

Entrepreneurial Activities and Technology-based Cluster Development*

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Purpose: Regional economic policy-makers and practitioners have been gripped by the possibility of developing clusters of technology-based businesses. Academic studies have adopted a variety of theoretical perspectives on clusters but many have understated the central role of entrepreneurial activities in cluster development. The danger is that a partial understanding of cluster development *processes* could lead to erroneous inferences about the best way for policy to promote and/or support cluster development. This paper seeks to explore and expose the dialectical relationship between entrepreneurial activities and the development of technology based clusters.

Design/Methodology/Approach: Following a review of the relevant literature, including some of the most salient recent contributions, a conceptual model of this dialectical relationship is proposed. The conceptual proposition is then explored through an examination of the empirical case of Ireland's indigenous software industry, a technology-based cluster that emerged to a position of international significance during the last two decades in a region of Europe not previously noted for indigenous technology-based development. Empirical evidence is drawn from an array of secondary data sources, including previous academic studies, company web-sites, sector-specific on-line news media, the general business press, and government and trade association publications.

Findings: Contrasts are highlighted between the prevailing entrepreneurial environment and character of entrepreneurial activities (specifically new firm formation and firm-building) at different stages of the cluster's development (dubbed the proto-cluster, emerging cluster and established cluster stages) and the role of entrepreneurial activities in the evolution of the cluster is exposed. Thus, the pioneering entrepreneurs of the proto-cluster/emerging cluster - through their entrepreneurial actions - influenced and improved the entrepreneurial environment for starting and building a software firm in Ireland during the established cluster stage, and this more favourable environment in turn led to, and supported, further entrepreneurial activity in the software industry.

Implications: The paper supports recent calls for greater attention to the role of entrepreneurial activities in academic studies of cluster evolution. It also questions the efficacy of regional cluster-type policies which aim to replicate the characteristics of successful (and *established*) clusters on the assumption that this will lead to improvements in regional economic performance. Whether there is a role for policy to stimulate and support the entrepreneurial activities that initiate and build clusters is open to debate.

Originality/Value: Adds to, and provides support for, the small number of existing studies on the link between entrepreneurial activities and the development of technology-based clusters.

Key Words: entrepreneurial activities / new firm formation / firm-building / cluster development / software industry / Ireland.

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Entrepreneurial Activities and Technology-based Cluster Development

Introduction

In the last decade, regional economic policy-makers and practitioners have been mesmerized by the possibility of developing clusters of technology-based businesses; becoming the 'new Silicon Valley'. Academics have assembled a wealth of detailed case study evidence and proposed a variety of theories in their attempts to understand clustering - including classic Marshallian agglomeration economies, Porter's competitive diamond, 'institutional thickness' and - more recently - various knowledge and learning-based theories (e.g. innovative milieux/collective learning, learning regions, regional innovation systems) - but many studies have understated the central role of entrepreneurial activities in cluster development and few have convincingly explained how clusters start and evolve over time. The danger here is that a partial understanding of cluster development *processes* - often derived from observations of successful, established clusters - could lead to erroneous inferences about the best way for policy to promote and/or support cluster development. This paper contributes to an emerging strand in the clusters literature by exploring and seeking to expose the dialectical relationship between entrepreneurial activities and the development of technology based clusters.

Following a review of the relevant literature, including some of the most salient recent contributions, a conceptual model of this dialectical relationship is proposed. The conceptual proposition is then explored through an examination of the empirical case of Ireland's indigenous software industry, a technology-based cluster that emerged to a position of international significance during the last two decades in a region of Europe not previously noted for indigenous technology-based development. Contrasts are highlighted between the prevailing entrepreneurial environment and character of entrepreneurial activities (specifically new firm formation and firm-building) at different stages of the cluster's development (dubbed the proto-cluster, emerging cluster and established cluster stages) and role of entrepreneurial activities in the evolution of the cluster is exposed. The paper concludes by reflecting on this evidence and its contribution to our understanding of technology-based cluster development, and by offering some preliminary thoughts on the possible implications for regional policy-makers and practitioners.

Literature review and conceptual model

Academic and policy interest in the phenomenon of industrial clustering has reached fever pitch over recent years. Although spatial concentrations of similar or related firms have been the subject of academic enquiry for decades, the current interest under the 'clusters' banner owes much to the highly-publicised work of Michael Porter, and other consultants and management gurus like Michael Enright. The extent of influence of 'clustering' is evidenced by the fact that almost every nation and region in the developed world, and many beyond it, has adopted some kind of cluster-based economic development strategy during the last decade or so. In terms of technology-based clusters, which are something of a holy grail for many policy-makers, the particular inspiration has been California's Silicon Valley, which hundreds of regions have tried - and more often than not failed - to emulate. From an academic standpoint, perhaps the two key questions are 'Why do clusters exist/persist?' and 'How do clusters start and evolve?'. Below we review some of the key literature on clustering, noting the preponderance of theories on the former question and relatively paucity of theories on the latter.

Theories of clustering and two criticisms

Traditional approaches to explaining industrial clustering focus on the role of 'agglomeration economies' or 'external effects'. The pure agglomeration economies approach focuses on cost savings that accrue to a firm from its location within a concentration of similar or related firms. The idea of agglomeration economies - sometimes known as 'external economies' of industrial clustering - can be traced back to the work of Marshall (1890). Marshall proposed three reasons why firms would continue to be localised within the same area. These relate to the costs savings that result from (1) the development of a local pool of specialised labour, (2) the increased local provision of inputs specific to an industry, and (3) the maximum flow of information and ideas

between proximate firms (Gordon and McCann, 2000, p.516). In the case of high-technology industries, a fourth factor that might be added to Marshall's list of agglomeration economies is that clustering can bring common infrastructure benefits, such as access to major telecommunications hubs/networks (Swann and Prevezer, 1996). As Gordon and McCann (2000) observe, "the key to Marshall's approach is that what links each source of economic benefits is the fact that this accrues to firms within the local area primarily because of their geographical proximity. None of the sources or results of these benefits is internal to a particular firm, but each is external to all the firms" (p.516).

Marshall's ideas have recently been revisited and modified by the economist Paul Krugman (1986, 1991). Krugman's approach to regional agglomeration (i.e. clustering) involves two basic concepts. First, there is the idea that regional specialization evolves for accidental reasons, and second, the notion that once these regions become established, they are sustained by the agglomeration economies or 'external scale economies' (Pinch and Henry, 1999). In terms of external scale economies Krugman identifies the same three types of factor as Marshall; i.e. labour market pooling, the creation of specialist suppliers, and the development of knowledge spillovers. However, Krugman concentrates upon the first two types of factor arguing that knowledge spillovers are limited to a few high-technology agglomerations, are national or international - rather than regional - in scope, and are difficult to model quantitatively (Pinch and Henry, 1999).

These traditional approaches to explaining industrial clustering have been subject to two important criticisms in the recent literature. First, in relation to technology-based or knowledge-intensive clusters, some authors have noted that localized spillovers of knowledge (Marshall's third factor) are – contrary to Krugman's assertions - likely to be a particularly important part of the explanation (e.g. Swann and Prevezer, 1996). This point has been illustrated in an empirical context by both Pinch and Henry (1999) and Keeble and Nachum (2001). Both studies have shown that the pure cost-based agglomeration economies approach has limited utility in accounting for the clustering of certain knowledge-intensive industries¹. The chief problem concerns the argument that clustering can be explained by transport and transaction cost savings resulting from proximity to supply industries co-located within the cluster. This argument, which may be quite valid for certain manufacturing activities, does not seem relevant for many technology-based and knowledge-intensive clusters which rely for their competitive advantage on the development, acquisition and application of knowledge rather than on minimising the costs associated with the supply of physical inputs.

This criticism has inspired a search for alternative explanations of clustering in technology-based and knowledge-intensive industries. In particular, there have been several new theoretical propositions - e.g. innovative milieux/collective learning, learning regions, regional innovation systems - which argue that a focus on knowledge, learning and innovation should be at the centre of any investigation into clustering (e.g. Keeble et al, 1999; Malmberg and Maskell, 2002). For example, the 'collective learning' approach – which can be traced to the work of Camagni (1991, 1995) and the GREMI group of researchers - is "distinguished by its identification of particular processes as crucial for the development of a localised collective learning capacity and resultant enhanced innovativeness in a knowledge-based cluster" (Keeble and Nachum, p.10). A number of empirical studies have demonstrated that the 'collective learning' approach offers greater insights into clustering than the pure agglomeration economies (e.g. Pinch and Henry, 1999; Keeble and Nachum, 2001).

Importantly for the point of view of this study, collective learning-style ideas are also the key underlying theme in some important and useful concepts from the literature analyzing the Silicon Valley high-tech cluster, which we briefly review here: these are the related concepts of the 'Economy Two' (after Kenney and von Burg, 2000) and the 'Habitat' (after Lee et al, 2000). Kenney and von Burg's Economy Two refers to the plethora of organisations whose sole purpose, or a significant component of their business, is related to servicing start-ups (including venture capitalists, lawyers, and various business service firms, etc). These Economy Two firms are said to underpin collective learning within Silicon Valley as follows: "After dealing repeatedly with similar issues, the local organisations evolve knowledge and expertise suited to the unique needs of high-tech start-ups... This accumulation of expertise contributes to the acceleration of the start-up process and the success of the new firms" (Kenney and von Burg, 2000, p.225). A

closely related concept is the Silicon Valley 'Habitat' devised by Professor W F Miller of Stanford University, which comprises a mobile workforce with specialized expertise and extensive personal networks; a supportive business and regulatory environment and appropriate attitudes toward entrepreneurship, risk taking, job mobility, failure, openness, etc; a wide variety of support firms and consultants who fill in temporarily to perform a function that would be routinely done by a department in a larger firm (Barr & Tessler, 1999). The rationale for, and contribution of, the habitat to Silicon Valley's success is explained as follows: "The habitat is, in a sense, a *repository of knowledge* that can be tapped by start-ups... The various players work for many different start-ups over the years (different technologies, markets, business situations, etc). They learn a great deal that makes them more and more effective in helping in the next start-up" (Barr & Tessler, 1999, p.47 – *emphasis added*).

A second point of criticism is that many accounts of clustering have adopted a *post facto* approach and are marked by a static research design. These studies tend to portray interfirm relations and patterns of interaction at one point in time, usually a time when the cluster is already established, and attempt to draw conclusions about the dynamic process of cluster development based on cross-sectional data (Malmberg and Maskell, 2002, p.435). These studies tend to explain the existence of the established cluster with reference to the various benefits of cluster membership, usually – but not exclusively – expressed in terms of agglomeration economies. However, as Bresnahan et al (2001) observe, "the processes of *starting* and *sustaining* a cluster have different economics" and "founding a new cluster, or the early firms in a new cluster, is a very different entrepreneurial and economic activity than founding a firm in an established cluster" (Bresnahan et al, 2001, p.10). Similarly, Feldman (2001) has argued, "Once established, clusters benefit from virtuous, self-reinforcing processes. A critical question is how these entrepreneurial processes begin, take hold and transform a regional economy" (p.861). Thus whilst agglomeration economies may be a useful theoretical framework for explaining the advantages of cluster membership for members of an established cluster, they do not tell us much about the origination and initial establishment of a cluster. In the very early stages of cluster development, when only a handful of pioneering firms are present, agglomeration economies are unlikely to be available, nor indeed is there likely to be much scope for collective learning. This analysis points to two requirements of a convincing theory of clustering: first, a dynamic perspective and an appreciation that clusters evolves through various 'stages'; and, second, an understanding of the processes which underpin this transition. It is here that a handful of researchers have advanced the proposition that *entrepreneurial agency is the key ingredient in the foundation and development of high-tech clusters* and, as such, should be central to attempts to theorise and understand clustering (e.g. Bresnahan et al, 2001; Feldman, 2001; Feldman et al, 2005; Harrison et al, 2004).

Stages of evolution and the role of entrepreneurial agency: the basis of a conceptual model

In an international comparative study of several emerging technology clusters, Bresnahan et al (2001) found that all the locations that were able to take advantage of a structural 'window of opportunity' in the global economy were characterized by favourable pre-conditions in the pre-cluster stage (typically an abundance of highly skilled labour). However, they also noted that such endowments were a necessary, but not sufficient, condition for cluster formation. In the search for the missing further ingredient, Bresnahan et al (2001) point to the need for "a spark of entrepreneurship" to get a cluster going, followed by "years of firm-building and market-building efforts" (p.11). More specifically, they highlight the need for "significant and systematic efforts by the 'pioneers' of a cluster to promote organisational and technological capabilities of various sorts, create new firms and institutions etc." (Bresnahan et al, 2001, p.13). Similarly, Feldman's (2001) work on the US Capitol region emphasizes the relationship between entrepreneurial events and the regional (cluster) context. Specifically, Feldman's (2001) analysis of the evolution of the region from a sparse to munificent entrepreneurial environment "incorporates a role for individual entrepreneurs as agents of change who make decisions to start companies, shape local environments and institutions, and develop the resources and relationships that favour their interests" (p.863). Hence there is a suggestion of a dialectical or iterative relationship between entrepreneurial agency and the entrepreneurial (cluster) environment, throughout the period of the cluster's evolution².

It is from this idea of a dialectical relationship between entrepreneurial activities and the entrepreneurial (cluster) environment, that we now propose a conceptual model of cluster evolution (Figure 1). The model is also inspired by a number of recent studies that have proposed a more dynamic or evolutionary perspective on clustering, which focuses on different stages of development (e.g. Brenner and Fornahl, 2003; Fornahl and Menzel, 2003; Dahl et al, 2003; and also implicit in Teubal et al's, 2002, study of Israeli software industry, which identifies three stages of development). The model has the following key features:

- Taking a lead from Fornahl and Menzel (2003) we assume that a cluster develops through a number stylised stages (here dubbed the pre-cluster stage, proto-cluster, emerging cluster, established cluster). Note that this stage-based approach serves as an analytical tool and should not be regarded as a deterministic life cycle model. The different stages are separated here by the number of firms in the region in the particular industry (after Fornahl and Menzel, 2003, p.6) and the changing nature of the entrepreneurial (cluster) environment – specifically the degree to which 'habitat' or Economy Two institutions and support firms are present.
- The model also incorporates "entrepreneurial generations" – i.e. groups of firms founded at different stages in the cluster's evolution. These generations represent the entrepreneurial activities that Feldman (2001), Bresnahan et al (2001) and Harrison et al (2004) argue are so fundamental to the evolution of technology-based clusters. The generations incorporate both *bone fide* new entrants and also, importantly, spin-offs from incumbent firms. Localised spin-offs have been shown to be a key mechanism in the growth of clusters (e.g. Klepper, 2001; Helfat and Lieberman, 2002; Brenner and Fornahl, 2003; Dahl et al, 2003).
- The third element of the model is the interaction effects between the entrepreneurial generations and cluster stages, which represent a dialectical or iterative relationship. The key ideas here are that (1) clusters can have positive impacts on entrepreneurial attitudes and entrepreneurial activities in a region (e.g. Sternberg and Litzenberger, 2004) - here Type A effects; and also that (2) entrepreneurs act as agents of change who can shape local (cluster) environments and institutions, and develop the resources and relationships that favour their interests (after Feldman, 2001) – here Type B effects. On the former, note that - all things being equal - the probability that a person will start a firm within a certain region increases as a function of the number and size of incubator organisations (incumbent firms) within the region (cluster) whose fertility is sufficient for the emergence of start-ups (Sternberg and Litzenberger, 2004, p.770). The development of existing start-ups also profits from a positive regional environment, for example, through demonstration and role model effects, agglomeration economies (especially those related to the labour market) and from the presence of a supporting habitat and collective learning processes.

The conceptual model seeks to demonstrate how entrepreneurs and their activities (e.g. firm formation and building) interact with the cluster environment, and contribute to, the transition or evolution through the various cluster stages. Thus in the beginning, where there is no cluster, the first pioneering firms are unable to benefit from Type A effects. In overcoming the difficult environment for firm formation and firm-building efforts in the early stage, successful entrepreneurs ('cluster pioneers') sow the seeds of the future cluster – their success provides the example to subsequent start-ups (Type B effect). Soon, the second generation of start-ups and some spin-offs from successful first generation firms are founded. These firms may benefit from some demonstration and learning effects (Type A effects). In time, there may be the beginnings of critical mass and the increased number of firms may stimulate the beginnings of a supporting habitat – e.g some supporting service firms, some venture capital, state agency responses – and make agglomeration economies and collective learning more feasible (Type B effects). As a result, the entrepreneurial environment has improved, making it more appealing, and maybe easier, for the next generation of start-ups and further spin-offs from incumbents (Type A effect). Gradually, a critical mass of firms is accumulated and the habitat will become deeper and more specialized/tailored and knowledgeable (Type B), and a 'learning region' may evolve, resulting in a fertile entrepreneurial environment by the established cluster stage.

In the main empirical section of the paper, this conceptual model is explored through an examination of the empirical case of Ireland's indigenous software industry but first we introduce this case and its salient features.

Ireland's indigenous software industry – an illustrative case study

During the 1990s, Ireland has emerged as a hotbed of software development activity and a key node in the global software industry. The software industry was one of the leading sources of employment growth in Ireland's 'Celtic Tiger' economy, with employment in the sector growing at a rate of 16% per annum during the 1990s (compared to 6% for the economy as a whole). By 2000, the Irish software industry comprised approximately 900 companies, with an estimated 30,000 employees and a combined annual turnover of €10 billion (National Software Directorate statistics cited in HotOrigin Ltd, 2002).

One ingredient in the emergence of the Irish software industry was a major influx of foreign direct investment in the sector, starting in the mid-1980s and continuing through to the present day (Coe, 1997; NSD, 1997; Ó Riain, 1997). The 'overseas' segment of the Irish software industry includes most of the world's leading software multinationals (e.g. Microsoft, Oracle, IBM/Lotus, Symantec, Sun Microsystems)³. The second, and arguably more interesting, component of the Irish software story is the parallel emergence of a vibrant 'indigenous' software industry⁴. By 2000, the indigenous industry comprised over 700 firms, employed around 14,000 people and generated annual revenues of €1.4 billion. It was highly export-oriented, had growing productivity and was increasingly innovative. During the late 1990s, several of the leading firms floated on the Nasdaq stock exchange or were acquired by leading multinational firms and some firms were global players within their particular market niches. The indigenous software industry provides an excellent opportunity to explore the issue of clustering and cluster development since its emergence is relatively recent and can be realistically studied from the present day using statistics and qualitative secondary data sources.

The National Software Directorate, within Enterprise Ireland, provides the best series of statistics on the Irish software industry. Headline statistics are available for the period 1991-2003 covering employment, the number of companies, revenue and exports - disaggregated into indigenous and overseas segments. The data show that the indigenous software industry experienced a dramatic and significant expansion on all four indicators during the 1990s. Total employment expanded from around 3,800 in 1991 to a peak of over 14,000 in 2001, before declining during 2001-2003 in the aftermath of the global technology downturn (Figure 2). Employment growth in the second half of the 1990s (24% p.a.) was almost two-and-a-half times that in the first half (10% p.a.). Total revenue grew by nearly 30% p.a. during the 1990s - reaching €1.5 billion per year by 2002-03 - and total exports grew even faster (at 37% p.a.) as the indigenous industry became more export oriented over the decade (Figure 3)⁵. The indigenous software industry was characterised by a particularly high start-up rate and a low closure rate during the 1990s (O'Gorman et al, 1997). In addition to the volume of start-ups, the industry also saw an increase in the number of larger firms. In 1989 there were only 4 indigenous software firms with 50+ employees but this had increased to 24 by 1995, 34 by 1998 and at least 60 by 2001 (Crone, 2002a). Average revenue per employee (productivity) also increased steadily and significantly during the 1990s. By any standards, the Irish indigenous software industry was a success story during the 1990s but the global technology crisis of 2000-01 brought an end to the expansionary phase and introduced a period of crisis and restructuring, the outcome of which is still uncertain. This brief overview shows that the IISI presents a useful case study of cluster evolution. In fact we can detect a movement through a number of stages of evolution over a period of twenty years or more: a nascent or proto-cluster stage (arguably spanning the period up to the mid-to-late 1980s); an emerging cluster stage (perhaps extending from the late 1980s to mid 1990s); an established cluster stage (mid 1990s to 2000/01); and a restructuring/renewal stage (2000/01 to present). Table 1 summarises some of the key characteristics and notable developments in each of these four stylized stages of cluster development.

Other salient features

The growth in exports in the indigenous software industry was been mirrored by an increase in the number of overseas offices operated by Irish firms. Overseas offices are established to assist with product sales and marketing, and in some cases to deliver local customer support services. The total number of overseas offices operated by indigenous software firms nearly doubled from just over 50 in 1991 to nearly 100 in 1997 (Source: NSD web-site). The leading location for overseas offices in 1997 was the UK, followed by North America, which showed the greatest increase during the 1990s. In recent years, another form of internationalisation has become important, namely acquisition activity by Irish firms. Based on an analysis of the TIU TechWatch news archive (www.techwatch.ie), Irish software firms made 37 overseas acquisitions during 1999-2001 including 15 firms in the United States and 13 in the UK (Crone, 2002a).

The dominant activity of Irish indigenous software firms is software product development. According to Arora et al (2001) 44% of indigenous software firms are involved in the development of software products (Table 5). HotOrigin (2001, p.5) corroborate this evidence claiming "there are at least 250 local companies engaged directly in the development of software products". This product-oriented business model has been adopted by many of the most successful indigenous firms. Product-oriented firms tend to be more focused on exporting than service-oriented firms (Ó Riain, 2000b). In terms of product/technology focus, the indigenous product development industry is heavily concentrated on enterprise application integration (including middleware) and wireless technologies (applications and infrastructure). Other strong niches in Ireland are said to be CRM, e-learning, Java components and XML-based tools (HotOrigin Ltd, 2001, p.8). In terms of industry focus, the main target sectors are the financial services industry, the telecommunications industry and other high technology industries. The main areas of specialisation include: financial services applications/solutions, e-security/secure payment solutions, e-learning/computer based training, open systems-based middleware and telecommunications software.

Finally, it is important to highlight the geographical distribution of the indigenous software industry. In 1991, the fledgling indigenous industry consisted of 291 companies, of which 71% were located in Dublin (NSD, 1992). An analysis of a list of 126 leading indigenous firms in 2001 shows that 76% of these firms were located in Dublin, and 87% of their employment was (Crone, 2002a). This concentration on Dublin is much stronger than in other industry sectors of the Irish economy. For example, the Dublin region accounts for just 27% of Ireland's industrial establishments and 24% of its industrial employment⁶. Dublin also has only 40% of Ireland's services employment (O'Gorman et al, 1997, p.15).

Entrepreneurial activities and the entrepreneurial environment in the proto-cluster/emerging cluster stages

Pre-ambles

The main empirical section of the paper consists of a discussion of contrasts between entrepreneurial activities (specifically new firm formation and firm-building), and the entrepreneurial environment, at different stages in the cluster's development (particularly the proto-cluster/emerging cluster stage and the established cluster stage, as per Table 1). In the first instance we examine the origins and emergence of a group of firms that were founded between the mid 1980s and early 1990s and went on to become some of the leading lights of the indigenous industry in the late 1990s (see Table 2 for details). Then we examine the origins and emergence of a second group of firms comprising growth-oriented start-ups founded between 1996 and 2000, many of which could be characterised as the emerging or potential future stars of the indigenous industry (Table 2). The chief concern throughout is expose and explore the dialectical relationship between entrepreneurial activities and the development of the cluster.

Before commencing with the discussion of empirical evidence, however, it is important to acknowledge that the entrepreneurial activities, which are the focus of the paper, occur within a wider context. Crone (2002b) has previously portrayed this wider context by attempting to tell

the overall story of the development of the Irish indigenous software industry, including full consideration of the structural context within which IISI developed, the role played by various factor conditions/pre-conditions (especially skilled labour supply) and the role of the state development agencies. This wider context must be taken as given in this paper in order to allow sufficient space for a thorough examination of the relationship between entrepreneurial activities (new firm formation and firm-building) and cluster development.

New firm formation in the proto-cluster/emerging cluster stages

The questions which I seek to address in this section are: where did the start-ups in the proto-cluster/emerging cluster come from and how did they begin? Here I am referring to the early stages of the cluster's emergence around the late 1980s/early 1990s⁷. Two pieces of evidence are considered here: Ó Riain's (1997) evidence and an analysis of the origins of the leading firms in the cluster, which were established in the 'proto-cluster' phase.

According to Ó Riain (1997) the early Irish indigenous software product firms emerged by three main routes:

1. Services to products - Many indigenous software product companies began by providing 'bespoke' or custom services to businesses, then expanded this business into making consultancy kits and subsequently into products, gradually expanding into export markets (Ó Riain, 1997, p.29). Early customers within Ireland - who commissioned various IT development projects - are said to have provided an important catalyst. Among these customers were MNC subsidiaries in various industries and it has been argued that Ireland's general success in attracting FDI was important in creating additional local demand for fledgling software firms (O'Gorman et al, 1997; Ó Riain, 1997). Ultimately, the limited size of the Irish market may have contributed to the success of the indigenous sector by forcing it to become export-oriented from an early stage (Grimes, 2003).

2. Spin-outs from larger firms - The second route by which indigenous software firms are said to have emerged is through various types of 'spin-out' from larger firms. Some indigenous software firms were created when firms in other industries, such as telecommunications or computer hardware, spun off their software divisions. Other firms emerged from divisions of MNCs, semi-state bodies and Irish firms (Ó Riain, 1997). Ó Riain (1997) argues the key dynamic in this process was local in that "domestic managers created new competencies and business for their divisions and convinced the management of the parent company to support their projects" (p.30). A further type of spin out occurred when users of software - in vertical markets such as banking and training - applied their detailed knowledge of these markets to open up opportunities for new software businesses (Ó Riain, 1997, p.30).

3. Firms based on academic research - The third main group of indigenous firms are those that emerged almost directly from academia, being set up by professors and graduate students based on their on-campus research (Ó Riain, 1997, p.30). Whilst the university spin-off/start-up route was probably not the most numerically significant this should not hide the fact that some of the most successful indigenous software companies originated from a university environment (e.g. IONA Technologies, Baltimore Technologies, Trintech). It is widely acknowledged that university spin-offs are among the most technically-sophisticated and fastest-growing firms in the indigenous industry, operating in areas such as development tools, system software, computer-based training and telecommunications (Arora et al, 2001, p.8).

Finally on this subject it is interesting to examine the origins of those firms that were founded in the proto-cluster/emerging cluster stage and went on to be achieve recognition/success in the late 1990s. We focus on firms that 'exited' via a Nasdaq IPO or M&A1 (foreign acquisition). Firstly, consider the six indigenous software firms that were founded in the proto-cluster/emerging cluster stages and floated on the Nasdaq stock exchanges in the mid-to-late 1990s (established cluster stage). The first observation is that these firms emerged from a variety of sources. SmartForce (previously known as CBT Systems now SkillSoft), the e-learning/computer-based training specialist and Ireland's first Nasdaq IPO, is said to have emerged on the back of an Irish government-led 'courseware' initiative in the mid-1980s (Ó Riain, 1999; HotOrigin Ltd, 2002)⁸. Datalex, a provider of IT solutions to the airline and travel

industry, was established when the in-house IT development team at Aer Lingus spun-off in 1985 (HotOrigin Ltd, 2002). Parthus (now ParthusCeva), which develops software for semiconductor design, was established in 1993 when Digital Equipment Corporation closed its Irish R&D operations and the core development team stayed together to form a new company (HotOrigin Ltd, 2002). The most common origin among the seven Nasdaq firms, however, is the academic research route. IONA Technologies, for example, was founded in 1991 on the back of research at Trinity College Dublin on distributed computing (refer Box 1). Baltimore and Trintech also have their origins in academic research.

It is harder to determine the origin of those successful indigenous companies that were acquired by foreign multinationals during the 1990s (dubbed 'M&A1', after Teubal et al, 2002). Euristix, which was acquired by Fore Systems of the USA in 1999 for US\$80 million, was founded by Dr Jim Mountjoy who had a background in academia and the public sector and had been MD of Baltimore in the late 1980s. The founders of Kindle Banking Systems – sold to Misys of the UK in 1995 - came from a background in the banking industry. Other leading indigenous firms acquired in the late 1980s and 1990s include Insight, Credo, Quay, Aldiscon, Isocor and Saville Systems.

The key message from this evidence is that there was no single source of knowledge which was being exploited by the early software product firms. Rather, the emergence of these firms can be attributed to the entrepreneurial efforts of a small group of pioneering entrepreneurs who sought to capitalise on their own particular expertise - gleaned from their varied work experience in industry, academia and the public sector – and the commercial opportunity presented by the emerging market for software products.

Firm-building and the entrepreneurial environment in the proto-cluster/emerging cluster stages

To examine the environment for firm-building/firm growth in the early stage of the Irish software industry cluster (i.e. late 1980s/early 1990s) I review the experience of IONA Technologies, which is arguably the most successful Irish indigenous software firm to date⁹. IONA was founded in 1991 and underwent an IPO on the Nasdaq stock exchange in 1997. Hence the key phase of IONA's development falls within the early stage of the cluster's development as defined here. I begin with some background facts on IONA, before reviewing the history of its development, then drawing out some general lessons (also refer to Table 1 key developments at IONA during four phases of evolution).

IONA Technologies has its joint headquarters in Dublin, Ireland and Waltham, MA (near Boston). In 2000, it had revenues of US\$153 million (69% from product licences, 31% from services), over 4,500 customers and partners (including numerous Blue Chip clients), and over 900 employees in 30 offices worldwide (including sales force of 300+). IONA's core product offering is a web services platform for total business integration (Orbix End 2 Anywhere™). This builds on the original core product of the company, which was based on the CORBA industry standard for open systems-based middleware (IONA has been an influential founding member of the Object Management Group – the industry standards body which established the CORBA standard).

Between 1985 and 1991, Trinity College Dublin's Department of Computer Science was engaged in leading edge research on distributed computing (funded by the EU Esprit programme). IONA CEO Dr Chris Horn was one of the original researchers on this programme. In 1991, the EU funding was drawing to a close and the researchers were keen to see the technology commercialised. TCD had an active 'campus company scheme' and offered the academic researchers a three year window of opportunity to build a company and commercialise the technology. The academics were offered a reduced teaching load and incubation space by TCD, with the opportunity to either resign their faculty positions or stay on at TCD at the end of the three years. Hence IONA was founded in March 1991 by Chris Horn, along with colleagues Dr Sean Baker and Annrai O'Toole, in a 200 sq ft office in the TCD Innovation Centre.

At the outset, the IONA founders had very little capital, little commercial experience, and - as Horn now admits - a business plan which was not credible. In terms of external financing options for IONA, Irish private investors were wary of indigenous technology firms after a

number of high-profile failures in the 1980s; there were no local venture capitalists in Ireland; the major banks would not lend to software firms who had no tangible assets against which to secure a loan; and the Industrial Development Authority was showing only limited interest. IONA then tried, without success, to secure VC from 3i in the UK and some French funds. Finally, IONA found interest from Atlantic Partners in Boston but they wanted IONA to relocate to the United States, a suggestion which was strongly resisted by the founders. Faced with this harsh funding environment, IONA was forced to adopt a 'bootstrapping' strategy (i.e. selling consultancy and training services to generate funds). By mid-1992 IONA was able to hire two full-time employees and by mid-1993 its first product was ready for commercial sale. IONA secured its first customer at a trade show in San Francisco that year but more significantly it met with executives of Sun Microsystems, who became interested in IONA's product. Sun bought a 25% stake in IONA for US\$600,000 and took two board seats, in December 1993. There was also an OEM agreement whereby Sun incorporated IONA's middleware software on their Workstations. Sun's name was also useful as a 'badge of credibility' for IONA, especially in the tough US market. Note that IONA was export-oriented from the outset because the Irish domestic market for its software was almost non-existent. Ireland's Industrial Development Authority became interested around this time and made a significant investment in IONA. Motorola and Boeing were the first Blue Chip customers. In 1996, Sun offered to buy the remaining 75% of IONA for US\$45 million but IONA said no. IONA aspired to an IPO but this was blocked by Sun's board members. Eventually IONA was 'set free' by Sun, who sold their 25% stake for US\$60 million in 1997. IONA's 1997 IPO on Nasdaq was the fourth largest ever, valuing the company at US\$240 million (revenues at this time were only US\$16 million).

The IONA story serves to highlight the difficulties faced by Irish software companies who were founded and in the firm-building phase during the proto-cluster/emerging cluster stages of the industry's development. Not only was there a weak domestic capital market at this time but there was also a lack of experienced entrepreneurs, managers and sales personnel in Ireland (O'Riain, 1999, p.248); an absence of specialised supporting business services firms; and a lack of understanding of the requirements of technology start-ups in the State development agencies. In addition, there was also no precedent of an Irish software firm 'breaking' the US market or making an IPO (CBT Systems was the first Irish Nasdaq IPO in 1995). In the late 1980s the first generation of Irish software firms had either failed commercially (e.g. Generics) or been swallowed up and run-down by foreign multinationals (e.g. Glockenspiel, Software Labs, RTS, Intelligence Ireland, COPS and Workhorse) (O'Riain, 1999). Several other promising Irish software firms were then acquired by foreign multinational during the late 1980s and early 1990s and continued to operate as subsidiaries of their new parent companies (e.g. Insight, Kindle, Quay and Credo) (O'Riain, 1999). The fact that IONA was able to overcome this difficult environment can be attributed to its excellent technology, which coincided with a surge in demand driven by the Internet and the widespread adoption of network computing; to the excellent leadership of CEO Chris Horn (which is widely acknowledged in the industry); to a degree of learning from the commercial shortcomings of earlier Irish firms like Glockenspiel; and to some novel strategies for developing the company (e.g. bootstrapping, OEM agreement with Sun, membership of Object Management Group standards body).

Entrepreneurial activities and the entrepreneurial environment in the established cluster stage

A transformed entrepreneurial environment in the established cluster stage

In this section, I seek to highlight some important contrasts between the environment for new firm formation and firm-building in the established cluster, as compared with the proto-cluster/emerging cluster stages, which were discussed previously. My central argument is that there was an improved environment for entrepreneurial activities in the established IISI cluster, which had gradually developed as a result of the interaction between earlier entrepreneurial efforts, notably by the cluster pioneers, and the regional environment over the preceding period (along the lines suggested previously in the conceptual model, Figure 1). Here I highlight and discuss five key changes in the entrepreneurial environment, namely: the establishment of industry-specific institutions and improvements in government support for the software industry; the development of a 'thick' labour market in experienced managerial and technical labour; the role of experienced cluster pioneers as non-executive directors of young start-ups;

the development of an 'Economy Two' or supporting 'Habitat' – including the emergence of a local venture capital industry and various specialist business services companies; and the operation of demonstration and reputation effects¹⁰. The cumulative effect of these, and other, phenomena meant the established cluster could be described as an increasingly fertile entrepreneurial environment. This environment offered the benefits of agglomeration economies and collective learning effects to members of the cluster, potentially conferring competitive advantages on cluster companies and almost certainly encouraging a higher start-up rate than would have been the case without the cluster.

1. Institution building and improved government support – One significant distinction between the proto-cluster/emerging cluster and established cluster stages of the IISI is the development of a set of specialised supporting institutions. Institutions such as the National Software Directorate (an agency charged with the co-ordination of government policy towards the software industry), Irish Software Association (an industry association involving many of the leading foreign and indigenous firms), Irish Internet Association and Centre for Software Engineering (a technology transfer centre and centre of excellence based at Dublin City University) were all founded in the early 1990s *in response* to the emergence of the early industry pioneers. Note, as Feldman (2001) points out in another context, these institutional developments lagged the emergence of the cluster rather than pre-dated it. The specialist institutions – nearly all based in Dublin - played an important role in the industry's evolution during the mid-to-late 1990s. They facilitated knowledge dissemination and learning with the cluster through their various seminars, industry studies, strategy reports, networking events, etc. Of particular importance to the development of effective institutions was the close inter-relationship with industry: the first leader of the NSD (Barry Murphy) and head of the CSE (Robert Cochran) were both experienced industry insiders whose personal career histories traversed the private and public sectors (Crone, 2002b). Another effect of the emergence of a critical mass of companies in the emerging stage was to capture the attention of the State development agencies in Ireland. Notably Enterprise Ireland, formed in 1997 from an institutional re-shuffle, was quick to realize the indigenous development potential of the software industry and offer a range of hard and soft supports to emerging software firms during the late 1990s. The extent of the State's contribution to the cluster's development is a matter of debate. Ó Riain (2000) argues that the Irish state played an important developmental role whereas others are more skeptical. One seasoned industry observer does concede that "the state agency structure has shown an admirable flexibility over the years. It has never really instigated anything new. But it has been a good 'fast follower' and reacted quickly to emerging problems among the client firms" (Stern, 2003).
2. Development of a thick labour market - By the mid-to-late 1990s, Ireland had developed a thick technical labour market in software-related (technical, sales and managerial) skills, particularly in the Greater Dublin region. The prolific output of computing graduates from the third-level education institutions (universities and especially Institutes of Technology) since the mid-1980s – which was ramped up significantly during the 1990s in response to the cluster's emergence - has been supplemented by various labour market processes. First, there has been over decade of on-the-job learning within both the overseas and indigenous software sectors, and related sectors such as telecoms and ICT hardware manufacturing. Second, software firms invest heavily in employee training by comparison with other sectors of the economy (O'Gorman et al, 1997). Third, there was a wave of return migration to Ireland in the late 1990s, including many experienced technical and managerial personnel¹¹. Again note, however, that these developments in the labour market were a gradual process, occurring alongside the cluster's development, fuelled by earlier entrepreneurial successes.
3. Cluster pioneers as non-executive directors of young start-ups - Newly-formed software companies often lack the necessary breadth and depth of management expertise. Appointing individuals as either *non-executive directors* of the company or as advisory board members helps to fill this gap. Strong advisory board members typically have *commercial and networking capabilities* that can prove invaluable to the executive management team (HotOrigin Ltd, 2001, p.66). A notable phenomenon during the established cluster stage was the involvement of experienced 'cluster pioneers' as non-executive directors (NEDs) on the boards of young software firms. For example, around the time of the tech downturn, three of the most experienced and high-profile cluster pioneers Dr Chris Horn (IONA co-founder

and CEO), Dr Jim Mountjoy (Euristix founder) and Fran Rooney (former Baltimore CEO) together held a total 14 NED positions with 13 young indigenous technology firms. Press release and news coverage confirms they were appointed because the young companies, which were usually growth-oriented companies with venture funding, hoped to capitalise on the knowledge and experience of these pioneers during the firm-building process. The key point here is that there was no equivalent pool of experienced entrepreneurs and managers available to start-up companies in the proto-cluster/emerging cluster stage. This is an example of a mechanism for collective learning and knowledge spillover within the established cluster.

4. Development of an 'Economy Two' or supporting 'habitat' - There is a growing body of empirical evidence that the established IISI cluster was characterised by the emergence of an Economy Two or habitat of the type observed in Silicon Valley, albeit on a much smaller scale. This is evidenced firstly by the emergence of a local venture capital industry in Ireland during the late 1990s, including the increasing involvement of international VC investors. As Ó Riain (2000, p.32) notes, it was only in 1998/99 that private investment capital became abundant in Irish software. Since 1999, numerous emerging indigenous software firms have received first and second round venture funding, ranging from €0.5 to €30 million (see Crone, 2004). In fact, venture capital became the dominant source of external finance for 'build-phase' indigenous software companies and was said to be in abundant supply for good business propositions in the late 1990s (HotOrigin Ltd, 2001 and 2002)¹². The significance of VC is two-fold. First, VC provides the fuel for firm-building/firm growth. Second, and perhaps more importantly, there is a growing realisation that VCs play an important 'coaching' role through their involvement with young start-up companies (Hellman, 2000; Hellman and Puri, 2002). Specifically, VCs are believed to 'professionalise' the start-ups they invest in by recruiting experienced executives, introducing incentives such as stock options, etc. Other evidence of the emergence of an Economy Two or habitat in the established cluster phase of IISI cluster relates to the emergence of various supporting business service firms, such as consultancies, lawyers, recruitment specialists and PR firms (Table 3). In the case of the IISI, it is notable that Economy Two is developing by both the entry of new indigenous start-ups (e.g. International Ventures, HotOrigin) and the attraction of FDI by Economy Two firms from more established technology regions (e.g. Brown Rudnick, Eurolink Global). These firms are attracted by the market opportunity provided by the growing critical mass of start-up and build-phase software companies in Ireland, especially Dublin. In theory, start-ups in the late 1990s were better placed to succeed than their predecessors because they were able to draw on the advice and expertise embodied in the emerging Economy Two/habitat.
5. Demonstration and reputation effects - Members of a cluster may benefit from the reputation effects of successful firms originating from the cluster (Molina-Morales and Martinez-Fernandez, 2002). In the case of Israel, Teubal et al (2002) have argued that the leading data security software firms (e.g. Checkpoint, Aladdin) made an enormous contribution to other companies in the Israeli high-tech cluster "through the reputation effects they generated and the business models which they offered to these companies". Leading Irish software firms such as IONA Technologies, SmartForce and Baltimore may have generated similar reputation effects in Ireland. They certainly played an important role in raising the profile of the Irish software industry on a global stage¹³. Possible demonstration effects within the IISI relate to both firms and key individuals. Successful Irish software firms like Baltimore and IONA have acted as 'role models' and created a 'follow-the-leader effect' within the IISI. For example, by making it to the Nasdaq the leading indigenous firms have demonstrated a potential business model to the next generation of indigenous software start-ups, and made it easier for other Irish firms to follow in their footsteps. Key individuals such as Chris Horn and Jim Mountjoy also acted as 'role models' to the next generation of Irish entrepreneurs, demonstrating that Irish entrepreneurs can succeed in the global software industry. In the relatively 'small world' of the Irish industry, with its geographical concentration in greater Dublin, word has spread quickly, through both keynote speeches given to industry events and through word of mouth. The potential significance of demonstration effects in a country that is a relative newcomer to the world of high-tech entrepreneurship cannot be overstated.

New firm formation in the established cluster

As in the earlier section on new firm formation in the proto-cluster/emerging cluster, the questions which I seek to address in this section are: where do start-ups in the established cluster come from and how do they begin? Two pieces of evidence are considered here: HotOrigin's (2001) evidence from a survey of software product firms; and evidence on the mode of entry for a group of VC-funded start-ups founded during the established cluster stage (1996-2000).

In the late 1990s, there was a marked acceleration in the growth of the IISI. NSD statistics show that employment, the number of companies, revenues and exports all grew more rapidly during 1997-99 than in the preceding period. According to HotOrigin (2001), the rate of software product company formations increased markedly in the established cluster stage. Based on survey results, HotOrigin (2001) claim that fewer than 30% of the estimated 250 indigenous companies developing software products in 2001 were established before 1996, and almost half were established since the beginning of 1999. To answer the question of where this wave of new start-ups came from, we can first look at HotOrigin's (2002) survey results. HotOrigin found that 50% of indigenous software product companies in existence in 2002 were founded by former employees of indigenous technology companies. By contrast, only 25% of founders were former employees of multinational technology companies and 17% were from an academic background. The key contrast with the evidence presented earlier on the origins of software product firms founded in the proto-cluster/emerging cluster stages is that start-ups based on prior experience in the indigenous sector were not previously a major factor. This suggests that the process of cluster development in the IISI was becoming cumulative by the late 1990s, with success breeding further success.

The second source of evidence on the origins of start-ups is an analysis conducted by the author of a group of start-ups founded between 1996 and 2000 and receipt of VC funding between 1999 and 2001 (see Crone, 2004 for details). These companies were highly-export oriented (often 'born global'), with their key customers being most commonly located in North America and the UK and domestic customers being relatively unimportant. These companies are also involved in numerous inter-firm collaborations, alliances and partnerships, predominantly outside Ireland. Again North America is the most important location for collaborative partners.

Secondary data collated for the study allowed the mode of entry to be determined for 16 of the 19 firms in the study group; there was insufficient information to make a definitive judgement on three firms. Among the 16 firms, the least common of four defined modes of entry, with only two examples among the 16 Celtic Tiger Cubs, was the academic spin-off (Massana was spun-off from University College Dublin's Digital Signal Processing research group in 1996 and ChangingWorlds was spun-off from the Smart Media Institute at UCD in 1999). The single most important mode of entry among the 16 Celtic Tiger Cubs was the entrepreneurial spin-off. Among the six entrepreneurial spin-offs identified in the study group were three firms founded by former employees of IONA Technologies, arguably Ireland's most successful indigenous software firm (CapeClear, Rococo and Wolfe Group); IONA is said to have spawned up to 20 spin-offs (Linnane, 2001). The most notable of these IONA spin-offs is CapeClear where the three initial founders have been joined by a stream of other defectors from IONA's executive team. A former employee of another leading indigenous software firm (Baltimore) also founded Vordel. An interesting policy question is what motivates and triggers the spin-off decision? The literature on high-tech spin-offs suggests that discontent at the previous employer may sometimes be the prompt (Klepper, 2001). The two other entrepreneurial spin-offs in the study group, AmBeo and Macalla, are interesting in this respect; both were founded by senior executives who left leading indigenous software firms following their acquisition by multinationals. AmBeo's founders came from Saville Systems, which was acquired by ADC Communications of Canada in 1999, and Macalla's founders were six key executives and technologists from Quay Financial Software, which was acquired by CSK Software in 1993.

Although there were only three examples among the study group, the 'experienced entrepreneur' mode of entry is arguably of similar importance to the entrepreneurial spin-off mode; the three firms in this category (Qumas, CR2 and Network365) appear to be among the most successful of the Celtic Tiger Cubs. Qumas was founded in 1996 by Paul Hands and David

Grimes who were previously founders of QCL Technologies, a successful 16 year old Cork-based IT company (with 30 employees) that provides IT consultancy, software solutions, engineering services and hardware to major clients throughout Ireland. Qumas is said to be among Ireland's top 10 software exporters, with 2002 revenues over €10 million and many customers in the United States. CR2 was founded in 1997 by Cian Kinsella and Ron Downey, who were previously the founders of Kindle Banking Systems, which they sold to the UK multinational Misys Plc in 1995 (Ó Riain, 1999, p.235). CR2 was one of the largest firms in the study group with over 200 employees and a client base of over 120 banks in 80 countries. Network365 (now Valista) was founded in 1999 by Raomal Perera and Denis Hennessy, who were previously the founders of ISOCOR, an electronic messaging specialist sold to US multinational Critical Path in 1999 in a deal valued at over US\$250 million. The four residual firms (2PM, Headway, Sepro and Xiam) can be categorised as bone fide new entrants since their founders were not academics and have no previous entrepreneurial experience in the IT industry, nor could the firms could not be characterised as spin-offs from incumbent firms. However, it should be noted that even these firms were founded by very experienced professionals, who had typically worked for a number of large corporations, and were certainly not novices in the IT business.

Concluding comments

This paper has sought to explore and expose the dialectical relationship between entrepreneurial activities and the development of technology based clusters. A conceptual model of this dialectical relationship was proposed and used to inform examination of the development of Ireland's indigenous software industry. Contrasts between the prevailing entrepreneurial environment and character of entrepreneurial activities (specifically new firm formation and firm-building) at different stages of the cluster's development (dubbed the proto-cluster, emerging cluster and established cluster stages) and the role of entrepreneurial activities in the evolution of the cluster were exposed. Thus, the pioneering entrepreneurs of the proto-cluster/emerging cluster - through their entrepreneurial actions - influenced and improved the entrepreneurial environment for starting and building a software firm in Ireland during the established cluster stage, and this more favourable environment in turn led to, and supported, further entrepreneurial activity in the software industry. The paper therefore adds to the small number of existing studies on the link between entrepreneurial activities and the development of technology-based clusters and supports recent calls for greater attention to the role of entrepreneurial activities in academic studies of cluster evolution.

Any policy implications are extremely tentative at this stage but the conceptual model and empirical evidence in the paper seems to cast doubt on the basis for regional cluster-type policies which aim to replicate the characteristics of successful clusters with the presumption that this will lead to improvements in regional economic performance. In answer to Feldman's (2001) question "Is replication of a mature entrepreneurial environment sufficient to foster entrepreneurship?" it seems the answer is probably no. Whether there is a role for policy to stimulate and/or support the entrepreneurial activities that initiate and build clusters is open to debate. Certainly the Irish software story demonstrates numerous instances of State intervention in support of the developing cluster. Importantly, however, the State did little to steer or determine the development path, limiting itself to a supporting role and leaving the entrepreneurs to 'do their stuff'.

Notes

¹ Pinch and Henry (1999) reach this conclusion in their empirical study of the British motor sport cluster ('Motor Sport Valley') and Keeble and Nachum (2001) do so from their research on the clustering of small consultancy firms in London and South East England.

² Given this potential link, it is somewhat surprising that "there exist only few analyses to date of the relationship between cluster attributes of a region and entrepreneurship activities in the same region" (Sternberg and Litzenberger, 2004, p.767).

³ For a descriptive profile of the overseas software industry in Ireland see Crone (2002a).

⁴ The software industry is unique within Ireland's 'Celtic Tiger' economy in exhibiting a parallel development of indigenous industry alongside an influx of inward investment (O'Gorman et al, 1997). Other leading sectors (e.g. ICT hardware manufacturing, pharmaceuticals and medical instruments) are dominated by overseas multinationals.

⁵ The United States, UK and Continental Europe were all significant export markets by the late 1990s.

⁶ Table 5 of the Census of Industrial Production 1998 gives total persons engaged in industry as 63,518 in the Dublin region against a total of 260,357 in Ireland (24.4%), and the number of industrial units as 1,333 in the Dublin region against a total of 4,932 in Ireland (27.0%).

⁷ Stern (2003) points out that by the early 1990s, many of the people who headed Irish software firms were already on their second or third start-up, with the fledgling years of the industry being well over. However, given the overall size of the indigenous industry at this time, it is realistic to describe it as a proto-cluster/emerging cluster since there was a lack of critical mass and few firms had broken through at international level.

⁸ SmartForce spawned a spin-off, Riverdeep, which also operates in the e-learning niches and listed on the Nasdaq in the late 1990s.

⁹ This section draws heavily on Horn (2002) and O'Riain (1999), as well as O'Neill (2001).

¹⁰ Another process which contributes to knowledge dissemination and collective learning within the cluster is formal and informal networking by managers and professionals. Informal networking is notoriously difficult to measure empirically and no evidence is presented in this paper. However, see O Riain (2000, p.19-21) for a discussion of informal networking and social networks in Dublin's software industry.

¹¹ In terms of the return migration noted above, the international labour market provides a possible conduit for international knowledge transfers and associated learning, as noted in the cases of Bangalore and Taiwan by Saxenian's (1999 and 2000) research on 'brain circulation'.

¹² The Irish state played an important role in kick-starting the indigenous VC industry, notably through the EU Seed and Venture Capital Measure of the Operational Programme for Industrial Development 1994 –1999 (Enterprise Ireland, 2000).

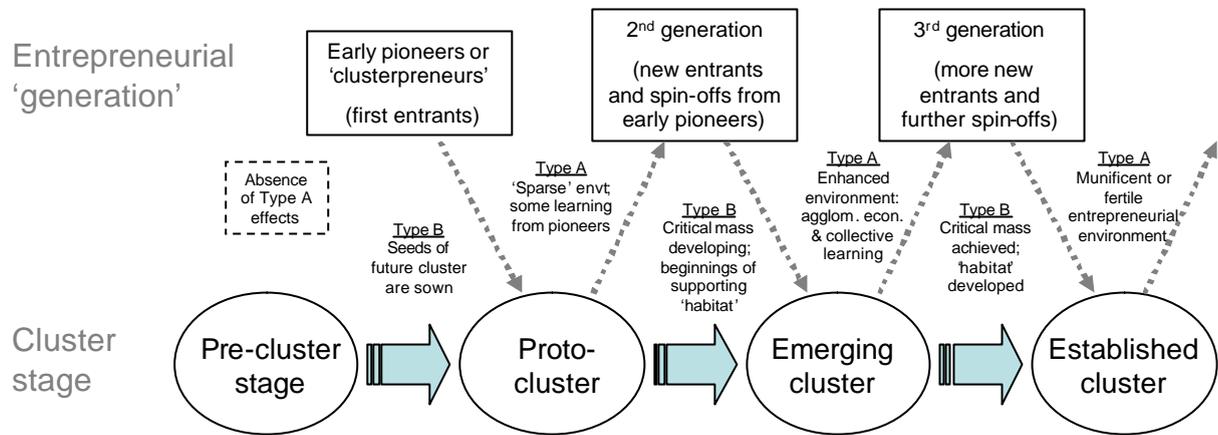
¹³ Note, however, reputation effects can also be negative (Molina-Morales and Martinez-Fernandez, 2002) and the potential reputation damage of the problems encountered by publicly-listed Irish firms during 2000-03 must also be considered.

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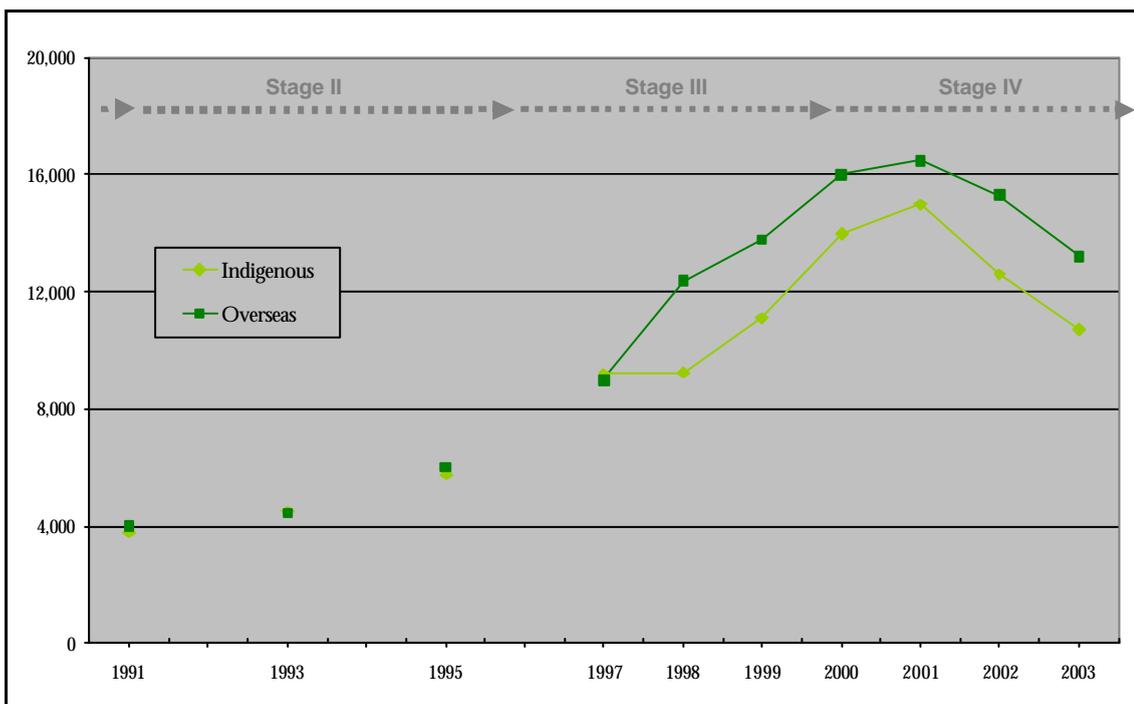
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Figure 1: A Stylised Conceptual Model of the Dialectical Relationship between Entrepreneurial Activities and Cluster Evolution



Type A effects: influence of regional environment on entrepreneurial activities. **Type B effects:** influence of entrepreneurial activities in regional envt
 Notes: the model does not consider the external environment and its influences, which can for example precipitate a crisis in the cluster; the model is stylised, the process is linear and path dependent (e.g. can't start at stage 3) but not deterministic (i.e. not all clusters 'make it' all the way)
 [Unanswered questions: What happens when: -an external shock? -cluster reaches maturity? -'lock-in'? -diseconomies of agglomeration kick in?]

Figure 2: Employment in indigenous and overseas segments of Irish software industry, 1991-2003



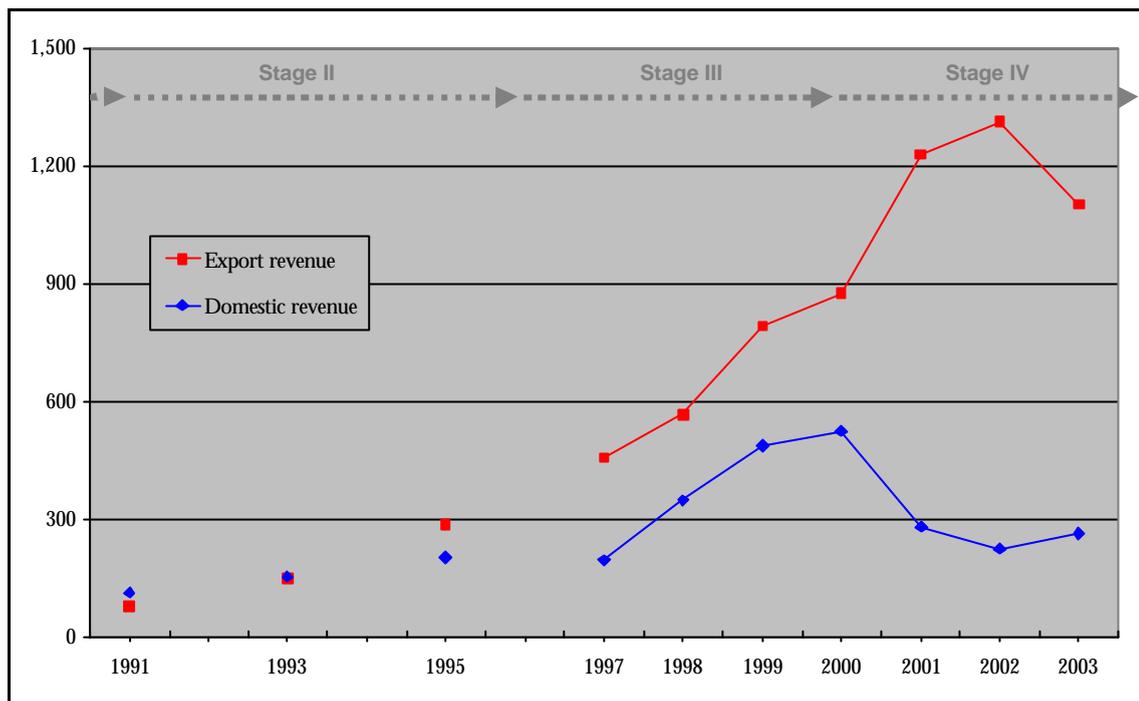
Source: National Software Directorate, Enterprise Ireland.

Table 1: Profile of Ireland’s Indigenous Software Industry in Four Stylised Cluster Stages

	Stage I: Proto-cluster (1970s to late 1980s)	Stage II: Emerging cluster (late 1980s to mid 1990s)	Stage III: Established cluster (mid 1990s to 2001)	Stage IV: Restructuring? (2001 to present)
(a) Key industry characteristics and developments	<ul style="list-style-type: none"> • Pioneering firms • Small population • Some high profile failures and asset-stripping M&A1s 	<ul style="list-style-type: none"> • Foundation of leading firms of Stage III (i.e. IPO and high profile M&A1 exits) • Beginnings of critical mass? 	<ul style="list-style-type: none"> • Critical mass attained • Nasdaq IPOs or M&A1 of leading firms • Internationalisation (overseas offices; more exports; and M&A2) • Increasing volume of start-ups, incl. spin-offs from incumbents 	<ul style="list-style-type: none"> • External shock: global tech downturn • De-listing of several key players • Rationalisation and cost-cutting • Limited number of high-profile failures
(b) Iona Technologies 'story'	<ul style="list-style-type: none"> • Antecedents: EU-funded ESPRIT research on distributed computing at Trinity College Dublin (1984-89) 	<ul style="list-style-type: none"> • Iona founded 1991 • 'Bootstrapping' strategy (selling services to fund product development) • Failed attempts to secure VC • Alliance with Sun Microsystems (1993) 	<ul style="list-style-type: none"> • Aggressive growth, based on <i>Orbix</i> middleware products • Nasdaq flotation 1997 • Internationalisation: offices and M&A2 • Peak employment (~800 worldwide) • 15-20 spin-offs (e.g. CapeClear, Rococco) 	<ul style="list-style-type: none"> • Crisis leading to de-listing, restructuring and job cuts • 'Experimentation' with new strategies (e.g. e-business integration solutions) • New products • Changes to executive team, incl. CEO
(c) Key developments in cluster environment (or "architecture")	<ul style="list-style-type: none"> • 'Accidental' creation of pre-conditions... • Expansion of 3rd level education, RTCs established • Upgrading of telecoms infrastructure • IDA attracts FDI by leading SW MNCs: esp. Microsoft 	<ul style="list-style-type: none"> • State agencies begin to recognise potential of indigenous SW industry • Industry-specific institutions formed (e.g. NSD, CSE, ISA) • Some internationally significant development work is done in Ireland 	<ul style="list-style-type: none"> • Establishment of local VC industry and inflow of foreign VC • International recognition of leading Irish software firms and the developing cluster • Emergence of 'Economy Two' firms, developing 'habitat' 	<ul style="list-style-type: none"> • Harsher investment climate/funding crisis • Some institutions have been disbanded or downgraded (e.g. CSE, NSD) • Doubts about sustainability (or 'adaptability') of cluster?

Notes: After Teubal et al (2002) we use M&A1 to indicate the acquisition of an Irish indigenous firm by a foreign firm and M&A2 to indicate an overseas acquisition by an Irish indigenous firm. VC = venture capital; NSD = National Software Directorate; CSE = Centre for Software Engineering; SDC = software development centre.

Figure 3: Export and domestic revenue of Irish indigenous software industry, 1991-2003 (€m)



Source: National Software Directorate, Enterprise Ireland.

Table 2: Characteristics of firms founded in proto-cluster/emerging cluster and established cluster

Group	Proto/emerging cluster	Established cluster
Founded	Mid 1980s-early 1990s	1996-2000
Status	Leading lights of established cluster (IPO on Nasdaq or acquired by leading foreign multinationals)	Emerging or potential future stars (VC-funded/growth-oriented start-ups, some tipped as future IPO candidates)
Example companies	Iona, Baltimore, SmartForce, Trintech, Datalex, Parthus, Aldiscon, Kindle Banking Systems, Quay Financial Software, Credo, Saville Systems, ISOCOR, Insight Software, Euristix, etc.	'Celtic Tiger Cubs' (after Crone, 2004): AmBeo, Buytel, CapeClear, CR2, Eware, Macalla, Massana, Network365, Norkom, Openet, Qumas, Rococo, Sepro, Vordel, Wolfe Group, Xiam (all rec'd VC, 1999-02)
Mode of entry	Mode of entry	Majority were spin-outs/offshoots from non-software firms or university spin-offs
Founder characteristics	<ul style="list-style-type: none"> Pioneers Mostly first-timer entrepreneurs Not always university educated? 	<ul style="list-style-type: none"> More experienced Teams of 2-5 founders University educated in computer science or maths/science/engineering
Firm-building strategies	<ul style="list-style-type: none"> Bootstrapping Services <i>and</i> product development Staged internationalisation? 	<ul style="list-style-type: none"> Venture capital financed Product-focused from outset Born globals Extensive use of alliances

Box 1: Examples of Economy Two/Habitat firms in the established cluster

HotOrigin Ltd - Is an early-stage venture capital and specialist consultancy company. HotOrigin was founded in March 2000 in Dublin by an experienced team from corporate, consulting and start-up backgrounds. Three of its founders, including its CEO David Dalton, are former consultants with Accenture in Dublin and its CTO was formerly Head of IBM's eBusiness Services in Ireland. HotOrigin's advisory board includes Chris Horn and Jim Mountjoy (x-refer Box 4). HotOrigin aims to facilitate the growth of young software companies during critical stages of development, by providing essential services such as management team building, business strategy development, technology strategy, strategic alliance partnerships and venture financing. HotOrigin has made 8 early-stage investments in Irish tech companies over the last 18 months.

International Ventures – Provides strategic consulting services for high technology companies supplemented by "tactical implementation support". The founders of International Ventures are two high profile figures in the Irish software industry. Paul O'Dea was a founder of banking software company Credo, which was acquired by Misys in 1994. He has a BE and MBA from University College Dublin. He has advised, invested in and mentored numerous high technology companies. O'Dea is the current chairperson of the Irish Software Association and has advised the government on strategy for the software industry. Donal Daly is one of Ireland's most successful IT entrepreneurs. His first company, founded in 1986 as Expert Edge Computer Systems and later known as Software Development Tools Inc (SDTI), was sold to Wall Data for IEP2 million in 1997. Daly then formed e-marketing company NewWorld Commerce which in February of 2002 merged with IQ Commerce to form NewWorld IQ (Daly remains as chairman). Daly is a former chairperson of the ISA.

Brown Rudnick Berlack Israels - The major Boston-based US law firm Brown Rudnick Berlack Israels opened an office in Dublin in early 2002. Brown Rudnick has annual worldwide revenue in excess of \$100m and employs over 200 lawyers. The Dublin office advises Irish technology firms doing (or planning to do) business in the United States about issues such as employment legislation, legal disclosure, product licensing, intellectual property protection, raising venture capital and setting up a US office. The firm is already working with nearly 20 Irish technology companies, including Eurologic Systems and Fineos.

Eurolink Global – This English multinational firm opened a Dublin office in late 2001. Eurolink specialises in the supply of hard-to-find and rare skilled IT professionals (both contract and permanent). Eurolink clients have instant access to a candidate bank of over 120,000 IT professionals and candidates can view up to 500 assignment opportunities received on a daily basis.

Simpson Financial & Technology Public Relations Ltd – Is a Dublin-based public relations company, founded in 1995, focusing on technology companies. Clients in the Irish software industry include Allfinanz, Horizon Open Systems, Norkom Technologies and the Irish Software Association. Simpson FT PR aims to help companies to build corporate profile and reputation and promote their products and services. Founder Ronnie Simpson is a Trinity College Dublin graduate (Business Studies) and was previously MD of the Irish subsidiary of Edelman PR Worldwide. Simpson FT PR is a member of the Eurocom PR Network, a global network of technology focused PR firms with offices in 50 locations worldwide.