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Configuration of supply chains in emerging industries: a multiple-case study in the wave-and-tidal energy industry

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Abstract

Companies in emerging industries face particular challenges in configuring effective supply chains. In this paper, we build on transaction cost economics to explore how supply chains can be configured in emerging industries. We focus on two key aspects of supply chain configuration: the *make-or-buy* decision and the *strength of the ties* between a focal firm and its suppliers. We utilise a multiple-case study methodology, including seven start-up companies in the emerging wave-and-tidal energy industry. We propose three models for supply chain configuration in emerging industries — 'The Market Model', 'The Ally Model' and 'The Maker Model' — and discuss the circumstances in which each model is suitable.

Keywords: Supply chain configuration, emerging industries, wave-and-tidal energy industry

Introduction

Emerging industries face particular challenges related to supply chain configuration and coordination (Kirkwood & Srai, 2011), and they are often dependent on established suppliers and market channels which are based in competing industries. Entrepreneurial ventures are common in emerging industries, and although these bring new and innovative technologies to the market, they often lack the contacts and partners that firms in mature industries have established over years of operation. This leads the new ventures to engage in unstructured searches for potential supply chain partners. While the need for research in this area is explicit (Baril, Harrington, & Srai, 2012; Forbes & Kirsch, 2011; Harrington, Srai, & Kirkwood, 2011), the availability of published empirically based papers remains limited and scattered. The objective of this paper is to explore supply chain configuration models for firms in emerging industries.

Emerging industries are new industries in the early stages of development (Low & Abrahamson, 1997). Firms enter emerging industries either as new firms or through diversification from other industries. Some emerging industries arise primarily through the entry of new, independent firms, such as the many 'dotcom' firms in the mid-1990s or the many biotechnology start-ups in the 1980s (Hopkins, Crane, Nightingale, & Baden-Fuller, 2013). In the early phases of industry creation, new firms need to search and reach out across industry borders in order to gain necessary knowledge, complementary assets, partners, suppliers and potential customers to develop their businesses (Doz, Santos, & Williamson, 2001). Firms attempting to develop a supply chain and engage with potential suppliers, customers and other stakeholders face challenges due to emerging industries' limited standards, limited numbers of renowned players, high market and technology risks and low external legitimacy due to limited track records (Aldrich & Fiol, 1994; Zimmerman & Zeitz, 2002).

The wave-and-tidal energy industry is one example of an emerging industry (Magagna et al., 2014). It is a pre-commercial industry comprising firms developing devices to harness energy from ocean waves and tides. Currently, the wave-and-tidal energy industry, and its special knowhow, is located in particular hot spots around the world, such as in countries around the North Sea. Earlier studies have found the industry to be characterised by small, young and highly international firms (Bjørgum, Moen, & Madsen, 2013; Løvdal & Aspelund, 2011). Such studies have also found that this industry faces a particular set of complicating factors. First, there is no dominant technological design, which leads to a broad variety of technical solutions (MacGillivray et al., 2013). Second, there are no current industry standards, which increases the difficulty of attracting investors and cost-effective insurance (Leete, Xu, & Wheeler, 2013; MacGillivray et al., 2013). Third, established players in the traditional energy sector have been reluctant to seek opportunities in the wave-and-tidal

energy industry, which has left the market open to new and independent ventures (Bjørngum et al., 2013). Fourth, a special characteristic of this industry is the substantial size and weight of the technology, which often requires capital-intensive yard equipment (quay, cranes, etc.) and favours local manufacture close to installation due to high logistics costs and risks (Magagna et al., 2014). Finally—and, partly, as a result of the other characteristics—there are no established supply chain networks in the industry (Krohn et al., 2013). Therefore, the wave-and-tidal energy industry is a particularly interesting case to study the configuration of supply chains in emerging industries.

Configuring supply chains is a crucial activity that can determine a company's success or failure in emerging industries (Kirkwood & Srjai, 2011). Despite their importance, methods for emerging industries to develop effective supply chain configurations are lacking (Baril et al., 2012). Through a multiple-case study of seven wave-and-tidal energy companies, we investigate which supply chain configurations are developed in each case and why. We focus on the first tier of the supply chains for the main structure of the devices (that is, we do not study the complete supply chain networks). Furthermore, we limit the analysis to two classic supply chain design parameters: the make-or-buy decision (Walker & Weber, 1984; Williamson, 1975) and the weak versus strong ties of supply chain relationships (Cooper, Lambert, & Pagh, 1997; Williamson, 1991).

We structure the paper as follows. In Section 2, we review transaction cost arguments for the make-or-buy decision and for the strong versus weak ties in supply chain relationships. These perspectives are then applied to examine the characteristics and context of the wave-and-tidal energy industry. In Section 3, we present our multiple-case research methodology. In Section 4, we present the details of the seven specific cases. In Section 5, we analyse the cases, present three models for supply chain configuration in emerging industries and discuss the conditions in which each model is suitable. In Section 6, we conclude, discuss limitations and suggest further research possibilities.

Literature review

The literature on supply chain network configuration has been primarily concerned with established firms in mature industries (e.g. Cheng, Farooq, & Johansen, 2011; Cheng, Farooq, & Johansen, 2015; Lambert & Cooper, 2000; Li, Sun, Gu, & Dong, 2007; Shi & Gregory, 1998; Zhang & Gregory, 2011). Although much of the literature is applicable to entrepreneurial firms in emerging industries, such industries also face a set of complicating factors and unique challenges that make supply chain configuration particularly difficult. The practical implication of these challenges has been that most companies attempting to scale their businesses in emerging industries develop their supply chains in unstructured patterns. Harrington et al. (2011, p. 8) argue that 'a lack of understanding of the entire

value chain and its supporting supply network will see companies fail to exploit their potential as the industry matures’.

Two strategic questions are of particular importance: First, which processes should the firm provide itself, and which should it buy in the market? Second, with regard to parts sourced from external suppliers, what level of integration should the firm develop between itself and its suppliers?

The make-or-buy decision

The make-or-buy decision is fundamental to operations strategy and defines the scope of a business. Transaction cost economics (Coase, 1937; Williamson, 1975, 1985) provides theoretical arguments for when to organise economic activities in hierarchies (make) and when to organise them in markets (buy). It involves two assumptions—people are rational and people are opportunistic—which lead to transaction costs in a business relationship (Grover & Malhotra, 2003). Transaction costs include the costs of searching for vendors, administering the transaction, risk hedging, control and follow-up. In addition to transaction costs, companies also face production costs, which are the actual costs of producing the product or service. The decision to make or buy is based on a comparison of the total costs of the two alternatives. According to Williamson (1975, 1985), there are three factors that particularly impact the transaction costs: transaction frequency, transaction uncertainty and asset specificity.

Transaction frequency refers to how often a transaction is repeated. The traditional argument is that if a transaction occurs often, internal transaction costs are lower than the transaction costs of an external relationship (Williamson, 1985). Hence, high transaction frequency suggests a hierarchical organisation of economic activity.

Judging the *uncertainty* of a transaction involves considering the degree to which deliveries can be detailed and specified in contracts (‘environmental uncertainty’) and the degree to which actual deliveries can be measured and controlled (‘behavioural uncertainty’). The traditional transaction cost argument is that high *environmental uncertainty* encourages hierarchical organisation (especially in the presence of transaction-specific assets) (Williamson, 1975). Similarly, when *behavioural uncertainty* is high (i.e. it is difficult to control whether actual deliveries comply with expected deliveries), transaction cost theory suggests a hierarchical organisation of economic activity. The argument is that firms have greater control over internal relations than they do over external relations.

Walker and Weber (1984) provide more nuanced advice regarding environmental uncertainty. They differentiate the following two types of environmental uncertainty: ‘technological uncertainty’ and ‘volume uncertainty’. *Technological uncertainty* describes the difficulty in predicting technical

requirements in the buyer-supplier relationship. In mature industries, researchers have argued that transaction cost theory suggests a market solution when technological uncertainty is high because such a solution allows the firm to shift faster to vendors with other technologies (Balakrishnan & Wernerfelt, 1986). *Volume uncertainty* describes the difficulty in predicting the demand of a product or service. When volume uncertainty is high, transaction cost theory suggests hierarchical solutions because the control of the supply chain is likely to reduce total production and transaction costs.

Asset specificity refers to the resources that are directly related to a transaction. High asset specificity means that a technology or resource has little value outside a specific business relationship. If the resources involved in producing the product or service are not easily deployed outside the specific transaction, then suppliers are likely to increase the transaction costs in order to hedge against risk. Moreover, suppliers' production costs are likely to be higher if they must invest in resources that cannot be employed in other transactions. Therefore, higher asset specificity encourages a hierarchical organisation of economic activity. Of the three factors which determine the transactions costs, asset specificity is regarded the most critical in make-or-buy decisions (e.g. David & Han, 2004; Shelanski & Klein, 1995; Williamson, 1985).

Level of integration

Despite being one of the most used, tested and confirmed theories in management literature, transaction cost theory is criticised for being under-socialised and mechanistic. Specifically, critics argue that traditional transaction cost arguments underestimate the value of trust and interpersonal relationships (e.g. Dubois, Hulthén, & Pedersen, 2004; Hill, 1990; Nooteboom, Berger, & Noorderhaven, 1997). Economists have replied to this critique by contending that social relations can also be modelled in terms of transaction costs. Transaction cost theory has, therefore, been expanded through an understanding of the strength of the ties in buyer-supplier relationships (Grover & Malhotra, 2003; Williamson, 1991), which allows differentiation between arms-length relationships (weak ties) and alliances (strong ties) in buyer-supplier relationships (Geyskens, Steenkamp, & Kumar, 2006; Hoyt & Huq, 2000; Williamson, 1991).

Alliances can be seen as hybrids of hierarchical organisations and market organisations (Geyskens et al., 2006; Nooteboom et al., 1997). The usual argument is that transaction costs can be significantly reduced by investing in trust and strong ties with suppliers (Dyer, 2002). In a buyer-supplier relationship, *high transaction frequency* and *high asset specificity* suggest that a tight relationship is the preferred choice precisely because transaction costs can be reduced. From a supply chain configuration perspective, Lambert and Cooper (2000) suggest that the suppliers of critical importance to a firm's operations (e.g. due to high asset specificity and/or transaction

frequency) should be managed more closely than others. Furthermore, Wu and Ragatz (2010) suggest that close relationships foster joint learning in product development processes. Geyskens et al. (2006) find that higher levels of all three types of *transaction uncertainty* (i.e. 'behavioural', 'technological' and 'volume') tend to have the opposite effect and, furthermore, were all associated with arms-length buyer-supplier relationships. High uncertainty works against the development of tight relationships because actors hedge against the uncertainty by keeping alternative supply chain options open.

Supply chain configuration in the wave-and-tidal energy industry

In general, both production costs and transaction costs are high in the emerging wave-and-tidal energy industry. The fact that many of the firms in the industry are small, lack manufacturing resources and face complex technology development processes (Løvdaal & Aspelund, 2011; MacGillivray et al., 2013) increases in-house production costs to a level where market solutions seem preferable. In addition, the industry's *low transaction frequencies* suggest that arms-length relationships (i.e. 'buy with weak links') may be the preferred solution. However, precisely because the industry is emerging, there is often a lack of market alternatives from which to choose, meaning that even established players have relatively high production costs. Consequently, alliances and in-house production facilities are often the more realistic options.

In particular, *technological uncertainty* is high in the emerging wave-and-tidal energy industry for numerous reasons. First, since it has existed in a pre-commercial phase for almost two decades, the industry has limited credibility. Second, the lack of a dominant design has led to a wide variety of technologies, with few industry standards or standardised solutions. This, in turn, has made potential suppliers cautious to engage in the industry because the customer base of new solutions might be inadequate (Magagna et al., 2014). Third, the size, weight and complexity of the technologies in this industry leave few options in the market, as these technologies requires expensive and specialised production assets. Finding and attracting potential alliance partners is, consequently, a challenge. The technology development process is long and capital-intensive, requiring several rounds of pilot tests and access to technological solutions from a wide range of industries. Full-scale pilots include large physical structures, sometimes weighing hundreds of tons, as well as installations and operations that occur in harsh ocean environments. These realities lead to high costs and high risks related to the technology development process. *High asset specificity with high uncertainty* encourages a hierarchical organisation of economic activity ('make'); however, if firms are not able to make their products themselves, *high asset specificity and high uncertainty* imply a tight buyer-supplier relationship (i.e. 'buy with tight links'). Finally, because *asset specificity* has been suggested

to have the most influence on the make-or-buy decision (Walker & Weber, 1984; Williamson, 1985), a *low asset specificity with high uncertainty* favours a loose buyer-supplier relationship (i.e. ‘buy with weak links’) (Geyskens et al., 2006).

In summary, all types of buyer-supplier relationships have some merit in the wave-and-tidal energy industry. The transaction cost perspective offers competing arguments in favour of all three generic configurations (make, buy or ally). The ‘best’ solution depends on a case’s particular situation. In this paper, we explore which configurations are the preferred choices under different conditions.

Method

We use a multiple-case study to explore supply chain configuration issues in the emerging wave-and-tidal energy industry. Case studies are particularly helpful when exploring the details of real-life and emerging phenomena (Eisenhardt & Graebner, 2007; Yin, 2009). To examine supply chain configuration in the emerging wave-and-tidal industry, we searched for case firms that either had conducted or were close to conducting prototype tests in ocean environments (a technological milestone for this industry). In other words, we wanted firms that had experience with making prototypes and cooperating with suppliers (i.e. ‘Technology Readiness Level’ 6–8). Furthermore, we chose companies from the UK and the Nordic countries because these are two of the leading wave-and-tidal energy regions. Table 1 presents details of the seven case companies included in the study. The chosen cases were small firms located in Denmark, Finland, Norway, Sweden and the UK.

Table 1 – Characteristics of the seven case companies.

Case firm	Founded	Number of employees (2013)	Technology	Country	Full-scale unit	Product development status (2014)
Floating Power Plant	2004	< 20	Hybrid wind and wave	Denmark	6 + 6 MW 1,800 tonnes 80 meters	Continuous ocean tests of a 1:2 scale device (37 m wide, weighing 320 tons) since 2008. Grid connected since 2012.
Flumill	2002	< 20	Tidal	Norway	2,1 MW 160 tonnes 18 x 48 meters	Development of a full-scale demonstration plant with two to four devices.
Langlee	2006	< 10	Wave	Norway	50 kW 70 tonnes 15 x 15 meters	Full-scale ocean testing is planned in the Canary Islands in 2015.
Minesto	2007	< 30	Tidal	Sweden	0,5 MW 7 tonnes 12 meters (wing)	A 1:4 scale pilot has been tested in the waters of Northern Ireland since 2012.
Pelamis	1998	< 50	Wave	UK	750 kW 1350 tonnes 180 meters	Has built and tested six full-scale units.

Seabased	2001	< 30	Wave	Sweden	100 kW 12 tonnes 4 meters (buoy)	Has manufactured the first 42 units (25 kW) of a 10 MW park, which is scheduled to begin operation in 2015.
Wello	2008	< 10	Wave	Finland	0,5 MW 220 tonnes 30 meters	Has since 2012 been testing a full-scale, grid-connected prototype in the Orkney Islands.

Our primary data sources are seven semi-structured interviews conducted in the case companies in 2012 and 2013 as part of a more comprehensive study of the emerging wave-and-tidal energy industry. The interviews lasted 60 to 90 minutes and focused on the basic product concept, the company background, investor involvement and financial challenges, the technology development process, the supply chain configuration and partnerships. All interviewees were senior managers or founders still active in the firms and were thus knowledgeable about their firm's history, development and status. All interviews were transcribed and manually coded.

Following the advice of Forbes and Kirsch (2011), we also collected an extensive amount of information from secondary sources, including the case companies' websites, news articles in local or national press, press releases, industry websites, industry reports, international industry-specific conferences (in the U.S., Canada, Scandinavia and the UK), publicly available consent applications and suppliers' websites. We combined the interview data with the data from the secondary sources to write 5- to 10-page case summaries of each company, which we sent to the interviewees for approval and fact checking.

We follow the usual instruction on conducting multiple-case studies (Eisenhardt, 1989; Miles & Huberman, 1994) by first analysing and reporting each case separately before conducting a cross-case analysis related to supply chain configuration.

Case descriptions

This section describes each of the seven case companies. The case descriptions briefly present the technological solutions before focusing on the firms' linkages to suppliers, their experiences in engaging suppliers and their organisation of device manufacturing. Figure 1 illustrates the main technology utilised in the seven cases.



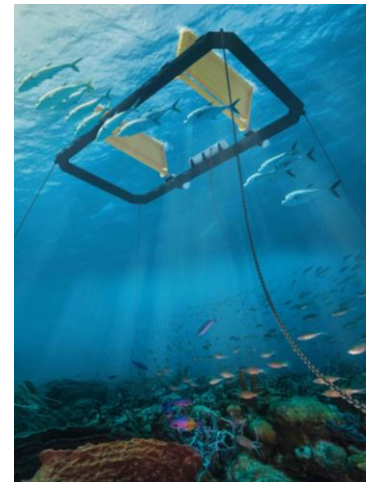
FPP (P80)

www.floatingpowerplant.com



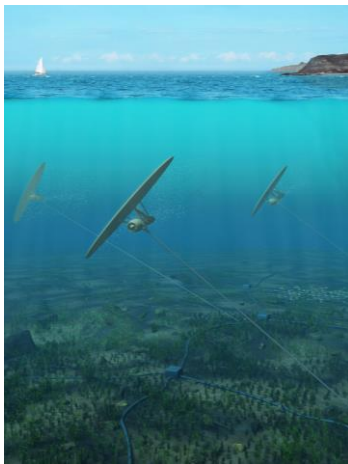
Flumill

www.flumill.com



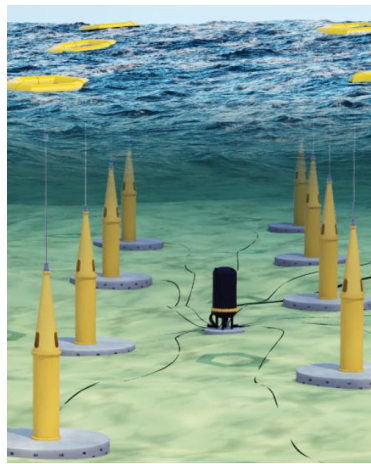
Langlee

www.langleewavepower.com



Minesto

www.minesto.com



Seabased

www.seabased.com



Wello

www.wello.eu



Pelamis (bankrupt 2015)

Figure 1 – Examples of the wave-and-tidal energy harvesting technologies of the seven cases.

Case 1: Floating Power Plant (FPP)

Floating Power Plant (FPP) has developed a hybrid floating structure generating energy from both a standard offshore wind turbine and a unique hydraulic wave power take-off system, which it has

developed in collaboration with a partner. FPP does not plan to manufacture anything in-house; instead, it has developed close relationships with suppliers of core technologies, and has organised these suppliers in a partnering network. According to FPP's CEO, this approach has both strengths and challenges: 'The way we approach innovation processes, there's a lot of benefits, you get a lot of resources, a lot of competence, a lot of experience, but our challenge is that we have to manage and motivate an organisation that is not ours'.

To engage suppliers in technology development, FPP has focused on understanding different suppliers' motivations for entering the industry (e.g. high profits due to future sales or an interest in learning about a new industry). For example, one of FPP's allied suppliers has been granted contracts related to the first sales if it can meet the market price. However, since its technology must be customised and tested over several years, FPP's ability to quickly switch to other suppliers is limited. Moreover, cooperating with *larger* suppliers has proved challenging for FPP. The rigidity of larger organisations often means that customising solutions to a small customer's needs is not a priority. On the positive side, FPP reports that large partners are extremely reliable and that, once they promise something, they do deliver on their promise. Being affiliated with large and established partners with solid engineering reputations also provides FPP with an increased legitimacy in the market. This legitimacy has opened doors to new partners and funders. In short, FPP's main strategy is to *ally* with both small and large suppliers for all manufacturing processes.

Case 2: Flumill

Flumill has developed the unique 'twin-corkscrew' tidal turbine. The main structure is mostly made of composite materials and will be mounted to the sea bottom in areas with a medium to high tidal stream. Because one of its owners is a firm that supplies composite structures to the offshore oil and gas industry, Flumill has been able to manufacture the main structures of the prototypes in its own production facilities. The largest of these was 48 meters long and 8 meters in diameter. The company plans to produce the future commercial units in-house. Suppliers are paid by the hour and develop the other components, such as the generator and electrical parts.

Because of the continuous emergence of new aspects and changes, Flumill cooperates with its suppliers in technology development. In the technology development stage, Flumill has found it easier to engage and work with small companies than with large ones. This is because Flumill has found smaller firms to be more agile and better able to move quickly, according to the changing requirements of the technology. Flumill has back-up suppliers for all different components, but the CEO emphasises that 'It's important for us to work together with our suppliers, so that we know what they are doing and can learn from them, but if we are not happy with them, we will replace

them'. In short, Flumill prefers to build arms-length relationships with contracted suppliers that deliver to the company's own manufacturing facility.

Case 3: Langlee

Langlee has developed and designed a semi-submersible oscillating wave surge converter, which converts motion from two hinged flaps placed just under the water, into electricity. The company has focused on making its design as modular as possible so that it can easily sub-contract parts of the design and manufacturing. According to the CEO, 'At Langlee, we want to make our device as simple as possible, use standard components and prepare it for mass production'. The technology is split into three main components: the steel frame, the generator module and the power electronics. Langlee sought module suppliers that could supply entire kits for each component. The assembly of the final device is designed to be simple enough so that it can be done by most shipyards. Throughout the technology development process, the suppliers have worked on a contract basis in which each firm has been given specific tasks. These tasks are carefully documented to ensure that all of the development projects' intellectual property rights stay within Langlee.

The supply chain network configuration was chosen to prevent the company from becoming too dependent on any single partner. Langlee has switched out several suppliers during the development phase and states that all suppliers are easily replaceable. Still, the company suggests that having an interactive relationship with suppliers is a priority because of suppliers' valuable feedback on specific solutions, which benefits production and after-sales services. In short, through a strategy consisting primarily of modularisation, Langlee seeks arms-length relationships with replaceable commodity suppliers and contracted manufacturers.

Case 4: Minesto

Minesto is developing 'Deep Green', which is a kite-like structure anchored to the sea bottom with a tether. It moves across a tidal current in a circular or an eight-digit path to harvest energy. Minesto has divided the development of its tidal energy device into several subsystems and has established close partnerships with the suppliers that will manufacture the most crucial of these subsystems. Ideally, the company wants its suppliers to sell products similar to those of other companies, as this can decrease costs. However, some of the developed key components are so unique that Minesto cannot switch out its suppliers on a short- or medium-term basis. The suppliers are located all over Europe and consist of both small and global firms. Minesto has experienced that it is easier to initiate technology partnerships with smaller suppliers, as these are more willing to adapt to the company's wishes and are easier to cooperate with on a personal level.

Larger suppliers have proven more difficult to engage and more rigid to work with, as they prefer to provide off-the-shelf solutions and have been less willing to modify their products to suit Minesto's needs. On the other hand, Minesto believes that the larger suppliers are very trustworthy and are more likely to be able to handle production increases. Minesto has also experienced that a partnership with well-known suppliers open doors to new suppliers and funding sources, as illustrated by this quote from the CEO: 'We do not have the industrial test procedures that larger firms have. A partnership with them increases the confidence in our technology'. In short, Minesto maintains alliances with both small and large suppliers of core technologies. It also has a tight relationship with a contracted assembly manufacturer.

Case 5: Pelamis

Before Pelamis went bankrupt in 2015, its wave energy device was an attenuating line absorber. It was a huge floating tube divided into five sections and measuring 180 meters long and 4 meters wide. It generated power by the waves' movements, which force the device to rise and fall in snake-like motions. Pelamis was one of the first companies conducting successful tests of their wave technology in the early 2000s. This gave Pelamis a lot of publicity and it acquired a significant amount of private capital in an earlier phase of the industry. This funding made the company an industry leader, which again attracted more capital and made it possible for Pelamis to build its own production facilities in Edinburgh, Scotland, where the company produced six prototypes of its device. The device required special facilities for assembly and deployment, and after having built their first unit it was clear that internal manufacturing was a desirable solution. The senior manager explained as follows: 'Instead of contracting someone for the design and somebody else for the assembly, we realised that it is through in-house manufacturing we really learn about the product'.

Pelamis experienced challenges engaging the right suppliers. In the beginning, engaging large manufacturers was extremely difficult because Pelamis' device was so radical and the wave industry was almost non-existent. Furthermore, attracting larger suppliers to produce one-off components proved problematic. Instead, Pelamis engaged smaller suppliers, which are more flexible but are still not ideal, since they have limited financial and human resources. Pelamis' production of its first three prototypes led to extensive publicity, which (along with the fact that the product was now 'proven') attracted large suppliers that had dismissed Pelamis earlier. As a result, Pelamis switched out some of its smaller suppliers for larger ones. Although several of its suppliers offer modifications of their original components, Pelamis avoided exclusivity deals, instead focusing on having alternative suppliers for all of the components. In short, Pelamis preferred arms-length relationships with small and large suppliers that delivered to the company's own manufacturing facility.

Case 6: Seabased

Seabased has developed a wave energy technology that consists of a unit placed on the sea bed connected to a buoy on the surface via a line, which captures the energy in the motion of the waves and thus enables it to generate electricity. The company is a spin-off of the Swedish University of Uppsala. It has collaborated closely with the university on research and development ranging from theoretical concept studies to extensive, multi-year empirical testing in real ocean environments. This collaboration has given Seabased access to the university's personnel and facilities, allowing the company to develop core knowledge in both energy conversion and electrical transmission processes. The research at the university has helped finance the technology development and enabled Seabased to maintain a significant level of independence and protect its expertise.

Seabased has previously made 16 different prototypes, including both full-sized and smaller-scale prototypes. In 2014, the company opened a manufacturing facility in Sweden, where it has begun the manufacturing of devices for a pilot power plant consisting of around 400 devices. The strategically most important components used in the manufacturing process are commodities (e.g. magnets, cables and springs) which can easily be delivered by alternative suppliers. The company's long-term strategy is in-house mass production of devices, as exemplified by the following statement by the CEO: 'We feel that our set-up has a big advantage in series production'. In short, Seabased is a vertically integrated manufacturer with arms-length relationships with commodity suppliers.

Case 7: Wello

Wello's technology, the 'Penguin', converts the movements of waves to electricity. An asymmetric sea vessel is equipped with spinning rotators, which generate electricity as the vessel continuously adjusts to the waves. The full-scale device is 30 meters long and weighs 220 tons. Wello has focused on using existing, off-the-shelf components from the wind energy industry in the product design. This has given the company at least two to three choices for all of its device's components, allowing Wello to replace suppliers if necessary. The CEO explains as follows: 'We do not want to depend on any particular supplier, and always want to keep our options open'.

Wello does not plan to build anything in-house. The manufacturing of the main structure and the assembly of parts can be done by most shipyards. Despite Wello's focus on using off-the-shelf components, some supplier-developed components require minor modifications. Engaging potential suppliers has been hard since several suppliers have been reluctant to do one-off deliveries due to Wello's small size, especially when their components need to be modified to fit Wello's device. For its prototype, Wello chose a smaller shipyard to handle building and assembly. This smaller shipyard was interested in a long-term relationship and was thus willing to discuss and help solve Wello's

problems, while larger shipyards were too difficult to cooperate with since building the prototype was such a relatively small order. In short, Wello's model is based on arms-length relationships with suppliers and contract manufacturers.

5 Cross-case analysis and discussion

Table 2 compares the case companies' component strategies, their decisions to make or buy their final devices and their ties to key suppliers.

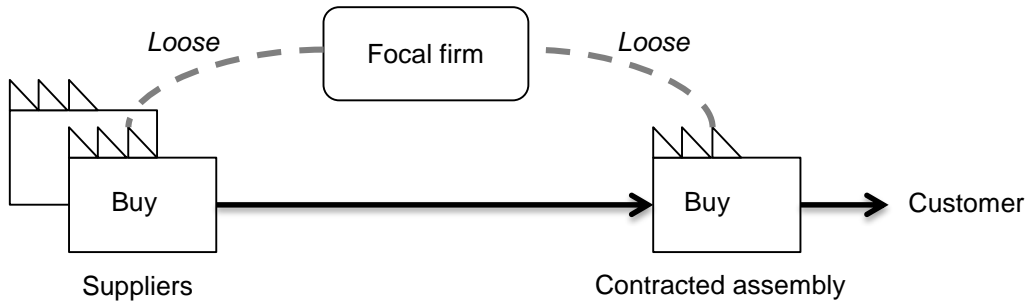
Table 2 – Cross-case comparison of central supply chain configuration parameters.

Company	Component strategy	Make or buy final device?	Ties to key suppliers
Floating Power Plant (FPP)	Components developed in collaboration with suppliers/partners.	Buy	Strong ties. Long-term partnerships; key suppliers hard to replace.
Flumill	Manufactures composite structure itself, while other parts are delivered by suppliers.	Make	Weak ties. Collaborative development, but with the ability to easily replace suppliers.
Langlee	System is split into three modules, which different suppliers will deliver.	Buy	Weak ties. Collaborative development, but with the ability to easily replace suppliers.
Minesto	Components developed in collaboration with suppliers/partners.	Buy	Strong ties. Long-term partnerships; key suppliers hard to replace.
Pelamis	All components are delivered by suppliers and most are modified versions of off-the-shelf components.	Make	Weak ties. Collaborative development, but with the ability to easily replace suppliers.
Seabased	Core technologies and components are developed and manufactured internally.	Make	Weak ties. Most components are off-the-shelf or easy-to-replace commodities.
Wello	Suppliers deliver off-the-shelf components.	Buy	Weak ties. Most components are off-the-shelf and easy to replace.

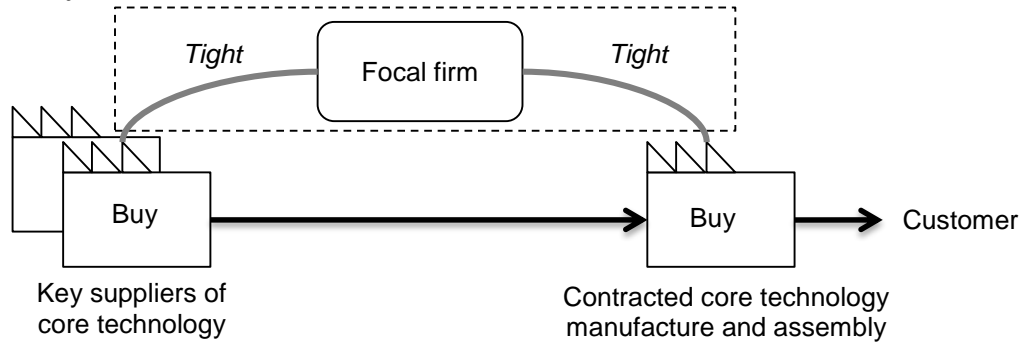
Aligned with the models suggested by Geyskens et al. (2006), three generic supply chain configuration models can be derived from Table 2. Wello and Langlee have configured the most flexible supply chains. They typically source modules and contract assembly capacity through arms-length relationships. We call this model *the Market Model*. Minesto and FPP are the only two firms with strong relationships with key suppliers in which the development of core components occurs collaboratively. These firms have also developed strong ties with assembly contractors. We call their model *the Ally Model*. Finally, the last three companies, Flumill, Seabased and Pelamis, manufacture

their final devices themselves and maintain weak relationships with materials suppliers. We call this model *the Maker Model*. Figure 2 illustrates the three models.

#1 The Market Model



#2 The Ally Model



#3 The Maker Model

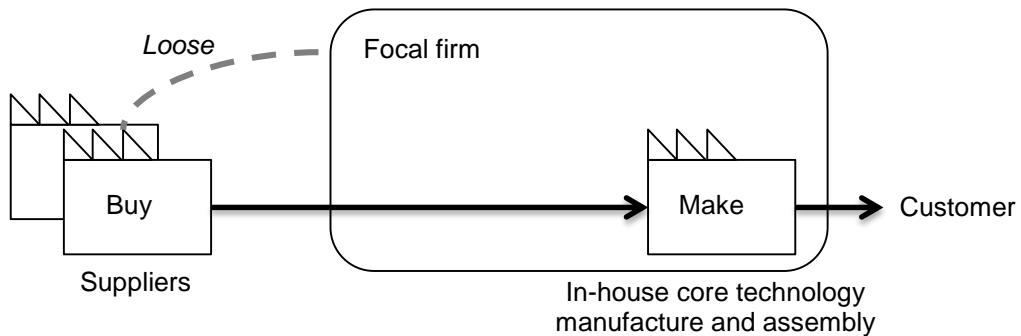


Figure 2 – Models of supply chain configurations in the wave-and-tidal energy industry.

The Market Model

The firms that utilise the Market Model outsource component production to suppliers and the manufacturing and assembly of the final device to contract manufacturers (e.g. yards). The firms do not regard any of their suppliers as key suppliers since they focus on using off-the-shelf components (i.e. components that already exist in the marketplace). They maintain weak ties to their suppliers

because they want the flexibility to replace any supplier within a short timeframe, if necessary. Furthermore, because the focal firms do not consider any of the single components to be key technologies, their strategy is to deliver the design and integration of the total solution.

As long as components are commodities or need only minor modifications, the asset specificity is relatively low, and an arms-length buyer-supplier relationship is preferred. This gives the focal firms the advantage of being able to choose from among a wide variety of suppliers (Williamson, 1985), which helps to keep costs down and the time to market short. Another advantage of buying off-the-shelf components from the marketplace is that this approach also lowers technological uncertainty, which reduces transaction costs. The arms-length buyer-supplier relationship gives focal firms the flexibility to terminate non-functioning relationships and switch to other suppliers (Balakrishnan & Wernerfelt, 1986; Geyskens et al., 2006). Furthermore, the strategy of buying existing components makes it easier to identify and engage suppliers than if their components required major modifications. Finally, a generally high transaction uncertainty results in a preference for arms-length buyer-supplier relationships, which makes it possible to quickly reconfigure the supply chain (Geyskens et al., 2006).

However, the Market Model is not without challenges. Arms-length relationships with suppliers give the focal firms limited legitimacy. This is a clear disadvantage for small firms in emerging industries, which face extraordinary technological uncertainty. Being associated with credible suppliers is often very helpful in efforts to obtain funding and engage other partners (Aldrich & Fiol, 1994). Another disadvantage of an arms-length buyer-supplier relationship is the limited potential for learning from suppliers during the dynamic technology development process (Wu & Ragatz, 2010), which could help lower the time to market and the high technological uncertainty.

The Ally Model

Firms that use the Ally Model outsource the production of key components to closely managed suppliers. They also outsource the manufacturing and assembly of the final device to a local partner for power plant installation. Hence, they focus mainly on designing the device and conducting simulations, while collaborating closely with suppliers in joint research and development. These firms develop strong inter-organisational ties with key suppliers, which can help to ensure that they maintain control over core technology, despite outsourcing the production of core components (Lambert & Cooper, 2000).

Both the final devices and the components developed with the suppliers are highly asset-specific. According to Williamson (1975), this should imply a decision to 'make'; however, as this is not a realistic option for these companies because of the high financial requirements, the preferred

solution is a close relationship with key suppliers, which can reduce transaction costs (Dyer, 2002). Furthermore, a close relationship with suppliers can enable those suppliers to commit to investing in the development and future manufacture of components, which can significantly reduce the transaction costs (Dyer, 2002) and capital requirements of the technology development process. This close relationship also limits the transaction uncertainties (and associated costs) between the supplier and the focal firm. Additionally, having strong ties with renowned suppliers gives a focal firm credibility with external stakeholders, such as policy-makers, investors and partners. This can be crucial for growing the market for small firms in emerging industries (Aldrich & Fiol, 1994; Zimmerman & Zeitz, 2002).

One of the drawbacks of the Ally Model is that development of strong ties with suppliers in the technology development process creates a lock-in effect. As a result, components can become *too asset-specific*, leading to higher production and transaction costs and making the final product less attractive or even obsolete (Williamson, 1985). This is especially the case for firms in emerging industries, which are often engaged in a dynamic technology battle with few industry standards. Moreover, numerous strong ties may be difficult to manage over time, especially for small firms with limited human resources. Hence, a central challenge for small firms in this model is to maintain good and fruitful relationships with key suppliers while simultaneously avoiding being locked into any exclusivity deals.

The Maker Model

The firms that use the Maker Model manufacture and assemble their devices in their own manufacturing facilities. They have arms-length relationships with their suppliers, which deliver commodities or components with only minor modifications. Key components are kept under internal control and are manufactured by the focal firms in-house.

When final devices are characterised by high asset specificity, transaction cost economics advises to organise the manufacturing hierarchically to minimise transaction costs. Furthermore, the high transaction uncertainty in emerging industries favours a hierarchical organisation, which gives focal firms greater control over internal relations (Williamson, 1975). Another clear advantage of a hierarchical organisation is that it gives firms full control over the development and manufacturing of core technology. Furthermore, as suppliers in this model only deliver commodities or components with minor modifications, focal firms can maintain arms-length buyer-supplier relationships. This configuration gives them a wide choice of suppliers in the short to medium term, thereby helping to reduce transaction costs (Williamson, 1985).

On the other hand, a clear disadvantage of this model is the significant financial investment needed to build manufacturing facilities and expand the organisation. In addition, the size, weight and complexity of the products require expensive and specialised production assets. This could represent a major obstacle for small firms, especially within capital-intensive industries like the wave-and-tidal energy industry in which funding is hard to obtain (Leete et al., 2013). As our case descriptions illustrate, the case companies have followed different paths that led to choosing the Maker Model. The position as a frontrunner in the industry helped Pelamis attract a considerable amount of private capital. Seabased's tight connection with the university directly benefited its technology development (and lowered its financing requirements), while Flumill accessed production facilities through one of its owners. This made it possible for these three firms to overcome the financial challenge and invest in developing their own technology and assembly or manufacturing facility. As in the Market Model, maintaining arms-length relationships with suppliers gives the focal firms utilising the Maker Model limited legitimacy via suppliers.

Implications for theory and practitioners

The findings offer several implications for theory and practitioners. We find that while transaction cost economics is useful in discussing make-or-buy discussions in the emerging wave-and-tidal energy industry, it also has its limitations. A problem with applying transaction cost theory in an emerging industry is the fact that it is not necessarily only the focal firms' decision to buy, make or ally. As our findings show, acquiring financing to build technology internally, engaging suppliers willing to make small-scale deliveries and modifying existing or developing new components could all be very difficult in the early stages of an emerging industry where uncertainty is high. Moreover, the central aspects of our analysis, such as a focal firm's legitimacy, are not directly incorporated in transaction cost economics. Collaboration with a respected supplier is likely to increase a firm's legitimacy among other actors and makes it easier to attract new suppliers willing to collaborate.

Our findings also suggest that when an industry is in the early stages—before any technology has become dominant—there is generally higher asset specificity among technologies than in mature industries. The high asset specificity limits the number of suppliers and contractors, which increases the likelihood that some of the focal firms cannot choose the buy option since there are few relevant components available to buy and integrate.

For practitioners, the three models in Figure 2 can be useful in strategic discussions of what type of supply chain configuration a firm in an emerging industry should aim to build in the first place. Instead of engaging in an unstructured search for suppliers and development partners, new

ventures in emerging industries could use the proposed models to make more informed make, buy or ally decisions.

The specific cases also offer advice regarding which types of suppliers to engage, which is a choice that all case firms noted to be particularly difficult in emerging industries. In particular, finding allies that are willing to take part in the technology development process is a challenge. A key question for many firms is which type of supplier to engage: That is, are large, established suppliers (e.g. Siemens, ABB etc.) better than small, specialised suppliers? Our case companies found engaging large suppliers to be more difficult than engaging small suppliers. Small suppliers are often more flexible with regard to customisation and product modification than larger suppliers. On the other hand, larger suppliers are generally not interested in small-scale production and are hard to convince regarding the potential of 'unproven' technologies in an emerging industry. Several of the firm's representatives reported struggling with bureaucratic decision-making and a heavy focus on intellectual property rights when collaborating with large suppliers. Smaller suppliers are more flexible and less formal, resulting in a better fit with the focal firms' characteristics. However, larger suppliers are usually very trustworthy in terms of delivering what is promised, which reduces behavioural and technological uncertainty. They can also scale up production if necessary, resulting in lower production costs. Finally, large suppliers have the advantage of a legitimacy effect, which is critically important in emerging industries. Some of the cases in this paper have used a stepwise approach where they initially have collaborated with a small supplier, but later (once their technology was more developed and 'proven') switched to a larger supplier.

Conclusion

This paper has focused on an understudied area in both the supply chain literature and the literature on emerging industries: the configuration of supply chains in emerging industries. Overall, the study confirms that it is very challenging to strategically configure supply chains in the early stages of emerging industries. In these industries, there are often no established supply chains in the first place. Therefore, firms often engage in unstructured searches for suppliers and partners. Our purpose was to explore how these firms can configure more suitable supply chains. Through a multiple-case study of seven companies in the wave-and-tidal energy industry, we identified three general models of supply chain configurations in emerging industries. We focused on the decision to either make or buy components and manufacturing capacity, as well as on firms' levels of integration with suppliers.

The three proposed supply chain models for emerging industries are as follows: (1) the Market Model, (2) the Ally Model and (3) the Maker Model. In short, the decision to manufacture or

assemble the final device (i.e. the Maker Model) gives the focal firm control over key competences or technologies. However, though classical arguments in transaction cost theory prefer this model, it is particularly difficult to realise in emerging industries due to resource requirements. A particular challenge is the need to attract the necessary investment capital. Hence, the more realistic models are the Ally Model and the Market Model. The Ally Model prescribes a close relationship with suppliers, which offers the advantages of access to the suppliers' technological competences and a potential credibility effect in dealing with external partners and funders. Whereas alliances with small and flexible suppliers is often the best option in early-stage development, alliances with larger, more established suppliers is preferable when a firm wants to scale its business for the market. Finally, the Market Model, based on arms-length relationships with suppliers, keeps alternatives open but lacks the benefits of cooperative technology development and legitimacy-building partnerships.

Limitations and future research

A particular challenge when researching emerging industries is the limited availability of cases. Firm turnover is generally very high, and the highly dynamic environments of emerging industries can quickly change the research setting. In this study, we include only seven cases from five Northern European countries. It would be interesting to see whether our findings are valid for companies in other geographical contexts and emerging industries. A second limitation of our study is that only one of our case companies has already begun commercial production. Hence, our data are based on the firms' development thus far and their plans for the future, and does not capture if their decisions to make-or-buy will further evolve before commercialisation. It is necessary to conduct more longitudinal studies to investigate how firms' make, buy or ally decisions develop over the course of the commercialisation phase. Third, this study has focused on the development of supply chains for small firms in the emerging wave-and-tidal energy industry; thus, we recommend caution in generalising to other emerging industries. However, we do believe that our findings could be transferable to other capital-intensive industries with characteristics similar to those of the wave-and-tidal energy industry, such as, for example, other renewable energy industries. Finally, whereas other theories could add to our understanding, we investigated supply chain configuration in emerging industries using the transaction cost economics exclusively. These limitations provide good opportunities for future research.

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