

Chapitre 7

Stage models of industrial symbiosis: A congruence analysis of Sustainable Connections in the port of Moerdijk

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Biographies

Wouter Spekkink is postdoctoral researcher at Delft University of Technology. He currently works in a EU funded project on the role of grassroots sustainability initiatives in the diffusion of green lifestyles. Before starting in this position Wouter was a PhD student at the Erasmus University of Rotterdam. He wrote his PhD thesis on the process through which communities of governments, firms, knowledge institutes and other relevant actors build up the capacity to collaborate on industrial symbiosis.

Frank Boons is Professor of Innovation and Sustainability at the SCI and MBS, University of Manchester. His research seeks to analyse the unfolding processes in which interacting producers and consumers seek to improve the sustainability of their practices. As an economic sociologist he has published widely in the interdisciplinary field of environmental science. He is currently associate editor of the *Journal of Industrial Ecology* and subject editor *Governance of Material and Energy Flows* for the *Journal of Cleaner Production*.

Introduction

Over the past decade several authors have developed conceptualizations of industrial symbiosis that explicitly model the evolution of industrial symbiosis networks as a stage-based process (Boons and Baas 2004; Domenéch and Davies 2011; Chertow and Ehrenfeld 2012; Paquin and Howard-Grenville 2012; Spekkink 2015). These stage-based models draw attention to the temporal dimension of industrial symbiosis, which fits well with recent calls to approach industrial symbiosis as a process (Boons, Spekkink and Mouzakitis 2011; Paquin and Howard-Grenville 2012; Boons, Spekkink and Jiao 2014). The various stage models that have been developed each distinguish between three stages, where the final stage usually represents the maturation of the industrial symbiosis network. Although similarities exist between the models (partly due to the fact that their architects have been building on each other's work), they emphasize different qualities of the process of industrial symbiosis, reflecting the differences in their underlying theoretical assumptions.

In this chapter we assess the comparative value of the different stage models in developing an understanding of the evolution of an industrial symbiosis network that is in development at the industrial park of Moerdijk. This allows us to assess the applicability of these models to the context of industrial symbiosis in Dutch port areas. In addition, it helps to solidify the empirical basis of those models that prove to be applicable to the case under investigation of this chapter. We adopt a research approach that is based on the principles of congruence analysis (Blatter and Blume 2008; Haverland 2010) and phasic analysis (Poole *et al.* 2000). Congruence analysis is a case study method that is used in the political sciences to compare empirical findings from a case study (or multiple cases) to concrete theoretical expectations derived from rival theories. The purpose of this approach is to assess the relative strength of different theories in explaining or understanding the case(s) of concern (Blatter and Blume 2008). Phasic analysis was developed by organizational scientists involved in the Minnesota Innovation Program and aims to identify phases in sequences of discrete events (Poole *et al.* 2000). The principles of congruence analysis are applied to systematically assess the comparative value of the different stage models of industrial symbiosis. We use principles of phasic analysis to demarcate different stages of development in the empirical analysis of the case of Moerdijk. More specifically, for each stage model we identify what Poole *et al.* (2000) refer to as 'phase markers' that can be used as indicators for the occurrence of different developmental stages.

In our case study of Moerdijk we focus explicitly on the emergence and development of the industrial symbiosis network at Moerdijk. The most concrete manifestation of industrial symbiosis at Moerdijk is the Sustainable Connections

initiative, which is a public-private collaboration that aims to stimulate the development of residual material exchanges between companies at and around the industrial park of Moerdijk. The initiative was formally started in 2009, but the origins of the initiative can be traced back to earlier initiatives that started in the nineties. A rich longitudinal dataset with qualitative descriptions of relevant events in the emergence and development of Sustainable Connections was developed as part of the PhD project of one of the authors of this chapter, spanning the period between 1991 and 2012 (most events are concentrated in the period between 1997 and 2012).

Our central research question is as follows: *What stage model of the evolution of industrial symbiosis networks fits best with the empirical case of Moerdijk?*

In the next section we discuss the methods that we used to collect and analyze our data. Then follows a section in which we offer an overview of 5 stage models of the evolution of industrial symbiosis networks that have been introduced in literature. Then we introduce the case of Sustainable Connections in Moerdijk, followed by our analysis of the case. We close the chapter with a discussion and our conclusions.

Methods

In this section we introduce the methods that we used for data collection and analysis. Overall, our approach can be understood as a form of congruence analysis. In this approach implications are deduced from different theoretical perspectives and confronted with empirical observations of one or more cases (Blatter and Haverland 2012). The overall goal of congruence analysis is not to establish universal generalizations across a broad range of cases, but to assess how particular cases of interest are related or different from the perspective of theories that have been built on earlier empirical studies (Goldstone 2003). Blatter and Haverland (2012) discuss two subtypes of congruence analysis:

1. The competing theories approach: Does theory A provide a better explanation in comparison to other theories?
2. The complementary theories approach: Does theory A provide relevant explanatory insights that no other theory has revealed?

It is the first approach that we take in this chapter, because we are primarily interested in the extent that the different stage models emphasize different qualities of the evolution of the industrial symbiosis network in Moerdijk. A longitudinal dataset for this case was developed from archival data following the approach developed by Poole *et al.* (2000). The data are recorded as chronologically ordered incidents, where each incident is represented by a

qualitative description of an action or interaction relevant to the emergence and development of the industrial symbiosis network in Moerdijk. These interactions concern, for example, orientation on problems and solutions, the development of plans or visions, research activities and efforts to implement plans. The incidents were drawn from news items, documents and web pages, which we collected from dedicated databases (newspaper articles) and the internet, following the rules of a search protocol that we developed in advance. We read through all of the collected sources, and recorded our data into our longitudinal dataset manually. The data collection process for our case study started September 10, 2012 and the last data were added on October 11, 2013. In total, 171 Web pages were collected, 143 documents, and 1620 news items, although there is overlap in the news items that we found in different searches.

Poole *et al.* (2000) propose that stages in a process can be reconstructed by identifying combinations of characteristic events that may serve as indicators of the stage to which they belong. The authors introduce a method called 'phasic analysis' that can be applied to identify phases in a sequence of events. In their approach, it is assumed that a unitary sequence of events (e.g., actions and interactions) can be reconstructed from the data, and that each individual event is then coded as an indicator for one of the stages of a stage model. In our case, it is quite difficult to reconstruct our data into a unitary sequence of events, and the stage models that we introduce in the next section of this chapter offer rather general indicators for the occurrence of different stages, which are often difficult to translate reliably to the level of events. Therefore, we apply the principles of phasic analysis in a more liberal way. For each stage model introduced in the next section of this chapter we draw several observable implications that are related to specific stages. We then compare these observable implications to our empirical data on the case of Moerdijk to assess the extent to which the different stages theorized by the models manifest themselves in the case.

Stage models of industrial symbiosis

In this section we offer an overview of the stage models developed by Baas and Boons (2004), Domenéch and Davies (2011), Chertow and Ehrenfeld (2012), Paquin and Howard-Grenville (2012) and Spekkink (2015), highlighting the specific characteristics that the authors of the various models use to identify different stages.

The earliest stage model that we include in our conceptual discussion is that of Baas and Boons (2004). The model was developed as part of an effort to develop a useful social science analytical framework for investigating regional industrial ecology and to provide prescriptions for the stimulation of such industrial ecology. The framework of Baas and Boons (2004) is based

on conceptual viewpoints derived from literature on economic geography, the evolution of groups of organizations, institutional theory, collective goods, and incrementalism. Baas and Boons (2004) apply the model in the investigation of the INES mainport project in Rotterdam (1999-2002). At the core of the framework is a stage-model with three stages that describe the evolution of industrial ecology initiatives:

- The first stage of the model is *regional efficiency*, which is characterized by autonomous decision-making by firms, and local coordination to decrease inefficiencies (i.e., utility sharing). These activities are possibly facilitated by local governmental organizations or business interest organizations.
- The second stage is *regional learning*, which commences after the involved actors have successfully reduced inefficiencies (i.e., the low-hanging fruits are picked) and move on to the development of more complex projects. This requires mutual recognition and trust between firms and other partners. Based on these relationships, the partners exchange knowledge and develop a broad definition of sustainability, based on which they act. Other stakeholders (e.g., citizens and grass roots movements) may also become involved at this stage.
- The third stage is *sustainable industrial district*, which is characterized by the development of an evolving strategic vision on sustainability, which becomes the guide for the activities that the involved actors engage in.

The authors use their stage model as a point of departure for studying learning processes in regional industrial system, focusing on the types of goods typically produced in different phases and the governance mechanisms used to produce them. However, the collective goods produced and the governance mechanisms them are treated as empirical variables, and no explicit theory on their evolution is provided by the authors.

Domenéch and Davies (2011) developed their stage model of the evolution of industrial symbiosis networks in an attempt to contribute to a better understanding of the role played by trust and embeddedness in the evolution of industrial symbiosis networks. Their stage model is the result of a Grounded Theory approach, and builds on insights derived from case studies of Kalundborg in Denmark, the National Industrial Symbiosis Programme (NISP) in the United Kingdom and Sagunto in Spain. The first stage in the model of Domenéch and Davies (2011) is that of *emergence* of the industrial symbiosis network. The authors pay specific attention to the conditions under which the emergence stage may commence:

1. Stringent and rapidly evolving regulatory frameworks ;

2. Waste-flow exchanges require customized, non-standard or an innovative approach, implying uncertainties with regard to process and outcome ;
3. Because of the need of customized solutions, high coordination is required, based on frequent interaction between companies, thereby contributing to the exchange of tacit knowledge, learning by doing and the creation of a shared culture.

In the emergence stage initial ties are developed and straightforward opportunities for cooperation are explored. The initial ties typically do not involve complex transformation processes but may serve as the basis for more complex cooperation in the future. The initial ties may develop spontaneously or through the activities of a facilitating policy actor. In the *probation* stage, the first experiences of exchanges developed in the first stage feed back into the network through formal and informal channels. As a result, a selected group of actors among whom exchanges have already developed become more strongly interconnected. Their experience with cooperation, and the trust and knowledge that result from the cooperation decrease the risks associated with further exchanges. In the third stage, which Domenéch and Davies (2011) coin *development and expansion*, new linkages are developed and existing relationships are deepened. Continuous interaction contributes to the accumulation of experiences of cooperation, trust, and knowledge, thereby increasing the ability of the actors to engage in joint problem solving and reducing the transaction costs associated with the interactions between the actors. New material exchanges are made possible by widening the material and knowledge base of the system and by identifying new potential exchange partners and linkages through referral and transitivity (i.e., identifying new potential ties through existing ones). This stage is characterized by an expansion of the industrial symbiosis network in terms of its size and/or its density.

Chertow and Ehrenfeld (2012) draw on the work of Schwartz and Steininger (1997), Baas and Boons (2004) and their own work to develop their three-stage model. The authors conceptualize industrial symbiosis networks as complex adaptive systems in which dynamics of self-organization play a key role. The first stage in their model is that of *sprouting*. In this stage firms begin to exchange resources for a variety of reasons, without immediately leading to a larger network of interlinked exchanges. In the second stage, which Cherow and Ehrenfeld (2012) call *uncovering*, actors become aware of the positive environmental externalities that are created by the early exchanges. The externalities are consciously revealed by an actor (also referred to as a champion) whose focus is beyond the transactional network (also see Chertow 2007; Hewes and Lyons 2008). At this stage, a more cooperative culture begins to develop and an incipient institutional structure arises that expresses the public values that have been articulated, or newly created as a result of uncovering environmental externalities. Concretely,

Chertow and Ehrenfeld (2012) refer here to organizational bodies that typically have representatives from participating companies and other relevant actors, and that perform a coordinating role in the further development of industrial symbiosis. Chertow and Ehrenfeld (2012) refer to the third stage of their model as *embeddedness and institutionalization*. In this stage the network further expands as the result of the activities of the institutional entity that was created in the phase of uncovering. The relationships between the involved actors are strengthened further, and coordination and cooperation become embedded in local norms.

Paquin and Howard-Grenville (2012) developed a stage-model based on insights from literature on industrial symbiosis and organizational theory. Their model is intended to offer insight primarily into the evolution of facilitated industrial symbiosis network development. Similar to Domen ch and Davies (2011), the stage-model is partly a product of a Grounded Theory approach. Paquin and Howard-Grenville (2012) distinguish three stages in the development of the NISP programme based on the relative dominance of one of three different types of actions of NISP's facilitators:

1. *Conversation actions* contribute to awareness and interest building among potential participants, and typically precede actually bringing companies together for the development of exchanges. This includes taking a strategic view of a region's resource needs to identify potential exchange partners and exchanges, using pre-existing contacts to engage companies, and facilitating interaction spaces (workshops and meetings).
2. *Connection actions* bring together potential exchange partners to develop specific exchanges. More specifically, connection actions include strategically introducing potential exchange partners around specific exchanges, and deepening the involvement with particular companies.
3. *Co-creation actions* concern supporting the development of industrial symbiosis infrastructures around important resource streams by replicating high value exchanges and developing capacity around processing key resource streams.

In the stage-model of Paquin and Howard-Grenville (2012) the first stage, referred to as *pre-network development*, is dominated by conversation actions. In this stage the interest of companies in the idea of industrial symbiosis is captured, and potential exchanges and exchange partners are identified through workshops and other events. The authors find that this stage is dominated by serendipitous processes as it primarily involves the facilitation of informal meetings between people that would otherwise be unlikely to meet. The

second stage identified by Paquin and Howard-Grenville (2012) is that of *early network development*, which is dominated by connection actions. Building on the opportunities identified in the pre-network development stage, potential exchange partners are brought together, and facilitators actively invest in the development of relationships of trust between the partners. Although goal-directed processes (targeting specific companies and exchanges) become more prominent at this stage, serendipitous processes still occur as a result of conversation actions. The third stage, *later network development*, is dominated by co-creation actions and involves an increased focus on the development of replicable exchanges and the development of resource infrastructures. These activities build on the relationships of trust that have been developed in the earlier stages of development, and are primarily of a goal-directed nature.

Spekkink (2015) introduces a stage model in the conclusions of his analysis of several developments in the Sloe Area and Canal Zone. The model builds primarily on the author's analysis of the evolution of Biopark Terneuzen (also see Spekkink 2013), and is inspired by the models of Baas and Boons (2004) and Chertow and Ehrenfeld (2012). It also builds on Simon's (1962) view that complex systems may evolve from simple ones more easily if they are assembled from stable intermediates. Spekkink (2015) does not elaborate on the specific characteristics of the three stages of the model and the mechanisms that are behind the progression from one stage to the next, but a more elaborate account of the model is offered in the conclusions of the forthcoming thesis of the first author of this chapter. The core logic of the model is that collaborations that drive the development of industrial symbiosis networks can be assembled from prior, smaller scale projects that are started for disparate purposes and that develop more or less independently from each other. This occurs in the phase that Spekkink (2015) coined *building intermediates*. Because the smaller scale projects address similar issues, they develop a common ground, even though the involved actors may not have the intention to do so. If there are actors that are involved in multiple projects at the same time (referred to as bridging actors), they may become aware that a common ground exists, and decide to bring the actors involved in the different projects together to capitalize on that common ground. This starts the second stage of the process, *assembling intermediates*, in which actors are brought together to develop a shared vision on industrial symbiosis that is rooted in the common ground. This includes actors involved in the different antecedent projects, as well as additional actors (e.g., knowledge institutes) that are attracted from outside the original community. After developing the vision, the involved actors start working on its implementation in the stage that is referred to as *continued existence as stable assembly*. The vision is implemented through parallel projects that each address different components of the overall vision. Instead of forming a tightly knit community, the network of actors involved in the implementation of the vision is characterized by a small, stable core of heavily involved actors, and a larger periphery of actors that are only involved on an

incidental basis. The stable core allows actors coordinate their activities among each other, and the actors in the periphery are mobilized only occasionally for the resources and capabilities that they can bring into the process.

Table 1 provides an overview of the five stage models presented above, including the phase markers that we distilled from the models, and that can be used to identify the various stages in empirical studies.

Table 1: Summary overview of different IS stage models

	Stage 1	Stage 2	Stage 3
Baas and Boons (2004)	Regional efficiency <ul style="list-style-type: none"> Autonomous decision-making by firms, possibly facilitated by local government or business associations Focus on win-win situations 	Regional learning <ul style="list-style-type: none"> Exchange of knowledge Broader definition of sustainability Addition of new stakeholders 	Sustainable industrial district <ul style="list-style-type: none"> The actors develop a strategic vision on sustainability Actions based on strategic vision
Doménech and Davies (2011)	Emergence <ul style="list-style-type: none"> Stringent and rapidly evolving regulatory frameworks Frequent interaction Creation of a shared culture Initial (and relatively simple) ties develop spontaneously, or through actions of facilitating policy actor 	Probation <ul style="list-style-type: none"> Learning takes place based on the experiences generated from early exchanges Embeddedness of a selected group of actors 	Development and expansion <ul style="list-style-type: none"> New linkages are built and existing ones are deepened through continuous interaction and accumulation of experiences of cooperation Widening material and knowledge basis of system Identification of new potential linkages
Chertow and Ehrenfeld (2012)	Sprouting <ul style="list-style-type: none"> Few linkages form for various reasons Network is not more than a few pairs of bilateral exchanges 	Uncovering <ul style="list-style-type: none"> Positive environmental externalities of exchanges are uncovered Development of a cooperative culture Coordinating institutions arise to tie different actors together 	Embeddedness and institutionalization <ul style="list-style-type: none"> Coordinating institutions continue to play a key role Relationships and institutions become stronger Coordination and cooperation become embedded in local norms
Paquin and Howard-Grenville (2012)	Pre-network development <ul style="list-style-type: none"> Facilitation of interaction spaces, such as workshops Taking a strategic view of region's resource needs Using pre-existing contacts to engage companies in interaction 	Earlier network development <ul style="list-style-type: none"> Strategically introducing potential exchange partners around specific exchanges Deepening involvement with particular companies Building relationships of trust 	Later network development <ul style="list-style-type: none"> Increasingly hands-on selection of IS opportunities and participants, focusing on replicable exchanges Development of supporting resource infrastructures

	Stage 1	Stage 2	Stage 3
Spekkink (2015)	Building intermediates: <ul style="list-style-type: none"> • Independent building block; • Development of common ground • Presence of bridging actors 	Assembling intermediates <ul style="list-style-type: none"> • Common ground is recognized by bridging actors • Actors are mobilized to translate common ground into shared vision 	Continued existence as stable assembly <ul style="list-style-type: none"> • Implementation of vision through parallel projects • Network with a small stable core of actors and many actors that are involved incidentally

To highlight the differences between the models presented above we specified their assumptions on (1) the evolution of the industrial symbiosis network throughout the stages of the process, (2) the evolution of the social network throughout the stages of the process (3) the governance mechanisms that are emphasized, and (4) the mechanisms that underlie the transitions from one phase to the next (see table 2).

Table 2 : Specification of stage models along 4 dimensions. Not all models are explicit on all dimensions. *One mechanism is identified for each phase transition.

	Baas and Boons (2004)	Doménech and Davies (2011)	Chertow and Ehrenfeld (2012)	Paquin and Howard-Greville (2012)	Spekkink (2015)
Evolution of IS exchanges	Initial focus on decreasing local inefficiencies, followed by focus on production of collective competitive goods.	Actors engage in increasingly complex exchanges over time.	From bilateral exchanges to expanding network.	Initial focus on low hanging fruits, followed by increased focus on replicable exchanges.	Development of network of exchanges through parallel projects.
Evolution of social network	Network expands in size and diversity over time.	Increasing strength of connectedness among selected group of actors.	Inter-firm relationships strengthen as a result of activities of champions.	Network expands as exchange partners are brought together by facilitators.	Presence of bridging actors followed by the development of a stable core and fluid periphery.
Governance mechanisms	Development from local coordination to actions based on shared strategic vision.	Joint action based on increasing experience with cooperation.	Central role for champions of industrial symbiosis.	Central role for facilitators in establishing and strengthening relationships.	Central role for bridging actors in mobilizing actors and for stable core of actors for coordination of collaboration.

	Baas and Boons (2004)	Doménech and Davies (2011)	Chertow and Ehrenfeld (2012)	Paquin and Howard-Grenville (2012)	Spekkink (2015)
Mechanisms for phase transitions*	<ol style="list-style-type: none"> 1. Switch from focus on local inefficiencies to focus on more complex projects. 2. Development of strategic vision. 	<ol style="list-style-type: none"> 1. Feedback of lessons from early cooperation. 2. Development of new linkages. 	<ol style="list-style-type: none"> 1. Uncovering of environmental externalities. 2. Institutionalization of coordinating bodies. 	<ol style="list-style-type: none"> 1. Shift from conversation actions to connection actions. 2. Shift from connection actions to co-creation actions. 	<ol style="list-style-type: none"> 1. Recognition of common ground and mobilization for development of shared vision. 2. Implementation of vision.

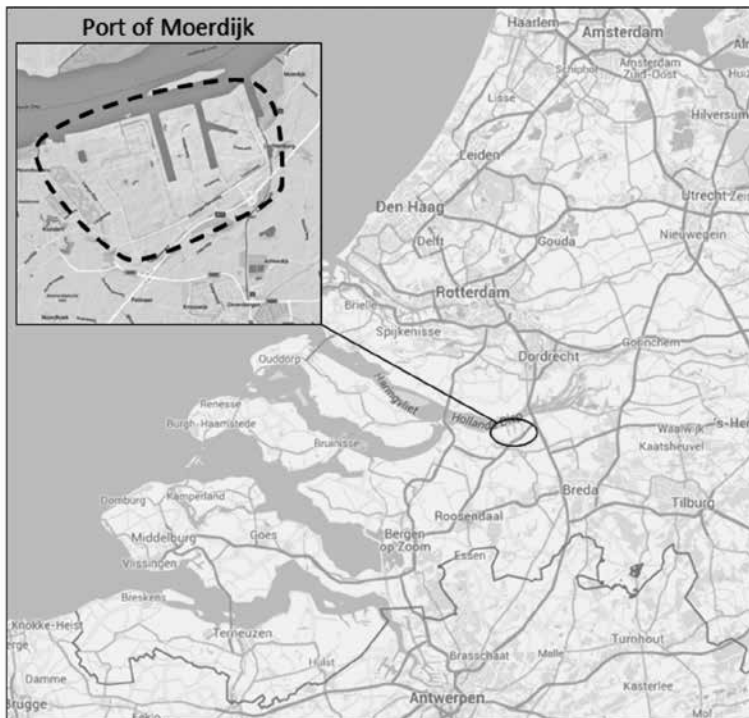
The models of Chertow and Ehrenfeld (2012) and Paquin and Howard-Grenville (2012) emphasize the growing size of the network (i.e., quantitative changes), while the models of Baas and Boons (2004) and Doménech and Davies (2011) emphasize increases in the complexity (or ambition) of the exchanges themselves (i.e., qualitative changes). The model of Spekkink (2015) suggests that the actual development of the industrial symbiosis network commences in the third stage of development, through the implementation of parallel projects that are connected by a common underlying vision. With regard to the evolution of the social network, the models of Baas and Boons (2004) and Paquin and Howard-Grenville (2012) emphasize network growth (i.e., quantitative change), while the models of Doménech and Davies (2011) and Chertow and Ehrenfeld (2012) emphasize the strengthening of existing relationships (i.e. qualitative change). The model of Spekkink (2015) emphasizes the special position of bridging actors before the start of collaboration on industrial symbiosis, and the existence of a core-periphery structure after collaboration commences. With regard to governance mechanisms, the models of Chertow and Ehrenfeld (2012), Paquin and Howard-Grenville (2012) and Spekkink (2015) are similar in that they emphasize that a relatively small group of actors plays a leading role in the coordination of the process. By contrast, the models of Baas and Boons (2004) and Doménech and Davies (2011) emphasize a more networked type of coordination.

The port and industry area of Moerdijk

The Sustainable Connections initiative was started in the port and industry area of Moerdijk in April 2009. The port of Moerdijk is situated alongside the Hollands Diep, which is an estuary of the Rhine and the Meuse (see figure 1). It is the farthest inland seaport of the Netherlands. The Hollands Diep is an important part of the route from Rotterdam to Antwerp. In addition, it is connected to the Scheldt river through the Scheldt-Rhine Canal, from which it

is possible to reach the ports of Antwerp. In addition to river connections, there are also connections to the road network, the rail network, as well as a pipeline infrastructure that branches out to Rotterdam, Antwerp, Zeeland, Limburg, and Germany. The pipeline infrastructure is used primarily for the transport of (petro)chemical products and gasses. Several village cores are established in the direct vicinity of the port and industry area. The port and industry area is 2500 hectares large, and about 400 companies are situated in the area. The largest sectors established in the area are the chemical industry, process industry, and logistics. The port and industry area provides jobs to about 17.000 people, and the economic activities in the area generate an added value of €1,3 billion. Developments that the port authority considers to be important for further economic growth of the area include cooperation between the various ports located in the Dutch-Flemish Delta, the increased use of IT-systems in logistics, sustainability trends in logistics, chemical industry, and energy supply, and recycling and reuse of resources. Another concrete development concerns the development of Logistical Park Moerdijk (LPM), which will be situated nearby the existing port and industry area (Port of Moerdijk 2014).

Figure 1 : Geographical location of the port of Moerdijk



The port authority is organized as a so-called common arrangement of the province of Northern Brabant and the municipality of Moerdijk. The board of the port authority includes representatives of the provincial council and the provincial executive, as well as representatives of the municipal council and the mayor and alderman of Moerdijk. The port authority of Moerdijk is one of the few in the country that have not yet been privatized. A feasibility study of privatization has taken place in 2010, and the involved parties wanted to make a final decision on this matter before 2015 (Port of Moerdijk 2014). Responsibilities of the port authority include the development, maintenance and exploitation of the port and industry area, the maintenance of the infrastructures of the area, active facilitation of the establishment or expansion of companies, the active facilitation of companies in making their business processes more sustainable, the provision of public facilities (e.g., safety, security and maintenance), serving as a secretariat for several intra-organizational arrangements, such as the Business and Industry Circle of Moerdijk (a business association), and bringing together companies, governments and other organizations (Port of Moerdijk, n.a.). The port of Moerdijk has been working closely together with the port of Rotterdam for years, and in 2012 agreements have been made on sharing knowledge on market development, environment and sustainability, safety, and management of shipping traffic. The port of Moerdijk is also involved in other cooperative arrangements, such as the DelTri Platform (a regional cooperation in the Southwestern Netherlands, aimed to improve the economy, the reachability and livability of the region), the Dutch Branch Organization for Sea ports (BOZ) and the European Sea Ports Organization (ESPO).

Case summary of Sustainable Connections

The Sustainable Connections initiative formally started when a steering group formed by the province of Northern Brabant, the municipality of Moerdijk, the port authority of Moerdijk, the Business and Industry Circle of Moerdijk (the local business association), the Department of Waterways and Public Works of South Holland, and the water authority Brabantse Delta signed a declaration of intent. The parties declared that they would cooperate on the development of a pipeline infrastructure for the exchange of residual heat between companies, the optimization of water loops at the industrial park of Moerdijk, the improvement of the reachability of the industrial park, the improvement of employment opportunities, the improvement of (the efficiency of) permitting procedures, and the stimulation of sustainable entrepreneurship among companies of the industrial park. A short period before the declaration of intent was signed, the province of Northern Brabant had started the project 'Testing ground clean industrial park Moerdijk,' and after signing the declaration of intent the project continued as 'Sustainable Connections Moerdijk.' The initiative has more antecedents, as the

initiative built on several antecedent (and smaller) initiatives, some of which had been in development since the nineties.

One of these antecedents is a collaboration that has been in development since 1997. In that year a steering group was formed (with a constellation of actors similar to that of Sustainable Connections) with the aim to stimulate sustainable development and safety at the industrial park of Moerdijk. Since 1999 the steering group has published environmental monitoring reports on a yearly basis. With the report, the steering group monitors the environmental performance of the industrial park, and also keeps track of sustainability related developments that occur at the industrial park. In 2005 the group decided that a more explicit vision on sustainable development was required. To this end, a masterplan was developed in 2007 and the group was renamed to Sustainable Port and Industry Area Moerdijk (SPIAM). The group continued its monitoring activities, and also formulated more explicit goals for sustainable development of the industrial park. In the period of 2007 and 2008 the actors involved in SPIAM made an inventory of residual material exchanges that had been implemented at the industrial park.

Around the same time, a similar inventory was made in an investigation on residual material exchanges in Western Brabant that was commissioned by the province of Northern Brabant. Through these projects several existing residual material exchanges have been identified, as well as a number of potential new exchanges. Exchanges that already existed include a set of exchanges between Attero, Essent and Shell that was already implemented in 1997, an exchange between Shell and Omya that was implemented in 1999, and an exchange between SNB and Omya that was implemented in 2004. The actors responsible for developing the overview of existing and new projects decided to use the test ground cleaner industrial park Moerdijk project to stimulate the further development of these exchanges. It was explicitly decided to use the SPIAM as the platform for the new project, because this would allow the project to build on relationships that had already developed at the industrial park. The SPIAM project and the Sustainable Connections project co-existed for some time, but in 2011 it was decided to merge them and to continue under the header of Sustainable Connections Moerdijk. At this time, a multiannual program for 2011-2015 was also developed by the involved actors.

The main achievement of the Sustainable Connections initiative so far has been the realization of part of the heat exchange infrastructure, used by a company called Bewa (operating a biogas plant) to supply residual heat to the neighboring Bolsius and DCS. The idea for the exchange was developed by the companies themselves before the Sustainable Connections initiative had started. The idea was also one of the potential exchanges identified at the time that inventories were being made of the existing and potential exchanges at the industrial park of Moerdijk in 2007 and 2008. By the end of 2012 there are several plans to expand the network further, both within and outside the boundaries of the industrial park.

For example, there were plans to supply residual heat to greenhouses situated in the nearby Spiepolder. There were also advanced plans for the development of a logistical park nearby the existing industrial park of Moerdijk. Companies that will establish at the new logistical park are also supposed to use residual heat of the existing companies at the industrial park of Moerdijk.

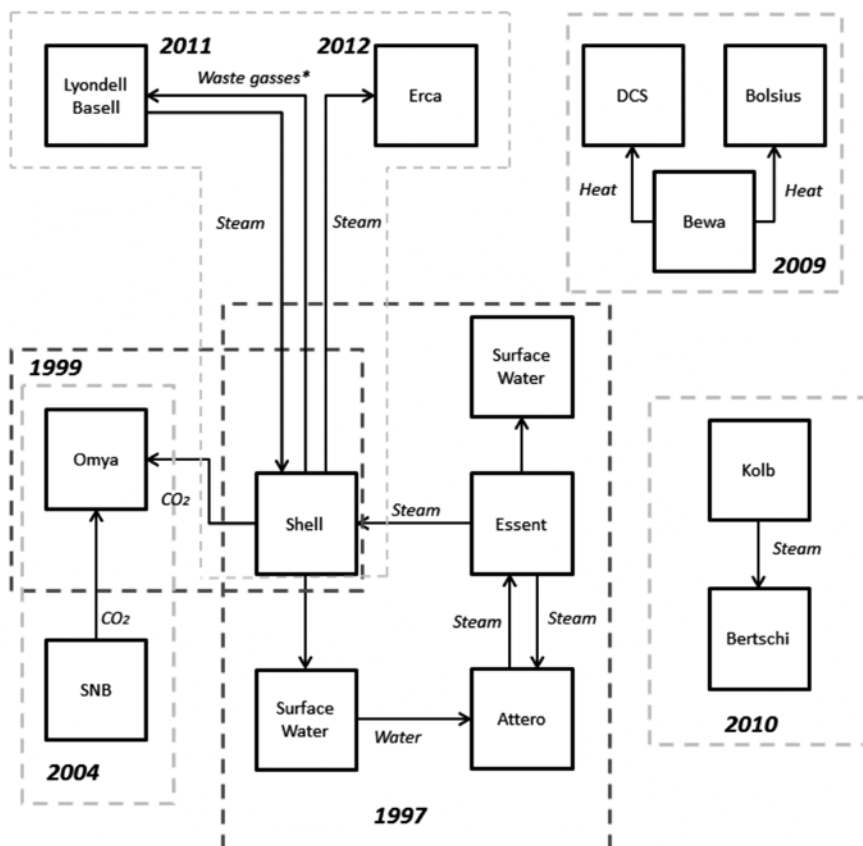
Other possibilities for residual material exchanges are being explored as well. One of the initiatives that was taken to explore these possibilities is the presentation of so-called 'opportunity boards' by the BIM. These boards list opportunities for companies at the industrial park of Moerdijk to reuse other's waste materials. With regard to the optimization of water loops the responsible project group found that optimization is technically feasible, but financially unattractive. With regard to the other ambitions several projects have been started. For example, a conference on mobility-related issues (e.g., reachability of the industrial park) was organized shortly after signing the declaration of intent, and the municipality and the province started an experiment with new permitting procedures in 2009. The Sustainable Connections initiative is still in progress. More details on the evolution of industrial symbiosis at Moerdijk are offered in the analysis below.

Analysis

From the perspective of the model of Baas and Boons (2004) the first stage in the evolution of industrial symbiosis networks is characterized by autonomous decision-making by companies (possibly facilitated by governmental organizations or cooperative arrangements between entrepreneurs), and making use of existing win-win situations. At the industrial park of Moerdijk, several exchanges have developed in the nineties and the early 2000s based on autonomous decision making by firms. This includes a number of exchanges between Shell, Attero and Essent that started in 1997, when Attero (AZN at the time) and Essent (EPZ at the time) finished the construction of a waste incineration plant combined with a cogeneration plant. The two plants exchanged steam, and the plant of Essent also supplied steam to the nearby plant of Shell. In 1999 the supply of CO₂ from Shell to Omya was implemented, and a similar supply of CO₂ from SNB to Omya was implemented in 2004. Also, before the heat infrastructure for the supply of residual heat from Bewa to DCS and Bolsius was created as part of the Sustainable Connections initiative, the three companies had developed their own plans for such an exchange autonomously. Bewa had already been working on such plans after finishing the construction of its biogas plant in 2005. Although we have no evidence of other actors being directly involved in these exchanges, the steering group that was formed at Moerdijk in 1997 did record such developments (as part of the environmental monitoring activities) in order for them to serve as examples for other companies. The environmental monitoring activities of the steering group may be understood as a weak form

of facilitation. Figure 2 gives an overview of various exchanges that have been developed throughout time.

Figure 2 : Overview of exchanges. Based partly on more detailed overviews offered by Stift (2011).



* The supply of waste gasses was already established long before 2011.

The foregoing observations fit rather well with the stage of *regional efficiency* in the model of Baas and Boons (2004). The stage of *regional learning* is much harder to identify in the case of Moerdijk. To some extent, mutual recognition, trust, and the exchange of knowledge among a limited group of actors were already present from the late nineties. Public and private parties had already been working together through the steering group that was formed in 1997. Over the years, representatives of these parties met in meetings of the steering group as well as in various working groups. The environmental monitoring activities can also be understood as an elaborate example of knowledge exchange between the involved actors. However, the number of actors actively involved in these activities is rather small compared to the total number of actors active in the industrial park

of Moerdijk (about 400). The constellation of stakeholders involved has also remained relatively stable over time. The steering group has undergone only slight changes over time, and the biggest changes in the number of actors involved have occurred with the formal start of Sustainable Connections in 2009. By the end of 2004, a so-called Neighbors Council was set up by the port authority of Moerdijk. The members of the council are representatives of various citizen groups active at and around Moerdijk. The purpose of the council is to improve the communication between companies of the industrial park of Moerdijk and citizens from neighboring villages. The Neighbors Council has always been an important platform for communication with citizens about the various initiatives developed at the industrial park of Moerdijk, and its establishment can thus be understood as an expansion of the constellation of stakeholders involved.

In 2006 and 2007 the steering group that was formed in 1997 started develop the SPIAM, in an attempt to develop more explicit goals for sustainable development. The vision was based on individual mission statements of the members of the steering group, and it covered the people, planet and profit dimensions of sustainability. To some extent, the development of the masterplan can be understood as a broadening of the definition of sustainability of the involved actors. However, the masterplan is better understood as a strategic vision that guided the further activities of the involved actors. In that sense, the development of the masterplan indicates the start of the *sustainable industrial district* stage. The vision is also an evolving one. The vision underlying the Sustainable Connections initiative can be understood to be an expansion of the vision promoted in the masterplan. In 2010 the Sustainable Connections initiative and SPIAM were evaluated, after which it was decided to merge the two initiatives. To this end, a new strategic vision for the period of 2011-2015 was developed.

The model of Domenéch and Davies (2011) articulates a number of conditions for the emergence of industrial symbiosis, which include stringent and rapidly developing regulatory frameworks, the need to come up with innovative solutions for waste exchanges, and frequent interaction among stakeholders. Under these conditions, relatively simple ties between companies could develop that set the stage for more complex developments at the long term. We have no evidence that the early ties that developed at Moerdijk were developed as the result based on the motivation to comply with stringent regulations. One exception concerns a project that never became integrated into the industrial symbiosis network of Moerdijk. From the nineties a cooperation of poultry farmers has been working on the development of a poultry manure incineration plant, a waste-to-energy project. The plant itself was a response to increasingly stringent regulations on the amount of manure that poultry farmers were allowed to produce. Also, the cooperation occasionally negotiated with other companies at Moerdijk on possibilities to reuse heat and CO₂ emitted by the plant, although we have

no evidence that any of these exchanges were ever implemented. The early exchanges that have been implemented by other companies were developed primarily based on business motivations. It is also unclear to what extent the condition of frequent interaction applies to the case of Moerdijk. Frequent interaction did occur among the members of the steering group, but these are not the actors responsible for the development of the early exchanges at Moerdijk.

A similar observation can be made for the *probation* stage of the model of Domenéch and Davies (2011). In the case of Moerdijk learning from the experiences with early exchanges did occur explicitly from 2007 to 2009. In 2007 and 2008 two inventories were made of the existing exchanges at the industrial park of Moerdijk, and several new potential exchanges were identified. These inventories served as input for the Sustainable Connections initiative. During the Sustainable Connections initiative itself, the development of the pipeline infrastructure for the supply of residual heat from Bewa to DCS and Bolsius was used as a pilot for the development of an even larger infrastructure. The learning process can also be understood to have contributed to increased embeddedness of a selected group of actors, but this applies more to the steering group than to the companies involved in the early exchanges. In this regard, the environmental monitoring activities of the steering group have also contributed to their learning process. It is difficult to distinguish between the stages of *probation* and *development and expansion* for the case of Moerdijk. In Moerdijk learning from early exchanges and the development of new ones to some extent occurred at the same time. However, the start of the Sustainable Connections initiative did entail an increased focus on the identification of new potential linkages, especially after finishing the heat exchange infrastructure of Bewa, DCS and Bolsius. The Sustainable Connections initiative can be understood to have contributed to the knowledge basis of the system, as it has contributed to a better overview of opportunities for residual heat and CO₂ exchanges through the development of several business cases and the opportunity boards that were developed by the BIM. However, this has not yet contributed to a widening of the material basis of the system, as the focus has remained primarily on the exchange of residual heat and, to lesser extent, CO₂.

From the perspective of the stage model of Chertow and Ehrenfeld (2012) the stage of sprouting can be understood to occur from 1997 to 2006, as this is the period in which individual linkages form between companies. Contrary to what the model suggests, the companies that engaged in these exchanges were mostly well aware of the positive environmental externalities associated with these exchanges. In that sense they didn't require uncovering. In addition, a cooperative culture and coordinating institutions can be understood to have developed with the activities of the steering group that was formed in 1997, whereas the model of Chertow and Ehrenfeld (2012) suggests that these are mostly absent until the stage of *uncovering*. However, the steering group

can be understood to have acquired new functions that relate more explicitly to the stimulation of industrial symbiosis from 2007 (when the masterplan for SPIAM was published). The steering group had already promoted sustainable development from 1997, but the emphasis was primarily on the environmental monitoring activities. Although the focus on the stimulation of residual material exchanges was not necessarily new, it has become more explicit with the development of the masterplan for SPIAM, and even more so with the start of the Sustainable Connections initiative.

Chertow and Ehrenfeld (2012) suggest that the boundary between the stages of *sprouting* and *embeddedness and institutionalization* is porous. In our view, it is not possible to distinguish between the stages of *uncovering* and the (the beginning of) *embeddedness and institutionalization* if we apply the model to the case of Moerdijk. Again, to some extent coordination and cooperation had already become embedded in local norms through the existence of the steering group since 1997, although the explicit focus on industrial symbiosis was introduced primarily with the Sustainable Connections initiative. However, the model of Chertow and Ehrenfeld (2012) also raises the question to what extent the coordination of industrial symbiosis activities becomes institutionalized. In this regard, it is important to note that the Sustainable Connections initiative is still organized as an initiative with a limited duration. The fact that the duration of the initiative was extended in 2010, accompanied by a multiannual program for 2011-2015, could be interpreted as a step in the further institutionalization of industrial symbiosis at the industrial park of Moerdijk. However, it is unclear what happens after this period ends. We think it is likely that the steering group continues to exist in some form, but it is not yet possible to say to what extent industrial symbiosis will continue to be a major part of their efforts.

The framework of Paquin and Howard-Grenville (2012) was developed primarily for cases of facilitated industrial symbiosis. As the early exchanges at Moerdijk developed primarily based on the autonomous efforts of companies, the first stage of the model of Paquin and Howard-Grenville (2012) may have less relevance to our case. Nonetheless, we do recognize elements of the *pre-network development* stage of the model in the early stages of the Sustainable Connections initiative. For example, the inventories that have been made of the existing and potential new exchanges at the industrial park of Moerdijk correspond to the idea of taking a strategic view of the resource needs of the industrial park, and its surroundings. Also, the presentation of opportunity boards by the BIM may be understood as the facilitation of interaction spaces. The BIM also organized other events where companies met in the context of sustainable development. For example, several companies have been awarded a frontrunner position in recognition of the efforts that they have made for sustainable development.

Elements of *earlier network development* can be observed simultaneously. For example, the development of the residual heat exchange between Bewa, DCS,

and Bolsius, as well as the other residual heat exchanges that have been planned as a follow-up of this first exchange can be understood as cases of strategically introducing partners around specific exchanges. Here, it is also important to note that the involved companies have indicated that the first heat exchange might not have been realized without the facilitation activities of members of the steering group.

As was mentioned before, the heat exchange project between Bewa, DCS and Bolsius was used as a pilot for other potential heat exchanges at the industrial park. After the initial heat exchange was finished, the members of the steering group developed business cases for similar heat exchanges within the park, as well as heat exchanges with a nearby greenhouse area and the logistical park that was still to be developed. These are activities that Paquin and Howard-Grenville (2012) associate with the *later network development* stage, as it points for an increasingly hands-on selection of industrial symbiosis opportunities with a focus on replicable exchanges. The development of the supporting infrastructure has been part of these efforts from the very start, as the port authority of Moerdijk (one of the members of the steering group) was made responsible for the maintenance of the pipeline infrastructure that is used for the heat exchanges.

The model of Spekkink (2015) emphasizes that collaborations on industrial symbiosis can be assembled from antecedent projects that are started for disparate purposes in a stage of the process that is coined *building intermediates*. In the case of Moerdijk several such 'intermediates' for collaboration on industrial symbiosis can be identified. To some extent, the various exchanges that have been developed by companies before the start of the collaboration can be understood as intermediates, although these exchanges were only used as examples and were never fully integrated as part of the collaboration. However, other intermediates were explicitly included in the collaboration, including the SPIAM collaboration that was started in 2007, and the plans for the heat exchange between Bewa, DCS and Bolsius that the involved companies had already developed themselves. Some of these intermediates had been in development since 1997. The common ground of these intermediates includes their focus on the reuse of waste materials, and more generally their contribution to the sustainable development of the industrial park of Moerdijk. The public actors in the region (the province of Northern Brabant, the municipality of Moerdijk, and the port authority of Moerdijk) were involved in several of the intermediates, which is largely a result of their administrative responsibilities in the region (e.g., permitting procedures and development of the industrial park). Thus, these public actors naturally assumed a position as bridging actors between the different developments. This also allowed them to develop an overview of the various developments in progress at Moerdijk, as well as the (potential) contributions that these developments made to the sustainable development of the industrial park. This overview was also partly made possible through the environmental monitoring reports that were developed by the steering group of which the public actors were also members.

The stage of *assembling intermediates* can be understood to have commenced in 2007. The common ground, of the intermediates was explicitly recognized when the public actors made their inventories of existing and potential symbiotic exchanges at Moerdijk. To some extent this common ground was already made concrete in the vision that is at the basis of the SPIAM collaboration that started in 2007, but the actual translation of this common ground into a vision occurred with introduction of the Sustainable Connections initiative. Public and private actors that had been involved in the development of the intermediates were brought together in 2008 to discuss the potential for a cleaner industrial park at Moerdijk. The declaration of intent that was signed in April 2009 is the product of their meetings.

The stage of *continued existence as stable assembly* can be understood to commence from the moment that Sustainable Connections officially started in April 2009. From that moment, the actors involved in the collaboration started working on parallel projects aimed at implementing various aspects of the vision of Sustainable Connections. The SPIAM collaboration was only formally integrated into the collaboration in 2011, suggesting that the assembling of intermediates to some extent continued after the collaboration had already started. During the collaboration the steering group that had already formed in 1997 served as the core of the collaborative network. In that sense, the steering group can be understood to have played the role of bridging actor after the collaboration had formally commenced. Other actors were also attracted, but these were typically involved in specific projects, and their involvement was not necessarily continuous. This corresponds with the notion of a stable core and the fluid periphery of the model of Spekkink (2015).

Figure 3 : Overview of occurrence of different phases

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Baas and Boons	Regional efficiency & regional learning										Sustainable industrial district					
Domenéch and Davies	Emergence										Probation			Development and expansion		
Chertow and Ehrenfeld											Uncovering (until 2009) & embeddedness and institutionalization					
Paquin and Howard-Grenville											pre-network & earlier network development			Later network development		
Spekkink	Building intermediates										Assembling intermediates			Continued existence as stable assembly		

Discussion and Conclusions

In this section we discuss the comparative value of the different stage models by reflecting on how well their implications along the dimensions identified in table 2 fit with the empirical observations on the case of Moerdijk.

Focusing on the *evolution of the IS exchanges*, the models of Baas and Boons (2004), Doménech and Davies (2011) and Paquin and Howard-Grenville (2012) correspond most closely with what was observed in the case of Moerdijk. The exchanges created at Moerdijk in the early stages of development are sometimes complex in themselves, but they are still relatively simple compared to the exchanges that are developed (or planned) as part of the Sustainable Connections collaboration. This increase in complexity is underemphasized in the models of Chertow and Ehrenfeld (2012) and Spekkink (2015), which focus more on the fact that a shift in focus occurs from the implementation of bilateral exchanges to the development of a network of exchanges. If we consider the *evolution of the social network*, then the models of Doménech and Davies (2011) and Spekkink (2015) have the best fit with the empirical observations on the case of Moerdijk. The models of Baas and Boons (2004) and Paquin and Howard-Grenville (2012) predict that the network of involved actors expands over time. Although this is true to some extent, the group of actors that is involved on a structural basis remains relatively small. The model of Chertow and Ehrenfeld (2012) also emphasizes increasing strength of relationships among firms, but the focus on firms underestimates the role that public actors still have throughout the later stages of collaboration. The model of Baas and Boons (2004) is the only model that explicitly emphasizes the increase in the diversity of involved actors that may occur.

With regard to *governance mechanisms* the models of Chertow and Ehrenfeld (2012) and Spekkink (2015) fit best. It is clear that in the case of Moerdijk public actors played an important role in bringing actors together and coordinating the collaboration on industrial symbiosis, whereas in the other models there is a stronger assumption that a more networked type of coordination is used. Paquin and Howard-Grenville (2012) also recognize the role of facilitators, but their model doesn't highlight the way in which facilitators may build on ongoing activities in the way that the champions and bridging actors in the models of Chertow and Ehrenfeld (2012) and Spekkink (2015) do. With regard to the *mechanisms for phase transitions* we consider the two mechanisms separately. The models of Baas and Boons (2004), Doménech and Davies (2011) and Spekkink (2015) have the closest fit with the case of Moerdijk when it comes to the mechanism held responsible for the shift from the first phase to the next, although they emphasize different aspects of this transition. Spekkink (2015) emphasizes that actors are mobilized for the development of a joint vision, based on the recognition of the common ground that actors have developed through their earlier projects. The model of Baas and Boons (2004) complements

this view by highlighting that this transition also entails a shift of focus from relatively simple projects to more complex ones. To some extent, the effort to build a vision on common ground can be understood as a way to consolidate the lessons learned in earlier cooperation, which is emphasized by the model of Doménech and Davies (2011). The model of Chertow and Ehrenfeld (2012) assumes that the first phase transition occurs as a result of uncovering environmental externalities, but there is strong evidence that in Moerdijk actors were already aware of these externalities from the early stages of development.

The model of Paquin and Howard-Grenville (2012) assume that facilitators have already attempted to bring actors together for discussion in the first stage of development. With regard to the mechanism for the second phase transition the models of Baas and Boons (2004), Paquin and Howard-Grenville (2012) and Spekkink (2015) have the closest fit with the case of Moerdijk. The models of Baas and Boons (2004) and Spekkink (2015) explicitly recognize the important role that visions play in helping the collaboration on industrial symbiosis take off. The model of Paquin and Howard-Grenville (2012) highlights the fact that in the case of Moerdijk this also entailed an effort by public and private actors to jointly develop an infrastructure specifically for the facilitation of residual heat exchanges among a multitude of actors. In the case of Moerdijk the development of new linkages (Doménech and Davies 2011) can be better understood as a consequence of the transition rather than its underlying mechanism.

Table 3 summarizes our reflection on the different models and the extent to which the models correspond with the empirical observations on the case of Moerdijk.

Table 3 : Fit of models with empirical data on Moerdijk. “X” indicates a good fit. “/” indicates a moderate fit.

	Baas and Boons (2004)	Doménech and Davies (2011)	Chertow and Ehrenfeld (2012)	Paquin and Howard-Grenville (2012)	Spekkink (2015)
Evolution of IS exchanges	X	X		X	
Evolution of social network	/	X			X
Governance mechanisms			X	/	X
Mechanisms for phase transitions*	1: X 2: X	1: X 2:	1: 2:	1: 2: X	1: X 2: X

Overall, the model of Spekkink (2015) has the closest fit with the case of Moerdijk, with the model of Baas and Boons (2004) as a close second. In our view, this also reveals an important quality of the various models, namely that their design is strongly determined by the contexts that are most familiar to their architects. From this perspective, it is unsurprising that the models developed by authors that

are more familiar with the Dutch context have the best fit. Based on the material presented in this chapter it is not possible to determine exactly how culturally embedded the different models are, but we suggest that a closer examination of this aspect of the models will be interesting, because it may reveal wider cultural and institutional conditions that influence the way that industrial symbiosis unfolds in different parts of the world. Where these conditions are still implicit in the current versions of the models, a closer examination of these conditions may help to explicate them.

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