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Critical Success Factors and Cluster Evolution:

A case study of the Linköping ICT cluster lifecycle

Sam Tavassoli [1†]

Department of Industrial Economics, Blekinge Institute of Technology, Karlskrona, Sweden
Email: sam.tavassoli@bth.se
Phone: +46 455 385688
[†] Corresponding author

Dimitrios Tsagdis

Hull University Business School, Filey Road, Scarborough, YO11 3AZ, UK
Email: d.tsagdis@hull.ac.uk

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[1] Sam Tavassoli is also a research affiliate to CIRCLE, Lund University, Sweden.

Abstract

This paper investigates the variation in the importance of critical success factors (CSFs) in the evolution of the Linköping ICT cluster in Sweden. The international empirical evidence of CSFs in ICT clusters reported in the literature is systematically reviewed. On its basis an object-oriented conceptual model is developed encompassing 15 CSFs; each attributed to one or more objects, e.g. firms, institutions, entrepreneurs. The lifecycle of the Linköping ICT cluster is delineated and its stages segmented. The existence and importance of each CSF in each stage of the cluster lifecycle is established empirically on the basis of interviews with key experts. The main findings comprise a stage-specific group of CSFs whose importance varies across the cluster's lifecycle stages with different patterns. The above findings aim to stimulate policy makers and researchers alike to further pursue the line of enquiry developed in this paper.

Key words: ICT clusters; Critical success factors; Cluster lifecycle, Cluster evolution

JEL classifications: R58; O21; E61

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1. Introduction

There is an on-going debate concerning the factors that underpin the success of clusters, hereafter critical success factors (CSFs) (Saxenian, 1994; Sainsbury, 1999; Adams, 2005; Weil, 2009).[2] The debate is yet to reach any solid consensus about the range of relevant CSFs even in particular clusters; let alone about clusters in general, or of any given industrial specialisation. Moreover, the importance of CSFs throughout the evolution of a cluster is rarely discussed (Boschma and Fornahl, 2011) and when it is, it is often in terms of a narrow set of CSFs; e.g. policy measures (Brenner and Schlump, 2011). Often theoretically evaluated, or on the basis of simulations, or secondary evidence from clusters across different specialisations.

Nonetheless, there is an emerging literature concerned with the evolution of clusters, their life cycle, and phases/stages (reviewed in section 2.3) and indeed empirical evidence that the "factors that give raise to the start of a cluster can be very different from those that keep it going" (Bresnahan et al., 2001, p. 835). However, even when it comes to clusters of a similar specialisation, this evidence is patchy at best as to the importance of CSFs in the cluster's evolution. For example, a growing company base (e.g. thriving start-ups) as a CSF is suggested to be crucial during the birth of the Silicon Valley (Adams, 2005), while Parker (2010) reported on its importance in all phases of the Sofia Antipolis evolution.

Although insightful, this is not a helpful situation for systematic learning, and for the effective allocation of scarce resources in clusters that are in different evolutionary phases. Nor does it help in identifying the range of actors and relations that need to be targeted.

[2] This study adopts the Borrás and Tsagdis (2008:9ff) minimal-set of three criteria for recognizing a cluster: "1) geographical concentration of firms, in particular industrial specialisations; 2) number of SMEs has to be larger than the number of large size enterprises; and 3) presence of inter-firm and institutional networks".

This study aims to make some first steps towards filling the above gaps in the following manner. First, a systematic review of the literature on cluster CSFs in a given industrial specialisation, viz. ICT, is undertaken (in section 2.1). This is used to develop a conceptual model of the entities and their relations underpinning the CSFs of ICT-clusters (in section 2.2). This is a static model, mainly due to the fact that variation in the importance of CSFs across a cluster's evolution is rarely reported in the extant literature (as reviewed in section 2.1). As there are additional benefits from casting the dynamics of such a model (e.g. predict cluster success, signal the kind and timing of requisite interventions) the main strands of the literature on cluster evolution are discussed in section 2.3 to inform their empirical operationalisation.

Second, to illustrate empirically the dynamics of the aforementioned model, a successful ICT cluster in Linköping, Sweden is focused upon, and its evolutionary pattern is delineated and segmented in section 3.

Third, the presence and importance of each CSF throughout the cluster's evolutionary stages is tested (in section 4). The findings suggest that about half of the CSFs tend to be equally and stably important throughout the cluster's evolution; whereas the importance of the other half of CSFs tends to be rather *stage-specific*. These, and other key findings, are discussed in the context of the wider literature (e.g. involving alternative cluster specialisations).

The paper concludes by delineating what can be accomplished with such data and models, their policy implications, and some areas for further research (in section 5).

2. Literature review

2.1. Reviewing the international empirical evidence on CSFs of ICT clusters

Cluster CSFs could be traced back to Marshall's (1890) original writings. However, it is mainly in recent years that their study has intensified, popularised by the Sainsbury (1999) and Ecotec (2001) reports. Sainsbury (1999) delineated no less than ten CSFs for the development of biotech clusters in the UK, and played an instrumental role in their generalisation to clusters of other specialisations in the Ecotec (2001) report as Minister for Science and Innovation (1998-2006) at the UK Department of Trade and Industry.

This study goes further, reviewing systematically (Denyer and Tranfield, 2006) the international empirical evidence on CSFs particularly in ICT clusters. This is in an effort to develop a robust, yet flexible model, capturing how such CSFs may be inter-related and the objects involved. However, this section is rather static, in the sense that it reports CSFs (and their objects and relations) without acknowledging their importance over time (this is rectified in the subsequent sections where the requisite dynamics will be added through the use of a critical case study).

To accomplish the above, the contemporary (i.e. 1995-2010) ICT cluster CSF literature was initially delineated through extensive database searches (e.g. for 'cluster', 'ICT', and 'success' keywords), systematic reviews of periodicals, and sifting references. The identified literature was subsequently reviewed using scientometric and content analyses [(3)] in an effort to distil generic/elementary CSFs. For example, hard and soft infrastructure constructs were not bundled under a single infrastructure CSF. Instead, they were disaggregated across a number of more elementary CSFs related to physical infrastructure, innovation, and support

[(3)] For the present purposes scientometrics should be understood as the measurement of scientific information (e.g. number of scientific articles published in a given period); see Leydesdorff (1995). Conversely, content analysis can be broadly construed for the present purposes as "any technique for making inferences by objectively and systematically identifying specified characteristics of messages" (Holsti, 1969, p.14). That is, messages encountered in empirical studies concerning cluster CSFs.

organizations. In addition, a quality criterion was applied requiring that for each elementary CSF sufficient empirical evidence was reported in at least two empirical studies, by different authors, concerning different ICT clusters, in a range of developed economies.[(4)]

Turning thus to the ICT cluster CSFs included in this study, their first explicit appearance in recent years appears to be in Klofsten and Jones-Evans (1996) who introduced the importance of having both the right vision (e.g. clear, focused, flexible) and trust.

Starting with the ***right vision*** (CSF1), Klofsten and Jones-Evans (1996) broached the importance of a focused vision in the cluster's support organisation, and in particular among its board members (constituted by CEOs from six large cluster firms) in the development of the Linköping ICT cluster. For example, in order to communicate effectively their plans with potential investors (ibid. p. 192). However, in a subsequent study of another ICT cluster, viz. Silicon Valley, Benner (2003, p. 1815) reported that such developmental networks can take the form of joint ventures constituted by firms and government.

In terms of ***trust*** (CSF2), Klofsten and Jones-Evans (1996, p. 192) reported on the importance of firm-trust on the cluster's formal association. In recent years, Bramwell et al (2010) recognized the ability of key actors to develop the underlying conditions of trust as the important factor for development of the Waterloo ICT cluster in Canada. The aforementioned studies can also be taken to suggest that trust (CSF2), unlike vision (CSF1), is of a different nature in that it is not a mere property of one or more object(s), but also a relation between such objects; e.g. policy makers, firms, and Higher Education Institutions (HEIs).

[(4)] Preliminary investigations by these authors (Tavassoli and Tsagdis, 2010; Tsagdis and Tavassoli, 2012) identified close to 20 CSFs for clusters in different industrial specialisations. Thus, it should be informed that the 15 CSF reported in this study are a true subset of CSFs shared across several industries, and that for clusters in other industrial specialisations this list would simply be added to with CSFs such as addressing or avoiding negative lock-ins, skilled labour, and political setting. For example, there is positive and counterfactual empirical evidence for lock-ins as a CSF in industrial specialisation like the Rhur districts in Germany (Grabher, 1993) and Silicon Valley (Benner, 2003).

It should thus be unsurprising that geographical ***proximity***, expressed in terms of both inter-firm proximity and firm proximity to other actors, has also been reported as a CSF(3). In terms of firm proximity to other actors, increased emphasis has been placed on HEIs. For instance, in the case of the Mjärdevi Science Park in Linköping, Sweden (Etzkowitz and Klofsten, 2005) and in Silicon Valley (Sölvell, 2008, p. 92; Weil, 2009, p. 12). It could thus be argued that CSF3 manifests both as a property of a single object, e.g. when a firm chooses to locate near some other firm(s) as well as a relation between other objects, especially HEIs (further discussed below).

Moving to CSF4, a number of subsequent studies identified ***pre-existing knowledge*** to be a property of the cluster-hosting region. Hi-tech and creative forms of pre-existing knowledge (mediated through formal educational programmes) in the region were reported by Hallencreutz and Lundequist (2003, p. 540ff) as underpinning the success of the Eskilstuna's information and graphic design cluster in Sweden. Similarly, across the Atlantic both Adams (2005) and Weil (2009) reported the often-neglected importance of the pre-existing knowledge in the region for what later became known as the Silicon Valley success story.

This last point also highlights the importance of a cluster's ***brand-name*** (CSF5) not just for Silicon Valley, but for other ICT clusters too. For example, Lyons (2000, p. 294) reported that the brand name of the Richardson ICT cluster, viz. 'Telecom Corridor' was a registered trademark by the Richardson Chamber of Commerce, not just to market the cluster, but also to define its geographic boundaries. Moreover, Lundequist and Power (2002, p. 699) found that branding in the Stockholm ICT cluster (Kista) strengthened its competitiveness.(5) They further suggested that the "public sector's access to broad channels of communication and the

(5) This is accomplished by fulfilling three main functions: a) "the attraction of investment, venture capital, and skilled workers", b) "unite[d] actors in a shared purpose and identity", and c) "complement[ed] firms' marketing and collaborative-marketing activities" (ibid.).

legitimacy its involvement confers" has been important to the Stockholm ICT cluster. More recent empirical evidence by Sölvell (2008) from the Silicon Valley pointed out that mass media (e.g. by creating 'stories') and the government (e.g. by creating initiatives), also contributed to the enhancement of a cluster's brand. These studies thus render this cluster property as being dependent on mass media, cluster supporting organisations, and the government. They also seem to imply that a government's vision (CSF1) may have a dependency relation to its brand (CSF5).

Building on the above, the presence of at least one ***strong actor*** within an ICT cluster has also been identified as a CSF(6). Among the earlier studies, Klofsten et al. (1999) as part of discussing the Triple Helix of the Linköping cluster, highlighted the important role of the Linköping University as a strong actor. Subsequent studies added support on the importance of HEIs and/or firms as strong cluster actors. The latter, are often referred to as anchor or lead firms (Wolfe and Gertler, 2004, p. 1074; Sölvell, 2008, p. 40). Raines (2000, p. 32) reported on the importance of both kinds of actors as CSFs of the ICT clusters in East Sweden and in Tampere, Finland, as well as in the semiconductor cluster of Scotland. Adams (2005) made similar observations concerning three ICT clusters in the US, viz. in Silicon Valley, Route 128, and the Research Triangle. The benefits from such strong actors also abound in the literature. For example, Harrison et al (2004) reported some additional benefits, like attracting and retaining highly skilled employees, from having both kinds of strong actors (which he termed "magnet organisations") for the success of the Silicon Valley North in Ottawa, Canada. Although HEIs and firms (especially MNEs) are on the main identified in the literature as the strong actors, some studies also pointed towards the involvement of additional actors that appear to be crucial for a cluster's success; especially during the birth/formative stages of a cluster. For instance, the government forming ex novo the HEIs and large firms that became subsequently the strong actors in the Hsinchu semiconductor cluster in Taiwan

(Parker, 2010, p. 254). Suggesting that CSF6 may be a property of clusters, firms, HEIs[(6)] and support organisations like those mentioned above.

This last proposition also provides a preamble to CSF7, viz. ***networking*** (collaboration); e.g. between HEIs and SMEs firms as highlighted by the Expert Group (2002) in the case of the Finish ICT cluster.[(7)] Borrás and Tsagdis (2008) reported on MLG support for establishing firm networks in the Scottish ICT cluster; whereas a year later Weil (2009) reported on the importance of networking between firms as well as between firms and HEIs in the success of Silicon Valley. Finally, the Parker (2010, p. 251) study of the Sophia Antipolis ICT cluster in France provided empirical evidence suggesting that collaboration through networks "is the real value added". Even though clubs and associations may have originally promoted networking, it was such networks that once fully developed, transformed the institutional context, and resulted in the evolution of the cluster. Taken together, the above studies suggest that CSF7, besides being a property of the firms and the cluster, is also dependent upon support organisations, HEIs, and the government (MLG).

The aforementioned studies also bring to the fore the importance of ***physical infrastructure*** (CSF8). As elaborated in the Link and Scott (2003) study of the Research Triangle Park (RTP) in North Carolina, US it was such infrastructure that has led to spur innovation. More recently, the Lerch et al. (2007) study of ICT clusters in the Baltic metropoles regions (viz. Berlin, Oresund, Helsinki, Stockholm, Riga, and Tallin) expanded on the requisite physical infrastructure as including technology parks, research institutes, and support facilities for the

[(6)] As Bresnahan et al (2001, p. 847) cautioned, "putting a university at the centre of the cluster can help, but it is neither a necessary nor a sufficient [success] condition". This applies mutatis mutandis to all CSFs in this study as a) it is argued that it is their combination that underpins success, and b) CSFs can have varied instantiations; in terms of CSF6, for example a firm could act as the sole strong actor.

[(7)] Although Saxenian (1994, p. 161) elaborated on the role of networking in 'reinventing' Silicon Valley and provided counterfactuals for Route 128 earlier than the above studies; the above appear to have been the first studies that explicitly elevated networking to a cluster CSF.

organisation of conventions and fairs. Taken together these studies seem to suggest that CSF8 is a regional property with a dependency on entrepreneurs and the government.

Of course infrastructure and several other CSFs are also inexorably linked to ***finance*** (CSF9). It is thus unsurprising that during this period studies such as those by Charles and Benneworth (2001) reported on the importance of government-based financing (in the form of military-procurement) for development and success of the Thames Valley ICT cluster in England. Subsequent studies (e.g. Adams, 2005) identified alternative finance providers especially for HEIs, viz. the government and the industry on the basis of evidence from the early years of Silicon Valley. Weil's (2009) more recent, and comprehensive study on this matter (using Silicon Valley as the case par excellence) added support to the aforementioned possibilities by suggesting CSF9 to be both a property of financial institutions (relating to firms) and the government (relating to both firms and HEIs). Based on the above evidence, finance as an ICT cluster CSF could be construed as a property of the government, firms, and financial institutions; that is provided to both firms and HEIs.

These actors also underpin ***innovation***/R&D capacity (potential). Among the studies exploring this CSF(10) it is worthy perhaps to single out Lyons (2000, p. 905ff) and Bresnahan et al (2001, p. 849) as they elaborated on the relation between innovation and (self-sustaining) growth in several ICT clusters in Ireland, India, Israel, Taiwan, US, UK, and Scandinavia. The former study going as far as to conclude that the Richardson ICT cluster may be the result of innovation rather than its cause. Taken together, these and other studies (e.g. Chaminade, 2001, p. 105) of CSF10 seem to suggest that it should be treated as a firm, HEI, cluster, and/or regional property with an additional dependency of firm innovation on HEIs.

Bridging the previous with the next CSF is ***entrepreneurship*** (CSF11) at the individual, organisational, and collective levels (e.g. culture) that can be stimulated among others by venture capitalists, and support organisations such as science parks. For example, studies by Link and Scott (2003) on the Research Triangle Park (RTP), Adams (2005) and Weil (2009) on Silicon Valley, and Bramwell et al (2010) on Waterloo ICT cluster in Canada, provide ample empirical support to that effect. These studies also suggest that although 'entrepreneurship' can be exhibited by several objects (e.g. HEIs and regions) it is actually the property of an entrepreneur with a dependency relation to financial and other support organisations (further discussed below).

A number of studies also reported on the necessity of a ***growing company base*** (CSF12) for cluster success, highlighting the role of both start-ups and established companies, which implies that this CSF should be construed as a cluster property. Adams (2005) for example observed this CSF in Silicon Valley, praising Prof. Terman of Stanford University as its father and facilitator of such company creation during the formative stages of the cluster. These imply that CSF12 could also be dependent on entrepreneurs. More recent studies of the Sofia Antipolis ICT cluster by Parker (2010, p. 251) highlighted the link between a growing company base and cluster success, acknowledging two sources of such growth: "an influx of national and international investments from large firms" and "local-led" as well as dependency relations to government (e.g. for physical infrastructure provision, tax-breaks).

Part and parcel of a growing company base is ***staff attraction*** (CSF13) from outside the cluster. This has been portrayed in the reviewed literature as the responsibility of a cluster's successful firms, albeit acknowledging the overall attractiveness of the region hosting a cluster (e.g. in terms of quality of life, natural beauty). For example, Weil (2009) and Parker (2010, p. 255) provided recent empirical support from the Silicon Valley and the Hsinshu ICT clusters to the regional property dimensions of this CSF respectively. Suggesting that it is a property shared among the cluster firms and the region hosting the cluster, with the underlying dependency on the government, when it comes to the attractiveness of the hosting region.

The outside cluster relations per se have been further emphasised as a CSF (14) summarised in this study under the notion of ***external links***.[(8)] Bresnahan et al (2001) for example, highlighted the importance of openness to international markets and knowledge sources in several ICT clusters in Ireland, India, Israel, Taiwan, US, UK, and Scandinavia; whereas Britton (2003) emphasized the importance of external sources of knowledge inputs, and the strength of distant market connections in the Toronto ICT cluster. More recently, Sölvell (2008) classified external links in terms of factors and goods.[(9)] Taken together, the aforementioned studies suggest that CSF14 is a relation between external markets, a cluster, and its firms.

Finally, and although a number of the studies reviewed in this section alluded to various degrees towards the importance of ***support organisations*** in ICT clusters, it was Lundequist and Power (2002) that explicitly elevated them to a CSF(15) due to their key role in the Karlskrona Telecom City in Sweden.[(10)] Support organisations frequently cited in the reviewed literature (e.g. Klofsten et al., 1999, Lyons, 2000, and Benner, 2003) as crucial for the success of ICT clusters (e.g. in Linköping, Richardson, and Silicon Valley respectively) comprise among others cluster associations and Chambers of Commerce. When these studies are combined with the rest of the literature reviewed in this section, they suggest that support

[(8)] The narrower notion of 'pipelines' was introduced in the Bathelt et al. (2004) study to refer in particular to external knowledge flows. Although their study reported that pipelines provide cluster advantages, it was not claimed nor were there empirical evidence provided that they are a CSF for ICT clusters.

[(9)] Goods markets are import or export destinations of product-related-goods such as raw materials, components, and final products; whereas factor markets are import or export destinations of production factors such as skilled labour and inward investment (Sölvell, 2008, p. 43).

[(10)] For example, coordinating an increase in R&D, inter-firm and firm-HEI cooperation, fostering spin-offs, attracting new entrants, and marketing the 'TelecomCity' brand (ibid., p. 694).

organisations, as an object, can exhibit the properties of a right vision (CSF1) and those of a strong actor (6) as well as underpin four other CSFs; viz. brand name (5), networking (7), physical infrastructure (8), and a growing company base (12).

2.2. Development of the conceptual model for cluster CSFs

In this section a conceptual model is developed on the basis of the systematic review of the literature in the previous section. This will convert the rich empirical evidence concerning the generic/elementary CSFs (gleaned from the above literature) into a robust yet flexible model (Tashakkori and Teddlie, 2003). This model can be used both for policy (e.g. diagnosis, intervention) and research (e.g. hypothesis testing, prediction) purposes.

As a first step, the systematic review was undertaken within an object-oriented (Coad and Yourdon, 1991; Graham, 1991) [11] mind-set so to describe the respective range of objects and relations involved (e.g. properties and dependencies). Then, a set-theory logic was applied (e.g. through the use of a Venn diagram) so to clarify the object classes involved, which made visible their unique and shared properties. The Venn diagram was subsequently converted into a property matrix depicting the relations (e.g. dependency, encapsulation) between object classes and properties. These were finally translated into the conceptual (object-oriented) model of Figure 1. Due to space limitations, the aforementioned interim stages of the model's derivation are not discussed any further in this paper but are freely available upon request.

[Figure 1 about here]

The model depicts the complete set of reviewed relations between CSFs and their implicated objects along with any dependency relations. Moreover, it is scalable and open ended so to be easily and rigorously revised at the face of additional (e.g. new) evidence. The model of

[11] An approach to modelling a system as a group of interacting objects, with each object representing an entity of interest in the system being modelled.

Figure 1 goes a long way in depicting the state (e.g. properties, relations) of the objects involved. However, for their behaviour to be understood a dynamic study is required. That is, involving time and in particular a cluster's evolution over time discussed next.

2.3. Clusters over time

Time is not always a great healer when it comes to clusters, and ICT clusters in particular. The Saxenian (1994) contrasting stories of the Silicon Valley and Route 128 clusters should suffice to illustrate that within the same industry, time-period, and nation ICT clusters can follow very different paths; viz. growing or declining respectively. A literature has thus been emerging grappling with the evolution of clusters over time. It consists of studies that can be divided in two broad categories: a) those dealing with specific stages or episodes in cluster evolution; e.g. birth/emergence, expansion (Brenner, 2004; Braunerhjelm and Feldman, 2006; Fornahl et al, 2010), and b) those investigating longer evolutionary periods. As it is the latter that are relevant to the task at hand, the rest of this section is focused upon them. It may thus be explicitly stated here that explaining cluster evolution lies beyond the scope of this study, whose main task is to segment such evolution in a rigorous, robust, and replicable manner. This is required to assess the importance of each CSF in each of these segments.

Having clarified the above, it also needs to be cautioned that the studies in question tend to be theoretical (i.e. lacking in empirical operationalisation) and utilise alternative evolutionary models; e.g. based on complex adaptive systems, population ecology, networks, triggers, and firm heterogeneity. Representative examples are reviewed below concluding with the one most suited to the context of this study (that is thus operationalised in the following section).

Starting with complex adaptive systems (CAS), that adapt, as their name suggests, to events in their environment a typical, albeit basic, example can be found in Press (2006). It made use of labour co-ordination and division as the internal cluster mechanisms for survival, and adaptability to change-events. More recent and complex CAS models were proposed by Martin and Sunley (2011) that made use of an adaptive cycle. In such models, a cluster is viewed as an adaptive process with different possible outcomes, based on episodic interactions of nested systems involving a range of mechanisms (e.g. resilience, innovation).

The next strand of models draws on ideas of population ecology (Carroll, 1984). One of the earlier models, by Maggioni (2004), suggested that entry rates are expected to increase with cluster size, until a threshold is reached where competition and congestion costs outweigh the benefits of locating in the cluster. More recent population ecology models; e.g. by Suire and Vicent (2009), take into account mimetic/herding behaviours and reputational effects according to which firms enter a cluster not necessarily because of agglomeration and co-location economies, but rather for legitimation reasons of being in the given location.

The next model developed by Li et al (2012) can be seen as an attempt to improve upon the limitations of the previous models, by conceptualising cluster evolution through the systematic interrelationship and feedback between context (e.g. institutional and economical structures), networks (e.g. social and economic relations), and action (e.g. agent behaviour, opportunity exploitation by individuals, collectives, and firms). Nonetheless, this model is rooted in a rather unique context; even by its authors own admission.

Overcoming context specificity could be found in the strand of models based on systematic reviews of the literature. Two such studies by Bergman (2008) and Belussi and Sedita, (2009) could be mentioned as examples to delineate the range of possibilities. The former, adopted previously labelled cluster lifecycle phases as a discussion template, and used extant concepts to investigate each phase and their transition but with limited guidance in the way such phases could be empirically delineated. Belussi and Sedita (2009) on the other hand, adopted a meta-analytical design, in which the extant literature of a dozen Italian industrial districts was used to identify the range of triggering factors between the transitions of a priori defined evolutionary phases; viz. formation, development, maturity, and decline or renewal. Although this approach seems more apt to directing empirical work in segmenting the Linköping ICT lifecycle, the lack of extant literature on its evolution rendered it inapplicable.

Finally, the Menzel and Fornahl (2010) model is based on the evolutionary concept of heterogeneity among a cluster's firms and organisations, and the way they exploit this heterogeneity. Suggesting that evolutionary stages ought to be understood in both quantitative (e.g. employment dynamics) and qualitative (e.g. knowledge heterogeneity) terms. According to Frenken et al. (2011, p. 16) this is the most comprehensive framework of cluster lifecycle which is thus to guide this study. Its operationalisation is discussed next.

3. Data and methods

As introduced at the opening of this paper, this study adopted a critical case study approach (Bryman and Bell, 2003, pp. 53-6). That is, a purposeful sample of a single case study was selected, viz. the ICT cluster located in the Linköping Municipality at the east-middle (NUTS2) region of Sweden. The vast majority of firms are located in the Mjärdevi Science Park, established in 1984 with governmental support. In the latest census, November 2012, the cluster comprised of 260 firms with approximately 6,100 employees.

It was purposefully selected as the critical case study for the following reasons: (i) pragmatic reasons of access to interviewees, (ii) long spanning time series of freely available secondary data for the cluster, the municipality, and the region, and (iii) being a successful cluster. The successful performance of the cluster and its region was reported in a series of studies by Klofsten et al. (1999); Etzkowitz and Klofsten (2005); Hommen et al. (2005); Feldman (2007)[(12)].

[(12)] Although these studies and the Linköping/Mjärdevi Science Park literature in general provides evidence that this is a successful cluster and identifies some of the CSFs investigated in this study to the authors' best knowledge it has yet to draw any strong conclusions about their variation across the cluster's lifecycle.

In addition, the performance of the region was established across a series of indicators, e.g. industry and service labour productivity (Tsagdis and Alexiadis, 2009), GDP per capita, qualified labour, and labour employed in advanced sectors (Tsagdis, 2010). The cluster also fulfilled the Sölvell (2008, p. 16ff) cluster success criterion [13] of going through a complete lifecycle, viz. birth, growth, maturity, and re-birth (renaissance), upon which the cluster enters a second loop.

In order to establish the importance of each CSF in each stage of the Linköping ICT cluster lifecycle, the actual stages need first to be identified. To that effect, this paper follows the Menzel and Fornahl (2010) theoretical framework (introduced in section 2.3), and operationalises its quantitative and qualitative dimensions. Two respective secondary datasets were used in the operationalisation. The first one concerned employment in the Linköping ICT cluster during 1984-2009, obtained via the Mjärdevi Science Park's official website, and triangulated with Statistics Sweden. This dataset concerned the quantitative dimension, and was used to draw the employment curve of Figure, 2 and identify the precise points of stage transitions (further discussed below). The second dataset concerned employment for all ICT specialisations in the Linköping Municipality during 1990-2009 was obtained from Statistics Sweden (disaggregated at 13 two-digit and the 48 five-digit codes, available upon request). This was used to build an index for knowledge heterogeneity (discussed below). Not only was the latter dataset used to satisfy the needs of consistency with the adopted theoretical framework of Menzel and Fornahl (2010), but also to demonstrate the empirical qualitative dimension support for the segmentation of the cluster's lifecycle developed on the basis of the first dataset.

[13] Alternative cluster success criteria can be found in the literature; e.g. "annual double digit growth" in firm number and export indicators (Bresnahan et al, 2001, p. 838). However, such criteria refer to one or two lifecycle stages and a narrow period, whereas the adopted one covers all stages, and thus, a much longer time span.

The task of segmenting the cluster's lifecycle required the identification of three 'transition years' from: (i) birth-to-growth, (ii) growth-to-maturity, and (iii) maturity-to-rebirth. Transition year (ii) was identified first through the use of a quintic function that was fitted to the cluster's employment data, and gave the best R^2 as reported in Figure 2. The second derivative of this function was used to compute the inflection point (i.e. the point that the increase in employment shifts from an increasing to a decreasing rate) of the employment curve in the year 2000. This was considered as the end of the cluster's growth stage, because the curve shifts from a concave-up to concave-down (Bergman, 2008, p. 118). For obtaining the transition years of (i) and (iii), the sharpest changes in employment in all pairs of adjacent years were computed using the Birch Index (*BI*) in the following manner:

$$BI_t = \frac{Emp_t - Emp_{t-1}}{Emp_t / Emp_{t-1}} \qquad \text{(Equation 1)}$$

Where Emp_t is employment in year *t* in the Mjärdevi Science Park (host of the Linköping ICT cluster), and *t* ranges from 1984 (emergence of cluster) to 2009; following Otto and Fornahl (2010). Among the candidates for the transition year (i) (i.e. all the years before inflection point (ii)) year 1994 showed the largest *BI*, meaning that the change in employment was the sharpest in this year. Hence, 1993 to 1994 was selected as the transition from birth-to-growth. Applying the same procedure for all the years after the inflection point (ii), year 2005 showed the largest *BI*, hence, 2004 to 2005 was identified as the transition (iii) from maturity-to-rebirth, i.e. when employment started growing again.[14]

Turning now to the operationalisation of the qualitative dimension, the empirical examples provided by Frenken et al. (2007) and Boschma et al. (2012) were followed. According to them, knowledge heterogeneity was approximated through diversity measures of related (RV)

[14] The above procedure was developed by these authors as an empirical method to identify the exact transition years between stages, as there is no widely accepted cluster lifecycle segmentation method available in the extant literature.

and unrelated (URV) variety. RV measures variety within sectors, whereas URV between sectors. Therefore, it is URV that seems to better capture what Menzel and Fornahl (2010) intended with their theoretical notion of knowledge heterogeneity.[(15)]

The URV index in year *t* was computed in the basis of equation 2 below:

$$URV_t = \sum_{i=1}^{I} Pg_t \, log_2 \left(\frac{1}{Pg_t}\right) \qquad \text{(Equation 2)}$$

Where, Pg_t is the employment share in the two-digit ICT specialisations in the Linköping Municipality in year *t*, and *I* is the maximum number of two-digit ICT specialisations.

[Figure 2 about here]

Figure 2 shows that employment increased during the birth and growth stages; stagnated, and then slightly declined during maturity, only to increase again during rebirth. Correspondingly, the URV declined during the birth, and growth stages (i.e. knowledge heterogeneity was reduced), fluctuated during maturity, and decreased once again during rebirth. Both evolutionary patterns are consistent with Menzel and Fornahl (2010), and corroborate the aforementioned segmentation.[(16)]

Having detailed the precise segmentation of the cluster's evolution, this investigation proceeded to establish the importance of each CSF in these segments. This required primary data collection that also involved two steps. During the first step, in the spring of 2009, semi-structured face-to-face interviews were conducted with eight key cluster actors (viz. firm

[(15)] Nonetheless RV was computed, following the above examples, as the weighted sum of entropy within each of the cluster's two-digit sectors and showed a similar pattern to URV; apart from a somewhat expected growth during the re-birth phase of the cluster. Due to space limitations RV results are not further discussed in this study but can be made available upon request.

[(16)] For example, the URV fluctuation during maturity peaks almost to the same height it had during birth while the extent and slope of its drop thereafter is rather similar to that during the 1991-1996 period (i.e. late birth-early growth stages).

CEOs, HEI and other institutional representatives) each lasted about one hour, detailed in Tavassoli (2009). These were used to: (i) test the presence of the CSFs gleaned through the systematic review of the literature, as reported in section 2.1, and to validate and calibrate the conceptual model introduced in section 2.2, (ii) obtain quantitative observations concerning the importance rankings of each CSF in each of the cluster's lifecycle stages (using the five-point Likert scale reported in Table 1), and (iii) gather in-depth qualitative observations concerning the importance of each CSF throughout the clusters evolution. During the second step, in the autumn of 2012, a follow-up self-administered questionnaire was emailed to the same eight interviewees that confirmed the results from the initial interviews, and reported no changes in the CSF importance rankings.

Although the number of interviewees may appear to be low at first sight (e.g. given the size of the cluster), there are less than 20 senior individuals (e.g. SMIL board members, company CEOs, research centre directors) that have continuously participated in the cluster's evolution so to be able to make judgements about the importance of each CSF *throughout* the cluster's evolution. This reduces substantially the target population, rendering the eight interviewees into 40% of targeted population. It also ought to be informed that in their vast majority the interviewees have been holding multiple positions (e.g. firm CEO and SMIL board member), and thus offered high quality reports of their experiences; e.g. from multiple and balanced perspectives.

The findings relating to the importance of each CSF throughout these stages are discussed next.

4. Empirical findings and discussion

The presentation of the findings starts from the quantitative evidence relating to the importance of the CSFs throughout the cluster's evolution and proceeds to the qualitative evidence. The former is summarised in Table 1.

[Table 1 about here]

The quantitative ranking preliminary suggest that there may be a set of CSFs whose importance appears rather stable throughout the cluster's evolution, e.g. trust (CSF2) and networking (CSF6); whereas most CSFs should be expected to exhibit some variation in importance due to the reported quantitative changes in the cluster.

The first set of observations worthy of report concerning Table 1 is that all cells have a value greater than one. This suggests that the set of 15 CSFs has been rather correctly compiled. Nonetheless, there is some small variation in the mean importance rank per stage (last row), which follows a downward trend from birth (4.0) through growth (3.8) and to maturity (3.4), only to increase during rebirth (3.7) to a similar level encountered during growth. This provides an initial level of support to the main argument of this study concerning CSF variation across the cluster's evolution.

The above preamble the most important set of observations relating to Table 1, which highlight the fact that most CSFs exhibit both a substantial variation, and one of the patterns further discussed below. These CSFs are henceforth referred to as *stage-specific*, in contradistinction to those being stable (stable-CSFs hereafter). Here lies the main argument of this study, in that there is a difference, at best partly recognised in the extant literature, if at all, between the importance of a CSF (and there are plenty of studies suggesting a range of CSFs as important) and the *variation* in this importance throughout the cluster's evolution.

However, Table 1 should at best be treated as an illustration, as due to the small number of observations involved, further statistical analysis could add some precision, but not necessarily any accuracy. As both precision and accuracy are required to establish validity, the latter is subsequently pursued on the basis of the qualitative evidence provided by the interviewees, and other (e.g. secondary) sources of data, while reliability will be demonstrated by placing such evidence in the context of the wider cluster literature (e.g. of other industrial specialisations).

Still it ought to be reminded that the extant cluster literature has not been very explicit or systematic about the importance of CSFs in difference stages. It was, after all, this unsatisfactory state of affairs that gave birth to this study. Thus, although what follows below may appear as a patchwork, it comprises nonetheless the best wider evidence available.

Starting thus from those stage-specific CSFs that exhibit decreasing tendencies in Table 1, and in particular clear vision (CSF1) that ranked its highest during the birth phase, while its importance declined thereafter until the rebirth stage, during which its importance increased. This appears a reasonable finding, if one considers the top-down nature of the Linköping cluster, in which the policy makers initially intervened explicitly in cluster's genesis. In such a situation, clear vision among policymakers (and other private actors) is expected to play a key role in the success of a cluster; especially during its earlier stages. For example, as interviewee-1 reported:

"We always have had the right vision here in the Linköping cluster, which is 'being a globally competitive ICT cluster'. This is thanks to both public and private actors. As a public actor, the Linköping Municipality has been instrumental in establishing formally the cluster in 1984 [birth] *and providing a supporting vision ever since, e.g. support for creation of the HomeCom project in 2000* [maturity]. *The public sector's vision has been complemented by*

strong visions from private sector leaders; e.g. Nokia established its head research office for Home Communications in 2000 [maturity and thereafter]"

Pre-existing knowledge (CSF4), strong actors (CSF6), and the growing company base (CSF12) exhibit a somewhat different pattern to vision (CSF1), albeit still decreasing. Their difference lies in the fact that these three CSFs appear to be more important in the earlier phases (birth and growth) relative to later phases (maturity and rebirth). In the case of pre-existing knowledge, this change manifests in the statements of interviewee-2 who said:

"I think Linköping University [founded in late 1960] *has been a fundamental actor to create pre-existing knowledge for the cluster, specially physics and electronic departments, which has been mostly useful in the early stages of cluster evolution in the late 80s and the beginning of 90s through successful university-based start-ups* [birth and growth]".

These patterns are encountered for example in the reports of interviewee-3 concerning the decreasing role of strong actors after the end of the growth stage:

"Besides Linköping University and SAAB as historically strong actors in the region, Eriksson arrived in 1987 [birth] *and Nokia in 1989* [growth] *...they also extended their facilities later, e.g. Ericsson in 1995* [growth]*... thereafter their importance somehow decreased."*

A succinct statement by the same interviewee about the growing company base conveys the higher importance of this factor during birth and growth stages: *"The growing company base of the cluster was very much reinforced by the arrival of Eriksson in 1987* [birth] *and of Nokia in 1989* [growth]*"*. Whereas, the relative decrease in importance of the aforementioned CSFs during a cluster's later stages may be due to the fact that during such stages a cluster becomes self-reinforcing, as suggested for example by Brenner (2004). Moreover, Brenner and Schlump (2011) used secondary evidence and mathematical modelling to demonstrate the importance of thriving start-ups (i.e. a growing company base) specifically during the early stages of a cluster. Concerning the importance of strong actors in the earlier stages in particular Giuliani (2011) observed in wine clusters the key role of gatekeeper firms as the important sources of learning during their earlier stages.

The last CSF with decreasing tendencies; viz. support organizations (CSF15) exhibits a further variation to the above patterns, in that it is of outmost importance only during the birth stage, while decreasing and then remaining stable during the next three subsequent stages. This is detailed by interviewee-4:

"Since the beginning, SMIL [established in 1984] *has been one of the main support organisation in the development of new technology* [birth] *... in 1994 the Technology Bridge Foundation was established to support the firms* [growth]. *Tiny Tots opened its international preschool to serve the children of multilingual employees in 1997* [maturity]*... in 2005, the Soft Landing scheme for foreign companies wishing to locate in Sweden was launched together with Rivstart a programme offering young companies furnished facilities and mentoring* [rebirth]*... we have seen several support organizations emerged in different stages of cluster evolution, but perhaps the earlier ones were more crucial to anchor the cluster when it was still fragile."*

The elevated importance of CSF15 at birth is also encountered in other specialisation, like shipbuilding in Korea, where Shin and Hassink (2011) reported, for example, on the importance of "support organizations" for building firm capabilities during the cluster's early stages.

Turning now to the only CSF in this study that exhibited increasing tendencies of importance, viz. brand (CSF5) or cluster identity, interviewee-2 averred:

"The brand name of Mjärdevi Science Park AB was developed in 1993 as a limited company responsible for the development and marketing of the cluster. It was especially

important in the mid 90s and afterward [growth and thereafter] *to be able to establish ties with world leading technology parks…"*.

This finding also seems to be in line with recent findings of CSFs in lifecycles of clusters in very different specialisations; e.g. in clock-making and medical instruments reported by Staber and Sautter (2011).

Last, but not least, two CSFs appear to exhibit some fluctuations, viz. finance (CSF9) and innovation (CSF10) albeit of a different kind. Finance received its top rankings during birth and rebirth, and lower rankings during the interim stages. As interviewee-4 described:

"We have seen the emergence of financial institutions that helped the start-ups to grow. An example is Novare Kapital that was first established at Mjärdevi Science Park in 1993 to provide risk capital to new companies [birth]. *Innovations Kapital, another venture capital firm, moved into the cluster in 1999. These financial institutions helped the cluster when it was struggling to escape from the IT-crises in early 21th century* [re-birth].*"*

The elevated importance of finance during rebirth has also been reported in Silicon Valley (Bresnahan et al., 2001) as well as in different contexts, like the aforementioned shipbuilding cluster in Korea.

Innovation (CSF10) however, exhibits another kind of variation. Although ranked highly in all stages, it was considered of supreme importance during the cluster's growth phase. As interviewee-2 pointed out:

"Since the beginning the Linköping University acted as the catalyst for stimulating the growth of innovation capacity in the cluster… the evidence is the several successful university-based start-ups throughout all stages of cluster lifecycle…innovation was considered vital throughout all stages, especially in late 90s [growth] *where the cluster really boosted."*

The elevated importance of innovation during growth has also been theoretically highlighted (Brenner and Schlump, 2011), as well as empirically in studies across a number of cluster specialisation, e.g. automotive, television receiver, and tyres (Klepper, 2007).

5. Conclusions, policy implications, and areas of further research

Previous studies of the Linköping ICT cluster suggested its success stories, and delineated several CSFs. However, similar to the general pattern encountered in the wider cluster-CSF literature, these previous studies of Linköping appear ambiguous in several respects, particularly concerning the empirical evidence about the importance of CSFs throughout the different stages in a cluster's evolution. As a starting point, to shed light on such ambiguity, a systematic review of this literature was undertaken, which makes it possible to develop a robust, yet flexible, model of elementary/generic CSFs for ICT clusters, and unearth their implicated objects. This conceptual model could be used to:

1. Identify *gaps* in the existing literature, such as the lack of relations between objects. For example, the literature appears silent concerning the declining importance of vision as a CSF in the lifecycle of ICT clusters, and in particular what happens to the 'vision'-relations between policy makers, firms, and support organisations during the post-birth phases.
2. *Diagnose* the extent of CSF presence/absence in clusters that are allegedly successful, and also the importance of each CSF in the different lifecycle stages. This formed the main thrust of this study. To that effect, the Linköping ICT cluster was used as a critical case study, and a rigorous technique was devised, and successfully applied to segment its lifecycle. The technique was applied to secondary independent data and required relatively simple computations. This technique could thus be transferred to other clusters. The key cluster actors were subsequently interviewed in 2009, with a follow-up

in 2012 so to improve validity. The actors ranked the importance of each CSF in each of the identified stages. This hybrid research design, making use of primary and secondary data, allowed the presence of all CSFs and their patterns of importance across the cluster's lifecycle stages to be established. Thus, even with the limited data and computation involved in this study, it was possible to establish that while a CSF-constellation may be stable (i.e. equally important for all lifecycle stages), the importance of other CSFs may be stage-specific (i.e. vary across lifecycle stages). For example, geographical proximity, physical infrastructure, entrepreneurship, staff attraction, and external links, are among the stable-CSFs which are recognized to be of equally high importance throughout the evolution of the cluster. It was further identified that the vast majority of the stage-specific CSFs exhibited decreasing tendencies in importance (viz. vision, pre-existing knowledge, strong actors, a growing company base, and support organisations); with only one CSF (viz. brand-name) exhibiting increasing tendencies in importance. Moreover, two CSFs (viz. finance and innovation) were identified as experiencing fluctuations in importance with rather different patterns.

3. *Measure* the impact of actual CSF-constellations on cluster success. Although not directly engaged with in this study (due to space limitations) one could easily surmise, for example, that the impact of the aforementioned constellation of stable-CSFs on the cluster's success could be argued to have been consistently high. Obviously, further research, as discussed below, could produce more precise and accurate measures of impact.
4. *Predict* cluster success in subsequent stages of its lifecycle, based on the presence/absence of the particular constellation of CSFs in its earlier stages. Even with the limited data of this study a series of predictions could be made. For example, one could predict threats to the future success of the Linköping ICT cluster (i.e. post-rebirth)

on the basis of detecting difficulties in the entities and relations underpinning the present constellation of CSFs. One could even attempt more risky predictions, on the basis of the established CSF constellations and their patterns, concerning the success of other ICT clusters in different lifecycle stages. The making and testing of such predictions, as part of further research, should enhance the present theorising.

5. Inform, support, redirect, and target *policy/intervention* efforts, e.g. when resources are misplaced on irrelevant CSFs. For example, the present findings seem to warranty the policy implication that no additional resources should be committed on cluster-branding in Linköping. It could also be argued that the relations underpinning the CSFs that are of increased importance during maturity should be closely monitored after the rebirth stage, and targeted intervention undertaken in case difficulties are observed in their underpinning relations (as depicted in Figure 1).

The possibilities thus from pursuing the line of inquiry developed in this paper appear to be rewarding for both policy makers and researchers alike. As this is a single case study, its limits of generalisation cannot be asserted with certainty, nonetheless, several implications can be discerned. For example, clusters could grow, and ultimately become successful, in less than perfect conditions, or that at least not all CSFs are equally important throughout a cluster's evolution for its ultimate success. This raises further implications for specific CSFs; for example, during birth the focus should be on attracting the giant firms, while in later stages increased attention should be placed on developing incubators, nurturing start-ups, and spin-offs. To such effects, the model of Figure 1 provides a generic map of the entities and relations that should be monitored and targeted during interventions aiming to enhance particular CSFs.

The above also delineate at least three key areas for further research. First, further research could enrich and refine the conceptual model (e.g. addition of CSFs, objects, relations) to the extent that subsequent versions can be safely transferred to other ICT clusters, as well as to clusters in other specialisations. To that effect, this study could act as a blueprint for investigations, not only in ICT clusters, but of any industrial specialisation, to which its toolkit may also come handy. The second area of further research concerns the extent to which the demarcation between stable and stage-specific CSFs, and the patterns within the latter group are context dependent. These could be investigated further using large scale surveys of the Global Entrepreneurship Monitor-type. Thirdly, as this has been an exploratory study, highlighting the varied importance of CSFs throughout the evolution of clusters, its main effort has been in charting this unexplored territory, rather than explaining at any great length why certain CSFs were ranked higher or lower than others, or their specific variation in certain direction. Thus, further research is suggested to investigate at greater detail the causes of the aforementioned patterns.

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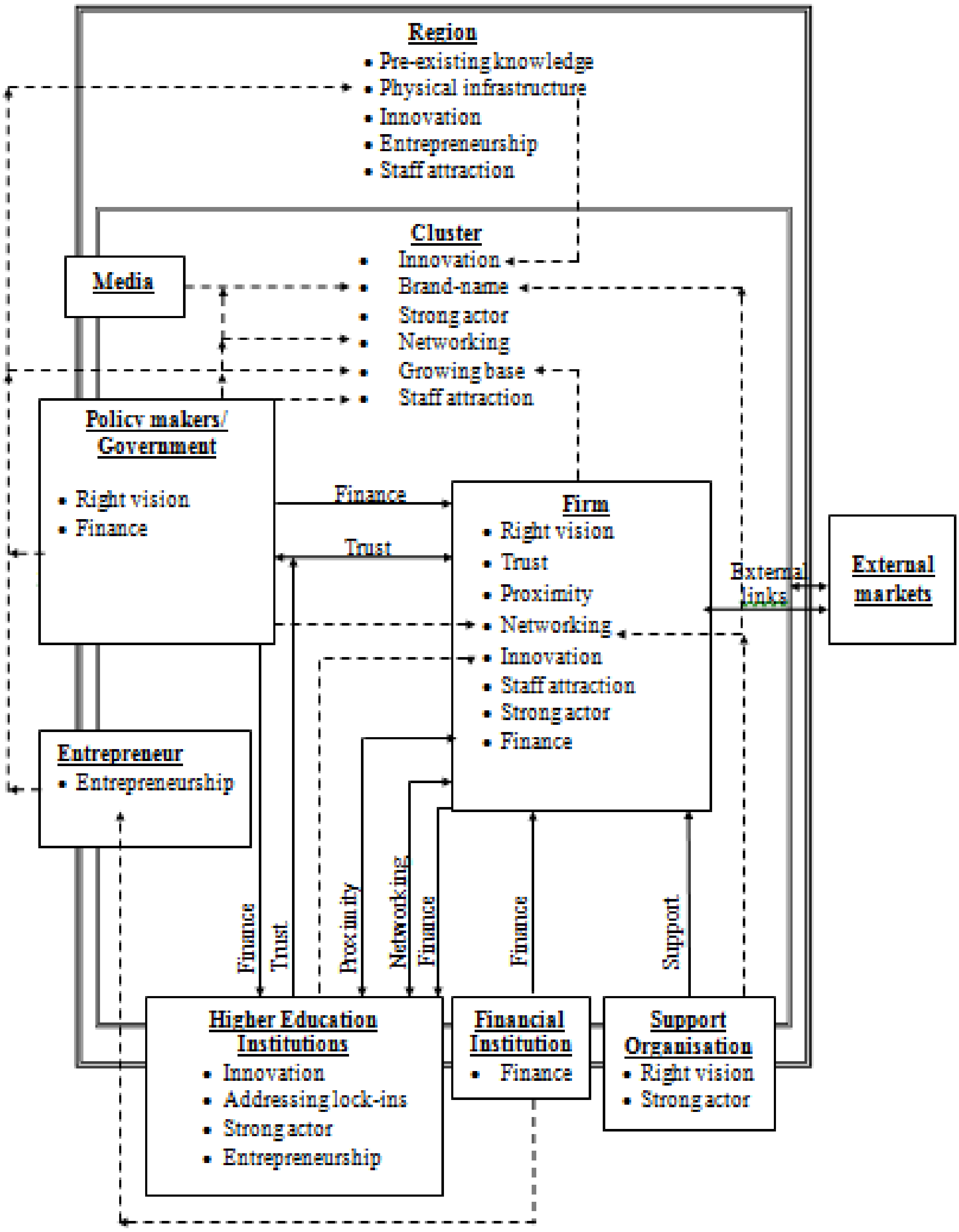
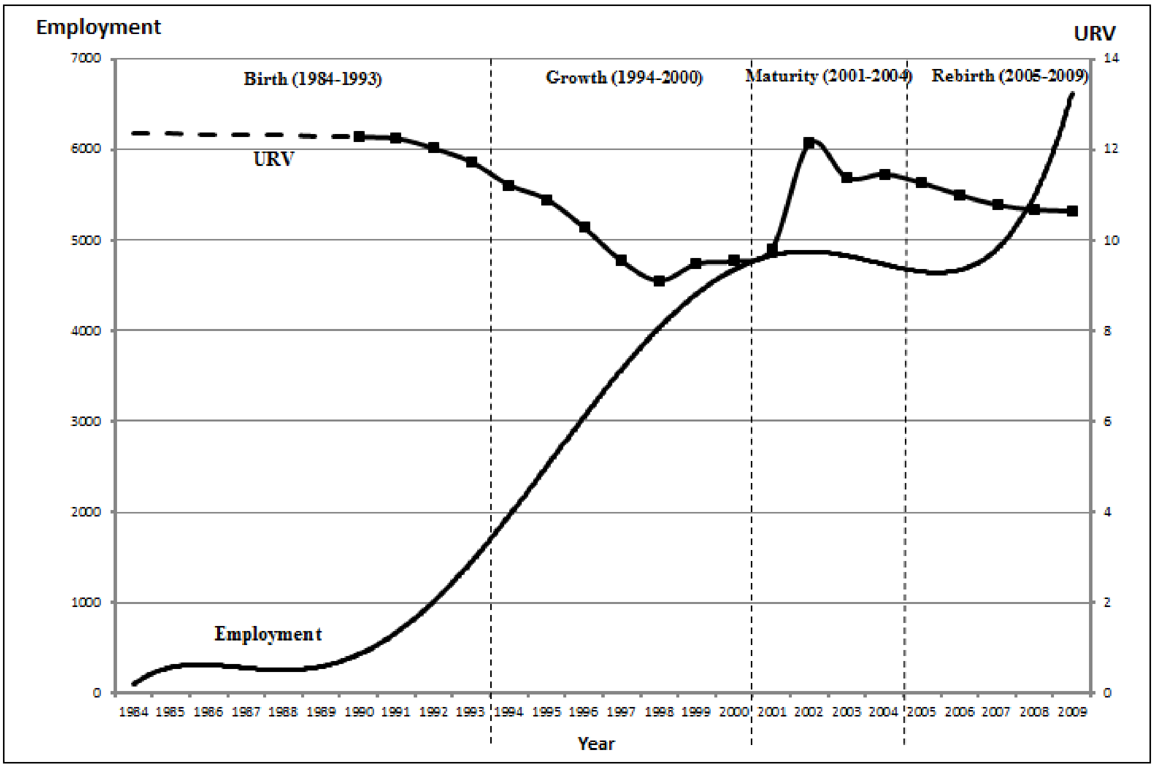
Figure 1. A conceptual (object-oriented) model of ICT clusters' CSFs



Notes: A box refers to an object (object names appear in bold and underlined) which may contain one or more CSFs. CSFs that are properties of the relation between two or more objects are indicated with a solid line. Solid lines can be uni- or bi-directional, depending on the directionality of the relations between the objects. A dotted line indicates a dependency relation between objects and CSFs, or among CSFs. An arrow in a dotted line indicates the direction of the dependency.

Figure 2. The employment and URV evolutionary patterns of the Linköping ICT cluster



Notes: The employment curve is estimated by fitting the employment data with the quintic function of $y = 0.0236x^5 – 1.4467x^4 + 29.772x^3 – 226.66x^2 + 684.55x – 392.8$, which gave the best R^2 of 0.9628 with y referring to employment and x to time (year). The URV curve is obtained on the basis of equation 2. As the respective data are only available after 1990 the dotted URV curve segment is a retrojection.

Table 1. Importance rankings of CSFs in the Linköping ICT cluster lifecycle stages

CSF	Importance of :	Birth	Growth	Maturity	Rebirth	Mean
1	a focused, clear, right ***vision*** in the policy makers, firms, cluster support organisations, so to be able for example to communicate effectively with investors, firms, and other actors.	5	3	3	4	3.8
2	***trust*** between the cluster firms, between the firms and LIU*, and/or support organisations.	3	4	4	4	3.8
3	***geographical proximity*** between the firms and between the firms and other actors (e.g. LIU*, policy makers, financial institutions).	4	4	4	4	4.0
4	***pre-existing knowledge*** (e.g. due to an engineering tradition or the presence of a relevant HEI) in the region prior to the formation of the cluster.	4	4	3	3	3.5
5	the cluster's ***brand-name***; e.g. in strengthening the attraction of investment, venture capital , skilled workers, new firms, uniting cluster actors, complementing the marketing of cluster firms.	2	3	3	4	3.0
6	of ***strong actor(s)*** in the cluster (e.g. lead/anchor firms and organisations like the LIU*, or trade associations) in providing for example technical expertise, incubation space, diffusion of best practice, innovation, attracting and retaining skilled labour.	4	4	2	2	3.0
7	local and extra-local ***networking*** (collaboration) between: firms, firms and other actors (e.g. HEIs, support organisations, policy makers) to increase knowledge integration and value added.	4	4	3	4	3.8
8	***physical infrastructure*** (e.g. transport, airports, communication, laboratories, research institutes, conventions/fairs hall, company and employee facilities) within the region.	4	4	4	4	4.0
9	***finance*** (e.g. from the government, financial institutions, venture capitalists, the industry) to firms	4	2	2	4	3.0
10	of ***innovation***/R&D within firms and LIU* as well as importance of LIU as catalysts for firm innovation/R&D.	4	5	4	4	4.3
11	***entrepreneurship*** at individual, organisational, and collective levels (e.g. entrepreneurial culture).	4	4	4	4	4.0
12	**growing company base**; e.g. thriving start-ups, mature companies as models	5	5	4	4	4.5
13	***staff attraction*** (due to firm or government efforts, and/or regional ambience) from outside the cluster.	4	4	4	4	4.0
14	***external links*** from the cluster and its firms to outside markets (e.g. for knowledge, labour, goods)	4	4	4	4	4.0
15	cluster ***support organisations*** (e.g. SMIL, LIU*, business development centres) in training, coordinating R&D projects, inter-firm and firm-LIU* cooperation, and fostering spin-offs.	5	3	3	3	3.5
	Mean	4.0	3.8	3.4	3.7	3.7

Notes: In the first four columns (Birth, Growth, Maturity, Rebirth), each cell contains the CSF mean rank (rounded at one decimal point) reported by the eight interviewees. The last column (All stages) contains the mean of each CSF. *LIU refers to Linköping University. Scale: unimportant (1), of little importance (2), moderately important (3), important (4), very important (5).