Guimón, J., & Paraskevopoulou, E. (2017). Factors shaping the international knowledge connectivity of industrial clusters: a comparative study of two Latin American cases. *Entrepreneurship and Regional Development*, 29 (9-10), pp. 817-846.

DOI: 10.1080/08985626.2017.1354400

Factors shaping the international knowledge connectivity of industrial clusters: A comparative study of two Latin American cases

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Abstract: Recent research has emphasized that success of industrial clusters is not only driven by intra-cluster knowledge sharing ("local buzz") but also by externally sourced knowledge ("global knowledge pipelines"). This article examines the factors that determine the channels through which clusters connect with global knowledge pipelines depending on the structure of the global value chain within which they are inserted, their knowledge base and their stage of evolution. Building on a comparative case study of the salmon farming cluster in Chile and the software cluster in Costa Rica, we adopt an evolutionary perspective based on historical analysis to better understand how the configuration of clusters' international knowledge linkages shifts over time. Our findings suggest that (i) the more hierarchical the global value chain structure, the less room for knowledge co-creation between local and foreign actors; (ii) clusters relying on analytical knowledge bases opt for more formal and coordinated links with high involvement of public actors, whereas in clusters relying on synthetic knowledge bases international knowledge interaction is based on less formal links mainly between business actors; and (iii) as clusters evolve the channels through which they connect with foreign knowledge increase in number and new "hybrid" varieties develop.

Keywords: cluster evolution; knowledge bases; global value chains; absorptive capacity; knowledge gatekeepers

1. Introduction

The importance of international knowledge connectivity has been steadily rising over the past few decades and has been linked to the sustainment of regional development and innovation (Cano-Kollmann et al., 2016; Cantwell, 2016). In the cluster context, as knowledge sourcing has become geographically more diverse, the claims on the dominance of localized learning are increasingly questioned (Bathelt, 2001; Malecki and Oinas, 1999) and the prominent role of external knowledge in cluster upgrading echoes in a growing body of literature (Asheim and Isaksen, 2002; Valdaliso et al., 2011; Lorenzen and Mudambi, 2013).

The necessity of external knowledge for cluster evolution and the modes for acquiring it are well expressed in extant literature, which identifies a large variety of channels such as organization-based or person-based linkages; transfer of embodied or

disembodied knowledge; arms-length, collaborative or equity relations; formal knowledge-transfer or informal knowledge conduits; social and professional networks, and so forth (Bathelt et al., 2004; Felzensztein et al., 2010; Hannigan et al., 2015; Lee et al., 2016; Lissoni, 2001; Mudambi et al., 2016). Yet, far less is known about the factors underpinning the choice among alternative channels and their changing role and use over a cluster's lifetime.

The objective of this paper is to explore the elements that guide the choice of channels to link with foreign knowledge by paying special attention to the cluster's production structure and knowledge characteristics, the main actors and institutions orchestrating international knowledge connectivity, and the different stages of cluster evolution. These issues have so far been discussed rather separately in the literature that addresses the positioning of the cluster in global value chains (Gereffi et al., 2005; Humphrey and Schmitz, 2002); its knowledge base and absorptive capacity (Asheim and Coenen, 2005; Giuliani, 2005); the role of knowledge gatekeepers (Giuliani, 2011; Graf, 2011; Morrison, 2008); and the stages of cluster evolution (Boschma and Fornahl, 2011; Lorenzen, 2005). Combining these insights, we seek to contribute to theory development by exploring more explicitly how industrial clusters link with international knowledge.

The global value chain (GVC) approach has emphasized the relevance of international linkages for accessing knowledge and enhancing learning and innovation (Gereffi, 1999; Gereffi et al., 2005; Humphrey and Schmitz, 2002). Power asymmetries between large multinational corporations and their international network of suppliers lie at the core of this framework that posits that different modes of governance should influence cluster upgrading differently (Pietrobelli and Rabellotti, 2007; Pietrobelli and Saliola, 2008; Pietrobelli, 2008). However, as pointed out by Morrison et al. (2008), this approach gives little attention to sectoral specificities and knowledge features, hence downplaying contextual factors. This constitutes an important limitation, as the embeddedness in different contexts has been found to be crucial for the possibility of integrating into global knowledge pipelines (Aslesen and Harichi, 2015; Meyer et al., 2011). Indeed, while the GVC framework can provide useful insights with regards to the scale and scope of international knowledge exchange along the value chain, it downplays the idiosyncratic nature of learning that depends on the participants' knowledge features (Morrison et al., 2008). Such limitation calls for deeper exploration of how different knowledge bases influence the international knowledge connectivity of industrial clusters, a task we take on board in this work.

Moreover, the analysis of international knowledge connectivity in GVCs is rarely approached from a dynamic and historical approach that looks into the different modes of connectivity throughout the different stages of a cluster's life cycle. Indeed, the core motivation expressed in the literature for clusters reaching out for external knowledge has been linked to developmental dead-ends, lock-ins or risks of over-embeddedness (Bathelt et al., 2004; Boschma, 2005; Uzzi, 1996) that are commonly related to the final stage of the cluster's life cycle when mutation, adaptation or re-orientation are required (Suire and Vicente, 2014). Such focus highlights the role of external links as solutions to static developmental problems at the maturity stage, but pays less attention to their contribution to cluster emergence and expansion. Then, the importance of clusters' connections with foreign knowledge at earlier stages seems to be somewhat downplayed (Giuliani, 2008; 2011), an issue that we hereby explore further.

Reaching out for foreign knowledge becomes particularly important for laggard clusters in emerging countries that lack the local capabilities and critical mass to tackle the costly, risky, and path-dependent nature of innovation (Altenburg and Meyer-Stamer, 1999; Fu et al., 2011; Lorenzen and Mudambi; 2013). Such a context has been

increasingly attracting the attention of scholars that seek to uncover the mechanisms through which the characteristics of laggard clusters affect economic outcomes (Ciravegna et al., 2016), and constitutes our empirical setting. More specifically, we operationalize our research objectives through a comparative longitudinal case study of the salmon farming cluster in Chile and the software cluster in Costa Rica. Building on a critical review of the existing literature, the following section develops further the theoretical framework. Section 3 explains the rationale behind the selection of the case studies and the methods used. Section 4 presents the empirical findings for each of the two case studies independently, that are then discussed jointly in Section 5. Finally, Section 6 provides some concluding remarks.

2. Channels for connecting with international knowledge: explaining differences between clusters

The objective of this paper is to explore how different industrial clusters connect with international sources of knowledge throughout their different stages of evolution. This is an ambitious goal given that regional development is a complex multidimensional process and, likewise, the connections between regions and international knowledge sources are shaped by a wide variety of institutional, political, cultural and economic factors (Asheim et al., 2016; Gertler, 2010; Pike et al., 2016; Vazquez-Barquero and Rodriguez-Cohard, 2016). While recognizing such complexity, in order to address the risk of over determination that often hampers comparative studies (Moses and Knutsen, 2007), we focus on three analytical categories: (i) the governance structure of the global value chain where the cluster is inserted; (ii) the knowledge bases that the cluster relies upon; and (iii) the stages of cluster evolution. As we shall discuss in the rest of this section, the existing literature allows us to infer that these factors (and the interaction among them) have a strong influence over the channels through which industrial clusters connect with foreign knowledge.

2.1. Governance of global value chains and cluster upgrading

The GVC framework is useful to map the distributed structure of production and other business activities, capturing intrafirm and interfirm linkages, thus allowing for a better understanding of the flow of economic and organizational activities across organizations and territories (Pietrobelli and Saliola, 2008). The capacity of clusters to integrate in GVCs and access knowledge through international linkages has been related to cluster "upgrading", understood as the capacity to make better products, improve production processes, or move to higher value adding activities (Gereffi, 1999; Humphrey and Schmitz, 2002). The structure and governance of GVCs affect the generation and diffusion of knowledge (Gereffi et al., 2005; Pietrobelli and Rabellotti, 2007) and point to the selection of distinct types of international knowledge links. Different GVC structures represent distinct levels of fragmentation that, in turn, determine the locus of production and storage of knowledge, a factor that is crucial when selecting the partner with whom to form the link. At the same time, different modes of GVC governance represent distinct combinations of power distribution among its constituents and their willingness to share knowledge, a factor that is crucial for the type and intensity of the links established (Dedrick et al., 2010; Saliola and Zanfei, 2009).

Considering the complexity of the information exchange and the extent to which it can be codified and absorbed, the taxonomy by Gereffi et al. (2005) of GVC governance systems constitutes a useful tool for interpreting how different modes of governance lead to different channels and intensities of knowledge exchange between economic actors. At

the lower end, the first type of GVCs are pure "markets", where the complexity of information exchanged is relatively low and transactions can be governed with little explicit coordination. Second, "modular" value chains refer to configurations where suppliers make complex intermediate products following customers' specifications. The need for coordination is higher than in markets as such relations require an initial exchange of codified knowledge regarding specifications and technical standards, and because suppliers take responsibility for developing technological competencies and acquiring specialized equipment to comply with customers' demands. Third, "relational" value chains involve complex interactions and mutual dependence between buyers and sellers. The complexity of transactions and the need to exchange tacit knowledge requires high levels of explicit coordination, trust, and frequent face-to-face interaction. Fourth, "captive" value chains are characterized by the presence of small suppliers that are highly dependent on much larger buyers that set the rules of the game and exert a high degree of monitoring and control. Suppliers are confined to a narrow range of basic tasks and depend on the lead firm for complementary activities such as design, logistics, component purchasing, and process technology. Fifth, the extreme level of coordination is reached in a "hierarchy" where the GVC is internalized by large firms through vertical integration. Most of the production takes place in-house and thus the governance of the value chain occurs through direct managerial control, from managers to subordinates or from headquarters to subsidiaries.

In extension, different levels of coordination and power asymmetry shape learning patterns and allow for distinct degrees knowledge co-creation. In particular, extant literature suggests that local partners of industrial clusters inserted in GVCs with more hierarchical governance participate less in the joint production of knowledge than clusters inserted in GVCs with more flexible coordination mechanisms (Pietrobelli, 2008; Humphrey and Schmitz, 2002). However, as pointed out in Morisson et al. (2008), the relationship between governance and knowledge is two-directional: namely, while the governance mode of GVCs affects knowledge availability, production and flows, the different degrees of complexity, tacitness and appropriability of knowledge affect the structure of GVC governance. As the authors put it:

"*We may expect that a higher (lower) degree of knowledge complexity will induce global buyers to establish closer (more distant) relationships with local producers, and consequently contribute to the emergence of specific modes of governance (more relational or more captive).* (…) *Similarly, the absorptive capacity of local producers may affect GVCs' opportunities to convey information and knowledge and provide opportunities for learning. Thus, we may expect GVC leaders to search for efficient and capable local producers and select them accordingly*." (Morrison et al., 2008:43)

Hence, the idiosyncratic nature of learning and the characteristics of knowledge convert governance into a dependent variable that varies with participants' knowledge features and with the knowledge characteristics themselves. In addition, these analytical types are not always found in perfect form in the real world; rather, the common scenario is to find hybrid modes of governance combining elements of the different types along the different stages of a product's supply chain. Moreover, historical case studies demonstrate that the governance structure of industries evolves over time (Humphrey and Schmitz, 2002; Gereffi et al., 2005; Pietrobelli and Saliola, 2008), with the trajectories of change driven by a combination of macroeconomic, microeconomic, technological and institutional forces.

2.2. Differentiated knowledge bases and absorptive capacities

The success of clusters has commonly been attributed to the stickiness and non-transferability of local tacit knowledge that is catalyzed by geographical proximity (Feldman and Audretsch, 1999; Lawson and Lorenz, 1999; Malmberg, 1997; Maskel and Malmberg, 2007). However, the increasing evidence of the integration of "local-sticky" and "global-ubiquitous" knowledge (Asheim and Isaksen, 2002), the simultaneous need for "local-buzz" and "global knowledge pipelines" (Balthelt, et al., 2004; Morrison et al., 2013), and the weakening of the argument that external knowledge is more codified than local knowledge (Håkanson, 2005; Johnson et al., 2013; Wolfe and Gertler, 2004), have increased scholars' interest for the simultaneous consideration of intra and extra-cluster knowledge that varies in types and level of codification.

Contributing to this line of thought, we find the distinction between "analytical" and "synthetic" knowledge bases useful for the exploration of idiosyncratic modes of learning from and interacting with foreign sources of knowledge. Industrial clusters grounded on analytical knowledge bases rely highly on scientific progress through basic and applied research. In these settings, knowledge outputs and products are more codified, knowledge processes are more formally organized, and innovations tend to be more radical (Asheim and Coenen, 2005; Mattes, 2012; Moodysson et al., 2008). In turn, a synthetic knowledge base refers to industrial settings where tacit knowledge is, comparatively, more important. Innovation in this case is mainly driven by specific problem-solving activities and the recombination of existing knowledge, while communication follows less standardized modes and learning is based on more personal interaction.

Existing research suggests that links with foreign knowledge tend to be more important for innovation based on analytical knowledge in comparison to local links for the development of synthetic knowledge (Asheim et al., 2011; Plum and Hassink, 2013). As the level of codification is related to the degree of stickiness of knowledge, industries and firms that rely more on analytical knowledge bases (i.e. the most codifiable type) will tend to interact more with foreign agents (Martin and Moodysson, 2013). Still, such argument relies in the strong link between tacitness and physical proximity or, reversely, codification and transferability. As knowledge production and learning increasingly take place in both proximate and distant settings (Malecki, 2010; Balthelt et al., 2004; Archibugi and Filippetti, 2015), geographical proximity alone cannot explain how industries with different knowledge bases link to their external partners. In fact, Mattes (2012) argues that for both analytical and synthetic knowledge bases, cognitive proximity is more important than geographical proximity, and suggests that the main difference is that institutional proximity is more important for synthetic knowledge while organizational proximity is more relevant for analytical knowledge. This argument is grounded in the different degrees of formality that characterize learning in the two types of settings, a distinction that can influence the structure of knowledge links. In sum, extant literature suggests that industrial clusters based on analytical knowledge tend to rely to a larger extent on formally constructed knowledge channels with explicit mechanisms of control over the result of the knowledge process, whereas synthetic knowledge based clusters tend to opt for linkages that are less coordinated and have less clearly defined objectives.

In any case, for foreign knowledge to set in motion the forces that drive cluster upgrading the constituents of clusters need to hold a threshold level of "absorptive capacity" that allows them to acquire, assimilate, and exploit external knowledge (Giuliani, 2005; Lazaric et al., 2008). Absorptive capacity is related to the capacity of actors to establish intra and extra-cluster knowledge linkages (Valdaliso et al., 2011). It

requires the presence of firms, universities and public institutes that are active in R&D, and a sound basis of networks and human capital (Giuliani, 2005; Criscoulo and Narula, 2008; Lane et al., 2006; Mudambi et al., 2016). The same factors contribute to the improvement of collective efficiency, namely the combination of incidental external economies and consciously pursued joint action of firms residing in a cluster (Schmitz, 1995; 1999). This blend of incidental phenomena and intentional actions brings our attention to the actors at the boundaries of such processes and their distinct yet reconcilable motives and incentives. Several studies have emphasized the dual role of "knowledge gatekeepers" for acquiring new knowledge from extra-cluster sources and fostering the intra-cluster diffusion of such knowledge (Asheim and Isaksen, 2002; Giuliani, 2011; Lazaric et al., 2008; Morrison, 2008). Existing studies analyzing collective action in clusters and the role of knowledge gatekeepers have mainly considered private actors (Tushman and Katz, 1980; Nadvi, 1999; Hervas-Oliver and Albors-Garrigos, 2014). Especially, large MNCs and industrial associations come to the spotlight as knowledge gatekeepers due to their strong connections outside the cluster and their capability of selecting and bringing in international knowledge (Agrawal and Cockburn, 2003; Giuliani, 2011; Morrison 2008; Rychen and Zimmermann, 2008).

Yet, the focus on large private firms as knowledge gatekeepers largely downplays the potential of public actors that can also perform such functions (Bell and Albu, 1999; Graf, 2011). Moreover, while MNCs may play a prominent role as knowledge gatekeepers, their presence, especially in developing countries, can also reduce the long-run potential for cluster upgrading, resulting in a "crowding-out" effect whereby local firms are displaced, out-competed or pre-empted by foreign multinationals (Agosin and Machado, 2005; Athreye and Kapur, 2015; Lall, 1992). When large MNCs end up dominating the knowledge dynamics of the cluster, diversity decreases as such firms tend to orient research to their own benefit, leading to a "truncation" of international technology transfer (Baglieri et al., 2012; Lall, 1992). In contrast, it has been argued that public actors (such as public research institutes or innovation agencies) acting as knowledge gatekeepers may be more aligned with cluster upgrading due to their incentive structure and willingness to share newly acquired knowledge with the local community (Graf, 2011). Coming back to the different knowledge bases, we would expect that clusters based on analytical knowledge tend to rely to a larger extent on public actors as knowledge gatekeepers due to the higher requirements of scientific knowledge, while the role of private actors is more prominent in the case of clusters based on synthetic knowledge.

2.3. Knowledge links throughout the stages of cluster evolution

The evolutionary nature of knowledge production and accumulation calls for a dynamic analysis that considers the stages of clusters' life cycles. Reaching out for external knowledge has been linked to clusters' developmental dead ends, lock-ins or over embeddedness (Uzzi, 1996; Boschma, 2005; Bathelt et al 2004). These phenomena are commonly observed during the advanced stages of the cluster's life cycle when mutation, adaptation or re-orientation are required (Suire and Vicente, 2014). Such focus has so far highlighted the role of external links as solutions to developmental problems but has paid less attention to their potential for cluster emergence and initial upgrading. Indeed, the importance of clusters' connections with foreign knowledge at earlier stages seems to be somewhat downplayed in the literature (Perez-Aleman, 2005; Giuliani, 2008; 2011). At the same time, links with foreign sources of knowledge take time to develop and require planned efforts (Balthelt et al., 2004), while global production systems and cluster hierarchy may change overtime (Markusen, 1996). As indicated by Mudambi et

al. (2016), the ongoing disaggregation of GVCs implies that the different nodes or activities located in different clusters may follow different evolutionary paths, allowing certain nodes to become innovative and act younger even within mature industries.

Such insights point to the importance of the temporal aspect in the analysis and contrasts the fact that while the importance of foreign knowledge has been recognized and analyzed for specific stages of cluster development, the dynamic nature of its contribution has not been adequately expressed. Existing research argues for the non-linear character of cluster formation and evolution (Boschma and Fornahl, 2011; Lorenzen, 2005; Karlsson, 2010) and includes: (i) analyses that focus on a *specific period* in the clusters' course of existence and explore in depth their emergence (Bresnahan et al., 2001), maturity (Bergman, 2006), lock-in (Hassink and Shin, 2005) or decline (Zucchella, 2006) and (ii) *life cycle* approaches that adopt a more holistic view, consider the clusters' development over time and identify distinct phases (Martin and Sunley, 2011; Maskell and Malmberg, 2007; Menzel and Fornahl, 2010). Given the objectives of this paper, we tap into this second strand of literature and use it as a guiding framework in order to identify the different stages of cluster evolution and link them to different types of international knowledge links. To this end, life cycle models provide an accessible framework for the description and analysis of clusters as they embrace a path-dependent, stage-structured course of cluster evolution that allows for some sort of sequence and recognizes knowledge processes as the core mechanisms of evolution. We sketch cluster evolution through three stages (emergence, expansion, and maturity) in order to systematically capture how the choice among different knowledge links evolves.

This evolutionary perspective leads us to suggest that cluster characteristics (GVC governance and knowledge bases, in this case) will play a more determining role in conception and planning of the first efforts to link with foreign knowledge and that as the cluster evolves and matures the variety increases and "hybrid types" of links are formed. In other words, we can expect that the channels to link with foreign sources of knowledge will fit the cluster's characteristics mostly at the early stages and will then tend to increase in volume and variety.

2.4. Types of international knowledge links

Maintaining our interest on the actors that embody, produce and transfer knowledge across the boundaries of clusters, we build on Archibugi and Filippetti (2015) and classify the different international knowledge links attending to the (i) the type of partners that establish the link and (ii) the degree of involvement of local actors in knowledge production (Table 1).

With regard to the type of partner we distinguish between public links (i.e. with universities and public research institutes) and business links (i.e. with customers, suppliers, and partners). With regard to the level of involvement of the local actors in knowledge production, we distinguish between (i) adoption and exploitation of knowledge generated abroad, (ii) global techno-scientific collaborations, and (iii) global generation of knowledge, as each of these categories implies different channels of international knowledge diffusion. The first category refers to inflows of knowledge that is already available abroad and is diffused into the cluster via public (P1) or business channels (B1). Global techno-scientific collaborations refer to the joint production of knowledge through collaborations of separate institutions that maintain their national identity. We also distinguish between public (P2) or business (B2) with regard to the type of actor involved. Finally, links under the global generation of knowledge category refer to more collective knowledge generation, in the sense that carriers of foreign knowledge become embedded in clusters. It occurs when knowledge is produced with the

participation of multinational firms (B3) or public research organizations (P3) from abroad which have established subsidiaries within the cluster.

Table 1. Classification of clusters' links with foreign sources of knowledge

	Public-driven links	**Business-driven links**
Adoption and exploitation of knowledge generated abroad	Foreign knowledge is disseminated into the cluster through a variety of channels of the academic community such as publications and conferences **P1**	Knowledge generated abroad by foreign firms is transferred into the cluster through trade, licenses or international production **B1**
Global techno-scientific collaborations	Knowledge is produced by members of the cluster in collaboration with scientists and institutions from foreign countries, generally within the context of joint research projects **P2**	Members of the cluster launch strategic technological agreements with firms located abroad to develop new products or technologies **B2**
Global generation of knowledge	Knowledge generated within the cluster by foreign-owned universities or public research institutes that establish a local campus or R&D center. **P3**	Knowledge generated within the cluster by the subsidiaries of multinational corporations **B3**

Source: Adapted from Archibugi and Filippetti (2015).

3. Context and method

Our empirical evidence is constructed on the basis of a comparative historical case study of the salmon farming cluster in Chile and the software cluster in Costa Rica. As indicated by Moses and Knutsen (2007), while the historical approach is often used in social science as part of a case study strategy, what distinguishes the social scientist from the historian is the deliberate use of deductive methods to tease out lessons from the historical record building on theory. Although such method is inevitably challenged by the risk of sampling bias and the ensuing generalizability limitations, it can still be taken as a useful illustration in the development of theory.

Echoing growing demands of more evidence on the mechanisms that drive industrial development in Latin American countries (Ciravegna et al., 2016) we sought to choose two clusters of such context that strike the right balance between contrast and comparability. Indeed, the salmon farming cluster in Chile and the software cluster in Costa Rica developed in two Latin American countries with comparable socio-economic backgrounds that maintain some points of variation. In both cases strategies to reach out for specialized knowledge were adopted, massive flows of FDI entered from the mid-1990s till recently, and both governments sought to build their absorptive capacity. Yet their evolution path is different, representing different sectors and idiosyncrasies in terms

of dominant knowledge bases and the governance structure of the GVC where they are positioned. In this sense, our research design aims to contribute to theory development by selecting cases where differences in the analytical categories of interest are observable (Eisenhardt, 1989).

Salmon farming is a "natural-resource-based" industry characterized by the importance of basic and applied research from public research institutes, while software is a "specialized supplier" industry that produces innovations mainly for use in other sectors (Tidd and Bessant, 2009). As such, salmon farming relies heavily on analytical knowledge coming mainly from biology, genetics, and environmental sciences. Meanwhile, the software sector relies to a larger extent on synthetic knowledge.

As far as their GVCs are concerned, following the classification of Gereffi et al. (2005), the governance model of the salmon GVC was originally mostly market-based but shifted towards a more hierarchical governance mode as a large share of local producers were acquired by foreign MNCs. The governance of the salmon GVC is characterized by the power of major international distributors and retailers which place a strong pressure on price reduction (Phyne and Mansilla, 2003) and by a high technological dependence on suppliers of equipment and other inputs (Pietrobelli and Rabellotti, 2004). In turn, the Costa Rican software cluster is inserted in a GVC characterized by a mix of relational and modular governance systems. In contrast to the importance of suppliers in the salmon GVC, in the case of software user-producer relationships are central and technological change relies strongly on learning from advanced users. Software is characterized by the increasing slicing and geographic fragmentation of the different tasks within the GVC, enabled by low barriers to entry and new digital business models (Niosi et al., 2012). Conversely, the salmon farming GVC is composed of fewer nodes and stronger vertical integration given the nature of the production process itself and the importance of economies of scale.

In fact, these two case studies have received much attention from scholars and their characteristics and historical evolution are well documented. Evidence on the positive and negative externalities relating to the Chilean salmon cluster have been discussed extensively (Hosono et al., 2016; Iizuka and Soete, 2013; Iizuka and Katz, 2011). Focusing on knowledge dynamics, existing studies emphasize the importance of local culture, learning and capability building for the cluster's upgrading and globalization (Guiliani et al., 2005; Pietrobelli and Rabellotti, 2010; Felzensztein and Gimmon, 2007; Felzensztein et al., 2010) and highlight the role of the institutions, private–public collaboration and policies towards this end (Pietrobelli, 2008; Perez-Aleman, 2005). With regard to the integration of local firms in GVCs, the development of technological capabilities and social networks have been found to be critical to avoid marginalization (Pietrobelli, 2008), extend intrafirm cooperation (Felzensztein and Gimmon, 2007) and foster internationalization (Felzensztein et al., 2015). With the exception of studies detailing the offspring of the cluster (Hosono et al., 2016; Iizuka and Soete, 2013; Iizuka and Katz, 2011), the role of external knowledge sources for Chile's salmon industry has not yet been treated as a core determinant of evolution. More importantly, its relevance, distinct manifestation and relative importance have not been followed across time, a task that we take on board.

In the case of Costa Rica's software cluster, existing studies provide a rich account of the different drivers of success such as its welcoming policies towards FDI, its well educated labor force relative to its cost, and its political and macroeconomic stability, among others (Parrilli and Sacchetti, 2008; Rodríguez-Clare, 2001; Sanchez-Ancochea, 2006). In turn, the barriers that have limited its upgrading trajectory have also been discussed, including the lack of local competence, unavailability of information,

technological distance, mismatch of activities and lack of alignment between MNCs and local actors operating in the cluster (Ciravegna, 2011, 2012a; Paus and Gallagher, 2008), the low absorptive capacity and weak technological capabilities of local firms (Ciravegna, 2009; 2012a, Giuliani, 2008; Jenkins, 2004), or the limited international scope of local firms and entrepreneurs (Lopez et al., 2009). However, previous studies have not explicitly examined the connection of Costa Rica's software cluster with international sources of knowledge throughout its evolution, which constitutes the main focus of our empirical analysis.

To address our research objectives, we built a longitudinal study relying mainly on secondary sources. After reviewing and reinterpreting the existing literature on both cases, data was validated and complemented by conducting a set of interviews with key informants, which assisted in focusing our attention on the most critical events. Interviews with high-level policy-makers, business managers and other experts were conducted between 2011 and 2016 and comprised of twelve interviews in Costa Rica and ten in Chile. The development of the case studies was structured in three phases. First, we followed the historic evolution of both clusters and identified the key trends and actors involved through the three archetypal stages of cluster life cycle: emergence, expansion, and maturity. Second, we explored the modes of linking with international knowledge and tracked the private and public links that appeared at different evolution stages. We then marked similarities and differences and interpreted them through the lens of the analytical framework presented in Section 2.

4. Empirical findings

4.1 International knowledge connectivity of Chile's salmon cluster

4.1.1 Emergence (Late 1960s-Mid 1980s)

Chile's salmon farming cluster emerged after a period of industrial experimentation and as a result of coordinated public-private collaboration aimed at the exploitation of the country's natural resources. The Chilean government led the efforts for building the local knowledge capability based on external resources since the cluster´s conception. In the late 1960s and 1970s, it signed agreements with foreign research centers (e.g. Oregon State University and the University of Washington) to study the technical feasibility and economic viability of salmon farming and conducted a series of bi-lateral cooperation projects with the Japanese government (Mendes and Munita, 1989; Perez-Aleman, 2005; Hosono et al., 2016). For over a decade, the "Japan-Chile Salmon Project" facilitated an intensive knowledge and technology transfer process through bilateral technical visits, whereby Chilean experts were receiving training (Iizuka et al, 2016). However, public efforts alone proved insufficient to convince entrepreneurs to enter the industry while FDI failed to take off (Maggi, 2006).

At this stage, the limited presence of local organizations with technical capabilities and capacity to absorb foreign knowledge induced public action towards the establishment of an organizational landscape conductive to entrepreneurship and private investment (Pietrobelli and Rabellotti, 2004; Pietrobelli, 2008; Perez-Aleman, 2005). Examples of organizations established to stimulate the creation of new companies and facilitate innovation and technology transfer include the establishment of the Fisheries Development Institute in 1965 and the creation of the Fundación Chile association in 1976.

Equipped with a more advanced knowledge and organizational base, the government commenced a new round of public investment, this time in close collaboration with domestic private institutions. The combination of foreign links with

local initiatives from public or semi-public agencies (e.g. Fundación Chile, CORFO, IFOP and SAG) contributed not only to the acquisition but also the diffusion of foreign knowledge, that was consciously treated as a "public good" rather than a more exclusive good available to a small number of agents (Hosono et al., 2016). At the same time, rising salmon prices and public funds promoting the scientific and technological development related to salmon farming made this 'high-risk/high-return' investment far more attractive to entrepreneurs. This resulted in an exponential growth in the number of domestic firms clustering in the region (Iizuka, 2004; Perez-Aleman, 2005) and the increased interest of foreign firms.

After the failed attempt of US owned Domsea Farms, the Japanese company Nichiro, benefiting from the established collaboration and organizational proximity between the two governments, started salmon sea farming in Puerto Montt in 1978 using public investment funds (Hosono, 2016). Nichiro's presence in Chilean soil not only convinced other investors of the viability of the industry but assisted to the development of new knowledge links. The company sought local suppliers of freshwater facilities that were finally provided by Llanquihue Ltd., the first privately-owned Chilean freshwater trout farming company founded in 1975. Such collaboration resulted in Llanquihue Ltd. developing the know-how required to be granted a loan from the Production Development Corporation (CORFO) and set up their own farming company. Similar examples of foreign knowledge entering the local milieu were found at different nodes of the value chain. In 1979, Mytilus became the first Chilean company to domestically produce eggs (Hosono, 2016), hence breaking the dependence of basic input imports.

4.1.2 Expansion (Mid 1980s–Mid 2000s)

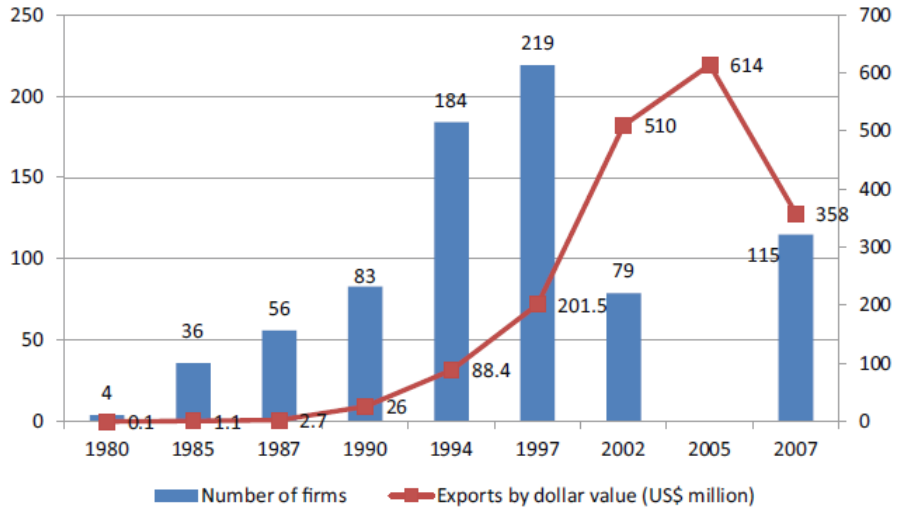
Foreign knowledge links were further developed throughout the 1980s to include the newly established organizations. In 1987, the Japan-Chile Salmon Project moved to a follow-up phase with the Fisheries Development Institute (IFOP) and JICA that induced the diffusion of knowledge in the local economy via the recruitment of many Chilean counterparts by several private aquaculture companies as experts in salmon farming. At the same time, the local government supported the entrance of more foreign firms in the country as a means to gain advantaged access to foreign markets. In particular, Nippon Suisan Kaisha, headquartered in Japan, won a tender to acquire Fundación Chile's aquaculture business (Salmones Antarctica) as the highest bidder and started the production of high value-added processed products targeting the Japanese market. Again, Japanese processing technicians came to Chile to provide technical guidance (Iizuka et al, 2016). Hence, publicly supported business links assisted both in knowledge and market development, while the willingness for collective action remained bilateral (Pietrobelli and Rabellotti, 2004; Pietrobelli, 2008). The Japanese government also cultivated such links by inviting Chilean representatives to trade promotion workshops while maintaining by the contribution of Japanese companies in the area of processing technology (Iizuka et al., 2016).

The development of supporting industries (e.g. fish handling, cold chain management, etc.) and the corresponding infrastructure, along with the increasing agglomeration of firms in the region, contributed to the exponential expansion of the cluster. The volume of production increased by 20 times – from 3000 tons in the 1980s to 600,835 tons in 2007, while the country's share in global salmon production increased from about 1.5 percent in 1987 to 35 percent in 2002 and salmon farming became the country's fourth main export sector (Alvial, 2003; Iizuka et al. , 2016).

FDI into the sector increased substantially after the mid-1990s and contributed to changes of the industry's structure including: (i) increase in mergers and acquisitions

leading to a higher degree of concentration (Figure 1) and vertical integration (Table 2); (ii) increase in value-added products and specialized inputs suppliers; (iii) increase in the variety of products, raising the scope for technical progress; (v) new entrants from sister industries; and (vi) enhanced collective capability to establish and comply with standards, allowing imperfect competition (Montero, 2004; Perez-Aleman, 2005; Iizuka, 2006; Maggi, 2007; Katz and Iizuka, 2011; Iizuka, 2016).

Figure 1. Consolidation of Chile's salmon farming industry



Source: Iizuka et al., 2016

According to Perez-Aleman (2005) inward FDI did not result in the cluster forming around a leading firm; rather, it brought about substantial indigenous efforts leading to local-global interdependence. Increased consolidation and vertical integration brought changes with regard to acquisition of technology, as larger firms started to purchase from abroad highly specialized equipment, automation process machinery and scientific food formulae, among others (Iizuka et al., 2016). For large firms, technological upgrading became less incremental and the technological gap between local practice and the international state of the art methods decreased. Such trend though was not homogeneous across the industry as smaller local firms that did not form part of such dynamics failed to catch up (Maggi, 2006; Pietrobelli, 2008; Hosono et al. 2016).

While business knowledge links among large firms proliferated and the stock of accumulated knowledge increased, public action continued, yet with a different focus. The government´s efforts concentrated on the regulation of the dynamically expanding industry (Alvial et al., 2012; Hosono et al., 2016), the positioning of the country in the global markets and the development of technological skills and capabilities in local firms. In the 1990s regional universities (e.g. Universidad Austral de Chile en Valdivia and Universidad de Los Lagos) launched new programs to supply the labor market with graduates and professionals in aquaculture production and business administration. The Salmon Technology Institute was created in 1994 to develop and diffuse food safety and quality control technologies in the salmon industry, and in 1996 it joined the national educational system and became the main institution for human capital development in the region. Moreover, the government funded new research centers with a focus on biotechnology, such as the Millennium Institute for Applied and Fundamental Biology, established in 2000 with a focus on providing improved levels of advanced human capital and applied research in areas of relevance to the salmon industry. Public-private partnerships intensified and joint ventures increased, further infrastructure was provided

and training programs to meet human resource needs were established (Katz, 2004; Perez-Aleman, 2005; Pietrobelli, 2008). At the same time, the Association of the Salmon Industry (SalmonChile) supported exporting firms through the establishment of quality standards and the realization of export campaigns in Canada, and the US. Salmon Chile contributed, sometimes unintentionally, in the development of business knowledge links between member as well as non-member firms as well as non-business links through its interaction with international NGOs (e.g. EcoOceano, Fundación Terram, OCEANO, WWF, Oxfam) (Hosono et al., 2016) .

Table 2: Representative firms of the Chilean salmon farming cluster

Group	Name of firm	Value of exports (US $ million)	Nuclear production phases	Origin of capital
First group	Marine Harvest	115	Pisciculture, farming and processing	The Netherlands
	AquaChile	84	Pisciculture, farming and processing	Chile
	Camanchaca	76	Pisciculture, farming and processing	Chile
	Multiexport	64	Pisciculture, farming and processing	Chile
	Mainstream	60	Pisciculture, farming and processing	Norway
	Fjord Seafood	54	Pisciculture, farming and processing	Norway
Second group	Salmones Antártica	45	Farming and processing	Japan
	Cultivos Marinos Chiloe	40	Pisciculture, farming and processing	Chile
	Aguas Claras	38	Pisciculture, farming and processing	Chile
	Invertec	29	Pisciculture, farming and processing	Chile
	Salmones Pacific Star	25	Farming and processing	Chile
	Salmopesnac	24	Farming and processing	Chile
Third group	Ventisqueros	17	Pisciculture, farming and processing	Chile
	Robinson Crusoe	15	n/i	Chile
	Cultivos Yadrán	15	Pisciculture, farming and processing	Chile
	Trusal	8	Pisciculture, farming and processing	Chile
	Fiordo Blanco	6	n/i	Canada

Notes: First group: large companies fully integrated companies with a significant foreign presence. Second group: medium firms ensuring sufficient capital of their own to be able to start new investment projects. Third group: smaller family owned companies, lacking adequate capital of their own to expand their activities.
Source: IIzuka et al, 2016, based on Montero (2004) and Maggi (2007)

During this phase, diverse types of actors, both public and private, became more interdependent and matched their goals towards globalization, increased productivity, efficiency and growth. However, the development of technological or scientific capabilities at local level did not receive similar attention, creating the conditions for unsustainable growth (Katz, 2016). During the early 2000s production expanded dramatically and by 2007 the industry provided around 25,000 direct and 20,000 indirect jobs, associated with a nucleus of approximately 40 companies and more than 1,200 affiliated suppliers (Alvial et al., 2012).

4.1.3 Maturity (Mid 2000s–Present)

This rapid expansion did not come without a price. Sanitary and environmental deterioration became evident after the outbreak of infectious salmon anemia (ISA) in 2007 caused by the overexploitation of natural resources and shortcomings in the production regime in search of individual profit-maximization (Katz and Iizuka, 2011; Hosono et al., 2016). As discussed in Zahler et al. (2014) regulation and collective action were weak, partly because Chilean businessmen pushed for self-regulation at a time when local knowledge was insufficient. The ISA crisis caused a strong decrease of production and resulted in job losses and financial problems. Indicatively, by 2009 around 60 percent of the cultivation centers were closed and production fell from around 700 thousand tones in 2006 to 200 thousand tones in 2010 (Iizuka and Katz, 2011, 2012).

This posed new challenges to policy-makers that were called to contain the crisis while incentivizing collective action that crossed national borders (Iizuka and Soete, 2013). With public-private collaboration now critical for recovery, the Chilean governmental agencies sought for new biotechnology methods, reached out to Chilean scientists abroad (e.g. by creating Fundacion Ciencias para la Vida, based in California), and commissioned research on the ISA vaccine. Ultimately, Fundacion Ciencias para la Vida developed the principal substance for the vaccine, while validation and clinical trials were performed by Fundacion Chile. Lacking the capacity for large-scale production, the government licensed the patent to Novartis, a multinational pharmaceutical company, and subsequently diffused it among Chilean farms. New actors entered the scene, and new international knowledge links were formed in an attempt to avoid the cluster's degrading (Hosono et al., 2016).

Both public and business links with foreign knowledge sources increased, contributing to the endurance of the cluster. In parallel to the endogenous development of research capacity, some foreign research institutes established a presence in the country. In 2007, three Norwegian institutes created a joint center in Chile to conduct applied aquaculture research. The name of the new center, AVS Chile, reflects the three mother institutes: AKVAFORSK, VESO and SINTEF. Another relevant example is the case of German research institute Fraunhofer, which established in Chile a new R&D center on biotechnology in 2009 that has since engaged in a research line to develop new vaccines for salmon epidemics. These complex international science, technology and innovation partnerships may contribute to the development of the cluster's absorptive capacity, but are also controversial if they do not engage with local agents or if they pursue 'techno-colonialist' strategies (Barandiaran, 2015; Guimon et al, 2016).

Additionally, Chile now participates in the International Cooperation to Sequence the Atlantic Salmon Genome (ICSASG), a research program led by public and private member organizations from Canada, Chile, and Norway. Likewise, SalmonChile forms part of the Salmon Aquaculture Dialogue (SAD), a science-based forum that aims at the development of standards initiated by the World Wildlife Fund (WWF) in 2004. Such initiative maintains science-based links through formal agreements that allow foreign

researchers and experts to visit Chile and conduct environmental audits of firms, publish environmental reports concerning business activities, and offer general consultation on environmental risks. On a more business-oriented side, ProChile, the Chilean Trade Commission within the Ministry of Foreign Affairs, continues to seek effective commercialization channels for Chilean goods abroad by facilitating strategic alliances and developing international business links.

Governmental efforts continue, the cluster remains, yet the increasing technological complexity, the fierce nature of competition in the industry and the environmental factors that directly affect the industry place challenges for local firms. While a new draft of sanitary regulation for salmon production was presented by the end of 2015, the red tide phenomenon and attached poisoning cases observed in early 2016, brought the industry back at the spotlight (Gonzalez, 2016). Explanations and solutions were sought by scientists and the industry, confirming that large international players did not remain immune to this new event. Indicatively, Norwegian Marine Harvest, which now leads operations in Chile's salmon farming, reported losses of US $6.6 million directly linked to the deceased fish and announced 500 layoffs (Diario Financiero, 2016).

4.2. International knowledge connectivity of Costa Rica's software cluster

4.2.1 Emergence (Mid 1980s–Late 1990s)

The software cluster in Costa Rica's capital, San Jose, dates back to the 1980s when a few local SMEs emerged with a focus on the commercialization and implementation of software developed abroad. This was primarily based on license and partnership agreements with foreign MNCs which dominate the packaged software segment. Local innovation activities were generally limited to certification programs and training provided by foreign software firms and consultants. Likewise, product development was limited to incremental efforts to adapt existing software packages to the specific needs of local users. The development of the cluster was constrained by the small size of the local market and by its relatively weak demand in technological terms.

During this first stage, the role of policies was rather passive, focusing on improving the general macroeconomic environment and business climate without targeting specific industries. In 1998, the Costa Rican Chamber of Information Technology and Communication (CAMTIC) was created as a private, non-profit business association that today groups around 90 percent of local software companies. CAMTIC has played an important role in supporting innovation and cluster upgrading, as well as in the establishment of international links that were further enhanced by national agencies to promote exports (PROCOMER) and FDI (CINDE).

4.2.2. Expansion (Early 2000s–Late 2000s)

Since the late 1990s an increasing number of foreign multinationals entered the country across different industries. In the case of ICT, the arrival of Intel in 1997 marked a turning point in positioning Costa Rica as an attractive destination for high-tech industries (Larrain et al., 2001; MIGA, 2006). As of 2012, Intel had over 3,000 employees in Costa Rica and accounted for over 20 percent of the country's exports (OECD, 2012). Although Intel's operations were not directly related to software, they had a strong reputational effect and attracted other multinationals that did work on software.

Despite the success in attracting FDI, most multinational subsidiaries in the ICT industry acted as "enclaves" that were not embedded in the domestic milieu (Ciravegna, 2012a; Paus and Gallagher, 2008). Their activities did not target the domestic market; rather, they used Costa Rica as a low-cost platform from which to serve either

international clients or other units of the multinational. Thus, FDI in Costa Rica was mostly driven by efficiency-seeking strategies, rather than market-seeking or asset-seeking strategies, which limited the extent of knowledge sharing (Giuliani, 2008). Many software related activities were in fact undertaken by companies from different industries that established in Costa Rica call centers, IT-enabled business support services and outsourcing.

As a result, the software cluster became a dual structure where national and foreign-owned firms evolved separately in response to distinct forces (Paus and Gallagher, 2008). Both tiers of actors benefited from the public goods and externalities characteristic of industrial clusters, such as the pools of skilled workers or the institutional system. But the two tiers sometimes competed rather than complemented each other. For example, Nicholson and Sahay (2007) argue that FDI produced a crowding-out effect on local software firms by recruiting the most skilled workers and altering the salary structure in a manner that local firms could not match.

In parallel to the cluster's FDI-driven expansion, a new wave of local firms emerged and grew substantially during the 2000s by successfully engaging in outsourcing contracts mainly with foreign companies. In particular, Costa Rica became a popular outsourcing location for large North American firms given the geographical proximity and time zone; the favorable business climate; the availability of well-trained employees and IT infrastructures; and the fact that the salaries of programmers were much lower than in the United States (Barrett, 2009). By 2011, the software and ICT services sector was composed of about 200 local firms and 40 multinationals (Ciravegna, 2012b).

In sum, during this phase the expansion of the cluster was driven by the specialization in low-end products and low-cost subcontracting, within a GVC dominated by foreign firms. Foreign sources of knowledge were critical for local firms to access new technologies and know-how, but the impact of FDI on knowledge transfer was limited due to the lack of knowledge-intensive links between domestic firms and multinational subsidiaries. This evolution was also observed in Bangalore, one of the most successful examples of software clusters in emerging countries (Lema, 2014). As discussed in D'Costa (2003), Indian firms tended to focus on the lower value-added stages of the software-development cycle, where opportunities for upgrading were limited, while innovation activities were typically bound to the locations of customers and software lead firms in developed countries.

4.2.3. Maturity (Late 2000s–Present)

Faced with increased global competition, the cluster could no longer aspire to compete in low-cost, basic software development and support services. Not only had competition from large emerging countries like India intensified, but other Central American countries had also erupted in the market and offered more competitive costs. Thus, upgrading local capabilities in order to better integrate into GVCs and competing internationally based on quality, innovation and differentiation became a core challenge. Beyond FDI attraction, public investments to improve the absorptive capacity of local firms became indispensable (Giuliani, 2008; Parrilli and Sacchetti, 2008). This stage of the cluster's evolution is characterized by increasing attempts to specialize in new market niches and more innovative, higher-end products and services. Along the way, links with foreign sources of knowledge have progressively become deeper and increasingly established through less hierarchical forms of collaboration, including strategic partnerships.

In recent years the activities of MNC subsidiaries have shown signs of evolution toward higher value-added segments of corporate supply chains including, to some

extent, R&D. For example, leading software companies like Microsoft, Oracle, HP, and Equifax, among others, have established more advanced software development activities in the country. In the field of business services, although back-office support and customer service centers still dominate, some MNC subsidiaries have engaged in more complex activities including advanced technical support, software development and maintenance, project management, and entertainment and media. In April 2014 Intel announced the closure of its manufacturing activities in Costa Rica, cutting 1,500 jobs in the country (The Economist, 2014). Yet it chose to maintain and expand its R&D, software, and services activities in the country, illustrating the kind of structural change underway towards a stronger specialization in high value-added segments of the GVC.

In parallel, a small group of local firms with advanced knowledge capabilities have emerged. These firms target international markets and operate at the technological frontier in several market niches like software migration solutions, call center software, data mining and fraud control, animation and digital design, mobile applications, avionics and orthodontic services, among others (Parrilli and Sacchetti, 2008; Vargas Alfaro, 2004). Some of these local firms have grown in size to become medium or large firms, and have entered other Central American countries in order to expand their market opportunities (Lopez et al., 2009). A downside of such regional focus is that opportunities to expand into other international markets and learn from lead customers abroad are not being sufficiently exploited (Lopez et al, 2009; Ciravegna et al., 2014). This focus on Central America also limits the capacity of local firms to collaborate with MNC subsidiaries established in the country to compete for opportunities in global markets.

Given the fast pace of growth of the software cluster and the increasing demand for highly skilled professionals, the shortage of skilled labor became a major bottleneck to the cluster's upgrading as the university system had not reacted sufficiently fast to growing demands (OECD, 2012). To address this gap, new postgraduate programs have been launched at the Costa Rican Technological Institute and the University of Costa Rica in the fields of software engineering and computer sciences. At the same time, new links with foreign universities have been established to ramp up the development of absorptive capacities. For example, in 2011 a program to train innovation managers was launched by the Ministry of Science and Technology, through an alliance with the Small Enterprise Promotion and Training Program of Leipzig University, Germany, in cooperation with the National Technical University of Costa Rica (Elizondo, 2011). Another example concerns the arrival of GeorgiaTech to Costa Rica, which created a Trade, Innovation and Productivity Center in 2009, an R&D center with around 50 employees and an initial investment of approximately 4 million US$. With a focus on supply chain and logistics research, the center has developed new software applications for industry and for the government.

With regards to FDI policies, a clear shift can be observed from quantity to quality (Monge and Tacsir, 2014). Indeed, in recent years the aim has been to attract higher value-added activities within the GVC (including design, R&D, advanced business services, and regional headquarter functions) and to promote the upgrading and embeddedness of already existing foreign subsidiaries in the national innovation system. For example, the Costa Rica Provee program launched by PROCOMER in 2001 to promote links between multinational subsidiaries and local manufacturing firms was expanded in 2010 to include software and IT services.

Furthermore, MNCs are also contributing to the cluster's upgrading by supporting entrepreneurship and establishing links with local start-ups. Along these lines, in the late 2000s the government developed joint programs with foreign MNCs, such as a prize for the best Technological Entrepreneurship project funded by Microsoft, Intel's Desafío

Intel Program, or Cisco's new Entrepreneur Institute in Costa Rica which was opened in 2010. Moreover, the government is also promoting a higher involvement of established MNCs in the development of specialized skills. For example, in 2000 a new center for technical training (CENFOTEC) was created in partnership with Microsoft, to provide training on software development, while the government signed several agreements with MNCs like Intel and HP, including their commitment to provide funding for scholarships.

5. Discussion

Taken together, these case studies illustrate the plethora of strategies available for connecting with international knowledge and point to their different combinations depending on the governance of the global value chain, the knowledge bases that the cluster relies upon, and the stage of its evolution. We now turn to a comparative analysis aimed at linking further the results of the case studies with the theoretical framework set forth in Section 2.

5.1. International knowledge connectivity and governance of global value chains

Our findings indicate that the structure and governance of the value chain in which clusters are positioned is mostly relevant for business links. In the Costa Rican case, the increased slicing and fragmentation of the value chain augmented the opportunities for entrance and knowledge acquisition. Adding to the findings of Ciravegna (2012a), our empirical evidence showed that the hierarchical relations in place limited, at least initially, the potential for establishing knowledge links with foreign businesses, as the kind of activities located in the country by leading firms were lower-end, hence learning opportunities remained low. Under these circumstances, links with international sources of knowledge tend to be less intense in terms of knowledge production and fall primarily under the first category of business links identified in Table 1, focusing on arms-length agreements and licencing rather than collaborative schemes or the joint generation of knowledge. Despite the massive arrival of FDI, knowledge spillovers remained weak as the industry became a dual structure where national and foreign-owned firms evolved separately.

In the Chilean case, international knowledge links developed as a result of policy efforts to enter the established value chain. In comparison with the software industry, in salmon farming knowledge-intensive activities and production activities are less easily separable location-wise, which means that firms need to master activities internally across the value chain. Then, business-driven knowledge links are less relevant at the time of entrance as firms need to possess a substantial stock of knowledge in order to form part of the GVC. The small number of players, the localized vertical integration, and the concentration of the industry had a dual effect on the production and exploitation of knowledge. On the one hand it facilitated the identification of relevant knowledge; on the other hand, though, the acquisition and absorption of such knowledge clashed against the fierce competition that characterizes oligopolistic industries. As a result, many of the Chilean firms that survived and grew globally ended up being acquired by global competitors, while business links did not reach the maximum intensity in terms of knowledge coproduction.

This evidence helps to illustrate how the local constituents of industrial clusters inserted in GVCs with more hierarchical governance participate less in the joint production of knowledge than in the case of clusters inserted in GVCs with more flexible coordination mechanisms. However, as discussed in Section 3, the two case studies exhibit GVCs with hybrid modes of governance. Moreover, the modes of governance

change along cluster evolution, thus a dynamic analysis is essential to understand international knowledge connectivity. For example, the salmon cluster in Chile was characterized by a market-based governance but shifted towards a more hierarchical governance mode as most local producers were acquired by foreign MNCs. Indeed, as discussed in Section 2.1., the empirical operationalization of Gereffi's taxonomy of GVC governance modes should be approached with the greatest caution and be treated as dynamic in time.

In addition, it is important to stress that the position of clusters in GVCs and the opportunities for upgrading are affected by other overreaching factors such as the maturity of the industry where the cluster is inserted, price and market conditions at each particular stage, the rules of the game, and the quality of institutions and government. For example, the market for Chile's salmon expands throughout the globe, while Costa Rican software cluster is very dependent on the U.S. and Central American markets. On the other hand, salmon farming is a mature industry while software is a much more emergent and dynamic one, subject to constant transformation. The two case studies unfolded in different territories, a peripheral region in Chile and the capital of Costa Rica, each displaying unique productive systems, market dynamics, cultures, and institutions.

5.2. International knowledge connectivity and differentiated knowledge bases

Comparative analysis of the case studies suggests that the dominance of a specific type of knowledge base can influence the type of international knowledge links built due to the different modes of innovation it prescribes, at least at the early stages of evolution. More specifically, clusters that require more analytical knowledge for their development (like the salmon farming cluster) tend to rely more on formal events, agreements and technical cooperations that have predefined output objectives (e.g. technical feasibility and economic viability studies). Once organizational proximity has been achieved and problem specificity increases, informal interaction contributes to the more efficient resolution of, still predefined, objectives (e.g. supply of freshwater facilities, domestic egg production). Such process seems to be iterative, with formal agreements frequently leading to more personal interactions contained in an established communication framework (e.g. planned visits of foreign experts). Evidence from the salmon farming industry confirm that the outcomes of such international knowledge links were easier to codify and came in forms of new scientific techniques, technological solutions, analysis reports and so forth.

In turn, in industries based in synthetic knowledge, international knowledge links are more informal and knowledge production is not fully intended nor linked to a predetermined objective. As observed in the Costa Rican case, the initial FDI projects were not directly linked to software and the investments made did not target learning or technology transfer. It was the day to day local accumulation of on the job experience that resulted in the improvement of local capacity and led to the emergence of more local firms. In later stages, as institutional proximity developed, business links started to emerge (e.g. outsourcing contracts) and links became more structured.

Turning the focus to the types of actors that facilitate the development of links and diffuse their results, our findings suggest that business links with foreign actors become of greater relevance for clusters that depend to a larger extent on synthetic knowledge (like the software cluster), while public links are central in clusters that rely mostly on analytical knowledge. Respectively, in the case of Costa Rica, the involvement of the public agencies, universities and research organizations was not as strong as in the case of Chile.

From this analysis we infer that when it comes to the selection or development of knowledge links with foreign agents, the structural characteristics of the clusters are important for framing the point of departure. However, the actual progression and combinatory use of different strategies to link with foreign knowledge depends on the evolution paths that different clusters follow. Similar as in the above discussion of the governance of the value chain (Section 5.1.), an important caveat is that clusters rarely rely only on one type of knowledge base, and the relative importance of different knowledge bases evolves throughout the life cycle of clusters (Manniche, 2012; Trippl et al., 2009). The next section attempts to unfold such dynamics across the different stages of evolution of the two clusters.

5.3. International knowledge connectivity throughout the stages of cluster evolution

Our analysis confirms the importance of foreign sources of knowledge throughout all phases of cluster evolution. Matching the categories identified in Table 1 with the three stages of cluster evolution, we observe different knowledge dynamics (Table 3). During their emergence, both clusters reached out to adopt knowledge produced by foreign public and private agents. In a short period of time knowledge links intensified and cluster residents actively participated in the coproduction of knowledge with foreign scientific institutions (in the case of Chile) and multinationals (in the case of Costa Rica). Hence, the first two categories of links were executed quite early and almost in tandem, yet we observe mostly public links in Chile and mostly business links in Costa Rica. At the expansion stage, the software cluster maintained the same two categories of links (B1 and B2) despite the arrival of large inflows of FDI, but collective knowledge production did not yet occur, possibly due to the lack of absorptive capacity. In the case of Chile, the cluster's expansion was accompanied by the maintenance of P2 types of links and the development of more knowledge-intensive business links. In this context, both public and private collaborations contributed to the intensification of knowledge exchange.

Table 3. Foreign knowledge links during cluster evolution

	Salmon Chile		Software Costa Rica	
	Public	Business	Public	Business
Emergence	P1 P2			B1 B2
Expansion	P2	B1 B2		B1 B2
Maturity	P2 P3	B2 B3	P2 P3	B3

Note: Codes refer to Table 1.
Source: Authors

Reaching the maturity stage, the growth of strategic alliances and exports, and the fact that some MNC subsidiaries and even foreign universities established R&D centers in Costa Rica, intensified the collaboration between businesses and, for the first time, with universities as well. Given the structural characteristics of the cluster and the individual strategies of corporate players, this cluster only combined scientific and

business links at the later stages of its development. Turning to the case of Chile, the maturity stage was marked by the intensification of both scientific and business links through the cluster's participation in transnational R&D consortia; the development of complex international science and innovation partnerships; and the tightening of public-private partnerships. In line with Trippl et al. (2009), we observe that as clusters mature and the need for radical innovation increases, the diversity of international links widens and the blending between public and business links becomes a prerequisite. In other words, as clusters evolve and knowledge needs become more complex, "combinatorial knowledge bases" become the fuel of upgrading and gradually blend scientific and business links while increasing their intensity in terms of knowledge co-production (Manniche, 2012).

5.4. Policy trends and implications

Safeguarding social welfare and sustainable cluster growth is a challenge that policy-makers are continuously trying to meet. Given that upgrading opportunities for clusters are determined by the confluence between GVCs and national innovation systems (Pietrobelli and Rabellotti, 2004, 2011), public policies have a critical role to play in strategically connecting the development of local human capital, technological capabilities, infrastructures, and institutions with the dynamics of GVCs (Morrison et al., 2008; Milberg and Winkler, 2013). Such an approach demands a flexible combination of instruments and support policies, since the appropriateness of alternative links varies according to the evolution stage of the cluster and the prevalent knowledge bases (Brennen and Schlump, 2011).

Table 4. Policies to link with foreign knowledge throughout cluster evolution

	Types of Policies	
	Salmon Chile	Software Costa Rica
Emergence	- Active search of opportunities through scientific international cooperation - Establishment of public institutions and regulatory framework	- Improving the general business climate without specific focus on software cluster
Expansion	- Public-private partnerships within the cluster - Education and training programs targeting the industry - Positioning in the global market	- Maximizing FDI inflows for all sectors - Promoting entrepreneurship - Support to quality certification in local firms
Maturity	- New regulatory framework for industrial sustainability - Support to R&D through public-private partnerships - Environmental management	- Improving human capital skills - Attracting higher quality FDI - Promoting links between foreign subsidiaries and local firms and universities - Assisting international expansion of local firms

Source: Authors

A first point to highlight from comparative analysis of the case studies is the different levels of public involvement. In the Chilean case, the government's deliberate will to establish a new sector based on natural resource availability led to the active seeking of foreign knowledge even before the formation of the cluster. In turn, the emergence of the software cluster in Costa Rica occurred spontaneously as part of a general opening up of the economy through the attraction of FDI. It was only in later

stages of its development that public policies became cluster-specific. As a general trend, we observe a transition from generic to more specific cluster policies in Costa Rica while the reverse holds for Chile (Table 4). Note that this is a tentative conclusion based only on comparative analysis of these two clusters. Any attempt to generalize this result would need to rely on further evidence from a wider set of case studies, and would also need to consider the large variety of technological and institutional profiles across clusters from similar industries but different geographies.

Our evidence confirms that governmental policies have an important role to play with regards to the configuration of international knowledge links. In the case of salmon farming such a relationship is evident as the types of knowledge links match the selection of foreign partners made primarily by the government aiming at fostering organizational proximity and building knowledge capacity. Even with the increasing participation of the private sector, public policies to link with international knowledge remained critical throughout the cluster's life cycle and evolved to address the cluster's changing needs, for example to survive and recover from the ISA crisis. Turning to the software cluster, the passive role of the government during the first two stages of cluster evolution explains, to an extent, the lack of public links and the slow intensification of business links. As seen in Table 4, it was mainly at the maturity stage that the government sought to improve the skills of local human capital, a core ingredient of absorptive capacity. Blending public and business links was realized when policy-makers adopted a broader perspective on links, networks, and spillovers; not limited to links between local and foreign firms, but also including collaboration between foreign firms and local universities, between foreign firms and local entrepreneurs, between local and foreign universities, between local and foreign human capital, and so on.

The combination of scientific and business knowledge links requires the presence of public policy in varying forms. The Chilean case shows that the government's involvement in establishing public links with foreign partners early on facilitated the emergence of the cluster and its initial upgrading. The same case indicates, though, that not balancing supply side policies during evolution can lead to negative implications. The Costa Rican case highlights that the lack of public links delays the intensification of business links due to the lack of absorptive capacity on the side of local players. The role of the government becomes vital then in promoting collective learning and controlling for dualism and crowding-out. The growing involvement of the Costa Rican government at the cluster's maturity stage did intensify knowledge sharing and contributed to the renewal of the cluster.

Our analysis serves to emphasize that the role of public policies is connected not only with stimulating international links but also with contributing to local learning and capability building (in line with Piertobelli and Rabellotti, 2007; Arangungen et al., 2007; Giuliani, 2008; Valdaliso et al., 2011). Absorptive capacity (or actually the lack of it) became, in several instances, a bottleneck for the clusters' upgrading. In the Chilean case, the transfer of technology alone, without the required tacit knowledge to manage such technology and the failure to develop early on a sound regulatory framework, led to a crisis as exemplified by the ISA outbreak. In addition, overreliance on foreign knowledge and the lack of local knowledge for the comprehension and production of key technologies resulted in the acquisition of well-established Chilean firms by foreign parties and the overall concentration of the industry. In the Costa Rican case, the lack of absorptive capacity prolonged the dependence on foreign knowledge and delayed the assimilation of benefits stemming from FDI. As a consequence, enhancing absorptive capacity has become the key policy priority in both clusters at their current stage of maturity.

6. Conclusions and limitations

This paper explores the factors shaping the international knowledge connections of industrial clusters across time. Considering the established need and ample variety of channels to link with foreign knowledge, we combine extant literature and develop theoretical propositions with regards to three analytical categories: the governance of GVC where the cluster is inserted, its dominant knowledge base and its stage of evolution. Such an approach allows studying *simultaneously* how the production structure, innovation dynamics and evolution of external knowledge links shape clusters' path to growth and constitutes our first theoretical contribution.

Exploring these propositions empirically, we find that: (i) the more hierarchical the GVC structure, the less knowledge co-creation between local and foreign actors; (ii) clusters relying on analytical knowledge bases opt for more formal and coordinated links with high involvement of public actors, whereas in clusters relying on synthetic knowledge bases knowledge interaction relies on less formal links mainly between business actors; and (iii) as clusters evolve the channels through which they connect with foreign knowledge increase in number and variety.

Moreover, attending to the different types of actors, we separate between public and business knowledge links and show how in some contexts the functions related to knowledge gatekeeping can be equally, or even better, performed by public actors, an aspect that has received less attention in the literature. Finally, our evolutionary analysis confirms that international knowledge links are not only relevant when lock in phenomena arise; rather, their role is critical even for the birth of clusters.

From a public policy perspective, our findings illustrate that alternative policy options for linking clusters to foreign sources of knowledge exist and exert an influence on the cluster's evolution and sustainability. Such analysis should be relevant for policy-makers and consultants charged with stimulating the upgrading of industrial clusters in emerging countries.

However, this study is not free from limitations. Given the complexity of contextual factors and their evolution overtime, our analytical framework focuses on one subset of the factors that influence the international knowledge connectivity of clusters, leaving other important elements underexplored. In addition, given its exploratory nature, our study is exposed to the inherent limitations of the case study method (e.g. sampling bias, generalizability of findings, etc.) that we chose to trade off in favor of detail and depth. Therefore, our results should be taken as preliminary theoretical insights to be further contrasted in future studies through richer empirical research. Surely, the generalizability potential of our findings would increase with their contraposition against more case studies, a line of research we aspire to continue.

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