concurrently, model 4 indicates that IDMs also have a greater tendency than fabless chipmakers to broker international R&D alliances with foreign partners ($H.2b$) – as indicated by the positive statistically significant $IDM\ ego * Betweenness$ (t = 128.29/33.97 = 3.78, one-sided $p < 0.01$) and $Fabless\ ego * Betweenness$ (t = 3.04/1.67 = 1.82, one-sided $p < 0.05$) interaction effects. The larger estimate for the former effect indicates that this tendency is relatively greater for IDMs in comparison to fabless chipmakers. In spite of this result, however, model 4 did not obtain good model fit as indicated by the overall maximum convergence ratio of 4.26.

Model 5 provides support for hypothesis 3a as indicated by the statistically significant $Transitive\ triplets$ effect (t = 0.86/0.40 = 2.15, one-sided $p < 0.05$) – suggesting that chipmakers are more likely to internationalise fundamental R&D alliances through integrated triads than dyads. Similarly, in model 6, the $Transitive\ triplets$ effect is also statistically significant (t = 1.91/0.36 = 5.31, one-sided $p < 0.01$), which indicates that chipmakers are also more likely to form international R&D alliances with technological complementors through integrated triads than through dyads. Model 7 further confirms support for hypothesis 3c with a statistically significant $Transitive\ triplets$ effect (t = 4.82/1.41 = 3.42, one-sided $p < 0.01$) – indicating that chipmakers have a greater tendency to form international R&D alliances with end-industry partners (systems companies) through integrated triads than through dyads. Overall, the results obtained from models 5-7 suggest that integrated triads for these R&D alliance strategies become a dominant form of internationalisation.

Models 8.1 provides support for hypothesis 4a as indicated by the statistical significant $Country\text{-}diffX$ effect (t = 0.012/0.006 = 2.00, one-sided $p < 0.05$) – suggesting that chipmakers have a tendency to form international cross-industry R&D alliances within integrated triads with at least one foreign R&D partner. However, the statistically insignificant $Region\text{-}diffX$ effect (t = 0.02/0.11 = 0.18, one-sided $p > 0.10$) obtained in model 8.2 suggests that chipmakers do not yet possess sufficiently advanced orchestration capabilities to utilise integrated triadic R&D alliances to cross regional border to search for and create cross-industry bridges to integrate complementary technologies and end-market capabilities or systems technologies, and align the development and commercialisation of new technological developments.

Chipmakers seem to be more capable of achieving this intra-regionally, at smaller psychic distances.

In addition, model 9.1 offers support for hypothesis 4b as indicated by the statistically significant $Country\text{-}sameX$ effect (t = 2.46/0.39 = 6.31, one-sided $p < 0.01$) – suggesting that when chipmakers conduct R&D through international cross-industry alliances (within integrated triads), they are more likely to source complementary technologies in geographical proximity to end-markets. Model 9.2 confirms a similar result in view of interregional R&D collaboration, as indicated by the positive and statistically significant $Region\text{-}sameX$ effect (t = 1.30/0.23 = 5.65, one-sided $p < 0.01$). This result is particularly interesting as it suggests that, with relation to model 8.2, configuring R&D alliances with geographically proximate R&D partners within integrated triads provides chipmakers with a more efficient and effective way of conducting interregional R&D.

5.6. Discussion of findings

The study conducted in this chapter builds on the framework introduced in Chapter 4, with the goal of demonstrating that the choice of triadic network tactic should be driven by strategic considerations about the implications of the configuration of alliance relations as well as the selection of alliance partners within triads for the internationalisation of R&D. This view on the internationalisation of R&D, combining the configuration of relations and the selection of R&D partners as the two core elements of any international R&D alliance strategy, is missing in the field of IB. Specifically, the central premise of this study is that strategic networking, through the orchestration of international R&D alliances within triads as opposed to dyads, enables (a) enhancing the value and the novelty of value created through international R&D and (b) accelerating the process of internationalising R&D.

The role of strategic networking in the internationalisation process of R&D goes beyond the mere formation of network ties to access partner-specific assets in foreign markets, as commonly viewed in the field of IB. It is critical for companies to strategically choose (1) the configuration of its ego network of international R&D alliances (i.e. a preference for protective versus inclusive triadic collaboration) and (2) the combination of foreign R&D partners in its ego network; intra-industry and cross-industry as well as intra-regional and cross-regional. This strategic choice at the level of the firm's ego network ultimately defines its position in the industry's wider global R&D network and consequently (a) its access to fundamental R&D expertise and (b) complementary technologies, resources and knowledge concentrated in regional innovation centres, as well as (c) access to foreign end-market knowledge and downstream commercial opportunities.

The findings of this study suggest that the effect of network ties on the internationalisation process of R&D is more complex than commonly conceptualised in the IB literature and that network ties should not be considered as another ownership advantage on the same line as firm-level resources. Firms choose a governance mechanism for their international R&D alliances which defines their choice of network tactic. The network approach may thus offer potential extensions to the transaction cost perspective on the internationalisation strategies of firms.

Firms might consequently utilise their chosen network tactics to establish collaborative environments based on mutual trust, commitment and cooperation in order to foster mutual knowledge sharing and enable fusing the strategic visions, objectives and cultural differences of international R&D partners. By integrating R&D alliance relations within triads, the firm may consequently shift away from the creation of new value on the basis of inter-organisational complementarities between existing resources in captive types of alliances, toward developing new assets, such as knowledge and technologies, by jointly applying technical skills and capabilities with foreign R&D partners in relational types of alliances.

Accordingly, the firm's network strategy has a very different role in facilitating the internationalisation process of its R&D. The outcome of this study suggests that the choice of network tactic will determine what value will be created through international R&D; how fast firms can commercialise their R&D outputs and reach foreign end-markets; and the extent of learning and new knowledge creation that can take place within the R&D alliances.

This is firstly demonstrated as we find that the integration of R&D alliances within triadic configurations facilitates the internationalisation of R&D by chipmakers overall (*H.1a*) and IDMs in particular (*H.2a*). This may, from a resource-based view, be due to IDMs' larger resource bases and more extensive market experience in comparison to fabless chipmakers, creating capacity to form and configure international R&D alliances within more complex network forms. These findings point at the unique advantage of integrated triads as compared to dyads in view of enhancing chipmakers' value creation abilities in international R&D; as well as potentially combining both (1) complementing existing resources and (2) learning, as a means of not only creating and capturing new value , but also creating new knowledge and technologies. Moreover, the findings also suggest that chipmakers utilise integrated triads to enhance their learning advantage through international R&D (*H.1b*), because integrated triads can function as effective governance mechanisms which encourage the exchange of knowledge and enable complementing the chipmaker's own absorptive capacity with that of a third partner.

Importantly, however, the facilitatory role of integrated triads in the internationalisation of R&D is not shared by the relatively nimble fabless chipmakers, who rather appear inclined toward more exclusive R&D alliance relationships as indicated by the negative $Fabless\ ego *$ 3-$cycles$ effect. Comparing this particular result to those revealed in Chapter 4, which showed that fabless chipmakers do have a greater tendency than IDMs to integrate their R&D alliances within triads, fabless chipmakers seemingly change their R&D alliance strategies when collaborating in foreign markets. This may be due to fabless chipmakers' constraints in their internal resources, such as financial resources and managerial capabilities and expertise, which large and long-established IDMs do have in relatively greater abundance.

Concurrently, the results also indicate that fabless chipmakers do pursue brokerage opportunities within the industry's wider global R&D network, which may again suggest that fabless chipmakers are not capable to extend their alliances across borders through configurations within integrated triads as this may require capabilities and skills beyond their internal resource base. However, as hypothesised, the tendency to utilise brokerage is relatively greater for IDMs (*H.2b*), which suggests that – in spite of poor convergence of model 5 – strategic networking through the brokerage of international alliances between R&D partners in (different) foreign markets, as an alternative triadic network strategy, does also facilitate the internationalisation of R&D – on the basis of exclusive and privileged access to non-redundant resources and knowledge. The evolution of the firm's ego network configuration is therefore not a choice of 'either-or', but instead a matter of the meticulous orchestration of complementary network tactics in line with its R&D strategy and objectives and external pressures.

Furthermore, the study suggests that the integration, and notably *bridging*, of alliance relations with strategically selection foreign R&D partners within triads might help chipmakers to (1) foster cross-industry knowledge exchanges across regional borders and (2) accelerate the internationalisation of R&D through access to fundamental research expertise in foreign innovation centres (*H.3a*), location-found technological complementor (*H.3b*) or foreign end-market knowledge (*H.3c*). This finding points toward the role of integrated triads in driving the regionalisation of semiconductor R&D and accelerating the internationalisation of R&D by providing chipmakers with access to location-bound partner-specific assets, located in regional innovation centres or foreign downstream end-markets. Namely, chipmakers can speed-up the process of creating value through international R&D by complementing their committed resources with the technological assets of their R&D partners or by leveraging and learning from the foreign market experience of foreign end-market partners.

The internationalisation of R&D is not, however, a function of exclusively resource complementarities or learning. Importantly, our findings suggest that chipmakers' internationalisation of R&D is facilitated by combining these two mechanisms via the integration cross-industry R&D partners, namely both a technological complementor and an end-industry partner, in one and the same triadic R&D alliance (*H.4a*) – as a means of generating cross-industry synergies to simultaneously enhance the value created through international R&D and accelerate the R&D internationalisation process in view of quicker cross-industry technology alignment and commercialisation. This effectively results in a higher level of internationalisation advantage.

Interestingly, however, these results suggest that chipmakers do possess the capabilities to orchestrate their strategic networks to unlock this superior internationalisation advantage intra-regionally, but not inter-regionally. At the same time, the apparent larger psychic distances in interregional R&D collaboration can seemingly be overcome by chipmakers when their technological complementor and end-industry partner within the same triadic R&D alliance are located in the same foreign country (*H.4b*). The integration of R&D alliances within triadic configurations, through meticulous strategic orchestration, therefore provides chipmakers with the potential to enhance the internationalisation as well as the inter-regionalisation of semiconductor R&D.

These findings provide significant contributions to the established theoretical models in the field of IB, as well as important implications for managers' decision-making in relation to the internationalisation of their R&D activities. This will be discussed in the next section.

5.7. Conclusions and implications

The available traditional methods to analyse the internationalisation of firms, which are still relied on by many IB scholars, are insufficiently capable to explain the internationalisation decisions of many modern businesses in an age where these businesses rely increasingly on collaborative modes to internationalise. Extant IB frameworks, namely, do not consider how distinct relational configurations might change the outcomes of companies' hybrid strategies in foreign markets and, therefore, do not explain how modern companies can utilise network tactics to maximise the R&D outcomes of their international hybrid strategies. Accordingly, we introduced a framework integrating (1) the fundamental internationalisation concepts of resource commitment and learning advantages with (2) the network approach to analysing the formation of international R&D alliances. This study offers important conceptual and empirical contributions to the field of IB in view of explaining the R&D internationalisation decisions of modern international businesses from a network perspective.

First and foremost, with our framework we provide an alternative approach to analyse and explain the internationalisation of R&D through strategic alliances. As such, this approach goes beyond the conception of dominant IB models that the firm's capability to internationalise depends on its ability to exploit and reconfigure its committable resources and learning advantages to create value in foreign markets through FDI, and explicitly accounts for the fact that many firms, notably in high-tech industries, increasingly internationalise R&D through networks of non-equity hybrid arrangements. We are certainly not the first to make this observation and to examine the formation as strategic alliances as a mode of R&D internationalisation; however, this study is different from many others in that it explores triadic network tactics as the essence of hybrid modes of R&D internationalisation.

Instead, capitalising on the conceptual and methodological tools made available by the field of network science, our framework considers alliances or network ties as strategic mechanisms which facilitate (1) the creation of (novelty) with resource commitments in foreign markets via (a) combining existing complementary knowledge and technologies and (b) jointly applying technical skills and capabilities; as well as (2) the acceleration of R&D internationalisation by bridging cross-industry relations between strategically selected foreign technology and end-market partners within triadic configurations. As such, this framework integrates what is increasingly being recognised by IB scholars, yet insufficiently captured by established IB models, namely that networks are not only used by firms to exploit their competitive advantages in foreign markets. The central contribution of this study, therefore, comprises an alternative view on R&D internationalisation through a network lens. In addition, this comprises a conceptual contribution which also extends the view on asset complementarities in the strategic management literature.

The IB literature typically considers the concept of 'networks' in light of the size of the firm's portfolio of foreign alliance partners or the types of foreign partners it has connections to, e.g. customers or technology providers; however, these conceptions only capture one core aspect of the strategic utility which firms can derive from internationalising R&D through triadic tactics – namely, the *partner composition* of the firm's ego network. Importantly, the *configuration* of its R&D alliance relations within its ego network is a second, arguably more strategically crucial, element of the strategic utility of networks, as the strategic configuration of alliance relations within integrated triads can help firms to develop effective governance mechanisms needed for the creation of new assets through international R&D. However, this has mostly been left out from analyses of international alliance networks. By combining and integrating these two core elements into a single framework, our approach offers an essential theoretical construct to analyse and explain the role of networks in the internationalisation of R&D as well as a way of empirically examining the network orchestration capabilities of MNEs, both of which had been missing from established IB approaches.

Accordingly, this study also offers methodological contributions in view of the application of stochastic actor-oriented modelling (SAOM), as opposed to traditional regression methods, to capture both the partner composition and relational configuration of firms' ego networks in empirical analyses and consequently develop more adequate explanations of the international network strategies of firms and differences in their internationalisation advantage.

The contributions of this study are not limited to academia, but also offer lessons to strategists and managers of international businesses – notably in high-tech industries. Firstly, the ability to strategically orchestrate a network of international R&D alliances is a distinctive competitive capability in today's global industry environments. Secondly, strategists and managers should recognise the distinct network advantages associated with integrated and protective tactics in view of enhancing the value creation potential of international R&D. For example, while integrated triadic tactics can enhance time-to-market and help to overcome challenges to value creation in international collaboration owing to cognitive and cultural differences, language barriers, and risks to opportunism; protective triadic tactics can be utilised to protect technological leadership and foreign market dominance. Thirdly, managers should also recognise, specifically, how strategic partner selections within integrated triadic strategies might enable them to simultaneously enhance the value creation potential of international R&D, accelerate access to specialised skills and technologies as wells as improve time-to-market. Finally, they should define a long-term international network strategy by aligning the necessary network advantages to their international R&D objectives and integrate this long-term network view in their partner selection processes for international R&D.

Finally, there are a few limitations to this study which should be acknowledged. Firstly, the focus of our empirical analysis on the semiconductor industry might mean that our findings are not directly applicable to companies based outside high-tech industries. Still, the framework developed in this study is not exclusively applicable to the semiconductor industry and therefore does provide a conceptual basis on which future work can build to analyse the internationalisation of companies in other industries. Importantly, however, future work should be done to explicitly test the direct links between network tactics and both internationalisation outcomes and innovation outcomes; to disentangle whether value created through international R&D collaboration differs between triadic tactics and whether the choice of network tactic has implications for novelty creation. In addition, the unavailability of data regarding specific contractual terms of the R&D alliances included in our sample, such as alliance duration, means that the execution of our empirical methodology is subject to some limitation. As such, future research should aim to control for specific contract terms, provided such data are available.

In conclusion, in this study we developed and introduced an alternative framework to analyse and explain the R&D internationalisation of firms from a network perspective. Using this framework, the outcome of this study suggests that networks resemble critical strategic mechanisms through which firms can develop and advance their firm-specific advantages and accelerate their R&D internationalisation. By strategically orchestrating the composition and configuration of their ego networks, firms can ultimately enhance their internationalisation advantage.

6. CONCLUSIONS

This research presented in this thesis has sought to demonstrate the strategic role of networks in the inter-organisational alliance strategies of companies and to advance the integration of social network analysis (SNA) into the fields of strategy and international business (IB). The idea that firms can orchestrate inter-organisational collaboration *strategically* within networks, through alternative microstructures as opposed to dyads, is not yet well explored by strategy and, notably, IB scholars. Through an in-depth investigation aimed at explaining how companies can construct alliance network strategies to facilitate achieving their desired outcomes from cross-industry and international collaboration in the semiconductor industry, this research offers important contributions to the fields of strategy and IB and improves our understanding of the cross-industry and international alliance strategies of modern companies.

6.1. Conceptual and methodological contributions

Spread over three independent but connected studies, this research has delivered several important findings and contributions. Set in the empirical context of the semiconductor industry, the research started from the premise that analysing the alliance network strategies of firms ought to begin with examining the overall network structure of the semiconductor industry landscape within which they operate.

In doing so, the first study (Chapter 3) advances existing strategic management frameworks for explaining the formations and outcomes of strategic alliances which do not consider the implications of how alliance relations are configured within networks. We achieved this by explicitly linking the inter-organisational routines and processes, such as the extent of relational commitment, investment and knowledge-sharing practices, which semiconductor companies choose to implement when collaborating for distinct value chain activities, to the outcomes related to distinct network architectures – to investigate how the strategic benefits associated with distinct network architectures might facilitate the implementation of inter-organisational routines and processes.

Using this multidimensional framework, the study first of all confirmed that the semiconductor industry is integrated as a highly complex network of interconnected organisations – based both within as well as beyond the core semiconductor industry and in various countries and regions – and collaborative relationships, built on both dyads and alternative microstructures such as triads; and revealed clear variation in the degree of connectedness, clustering and concentration between sub-networks of distinct value chain activities. Especially the network of technology partnerships stood out as highly complex, displaying substantially higher degrees of interconnectedness and clustering among semiconductor companies and their R&D partners. This implies that the formation of strategic alliances is a more complex process which cannot be explained only using existing theories and frameworks, such as the resource-based view (RBV) or transaction cost analysis (TCA), as they do not consider the importance and implications of network processes. As such, the network approach enables more comprehensively analysing and understanding industry structures, not just in terms of the number of competitors and their market shares, but as networks defined by interactions among rivals and strategic partners within and across industries, resource flows, concentrated knowledge hubs and power asymmetries. Networks consequently are a new source of competitive advantage.

The variance in the architectural properties of the distinct networks of value chain activities is unlikely to emerge due to chance and rather points at underlying strategic reasons linked to the *nature* of companies' alliance strategies upon which these networks are built in the first place. For example, the relatively interconnected and clustered architecture of the semiconductor R&D network, in particular, suggests that the formation of R&D alliances – often highly integrated, co-specialised and reciprocal in nature – is not merely driven by the companies' pursuit for firm-specific assets, as is still often assumed in strategy studies. Rather, it indicates a collective and systematic preference by semiconductor companies for *closure* and building a relatively interconnected network which can function as a governance structure facilitating the build-up of mutual trust and cooperation and the flow of knowledge and resources necessary for joint R&D between the organisations within the network. As such, the outcome of this study offered first indications that the strategic role of alliance networks goes beyond the provision of access to external resources, and suggests that analytical frameworks in the field of strategy should explicitly account for the structural properties of the networks within which companies form their alliances.

To adequately understand the strategic role of alternative microstructures vis-à-vis purely dyadic relationships in the orchestration of strategic alliances, deeper analyses into chipmakers' ego networks within specifically the complex R&D network were performed in the second (Chapter 4) and third (Chapter 5) studies. The concept of the strategic utility of triads introduced in Chapter 4 contributes to the literatures on strategic management and IB because it disentangles the complexity of strategic networks. This approach goes beyond the strategic implications of R&D partner choices within dyadic alliance formations and enables demonstrating the importance of network tactics to (1) the maximisation of R&D outcomes by chipmakers and (2) the reduction of uncertainty projected upon chipmakers by industry pressures, via the orchestration of intra- and cross-industry R&D alliances within triadic microstructures.

Empirical tests indicated that chipmakers overall, and fabless chipmakers in particular, exhibit a significant preference for collaborating for R&D within triads as opposed to dyads; and, importantly, with distinct combinations of different types of intra- and cross-industry R&D partners resembling distinct triadic R&D strategies utilised to respond to the increasing cost of R&D, increasing technological complexity, highly volatile product demand and intense competition. The study thus advance classic frameworks like the RBV of alliances, which assume that the company's alliance formation decision is driven by (1) a pursuit for the strategic assets of intra and cross-industry partners (as well as intra-regional and cross-regional), as it demonstrated that it is in fact based on a dual choice which also takes into account (2) the strategic benefits associated with the configuration of alliance relations within the company's ego network (i.e. exclusive dyadic relationships versus inclusive triadic collaboration).

The combination of these two ego network elements creates (1) a basis for alliance strategy formulation and (2) a structure for minimising uncertainty through effective governance of (a) the exchange of information and know-how and (b) the pooling of complementary resources between different groups of strategic partners on the basis of mutual trust and cooperation. Therefore, future research and theory building should view access to partner-specific assets through network tie formations as a part of the partner composition of the firm's ego network, and should consider this *jointly* with the way in which the firm's ego network of alliance relations is configured.

The third study (Chapter 5) built on this view to advance the integration of a strategic network perspective into the IB literature, and demonstrate the role of networks in facilitating the internationalisation of R&D collaboration. The study proposed and applied an alternative framework which advances established IB models, such as the OLI paradigm, to explain how firms can configure their hybrid strategies to enter into foreign markets and create (novelty) value through international R&D; going beyond TCA to explain that effective governance structures can be created within networks to facilitate (1) the creation of (novelty) value via (a) combining existing complementary knowledge and technologies and (b) jointly applying technical skills and capabilities; as well as (2) the acceleration of R&D internationalisation by bridging cross-industry relations between strategically selected foreign technology and end-market partners within triadic configurations.

The strategic orchestration of alliance networks can consequently enable companies to convert network advantage into internationalisation advantage. Empirical hypothesis tests confirmed that the formations of international R&D alliances by chipmakers display patterns reflective of the theoretical premises encapsulated in the proposed framework. The tests revealed a systematic and consistent preference of chipmakers overall, and IDMs in particular, for undertaking international R&D through alliances integrated within triadic network structures as opposed to dyadic structures – both in general as well as with distinct types of R&D partners located in foreign regional innovation centres and end-markets. By applying the developed framework, we were thus able to advance extant IB research in demonstrating the inherent complexity of the hybrid strategies through which firms internationalise R&D.

Notable results suggested that triadic network tactics (1) provide a way to shift the captive (exploitative) nature of international R&D alliances toward a relational (explorative) nature which enables enhancing the creation of novelty value; and (2) can be utilised to create effective governance structures to facilitate simultaneously enhancing value creation and accelerating R&D internationalisation by efficiently overcoming larger psychic distances to inter-regional cross-industry R&D partners. Indeed, these findings point at a 'network effect' which is much more complex than commonly conceptualised in the field of IB and suggest that future research and theory building should give consideration to the fact that the nature of strategic networks is inherently different from firm-specific assets and subsequently to the strategic role that networks fulfil in the internationalisation process. Importantly, new IB models need to adequately conceptualise the essence of the international hybrid strategies of modern companies by explicitly accounting for the relational configurations of these strategies within networks.

Beyond contributing to the advancement of theory building in the fields of strategy and IB, the research overall also contributes to these fields by demonstrating the application of methodological tools for SNA to the analysis of strategic alliance formations. The major advantage of these tools is that they are specifically designed to measure the structural features of networks, capture the relational configurations and governance structures of hybrid strategies, and estimate the magnitude of structural network effects on the formation of alliance ties and subsequently the evolution of the entire industry network. The first study (Chapter 3) demonstrated that overall network indicators for network interconnectedness, clustering and centralisation can be used to quantitatively describe the overall architecture of a network as well as measure the variation in the architecture of different networks.

Methodological contributions in the second (Chapter 4) and third (Chapter 5) studies are made by demonstrating the application of the stochastic actor-oriented model (SAOM) to analyse the probability and extent to which that alliance formations are driven by a firm-level preference for particular network configurations explicitly specified by the researcher, such as firms' preference for triadic closure. Accordingly, SAOMs are advantageous over traditional regression methods in that they allow explicitly capturing dependencies between alliance tie formations within a network. Future research on networks in strategy and IB would benefit from adopting this method in order to more precisely analyse the collaborative behaviour of organisations.

6.2. Managerial implications

The findings generated in this research are not limited to contributing to academia, but also offer lessons for strategists and managers of international businesses. Overall, the research underscores the fact that the ability of a firm to strategically manoeuvre through its network of R&D alliances nowadays resembles a distinctive competitive capability.

More specifically, managers should first of all consider the configuration of their alliance network as an integral part of their alliance strategy along with the strategic implications of distinct network tactics for the reconfiguration of existing technologies and the development of new technologies and knowledge. As such, they should strive to design their alliance strategies within a triadic framework, in line with a defined long-term network strategy aimed at (1) securing network dominance and power on the basis of exclusionary tactics and brokerage or at (2) building network closure through integrated triadic tactics to facilitate the exchange of knowledge and resources. This research argues that integrated triadic tactics, in particular, in modularised high-tech industries, are strategically advantageous in that they can help to create effective governance structures based on mutual trust between the manager and its external R&D partners and consequently facilitate the establishment of relational – as opposed to captive – alliances, enhancing the communication and mutual cooperation among them in relation to the exchange of knowledge, complementing technologies and knowledge, and jointly applying technical skills and capabilities.

Notably, integrated triadic alliance configurations are particularly beneficial to those managers who seek to reduce external uncertainty and enhance the novelty of their firms' innovative creations through cross-industry R&D collaboration, as well as to those who are contemplating or tasked with the formulation of alliance strategies for international R&D collaboration. Orchestrating alliances with cross-industry and inter-regional R&D partners within integrated triads, namely, enables capitalising on the absorptive capacity and (cross-border) collaborative experience of a third partner, and may help in developing mutual trust, reducing the risk of opportunism, and subsequently bridging the cognitive and cultural differences which managers may experience in international R&D alliances.

This is not to say that this research advises managers to consider integrated triads as a 'go-to' network strategy for their cross-industry and international R&D alliances. Although examining the optimal degree of network embeddedness was outside of the scope of this research, managers must consider the risks and consequences of a potential technological lock-in, especially in highly globalised industries, jointly with the recommendations of the current research. Managers may reduce the risk of technological lock-in, while maintaining technological leadership, by ensuring their firms do broker at least some alliance network relations between other companies, as a means of accessing non-redundant information, know-how and other strategic resources. As such, protective and integrated triadic tactics should ideally be viewed and utilised as complementary network tactics.

In conclusion, managers should recognise the benefits of distinct network tactics, align their R&D objectives with the network advantages which they can obtain from particular network positions, and subsequently form R&D alliances with those partners which would enable the firm to reach and maintain the desired network position. Importantly, managers should strive to integrate this process as an integral part of their long-term alliance strategy and alliance decision-making.

6.3. Research limitations

Ultimately, as this research has been focused specifically on the global semiconductor industry, the empirical findings that were obtained might not directly explain the cross-industry and international alliance strategies of companies in other industries. This is not to say that the research does not contribute to understanding the strategic role of networks; on the contrary, the frameworks developed and introduced in this research were not designed for exclusive application in the context of the semiconductor industry and can thus be used as guidance for analysing and evaluating the strategic role of networks in the context of other industries. This is a key contribution of the research, demonstrated in the context of the semiconductor industry. Importantly, however, this framework cannot be used to explain how network tactics might vary across different industries.

Notably, the execution of this research has, however, been restricted by the unavailability of data regarding specific contractual terms of the alliances included in the network sample. In particular, the unavailability of data on the duration of alliance agreements means that the empirical analyses conducted in this research are subject to some limitation. Future empirical research on the strategic role of alliance networks should aim to account for such specific alliance terms.

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APPENDICES

APPENDIX A: TOP 50 'OTHER' ALLIANCE PARTNER INDUSTRIES

'Other' industry	# firms	'Other' industry	# firms
Communications equipment	240	Household appliances	11
Electronic components	149	Computer storage devices	11
Software	115	Motor vehicles and passenger car bodies	11
Technology hardware, storage and peripherals	101	Electronic manufacturing services	10
Technology distributors	92	Information retrieval services	8
Consumer electronics	67	Photographic equipment	8
Application software	49	Radiotelephone communications	8
Systems software	39	Heavy electrical equipment	7
Internet software and services	31	Auto parts and equipment	7
Electronic computers	30	Lighting equipment	7
Aerospace and defense	28	IT consulting and other services	7
Electrical equipment	25	Radio and television broadcasting and communications equipment	6
Industrial machinery	24	Commodity chemicals	6
Prepackaged software	21	Video equipment	6
Electronic equipment and instruments	21	Auto parts	6
Healthcare equipment	19	Cable and satellite	6
Computer programming services	18	Kitchen cabinet manufacturing	5
Electrical components and equipment	18	Electric utilities	5
Applications software	16	Road and railway	5
Computer peripheral equipment	14	Computer integrated systems design	5
Renewable energy	13	IT consulting	5
Communications services	13	Consortium	5
Household audio and video equipment	12	Electronic parts and equipment	5
Distributors	12	Systems integration	5
Telephone and telegraph apparatus	11	Broadcasting	5

APPENDIX B: FULL SAMPLE COMPOSITION BY COUNTRY OF ORIGIN

Country	# firms	Country	# firms
United States of America	1,288	Philippines	4
China	340	Portugal	4
Taiwan	277	New Zealand	4
Japan	220	Turkey	4
United Kingdom	149	Saudi Arabia	4
Republic of Korea	145	Egypt	3
Germany	141	Argentina	3
Canada	84	Greece	3
France	80	Vietnam	3
Israel	72	Mexico	2
India	57	Luxembourg	2
Hong Kong	47	South Africa	2
Singapore	45	Hungary	2
Netherlands	30	Qatar	2
Switzerland	30	Slovakia	1
Italy	26	Slovenia	1
Sweden	23	Romania	1
Russia	20	Bangladesh	1
Finland	16	Virgin Islands	1
Australia	15	Cayman Islands	1
Belgium	15	Bulgaria	1
Denmark	15	Morocco	1
Ireland	15	Lithuania	1
Spain	14	Lebanon	1
Austria	14	Liechtenstein	1
Malaysia	13	INDONESIA	1
Brazil	12	Cyprus	1
Norway	12	Thailand	1
United Arab Emirates	5	Czech Republic	1
Poland	5		
		Total	**3,282**