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Cluster Life-Cycles: An Emerging Synthesis

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1.0 Introduction

Despite early and repeated predictions of a short half-life that afflicts merely fashionable ideas, regional cluster concepts continue to thrive in diverse policy theatres and benefit from the intense scrutiny of many disciplines, having already entered the provisional realm of numerous theoretical frameworks. Cluster concepts obtain their greatest traction in those fields concerned with aggregates of firms and near-market agents that self-assemble in progressively larger constellations and networks comprising whole economies, whether at regional, national or supra-national levels. Clusters also offer an analytically-appealing intermediate level of economic "granularity" that accords well with parallel theoretical developments in the new economic geography, endogenous growth theory, knowledge economy, innovation systems, etc. While economic clusters still remain theoretically-underdeveloped, they enjoy valuable face-validity that continues to propel policy interest, generate support and attract intellectual resources. Several other chapters of this volume develop various themes along these lines.

This chapter will focus attention on available concepts that permit better understanding of how clustered aggregations of dynamic firms come to dominate certain technologies and markets as powerful innovation and growth mechanisms, and why the same dominant aggregations may later morph successfully into novel combinations or decline into oblivion, becoming—in Wilbur Thompson's unforgettably term—"industrial hospices". While the policy interest in this topic is self-evident, theoretical interests might benefit from a more complete accounting of "why" clusters may, at different life-cycle stages, be dynamically innovative, highly productive, highly concentrated, yet in the end exhibit fatal vulnerabilities. We shall also use their "life-cycle"[1] as a

[1] Although not explicitly addressed in the literature, a cluster's cyclical dynamics should be measured by variations in aggregate outcome produced by all principal agents responsible for cluster performance. Therefore, to fully account for a "cluster" and its position on or movement along its life-cycle, one should a. account for all agents considered significant along each cycle segment, and b. devise an aggregation principle by which agent actions are weighted and summed. Collateral work concerning identification of cluster agents is available in the diffuse research regarding cluster identification and mapping, but little of it refers to the relative significance of agents at various cycle stages or the outputs of non-firm agents. The literature appears not to have considered any aggregation principle for weighting and summing the full cluster; most studies that examine a cluster's

selective lens by which to reexamine clusters, with the intent to reveal certain structural facets or relationships not previously considered or always made evident.

Maskell and Kebir (2005) use the terms "existence", "extension" and "exhaustion" to describe specific cluster life-cycle stages; attention to these stages is essential, they argue, because certain modern cluster theory versions replaced earlier, more robust concepts with "…a one-sided model that addressed the *existence* argument in novel ways *but almost totally disregarded the extension and exhaustion arguments*." (p. 6, emphasis supplied). The present intention is therefore to help remedy such oversights by explicitly evaluating literatures that consider the full range of cluster cycle stages and by unpacking their cycle-phase implications for further consideration[2]. Accordingly, the chapter will examine principal cluster cycle concepts, including selected overview of the dynamics that propel clusters along their life-cycles and consideration of key factors seen to be relevant at various cluster cycle stages.

2.0 Cluster Cycles and Phases

Cluster cycles are usually represented either in text or diagrams as stylized "S" curves, modeled generally after industry-, technology- or product-cycles[3] and often with the quite similar terms of reference. However, attention has also shifted to specific points on/stages along the curve associated with: the emergence of a cluster, its early development and expansion, its ability to exploit opportunities and resist competitive replication, its attaining hyper-growth and engaging in scale-expansion, its slowing near potential inflection points, and its successful transition to a newly-launched cycle phase or perhaps the "lock-in" and exhaustion of its final cycle phase. Changes in the cluster during its cycle phases can result from gaining new or losing old agents (mainly firms), shifts in the scale and scope of activities among stage-incumbent firms, or both[4].

Of the many distinctions drawn to categorize types of clusters, perhaps the most important for present purposes is traded (exported) vs. non-traded cluster division, which applies the classic export-base logic to clusters[5]. This distinction has increased in importance during recent periods of intense

performance or outcome rely upon a simple summation of some metric of cluster *firm* performance as its proxy. The absence of commonly collected metrics *at the cluster level* is a major stumbling block to progress along these lines, although it is unclear if all cycle-phase dynamics can be measured adequately with a *single* metric.

[2] Although a considerable policy-oriented literature is available that presents widely varying and occasionally conflicting measures, it will not be systematically reviewed here to focus on the underlying conceptual issues.

[3] "In Utterback (1994), the S-curve model is used to illustrate the life cycle, where the evolution of the technology, industry or product follow an S-shaped curve over time"(Dalum, Pederson, and Villumsen, 2005). See also Wolter (2004), pp 1-2.

[4] Most articles also adopt an implicit stylized version of a "representative agent"; a full cluster is then seen to move/age homogenously through each cycle phase as a synchronized ensemble. Empirically, this usually implies that the dynamics of a single lead sector (or even one firm) proxies the central tendency of the full ensemble, even though in fact, many firms of varying size or sectors and other agents of several kind could positioned at adjacent but not identical phases.

[5] See discussion in Porter, 2003, p. 559.

international trade and globalization, both of which further concentrate production and increase technological or industry specialization, a point remarked upon by Krugman (1991, p. 1) when he first considered the usefulness of spatial and geographic features to analyze international trade. As clusters become ever more specialized, they also exhibit stronger technological, product and industrial life-cycles that characterize their key building blocks. Clusters with the most pronounced life-cycle behavior therefore are likely to be specialized in globally-traded goods, while regionally traded goods (cultural-, territorial- or tradition-intensive) are less susceptible to dynamic life-cycles due to the slowly changing quasi-oligopolistic niches they occupy[6]. Non-traded clusters of locally produced and consumed goods or services are wholly creatures of their host regions, where local firms co-locate production or sales in accordance with sub-regional Hotelling—not inter-regional Marshallian—incentives.

The literature's focus on the dynamics of specific development stages is due in part to the relatively high frequency of stage-specific cases studied, which are necessarily positioned at the time and cycle-phase when the case was studied, or other specific cases may reflect a cyclical circumstance judged important by cluster study patrons[7]. Despite a marked preoccupation in the literature with "lock-in" phase issues, much cluster research continues as a matter of routine to dwell on the "existence" stage of successful, contemporary clusters, particularly among distinct research communities[8]; this leads Maskell and Kebir (2005) to observe that cluster theory remains incomplete and possibly misleading in the absence of life-cycle considerations. However, other recent research and publication reveal growing interest for a variety of reasons in examining more closely the broader question of cluster cycles and in discussing more than a single stage, a sampling of which will now be reviewed.

(Cluster Life-cycle Sources Table about here)

[6] Regionally traded clusters can, however, be highly innovative and advanced (van den Hertog, Bergman, and Charles, 2001). Regionally-traded clusters may also serve as valuable reservoirs of novelty for goods and services demanded by future customers, similar to presently growing consumption of cultural tourism. Culinary, sartorial and architectural consumer novelty now available in many regional reservoirs is also matched by locally specific capacities to manage environments (e.g., Alpine tunneling or Israeli desalinization technologies, Japanese quake-resistant construction, Dutch seawater management) and natural resources, any of which could gain importance in future global markets.

[7] Such studies are usually commissioned for emerging and growing clusters that have or are expected to become dominant. Lesser or merely aspiring clusters seldom figure prominently in life-cycle considerations, and "…we still wait for that famous case study of a cluster in *decline*." (Lorenzen, 2005, p. 207).

[8] "It is, perhaps, at this stage worth noting how later generations of mainly Anglo-Saxon scholars by deliberate decision or following the prevailing tradition in contemporary economic geography gradually turned to producing very descriptive, ideographic work…[which replaced former economics-based cluster explanations with] "…a one-sided model that addressed the existence argument in novel ways but almost totally disregarded the extension and exhaustion arguments" (Maskell and Kebir, 2005, p. 6). Hassink and Dong-Ho (2005) indirectly supports their view, by observing that many contemporary cluster scholars "…belong to the recently coined family of territorial innovation models….*They increasingly turned from "economic" reasons for growth of new industrial agglomerations to 'social' and 'cultural' reasons*... (p. 571, emphasis supplied).

To organize the discussion, we adopt the previously labeled phases: 1. existence, 2. expansion, and 3. exhaustion[9]. Discussion will focus on each of the principal stages separately, including additional sub-phases, drawing upon published and draft entries in Table 1 or from other works that have conducted research related to certain stages.

2.1 Existence Phase

This initial phase includes what must happen before a cluster emerges sufficiently to be recognized as "existing". For Maskell & Kebir (2005), existence could be triggered by a variety of processes that lead to co-location. In reviewing various accounts of the existence phase, they refer first to the presence of tightly packed Marshallian locational economies and spillovers[10] as the principal drivers of initial co-location, although how these first come into being as cluster factors remains undeveloped. Building on this view, co-location in existing agglomerations gradually permits the endogenous emergence in modern economies of positive externalities and generally favorable business conditions, to which additional firms are attracted and, in certain industries, are presumably better able to exploit (and develop further) through co-location (Lorenzen, 2005)[11].

Beyond the traditional Marshallian points, Maskell and Kebir (2005) note Michael Porter's (1990) stress on the importance of local rivalry plus intra- and inter-firm information conduits. In marked contrast to Porterian concepts of rivalry, innovative milieu theorists place emphasis on pre-existing community values, cooperation and social capital, which "…act as an uncertainty-reducing mechanism in the innovation process" (Maskell and Kebir, 2005, citing Camagni, 1995, p. 320), thereby building trust, common work ethics, and joint economic endeavors. A clear inference is that existing community and social practices establish hospitable circumstances in which innovative agents are eventually able to prosper, a point also frequently advanced in the social capital literature, most forcefully and earliest by Putnam (1993).

Whether Marshallian or milieu-centric in nature, such accounts of cluster existence are better at establishing the necessary, although not sufficient,

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[9]Perhaps a fourth "extinction" phase also applies, which in mild form simply refers to one cluster being replaced by its successor (see discussion in section 2.2.1). The utter collapse of a cluster *and* its host region is exceedingly rare, although places such as Bardou, a former "supply region" in Jane Jacobs view, represents the rare type of place history passed by as it became economically extinct and abandoned (Jacobs, 1984, pp. 34-5).

[10] Johansson (2005) provides a thorough dissection of the various externalities and spillovers discussed in the classic literature and much of its progeny.

[11] Wolter (2003) expands this notion first by acknowledging historical accident and by explicating what she calls the "set-up" phase, which is "…characterised by small, slowly growing numbers of companies… [*surviving where localization and*] agglomeration benefits and costs are weak, leaving a greater role for geographic ones in determining industry location and development" (p.6). Although the title of Wolter's paper suggests that it examines cluster life-cycles, and strong parallels are clearly evident, the text focuses heavily on the regional "agglomeration" context within which clusters play a major development role.

conditions for cluster emergence. Historical legacies and chance play important roles as well. As examples, Krugman's account of the origins of tufted rug innovations (1991, p. 59-61) suggest how sparks of local entrepreneurial consequence can arise from simple gift-giving between friends and strangers, while Tappi's (2005, p. 297-304) summary of accordion design-diffusion reveals the spark ignited locally by expatriates who acquired external contacts and information that enabled them to detect and organize overlooked local potentials (see also Sable, 1982, p. 222-223). Clusters therefore usually result from some early historical initiative. Even so, policy efforts to substitute publicly-sponsored programs of cluster stimulus for the Schumpeterian calculus of entrepreneurs are increasingly prevalent, even though conventional cluster wisdom by now firmly counsels policy support only *after* entrepreneurial activity has demonstrated cluster viability.

Among the most focused efforts to understand how clusters emerge are scholars who attempt to model theoretically and empirically the process of clusters coming into existence, drawing upon tools of population ecology, complexity analysis, agent-based modeling, etc. to characterize self-organization among cluster agents that may lead to later transitions between cycle phases. Brenner (2004) proposes that cluster emergence requires a minimal presence of industrial firms (i.e. naturally occurring presence of firms "seeded" by externally-driven industrial cycle dynamics) [12], plus increases in exogenous demand for the products of these firms. It is then a question of whether that demand becomes sufficiently strong to trigger an expansion of firms beyond a minimal, pre-cluster stable state to a critical mass that attains a higher stable state capable of setting off endogenous ("self-augmenting") cluster growth dynamics driven by firm entry and exit.

Maggioni (2004) employs a somewhat different population ecology model to account for cluster birth and take-off, which adopts the perspective of an existing firm that might wish to locate in a potential cluster. Early locators calculate their net benefits and, if warranted (e.g., a "critical cluster mass" has been attained), enter the cluster, thereby driving up the average profitability of this location to the next potential locator (enhanced spillovers and positive externalities), but also driving up congestion costs. Swann, et al (2002) also focus on critical mass as the essential "existence" event that stimulates co-location, although their interest is less in contributing to the development of cluster cycles than in examining entry variation of firms to a cluster at points along its cycle. In this view, entry by external agents is a function of the strength of a cluster in a given industry and the strength of clusters in all other industries.

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8 An *external* industry cycle "seeds" a new cluster in this and most modeling strategies; cluster cycle theorists assume external industries arise from an innovation, even though such innovations might endogenously *incubate initially within another parent cluster*.

2.2 Expansion Phases

Initially favorable existence conditions described above are the necessary pre-requisites for a cluster's critical mass to suddenly take-off, where self-organized "swarming" of new firms, technologies and innovations, products and cluster related activities occur rapidly and promiscuously. Perhaps this sub-phase could be distinguished and labeled as **Exploratory Expansion**: it is typically concentrated before the inflection point of the typical cluster "S" curve where rates of expansion in cluster scope activities is greatest. This phase[13] corresponds with a "entrepreneurial technological regime," identified by Winter (1984, p. 297), "…that is favorable to innovative entry, but unfavorable to established firms." The latter are, in Winter's term, "routinized technological regimes" that dominate the following **Exploitative Expansion** phase, during which systematic exploitation, cluster scale-economies, process technologies and efficient firm routines drive growth, often aided by the deliberate policies dedicated to the improvement and expansion of beneficial advantages. Such policies include—presumably—remedying any newly revealed scale-inhibiting bottlenecks that might limit the continued expansion of the cluster.[14]

2.2.1 Exploratory Expansion. Initial stages of the familiar Marshallian[15] „expansion" trajectory might be described at this sub-phase as an exuberant exploration of how initial pecuniary spillovers originating in cluster-specific infrastructure, specialized worker training and education, key supplies of skilled labor, emerging specialized suppliers, and increasingly compliant institutional or regulatory practices that favor expansion and competition might be incorporated into successful business models. Maskell and Kebir (2005, citing Porter, 1998, p. 241, 221) add that

> "…developing clusters also attract—and cluster participants seek out—people and ideas that reinforce the cluster. Growing clusters attract skilled people through offering greater opportunities. Entrepreneurs or individuals with ideas migrate to the cluster from other locations as well, because a growing cluster signals opportunity."

Incumbents and—presumably—opportunistic arrivals as well benefit from a cluster's innovative milieu, which "…facilitates mutual acquaintance, collaboration, dissemination and exchange of information, just as it allows for the development of trust relations" (Maillat, 1998, p. 19, cited in Maskell and Kebir, 2005). During this intensely exploratory period of self-organisation, the firms of each developing cluster may gradually and quite intuitively assemble and collectively refine a unique series of beneficial capacities, some of which may also become the "isolating

[13] Swann (1998, 2004) divides the overall cluster expansion phase into "take off" and "peak entry" of firms.
[14] Magioni (2005, 28-30) refers to those which expand the upper size limit or carrying capacity of a cluster as „K-policies", while those established to accelerate rates of growth during exploratory expansion are "r-policies".
[15] Strictly speaking, this phase could also be described as "Schumpterian", since it usually follows some previous disturbance that stimulate entrepreneurial ambitions and willingness to explore the potentials of new technologies, markets or business models, and whose dynamics are partially responsible for Schumpterian-cycles. However, the principal elements examined here and in the literature remain those of Marshall, which confirms general tendencies—as reported by Windrum (nd, p. 3)—to "bow to Schumpeter while talking of Marshall".

mechanisms" that help sustain growth and protect them from external regional competitors (Maskell and Malmberg, 1999, pp. 176-178).

Brenner (2004, ch. 2) reviews carefully a series of distinct mechanisms that have feedback-loops and are self-augmenting, i.e. are "growth inducing." These include mechanisms that arise between firms (e.g., Marshallian spillovers, spin-off firms, etc.) and interactions among firms and other cluster agents (human capital, research institutions, etc.). The intensity of the expansion process from endogenous self-augmenting processes is seen by Brenner as further tempered by global (mainly industry) and local (social, cultural, governmental) factors[16]. Maggioni (2005) confirms several of these and identifies a further series of mechanisms and agent behaviours that accelerate the exploratory phase, adding to the list models of success-signalling to external agents, anchor tenant and leader-supplier dynamics, legitimating agent-forms, emerging diseconomies, and information diffusion. Swann (2002, 59) notes that for innovative clusters "…in the formative (introduction and growth) stage of the life cycle, geographical proximity may be critical to tacit technology transfer—which is so essential to industry development—and hence the positive effects are large".

The speed with which all such factors propel a cluster is, from an ecological perspective, the difference between the birth and mortality rates of the firm population, which Magionni expresses as the net rate (r) that determines a cluster's growth potential. Swann's model (2002, 58) is similarly based upon firm entry as the principal dynamic, where entry rates are highest in the strongest of competing clusters; the model further implies that entry-driven growth will tend to favor specialized clusters "…if like firms convey benefits on incumbents while unlike firms do not, then if space is limited, it is better to group together with like firms."

Bergman (2006) observed that Austrian incumbent firms of *strong regional clusters* operating where opportunities to innovate or invest were self-reported as "excellent" also drew heavily upon universities, venture capitalists and regional firms to help generate and develop new innovations, while seldom relying upon formal cluster support organizations. They behave very much as Porter might predict by deliberately positioning their products in international markets, valuing highly-demanding customers both internationally and regionally, and by monitoring supplier quality and customer feedback from regional customers.

The most successful clusters progress directly from the exploratory to the next stage where some measure of dominance is attained through scale expansion, thereby fitting the stylized "S" curve dynamics; however, lesser—probably typical— clusters have considerable difficulty escaping their initially

[16] In understanding processes of cluster cycles and change, Lorenzen (2005, 205) favors theories and models that view cluster dynamics as products of both endogenous and exogenous processes, since "As can be seen, there is still quite some way to go before we reach a composite understanding of how exogenous and endogenous processes play together in changing clusters".

exuberant phase or to attain scale or industry dominance. Two examples illustrate the life-cycle interruptions faced by lesser clusters, each at different speeds.

Tappi (2005, 298-304) describes a lengthy series of periodic adjustments taken by the musical instrument cluster following its emergence in Marche (Italy), early in the 20th century. During that century, it moved from accordions to electric and electronic instruments to digital equipment and specialized digital applications as a matter of necessity during periods when demand and tastes shifted and new technologies began to penetrate its existing products, all which transpired through a cascade of family and small firm dynamics, temporary scalar expansions, mergers, spin-offs and startups. Originating as a household workshop, its entrepreneurial efforts and expanding firm population produced in the ensuing century a continuously evolving series of interrelated clusters, passing through several cluster "half-lives", rather than becoming a single cluster that faced maturity at a single point in its life-cycle. It might be argued that the vast majority of clusters have similar histories, gradually enriching their host regions over time by exposing them to an ever-broader palette of technologies and sectors that under-gird a capacity to learn and adjust over time, supportive of other clusters but never becoming dominant[17] in a specialized field, nor perhaps even dominant in their host region. However, this broader experience may also form the basis for what innovative milieu theorists envision by being "…potentially able to utilize the tensions that emerge during the process of change by guiding the localized production system towards a new state in which the territorial logic continues to manifest itself" (Maskell and Kebir, 2005, p. 12).

The Danish mobile-communications cluster emerged far more recently and has already adjusted numerous times during its relatively young life, a process accelerated by the profoundly rapid pace of innovation. Dalum, et al (2005, p. 231) focus on the role played by disruptive technologies to develop their "…analysis of sequential disruptions by using the concept of technological life-cycles, and to apply this to a single case over an extended period of time, including several (technological) cycles." An accelerated scenario of early entrants, enabling institutions and universities, buyouts, mergers, takeovers and exits reflect the highly unstable state of cluster development in North Jutland as repeatedly improved mobile telephone technologies shifted the attention of cluster agents swiftly from NMT to GSM to UMTS, only to be challenged again most recently by the WLAN family of technologies developed elsewhere. In comparison with the March musical cluster, it involves a much narrower group of technologies and sectors active over a far shorter 25 year time frame, but this cluster too has yet to "take off" as a scale-efficient growth cluster, and it too is probably quite representative of supporting—not dominant—technology-intensive clusters

[17] Dominance is a term based upon Utterback and Abernathy's concept of "dominant designs" to signify any of the few similar clusters whose principal product(s) control large market shares and which continue to produce a stream of innovations that support continuous cluster upgrading, incessantly diffusing uncritical phases and their organizational units across the cluster landscape. Lesser clusters in far larger numbers specialize in the components, modules, inputs or niche products that support and complement dominant clusters.

found throughout many modern regional economies. In this view, the vast majority of clusters may experience life-cycles that never pass to the succeeding phase.

2.2.2 Exploitative Expansion. Once this phase of cluster expansion has been attained—in Tichy's view (1999, p. 233)—it:

> "…appears to be the best of all worlds to participants. It is the phase, nevertheless, which may generate the first deviations [that] cause later troubles. Success is easy in this phase, so that little pressure exists to search for further development of the cluster's strengths, for other applications of its knowledge, etc. It is tempting to concentrate on the best-selling product and to produce it in ever-increasing quantity, utilising economies of scale.

Members tend to focus less on exploring new options and more on protecting advantages that earlier arose quite spontaneously, identified by Maskell and Malmberg (1999) as regional "isolating mechanisms", three of which are relevant to this stage:

> "…*isolating* mechanisms arose in innovative regions that sustain them by protecting them from external regional competitors. First, *asset mass efficiency* is the idea that historically agglomerated R&D and related innovation assets are not easily or readily duplicated in competing regions. Second, *time compression diseconomies* are the costly but necessary lags a competing region must overcome while trying to master and replicate the capacities of a superior region, which can busily continue to build upon its strengths through increasing-returns processes. Last, an externally inscrutable *interconnectedness of asset stocks* implies that simply replicating each asset stock produces no sense of how they are deployed effectively, which is another way of saying that accumulated assets develop DNA-like usage patterns not visible or apparent to outsiders or even to those who daily draw upon this embedded DNA." Bergman (2006)

Cluster members may complacently assume such isolating mechanisms are effectively permanent features, and perhaps also begin to rely more heavily upon membership in formally structured and managed organizations to protect initially advantaged positions. For example, Bergman (2006) found firms that self-identified membership in *relatively mature* Austrian clusters (i.e., featuring a broad range of firms and supporting institutions) indicated such membership provided access to good buyer trend information; these same firms sold relatively little of their output to demanding international customers or to non-European markets and perceived no advantages in ISO certification, thereby forfeiting opportunities to learn about global market changes and competitors. In contrast, their general orientation placed comparatively high value on *internal* member-supported R&D contacts, acquiring or developing innovative ideas principally from same-sector firms and cluster-organizations, but relatively little from university and venture-capital sources. While mature cluster firms welcomed the entry of additional firms to the cluster, they saw no relative benefits of competition.

Additional forms of complacency may also begin slowly to erode initial cluster advantages during periods of consolidation and slowdown. Very significant limits to growth and overall cluster carrying-capacity arise from the more rapid rise in congestion costs that offset advantages as clusters attain greater scale. Congestion costs are among the important classic factors that Maskell and Kebir (2005, p. 6) find most absent in much of the contemporary cluster literature: "The *extension* argument of centrifugal forces was, in contrast [with contemporary views], normally based on the costs of congestion, or the bidding-up of prices for land, labor or the services of goods provided, but could be extended to include negative spillovers when different industrial logics clashed." Escalating congestion costs of clashing industrial logics are explicitly incorporated by Swann (2002) who observes that congestion costs rise disproportionately as entrants from different clusters bid up local prices, while additional firms of each cluster add few or no Marshallian advantages to the other, therefore accelerating the loss of net benefits to potential entrants of either cluster, which probably favors initial tendencies toward single cluster specialization. Swann describes this as a pivotal situation:

> "[As] the industry enters its maturity stage, the benefits of clustering start to tail off, and eventually the costs of clustering outweigh the benefits…At this stage the cluster is approaching its peak, but has not entered the decline phase as such. It may be growing very slowly, but it is not getting smaller. That stage starts when the *industries* located in the cluster start to decline." (2002, p. 54).

Elsewhere, Swann (2004, slide 18) summarizes the process in greater detail, deploying a matrix that indicates the effect of successive cluster entrants on various agents, until the "final entrant" at which point no agents and only consumers benefit. In portraying the structure of congestion costs, Maggioni (2005, p. 13-28) deploys an ecological model that draws heavily upon an elaborately conceived micro-foundation of congestion costs to examine potential rates of cluster growth, cluster carrying-capacity and external challenges to mature incumbent clusters.

To this point, we have focused on the processes by which a cluster matures and moves beyond its earlier innovative phases by adopting standardized, scale-efficient process technologies; perhaps firms have even spun off establishments and facilities that no longer benefit from local cluster advantages. Swann (2004, p. 54) poses rhetorical questions whose obvious answers are responsible for slowing or halting the entry of firms to incumbent clusters:

> "As new industries emerge, firms in those industries may then be faced with location decisions of the following sort. Should they locate in an old cluster, where they have little commonality with incumbents, where the established infrastructure is dated and where congestion costs are still relatively high, although admittedly declining? Or do they locate in a new cluster where the incumbents, though new and small, are generating the sorts of spillovers that attract entrants and are based in more relevant industries, and where the infrastructure is better?"

Brenner (2004, p. 37) sees *consolidation* across clusters, with severe life-cycle consequences for some, as the natural outcome of entry decisions by firms, particularly at later stages of industry evolution:

> "At some point in time the global firm population and therefore also the supply increases faster than demand. As a consequence, competition becomes more fierce and finally leads to an increasing occurrence of shakeouts."

It seems clear that one cannot consider the life-cycle of a cluster in the absence of its core industry life-cycle. In their broad study of industry life cycles and clustering, Audretsch and Feldman (1996, p. 271) conclude that "…what may serve as an *agglomerating influence* in triggering innovative activity to spatially cluster during the introduction and growth stages of the industry life cycle, may later result in a *congestion effect*, leading to greater dispersion in innovative activity." Cluster growth may suddenly or gradually slow, oscillating around a stable state at some upper limit; the state of affairs obtained from this orderly and incremental development path is perceived by firms and other cluster agents in Tichy's words, "…as the best of all possible worlds…"

However, a mature cluster in such a stable state may not be prepared for the unexpected disturbances it absorbed easily during its earlier exploratory rise, disturbances that now threaten its stable maturity. Maggioni (2005, p. 21) describes the following effects on established clusters:

> "As long as the technology undergoes 'normal progress' (i.e. follows a technological trajectory) the interchange of knowledge within the established cluster will tend to preserve its leadership. When new technologies arrive that are discontinuous with those that came before (i.e. change the technological paradigm) existing industry concentration may be of little value and the result then is that new technologies tend to be exploited in new clusters that do not suffer the diseconomies associated with an established cluster."

Events of this kind pose qualitatively different challenges to mature clusters than to clusters at earlier stages, which suddenly interrupt the slow, graceful aging enjoyed by comfortable clusters.

2.3 Exhaustion Phase

Exhaustion arises at that point on a cluster's life-cycle when maturity itself poses a clear threat to continued cluster viability.[18] Tichy describes the situation thus (p. 230):

"As the number of firms is reduced, sophisticated networks are no longer necessary, as no new information has to be transferred; nor are clusters any longer competitive, compared with vertically integrated firms, as the number of nodes has been drastically reduced. The smaller the networks, however, the less—and the less new and stimulating—information they can provide, the lower therefore the chance of the cluster inventing new products, new processes, or a new organization. The cluster has aged; the region in which the cluster is located has become a problem area, a region with little endogenous potential to find new dynamics."What details characterize this situation and how do we understand the possibilities? First, the depletion of some vital mineral or material resource may lead to exhaustion, or the milieu deteriorates (Maskell and Kebir, 2005, p. 9, quoting Maillat, 1998, p. 15), which results when "…opportunistic behavior

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[18] As a cluster approaches a possible inflection point on its life-cycle curve, it could again turn upward as a revitalized, renascent cluster, or instead decline—as net location benefits plummet —more or less rapidly from an unsustainable maximum limit.

causes defiance or the outward openness becomes inadequate to ensure the enlargement of new cooperative relations or the replacement of technologies". A strongly contrasting view of competitive vs. cooperative behavior, perhaps addressing wholly different kinds of clusters, sees risk arising in both "…important intra-cluster forces (such as ebbing domestic rivalry, the development of internal rigidities and regulatory inflexibilities) as well as a number of externally induced influences (such as technological discontinuities, deteriorating factor conditions, and shifts in buyer's needs. (Porter, 1990, 166-169; 1998, 243-244, cited in Maskell and Kebir, 2005, p. 8).[19] Whatever the causes, growth and regeneration that occurred almost automatically in early phases grinds to a complete halt and the cluster pauses. At this point, either one of two different directions is possible. The pause extends and is "locked-in" for an extended period of time; alternatively, the cluster experiences a renaissance, perhaps immediately or following a temporary period of lock-in.

2.3.1 Lock-in. A significant strand of the cluster "lock-in" literature could be seen as framing the exhaustion phase in rich detail. Although seldom presented as a distinct life-cycle phase, lock-in describes well the inwardly-spiraled layering of events and decisions that steadily shrink "protectively isolated" clusters, thereby progressively insulating them from external influences or internal impulses for change. Developed as territorial analogs of technological lock-in concepts advanced earlier by David (1985) and Arthur (1994), industrial district lock-ins were applied first to clusters and regions by Grabher (1993), then extended by Hassink (2005a, 2005b) and others. This expanded literature typically drew upon accounts of lingering malaise that afflict certain sector-dominated clusters, particularly in German iron, steel and shipbuilding regions. Grabher identifies some of the factors described at the exploitation phase as responsible for effectively locking a cluster or region into an exhausted sense of possibilities: too much inward orientation and group-think (cognitive lock-in, which becomes difficult to "unlearn"), too tightly-tied local connections (functional lock-in among locally-oriented networks), and excessive dependence upon non-firm agents and compensatory support (political lock-ins that deny market viability issues).

It is not merely that such factors diminish a mature cluster's viability; rather, they appear steadily to anesthetize cluster agents, reducing their ability to recognize and make timely adjustments to fundamental changes brought on by radically altered markets, technologies and vibrant new global competitors that

[19] Additional symptoms of how a cluster's endogenous advantage-mechanisms (Maskell and Malmberg, 1999, p. 178-179) could disappear are summarized by Bergman (2006): "*asset erosion* …takes place as '…hitherto important institutions in a region are no longer reproduced at the same pace or to the same degree.' [R]*egional lock-in* can develop when initially important institutions and practices—often social and cultural in origin—focus on self-preservation or aggrandizement and become a sclerotic risk (Olson, 1982) to—rather than the life-blood of—regional progress."

swarm newly formed or renascent clusters. This is the fate experienced by a vast landscape of "old industrial area" clusters, whose former fortunes and privileged status often become irretrievably lost, although new futures might still be imagined, given a dramatic change in agents, industries and technologies. The continuing downward (and perhaps unstoppable) spiral of the U.S. auto industry and Detroit's auto cluster is mirrored worldwide, perhaps leading many eventually to near-petrification (e.g., iron and steel of Ruhr region). The chances, if any, for a successfully restructured innovative milieu may require considerable time: "As milieus tend to change more slowly than industries, a sclerotic milieu can remain in a region even after the industrial structure to which it belonged has already disappeared" (Hassink, 2005, p.573).

2.3.2 Renaissance. However, marked transitions—some quite dramatic—have been documented in former clusters of European (e.g., iron and steel in Styria to automobile production and supply) and U.S. regions (e.g., from tobacco and cigarettes in Durham, NC to medical-biotechnology)[20]. These are quite logically seen by many as success cases and scrutinized heavily by policy analysts eager to identify the specific measures and actions responsible. One must surely acknowledge some policies are better suited to triggering successful restructuring than others, but these often differ strongly across unique cases, thereby frustrating efforts to generalize about overall approaches that might be valuable. The identification of common cluster cycle factors at work might be a more appropriate first step, as these may then be leveraged from place to place with rather different policies[21]. The simple passage of time is surely necessary for a broad spectrum of spontaneous reactions to begin, following cluster recognition of an exhaustion crisis, not least of which is the gradual replacement (and perhaps reduction) of original agents with newcomers, the depreciation and replacement of obsolete infrastructure and institutions, the re-pricing of unit factor costs or capital assets, and a reactivated appreciation for external ideas, innovations and technologies. This can seldom be avoided, even though painful to absorb. It is equally painful to recognize that one's cluster is probably losing ground to competitors that meantime are rapidly establishing "time compression diseconomies" of their own, thereby extending an insurmountable lead in stronger versions of the old cluster[22]. Painful readjustments take place in nearly all exhausted clusters, although not all recover satisfactorily and some not at all, even with lengthy passages of time[23]. There are additional assets some clusters and regions enjoy that may help speed or ensure the process of restructuring.

[20] Toedtling and Trippl (2003); Bergman and Goldstein (2001).
[21] For example, Toedtling and Trippl (2005, pp. 1211-1215) offer a range of policy guidelines that apply to different types of regions.
[22] Recognition of local loss and competitive external clusters is often unacceptable in politically active regions, where „catch-up" and recovery measures are taken prematurely that work to retard the necessary readjustments and realignments.
[23] In addition to the typical resource boomtown stories, Jane Jacobs's discussion of Bardou in France (1984, p. 32-33) illustrate the fate of highly dependent regional economies that failed historically.

Of these, three will be mentioned that have received attention in various literatures: agent diversity, polyvalent technology sources, and knowledge/science base.

2.3.2.1 Agent Diversity

Clusters that face exhaustion and cannot self-regenerate easily have become deeply specialized along too many core dimensions, operating in extreme cases as a highly-specialized, homogenous cohort of agents captured in a self-constructed silo[24]. A mono-vintage homogeneity trap could result from extremely rates of rapid cluster development, during which nearly all agents, technologies and awareness of external environments originate over a very short span of time; this would effectively eliminate a temporally-varied portfolio of sustainable knowledge available within the cluster. Homogeneity is further enhanced in cases when congestion-cost increases favor the development of single-cluster regions; moreover, competences within a single cluster may hyper-concentrate if firms operating at the edge of a cluster are drawn inward towards its principal technological trajectory (Fornahl and Menzel, 2003, p. 5). However, single-cluster tendencies are comparatively infrequent in all but the smallest and a few larger regions, usually resource-intensive.

Cluster diversity of some type and degree is more the norm: "…London's success as a cluster also derives from its history of attracting a diverse mix of industries, and its pre-eminent success at exploiting convergence between technologies" Swann (2002, p. 63). London and similar cities reflect the so-called "Jacobs Externalities" of variety and inter-sectoral exchange that are characteristic of large metropolitan agglomeration economies[25]. At the same time, even in lesser regions, neighboring clusters include an ensemble of different sectors, industries, technologies, business models, and entrepreneurial or creative spirits that could help stimulate regeneration. While the pain of incumbents during the adjustment process is palpable, so too are opportunities and released resources made visible to *other* local cluster agents and their extended networks. Novelty and the ability to use existing resources in novel ways, "…is seen more likely in networks comprising actors with different backgrounds, e.g., in extra-regional or international networks…,(which engage) the support of selected outside specialists to help them counteract lock-in and survive" (Visser, E-J. and Boschma, R.A. (2004, p. 803)). Networked and even neighboring cluster agents are likely of varying age and origin, they conduct business with different models or under varying organizational structures, and satisfy innovative needs from differing knowledge bases[26], thereby providing new insights of considerable relevance to exhausted clusters.

2.3.2.2 Polyvalent Technology Sources

[24] See Fritz and Mahringer (1998) and Tichy (1998) for a review of risk-related issues that cluster agents and supporters should consider well before exhaustion sets in.
[25] Henderson, Kuncoro, and Turner. (1995, p. 1068).
[26] Hansen, Vang and Asheim (nd)

While an exhausted cluster may become wholly preoccupied with its deeply ingrained routines, common wisdoms, sunk costs and its technological predispositions, the surrounding region may contain overlooked technological resources and perspectives of great value. An exhausted cluster may eventually draw the attention of others to its unexploited local potentials for technological convergence: "If industry A generates spillovers of some value to new entrants in industry B, then the cluster, while an early centre for industry/technology A, will subsequently become a center for B. This, as much as movements in relative prices, is the key to cluster revival" (Swann, 2002, p.64). Swann further notes that chemical and ICT clusters are anything but silo-technologies: rather, they partner "polygamously" with several sectors (2002, p. 65). Of the 23 clusters formed by input-output relations and value-chains, 22 consisted of sectors that supplied inputs to more than a single cluster (Feser and Bergman, 2000, p. 5-7), thereby bridging common relationships between them; the top-3 ranked clusters (metalworking, vehicle manufacturing and chemicals/rubber) were each supplied by 23 to 28 specific sectors that also supplied inputs to at least one additional cluster[27]. This implies a broad palette of possibilities for tapping common supply-chain technologies that, if seized upon, could spark the regeneration or reconfiguring of an exhausted cluster.

At the same time, regeneration is likelier to succeed if the skill-set of the region's resident labor pool is capable of adapting to more than one industry or technology. Marshallian labor pooling assumptions focus upon the constellation of labor skills valued heavily by the few sectors of a single cluster, but perhaps it is more realistic to consider the key *occupations* of sectors that span several clusters. Feser (2003) reviews the literature of several skill-equivalent research studies as background to empirically estimate which combinations of over 600 specific occupations belong to 21 distinct and homogenously-defined skill clusters (including illustrations of 4 knowledge-intensive occupational clusters in 10 important U.S. regional economies). These skill clusters represent distinct knowledge-based labor pools within which workers are able to move between components of several industrial sectors and clusters, thereby potentially stimulating revitalization of an exhausted cluster.

2.3.2.3 Science-Knowledge Base

How and whether technological adjustments among clusters actually take place may—in the view of many—depend upon the effectiveness of the local system of innovation available to cluster agents. Local or regional (RIS) innovation systems have received much theoretical and policy attention, particularly conceptual arguments or specific case studies of how they are structured, populated, classified, and governed[28], but empirically-based generalizations concerning RIS potentials to reverse cluster or regional decline are notably absent. Universities and research institutes, essentially knowledge-

[27] Clusters ranked 4-10 also received, on average, inputs from 11 specific sectors that supplied at least one additional cluster.
[28] See Doloreux and Parto (2004) for a useful synthesis of this literature.

generating and diffusing institutions, are also considered key members of a local innovation system[29], although for Betts and Lee (2004, p. 35) "...there is a tendency in the literature to perhaps overplay the role of universities and underplay the role of the private sector…", a sentiment also echoed by Laursen and Salter (2004) who argue that direct customer and supplier relationships remain far more important in terms of innovation than the "…largely indirect, subtle and complex" relation with universities. One should therefore be cautious about the prospects for stimulating exhausted clusters based solely or principally upon the local availability of an active science base.

The presence of universities and research centers near exhausted clusters represents potential access to the local science base and its academically networked global science base as well. For Betts and Lee (2004, pp. 2-3), these potentialities may be expressed in one or more of the following: 1. *trainer* (human capital formation), 2. *innovator* (direct commercialization), 3. *partner* (joint projects and research), 4. *talent magnet* (attract external knowledge-intensive workers), and *facilitator* (networking), to which Goldstein and Renault (2005, p. 74) add 6. *knowledge generation and research infrastructure*, and 7. *innovation leadership*. UK universities were found to be most frequently involved at least once during 2002-3 with firms in conferences and meetings (65%), as consultants or contract researchers (56%) or joint research partners (45%), with higher frequencies being reported in chemistry, engineering and materials sciences, which are similar to overall findings reported by Mowrey and Sampat (2004) for U.S. survey respondents (industrial R&D managers).

Whether these potentials are well suited to existing firms now barely surviving in exhausted clusters remains in doubt: Prevezer (2002, pp. 233-4) states cluster incumbents "…do *not* absorb spillovers arising either from other sectors or from the science base", while Laursen and Salter (2004) report "…the propensity to use universities increases with the degree (percentage) of sales devoted to R&D", which affirms the importance of absorptive capacities of cluster firms at the exploratory—*not* exhaustion—phase in gaining access to scientific inputs. A study of European firms indicate that collaborations between firms and industries decrease as the share of firm sales accounted for by innovative products rise, which suggests only long range, pre-commercial possibilities are pursued in joint university efforts (Knudsen, Dalum and Villumsen, 2001, pp. 15-16): unwelcome news to exhausted cluster firms seeking short range remedies.

Clusters located near an accessible science-base may have indeed once enjoyed and perhaps still retain remnants of a strong R&D culture and absorptive capacity, but more distant clusters will surely lack these advantages, and even locally-based clusters may have become effectively insulated through inwardly focused activities. The risk of inward orientation is great: Laursen and Salter (2004) found that university impacts accrued very narrowly to a subset of

[29] For discussion of innovation systems and universities, see Betts and Lee (2004) and Mowrey and Sampat (2004).

UK firms in a few sectors that have maintained capabilities in R&D *and* have adopted an "open"—not closed—approach to innovative search.

3.0 Conclusions

The weight of findings and concepts discussed here is not intended to support a novel or revised version of cluster life-cycles. Rather, relevant life-cycle concepts are seen as leading to a better understanding of detailed phases and stages, using the conventional life-cycle as a discussion template. They also help illuminate further *other* important facets and features of clusters that may have been glossed over or perhaps draw attention to questionable generalizations concerning clusters observed at widely varying stages or phases that have been prematurely reached.

In conducting this review of concepts, several implicit assumptions embedded in the literature were needed to clarify various points, which may prove useful in future research concerning cluster life-cycles. First, at present there is no single best metric of cluster activity, nor is there an agreed-upon aggregation principle by which to create one. This means that firms, employees, capital investment, sales, output, value-added, etc. have been used in many different studies, with sometimes predictably opposing results. Second, the very idea of aggregating metrics raises the cluster to the level of a "representative agent", somewhere between a firm and an industry. This is usually observed in research papers that imply or attribute logic, motive, incentive and action to a cluster. Third, active clusters are frequently considered to exhibit homogeneous structures, e.g., all institutional elements "self-organize" along similar lines, including the possibility of creating support institutions to reinforce such behavior. Fourth, traded clusters alone are subject to forces and incentives that expose them to the possibilities of a full cluster cycle, particularly clusters that specialize in globally-traded products. Indeed, such clusters are truly "trade generators"—which surely attracts policy-makers so strongly to the concept—unlike locally-defined clusters that concentrate mainly to produce and distribute efficiently that output demanded within the local region. Finally, exposure to a complete life-cycle is likely only for a much smaller subset of traded clusters that at some point becomes dominant in national or global terms.

Additional points that arose within the discussion of specific cycle phases may deserve further exploration and research. Several authors try to establish the existence of a cluster with reference to the exogenous presence of an innovative product, technology or industry (PTI) available for exploitation in hospitable locales. This raises the question of whether PTI were in fact generated previously in *other* clusters that proved incapable of retaining and exploiting possibilities. Perhaps Cliometricians might wish to backtrack histories of scattered PTI families "separated at birth" to evaluate the endogenous origins of clusters: as a counter-factual example, assume one or two of the "Fairchildren" (Betts and Lee, 2004, p. 12) had initially exited Silicon Valley (e.g., Intel) and instead moved elsewhere to establish a new cluster.

Alternative cluster origins, i.e., non-PTI, worthy of consideration are the traditional products or practices embedded in formerly untraded regional clusters that somehow gain international cache and grow to become the traded products of concentrated clusters. One could argue that several Italian industrial districts arose through such a process; this appears to be one of the defining differences between such districts and the innovation-intensive clusters of more typical PTI origins.

Existence has also been attributed in certain clusters to chance and random events that happened in retrospect to have favored a location, but isn't there a story embedded somewhere behind *every* cluster, successful or not? Perhaps random events favor the first-mover rather than follower, amenity-rich chances may displace those in amenity-poor localities, or chance could more easily take root in SME-intense vs. company-dominated localities, and so on. The contribution of economic historians could be exceedingly valuable in untangling the origin of clusters that somehow reached the existence stage.

While the expansion phase has attracted much research and conceptual examination, there may still be opportunities to explore further key differences in agent behavior and cluster composition at what are called here the *exploratory and exploitive* sub-phases. While the expansion of a cluster is generally observable, there may be underlying shifts, for example, in the amounts, sources and uses of venture capital prior to some inflection point during the overall expansion; or perhaps major adjustments in relationships and channels through which innovative inputs are acquired help signal this point. Growth in sentiment for and progress toward establishment of cluster support institutions may trigger the shift, as might unit-price increases demanded by local factor owners who are able to valorize nearby externalities (congestion costs). Which shifts prove to be pivotal in triggering the continuing exploitative phase in clusters of various types is surely worthy of further investigation.

Equally interesting and relatively unstudied are the consequences for the much larger class of exploratory clusters that do *not progress* to an exploitive phase or eventually come to enjoy some measure of dominance, but rather as in the Marche and North Jutland cases[30] continue to host an ongoing series of supporting clusters, essentially providing key services or inputs to dominant clusters elsewhere until such opportunities are exhausted and then moving nimbly to the next opportunity. What may appear to be a "failure to thrive" and become a dominant cluster may in fact be an investigation-worthy key to understanding the sustainable, slowly developing economies in many regions and communities.

How to *avoid* lock-in remains a principal lesson of life-cycle policy research and formulation, and much has been learned about its avoidance even if not always observed in practice. Far less is known about how clusters *escape*

[30] The fabled inability of Route 128 to become and remain a dominant computer/ICT cluster may reflect similar tendencies , although at a more advanced stage of expansion and maturity. However, the Boston region has since entered other highly successful clusters, which may prove even more beneficial than its ICT predecessor.

once locked-in, perhaps because so few have managed it. Instead, various factors that appear to account for lock-in avoidance are proposed as potential escape measures. In addition to the timely mechanics of routine market adjustments, three measures were discussed from the perspective of offering lock-in remedies, however surprisingly little research has been devoted to studying their effectiveness in this respect.

Exhausted, locked-in clusters accessible to diverse agents, polyvalent technologies or strong science bases have difficulty applying these and other resources to their situation. The Michigan automobile cluster, for example, is situated nearby several universities, including one of the strongest public U.S. research universities, but appears incapable of drawing upon its exceptional science base to reverse cluster fortunes. Nor apparently has Pittsburgh effectively exploited Carnegie-Mellon University's formidable scientific prowess in its transitions, although Boston has weathered the near-total loss of its ITC cluster and entered wholly new clusters, clearly drawing on the strength of its university-rich science base. More focused research might help us understand, as examples, how Boston's released ICT cluster resources were redeployed in other local fields (or relocated elsewhere), how precisely automobile cluster firms in Michigan's extreme mono-culture now interact differently than before with local world-class universities, or how previously effective self-organized economic communities unravel in ways that prevent potential innovations from being recognized or deployed.

It is entirely probable that lock-ins are "technically escapable" in many cases, i.e., innovations are available that would permit various degrees of renewal or renaissance. However, there may be failures of action or effectiveness that remain serious impediments to unlocking cluster malaise. Perhaps an exodus of expertise has depleted the cluster of key talents or it is now afflicted by an exhaustion of willful energies and Keynesian "animal spirits". Forms of communal senility (Atkinson, 2000, Part 5) may have set in, seriously depleting hard-earned strengths of self-organization and reciprocal sacrifice that drove the cluster's earlier expansion. How to recognize and understand the possible reasons that underlie collective failures to act effectively surely deserve as much research attention as how these capacities were developed initially at cluster exploratory and exploitation phases. Although the literature concerning cluster life-cycles has grown rapidly and offers many useful points, it may have thus far collected only the lowest-hanging fruit.

Bibliography

Agryl, A., Byrus, B.L., M. Tripsus. 2005. "Abandoning Innovation in Emerging Industries", preliminary draft.

Arthur,W. B. 1994. *Increasing Returns and Path Dependency in the Economy.* Ann Arbor: The University of Michigan Press.

Atkinson, Philip. 2000. A Theory of Civilization. http://www.ourcivilisation.com/index.htm

Audretsch, D.B. and Feldman, M.P. 1996. "Innovative Clusters and the Industry Life Cycle" *Review of Industrial Organization* 11**:** 253–273.

Bergman, E.M. 2006. "The Sustainability of Clusters and Regions at Austria's Accession Edge". Zbigniew Bochniarz and Gary B. Cohen, eds., *The Environment and Sustainable Development in the New Central Europe* (New York: Berghahn).

Betts, J.R. and Lee, C.W.B.. 2004. "Universities as Drivers of Regional and National Innovation: An Assessment of the Linkages from Universities to Innovation and Economic Growth." Presented at John Deutsch Institute Conference "Higher Education in Canada", 13-14 February, Queens University.

Brenner, T. 2004. *Local Industry Cluster: Existence, Emergence and Evolution*. London and New York: Routledge.

Dalum, B., Pederson, O.R., and Villumsen, G. 2005. "Technological Life-Cycles: Lessons from a cluster facing disruption." *European Urban and Regional Studies* 12(3), 229-246.

David, P. A. 1985. ``Clio and the economics of QWERTY'', *American Economic Review*. 75: 332-337.

Doloreux, D. and Parto, S. 2004. Regional Innovation Systems: A Critical Synthesis. United Nations University, INTECH Discussion Paper 2004-17.

D'Este, P. and Patel, P. 2005. "University-Industry linkages in the UK: what are the factors determining the variety of interactions with industry?" Presented at Triple Helix5 Conference "The Capitalization of Knowledge", 18-21, Turin.

Feser, E.J. 2003. "What Regions Do Rather than Make: A Proposed Set of Knowledge-based Occupation Clusters" *Urban Studies*, 40(10), 1937–1958.

FESER, E. J. and BERGMAN, E. M. 2000. "National industry cluster templates: a framework for applied regional cluster analysis". *Regional Studies*, 34(1), 1–19.

Fornahl, D. and Menzel, M. P., 2003. "Co-Development of Firm Foundings and Regional Clusters," conference presentation at "Clusters, Industrial Districts and Firms: the Challenge of Globalization", Modena, Italy.

Fritz, O., Mahringer, H. and Valderrama, M.T. 1998. "A Risk-oriented Analysis of Regional Clusters." Steiner, M. (ed)., *Clusters and Regional Specialization: On Geography, Technology and Networks.* London: Pion.

Grabher G. 1993. ``The weakness of strong ties: the lock-in of regional development in the Ruhr area'', in G. Grabher (ed),*The Embedded Firm: On the Socioeconomics of Industrial Networks*. London: Routledge, pp 255 -277.

Hansen, H.G., Vang, Jan, and Asheem, B.T. (2005), "The Creative Class and Regional Growth: Towards a Knowledge-Based Approach", presented at Regional Growth Agendas RSA Conference, University of Aalborg, Denmark 28th-31st May.

Hassink, R. and Dong-Ho, Shin. 2005. "The restructuring of old industrial areas in Europe and Asia : Editorial", *Environment and Planning A*. 37, 571-580.

HENDERSON V., KUNCORO A. and TURNER M. 1995. "Industrial development in cities". *J. Pol. Econ.* 103(5), 1067-1090.

Jacobs, J. 1984. *Cities and the Wealth of Nations: Principles of Economic Life.* New York: Random House, 1984.

Knudsen, M.P., Dalum, B., and Villumsen, G. 2001. "Two faces of Absorptive Capacity Creation: Access and Utilisation of Knowledge". Presented at Nelson and Winter/DRUID Conference, June, Aalborg.

Krugman, P. (1991) *Geography and Trade*, MIT Press, Cambridge MA.

Laursen, K. and Salter, A. 2004. **"**Searching high and low: what types of firms use universities as a source of innovation?" *Research Policy* 33(8) 1201-1215

Lorenzen, M. 2005. "Why do clusters change?"" *European Urban and Regional Studies* 12(3), 203-208.

Maillat, D. 1998. 'From the Industrial District to the Innovative Milieu: Contribution to an Analysis of Territorialised Productive Organisations.' *Recherches Economiques de Louvain* 64: 111-129.

Maggioni, M.A. 2005. "The rise and fall of industrial clusters: technology and the life cycle of region". Institut d'Economia de Barcelona, Espai de Recerca en Economia, Facultat de Ciències Econòmiques i Empresarials, Universitat de Barcelona.

Maskell, P. and Kebir, L. 2005. "What Qualifies as a Cluster Theory?", DRUID Working Paper No 05-09, Department of Industrial Economics and Strategy, Copenhagen Business School.

Mowery, D.C. and Sampat, B.N. 2004. "Universities in national innovation systems" (chapter 8). Fagerberg, J., Mowery, D.C. and Nelson, R.R. (eds), *The Oxford Handbook of Innovation*. Oxford: Oxford University Press.

Olson, M. 1982. *THE RISE AND DECLINE OF NATIONS*. New Haven: Yale University Press.

Porter, M.E. 1990. 'The competitive advantage of nations', *Harvard Business Review*, March-April pp.73-93.

Porter, M. E. 1998. *On Competition*. Boston: Harvard Business School Publishing.

Porter, M.E. 2003. "The Economic Performance of Regions", *Regional Studies*, Vol. 37.6&7, pp. 549–578.

Putnam, R.D. 1993. *Making Democracy Work: Civic Traditions in Modern Italy*. Princeton: Princeton University Press.

Sable, C. 1982. *Work and politics: The division of labor in industry*. Cambridge: Cambridge U Press.

Swann, G.M.P., "Towards a Model of Clustering in High-Technology Industries", in G.M.P. Swann, M. Prevezer, and D. Stout, *The Dynamics of Industrial Clustering*. Oxford: Oxford University Press, 2002.

Swann, G.M.P. (2004): "Cluster Theory: Opportunities and Problems", presented at ESRC Conference *Regions in Context*, Durham, 17 November, slide 18.

Tappi, D. 2005. "Clusters, Adaptation and Extroversion: A cognitive and entrepreneurial analysis of the Marche Music Cluster." *European Urban and Regional Studies* 12(3), 289-307.

Tichy, G. 1998. "Clusters: Less dispensible and more risky than ever." Steiner, M. (ed)., *Clusters and Regional Specialization: On Geography, Technology and Networks*. London: Pion.

Toedtling, F. and Trippl, M. 2003. "Like Phoenix from the Ashes? The Renewal of Clusters in Old Industrial Areas." *Urban Studies*, 41:5/6, 1175-1195.

Toedtling, F and Trippl, M. 2005. "One size fits all? Towards a differentiated regional innovation policy approach". *Research Policy* 34 (8), 1203-1219.

Utterback J.M. and Abernathy W.J. 1975. „A dynamic model of process and product innovation". *Omega* 3(6): 639-656

VISSER, E-J. and BOSCHMA, R.A. 2004. "Learning in districts: novelty and lock-in in a regional context". *European Planning Studies*,12 (6), 793-808.

Windrom, P. 1999. "Unlocking a lock-in: towards a model of technological succession." MERIT, University of Maastricht, The Netherlands.

Winter, S., 1984, Schumpeterian competition in alternative technological regimes, *Journal of Economic Behaviour and Organisation*, 5, pp.287-320.

Wolter, K. 2003. A LIFE CYCLE FOR CLUSTERS? THE DYNAMICS GOVERNING REGIONAL AGGLOMERATIONS. Conference Presentation, "Clusters, Industrial Districts and Firms: the Challenge of Globalization", Modena, Italy.

Cluster Life-cycle Sources	Cycle Stages Identified	Featured Stage(s)	Evidence supplied	Principal Purpose of Contribution
Tichy (1998)	Creation Growth Maturity Petrification	All	Literature review, case illustrations and policy examples	Pose relevant policy actions at various cluster cycle stages
Swann (2002)	Critical Mass Take-Off Peak Entry Saturation	All	"Entry" firm simulations modeled for tech-intensive clusters	Framework to evaluate UK/US bio-tech and computer clusters
Fornahl and Menzel (2003)*	Emerging Growing Sustaining Stagnating	All	Literature review, concept exploration	Examine role of firm foundings at cluster life-cycle stages
Wolter (2003)*	Set-up Growth Change Adaptation	All	Literature review, model dynamics, case illustrations	Develop life-cycle theory of agglomerations
Brenner (2004)	Entry Exit Growth	All	Population ecology modeling of clusters	Propose complete cluster theory and life-cycles
Maskell and Kebir (2005)*	Existence Expansion Exhaustion	All	Marshall, "Millieu" and Porter concepts	Identify key gaps in "Cluster Theory"
Lorenzen (2005)	Arise Decline Shift	All	Contributions of edited volume, editorial overview	Develop editorial framework
Hassink and Dong-Ho (2005)	Positive Negative	Lock-ins	Contributions of edited volume, editorial overview	Develop editorial framework
Maggioni (2005)*	Birth/takeoff Golden age Maturity	All	Population ecology modeling of clusters	Relate cluster dynamics to other innovation
Bergman (2006)	Formative Growth Maturity Petrification	Maturity	Literature review, cluster survey evidence, simple correlations	Sustainability factors tested
*working drafts				

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