Development of the ICT Industry in Ireland 1960-2010: A Retrospective Roadmap

Abstract

This paper explores the origins of the ICT sector in the Republic of Ireland and its subsequent development from 1960 to 2010 inclusive. Through a retrospective roadmap analysis, the influence of government policy, education and technology development in the sector over this time period is explored.

The objectives of the research were to: identify key developments in technical education and to review how government policy affected or interacted with the ICT sector; explore the effect of technology developments on the emerging industrial sector, and to identify the relevant determinants in the form of drivers and inhibitors for the development of this sector in Ireland.

For the purpose of this study, the Irish electronic and software industry, currently called the Information and Communications Technology (ICT) sector, is defined as the foreign-owned and indigenous firms actively involved in the production and/or servicing of hardware and software electronic products within the Republic of Ireland.

Empirical findings are reviewed in light of the theoretical framework as well as the historical and archival sources. In addition to the industrial sector exploration, this research identifies management/social trends with implications for the sector. Conclusions and recommendations for government policy, technical education and the ICT sector are provided.

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1.0 Introduction

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The objectives of the research were to:

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For the purpose of this study, the Irish electronic and software industry, currently called the Information and Communications Technology (ICT) sector, is defined as the foreign-owned and indigenous firms actively involved in the production and/or servicing of hardware and software electronic products within the Republic of Ireland. This broad definition is a modified version of the definition used by Collins and Grimes, (2008). Maintaining a broad definition of the sector allows the exploration of its emergence and development from its beginnings in the early 1960s. This research is unique in tackling the development of a specific dynamic industrial sector over a fifty year time frame and in using a retrospective road-mapping framework.

This paper is structured as follows. In section 2, we review literature on relevant frameworks for industry analysis and industry development with specific emphasis on Global Value Chain and Technology Roadmapping. Section 3 discusses the methodological approach adopted, together with an overview of how industrial sector evolution matches to Critical Realism structures and mechanisms. Section 4 presents the findings in the form of two roadmaps from the actual and empirical stratum along with a discussion of the findings in relation to the industry determinants identified through the roadmap analysis. Finally, section 5 concludes and discusses the implications and limitations of the research.

2.0 Literature review

This paper draws on theory from the strategy literature on frameworks for industry analysis and industry development. Every industry begins with an initial structure and is configured by '*evolutionary processes*' (deWit and Meyer 2010). They identify some general evolutionary processes, such as, long-run changes in growth, changes in buyer segments served, buyer's learning, reduction

of uncertainty, diffusion of proprietary knowledge, accumulation of experience, expansion (or contraction) of scale, changes in input and currency costs, product innovation, process innovation, structural change in adjacent industries, government policy change and entries and exits. These evolutionary processes operate "*even if there are no important distinct events to signal this*" (Porter 1980, p.184).

Development in an industry means a change to its structure (deWit and Meyer 2010). Some of the key dimensions along which industry can change are:

- **Convergence-divergence** i.e. the degree to which firms are adopting/developing new business models
- **Concentration-fragmentation** i.e. less companies in the industry with an increasing share of the market through M&As or company exits / average market share of the largest companies begins to decrease through new entrants
- **Vertical integration-fragmentation** i.e. firms involved in more value-added activities /firms withdrawing from various value-added activities. Porter (1980, p.300) defined vertical integration as the "combination of technologically distinct production, distribution, selling, and/or other economic processes within the confines of a single firm"
- **Horizontal integration-fragmentation** i.e. where the boundaries between different industries lose distinction or firms strictly confine themselves to their core business
- **International integration-fragmentation** i.e. the lowering of the importance of geographical boundaries between different segments of an industry versus regionalisation of competitive interactions
- **Expansion-contraction** i.e. increasing versus decreasing demand for products and/or services of a particular industry. Where periods of expansion and contraction follow each other the industry is said to be cyclical.

Porter (1980) points to evolutionary processes as the forces that create the incentives or pressures for change. Evolutionary processes push industry from its initial structure towards one of many potential structures. Changes within industry are usually due to inter-actions of many drivers and inhibitors and industry dynamics, itself, can act as a driver. Phaal *et al.* (2011) find that enablers and barriers to industrial development are contextual, industry-specific and depend on the phase of industrial emergence of the industry under review. They identify a co-evolutionary process between the demand side (market forces) and the supply side (technological forces) as a key driver.

In analysing evolution of an industry, Porter (1980) indicates that identification of the underlying determinants is more useful than a simple description of industry evolution. Determinants for industry development can be divided into drivers and inhibitors. Drivers push industry to change in a certain direction and inhibitors resist changes in the industry. Inhibitors can lead to industry rigidity. Examples of inhibiting factors are: Underlying conditions, Industry integration, Power structures, Risk averseness , Industry recipes (cognitive map of industry structure held by industry incumbents), and Institutional pressure (deWit and Meyer 2010).

Technological change can act as either a driver or an inhibitor, depending on circumstance. Technological change plays a major role in industry structural change and is a key competition driver

(Porter 2004, p.164). It can even create new industries. Not only is technology a driver in and of itself but it can also affect the other cost or uniqueness drivers (Porter 2004). Technological change acts as an inhibitor when it erodes competitive advantage in well-established firms and propels new firms to leading positions by changing the industry structure. Despite technological change being an important driver, many high-technology companies can be less profitable than some low-technology companies (Porter 2004).

Frameworks for firm level and for industry level analysis were reviewed for the purposes of this study. The firm level frameworks were reviewed to see if they would allow broadening to an industry level. A summary of the frameworks reviewed is shown in Table 1 below. It contains a summary of the advantages and disadvantages, as well as the main features, of each framework considered. Where many frameworks were considered, the Global Value Chain (GVC) and Technology Roadmapping (TRM) are elaborated further here.

Table 1 Industry Analysis Frameworks

Framework	Features	Advantages	Disadvantages
SWOT (Strengths, weaknesses, opportunities and threats	General Planning – 1)identify current strategy position 2) PEST analysis 3) Resource profile	Well used and understood	Static Mainly applied at firm level Would need to be done numerous times to cover time frame
The Product Life-cycle	Four phases of development 1) Innovation 2) Growth 3) Maturity 4) Decline	Intuitive, well used well recognised, crosses both technology and industry	Doesn't account for global networks Debate as to whether it can be used for industry Duration of each stage not defined, Sequence not always followed
RBV (Resource Based View)	Based on both Country specific resources and Firm Specific resources	Widely used general strategy framework	More suited to positivist study where resources can be identified and quantified.
PEST (Political, Economic, Socio-cultural and Technology)	Broad environmental	Can be applied to analyse industry environment and firm environments Can be used to identify exogenous drivers	Needs to be used in conjunction with other models i.e. industry model +PEST
Porter's Five forces	Five Forces of 1) Potential new entrants 2) Threat of substitutes 3) Bargaining power of suppliers 4) Bargaining power of buyers 5) Rivalry among existing firms	Well known and used Industry structure framework	Static Not typically used to show industry development
Porter's Diamond Model	Four Determinants of national competitive advantage 1)Factor conditions 2)Demand conditions 3)Related and supporting industries 4)Firm strategy, structure and rivalry	Well known and used framework,	Static Identified as not suitable for small open economies Doesn't consider the importance of FDI, which is considerable in the case or Ireland Meant to be used with a narrow industry definition
Global Value Chain	Activities. Focus on organisation's activities, on configuration and inter-relationships. Based on Value System and Value Chain	Activities can be viewed across the three areas of industry, education and government policy Is widely associated with the ICT sector	Not particularly suitable for past indigenous firms but may have more relevance in future business models
Technology Road-mapping Framework	Three elements of 1) Technology based industrial emergence 2) Key themes and demand and supply-side drivers 3) Significant events and milestones	Used to understand dynamics and characteristics of emergence of industry Matches a critical realist perspective Flexible framework Views industry as a complex system Suitable for qualitative case study method Suitable for use with long time frame	Forward looking strategic mapping but can be adapted to include history. Full framework too large to achieve in scope of this research

The GVC has particular relevance for the electronics industry as this sector can use the twin strategies of outsourcing and offshoring quite easily resulting in the electronics industry being more geographically extended and more dynamic than any other sector which produces goods (Sturgeon and Kawakami 2010). The TRM framework was reviewed as it is based on the key themes of technology, strategy and transitions literature (Phaal *et al.* 2004) and therefore offered a promising means of reviewing the broad areas of technology development, ICT sector development, governmental industrial policy and technical education within a single framework.

In the value chain literature, Porter (2004) finds that industry structure shapes the value chains of the firms operating in an industry and is a reflection of the competitors' collective value chains. Sturgeon and Kawakami (2010) ask why GVCs are more extensive and dynamic in the electronics industry than in other industries. They point to the high value-to-weight ratio (assisted by miniaturisation and Moore's Law) of most electronics parts and final goods which make long-distance transport cost effective and mean companies can operate based on optimum geographic operating costs. Also, due to the rate of technological development, import substitution policies are unlikely to succeed and, indeed, incentives are often given for industry to invest, perhaps due to the "propulsive" nature of the industry.

Sturgeon and Kawakami (2010, p.10) characterise both the nature of electronics products and the associated value-chain architecture as highly '*modular'*. Electronic products and customer applications initially were non-standardised and exhibited wide variety. The industry developed '*de facto and de jure'* standards for components, systems and production processes. The development of Computer Aided Design (CAD) and the shift from analogue to digital systems simplified the codification of electronic systems and components. Digitisation led the way to the development of the internet and information technology. Digitisation served to further enhance the modularity of electronics and led to higher interoperability, where system elements could be combined or removed, without requiring a complete product/system redesign. The fact that the internet was not tied to any particular computer platform, facilitated global sharing of data, and added to the attractiveness and monitoring of GVCs. Similarly, the modularity of electronics production also added to the attractiveness of GVCs, whereby key business processes such as CAD, production planning, inventory control, logistics and the production processes of assembly, test, quality inspection, can exist independently of the other processes.

Sturgeon and Kawakami (2010) examined the importance of electronics GVCs to the global economy. They identify three main firm-level actors in GVCs. These are: lead firms, contract manufacturers and platform leaders. Lead firms sell branded products and/or systems to end-users. They are called lead firms as they initiate GVC activities by placing orders with suppliers. Contract manufacturers (CMs) make products for lead firms and sometimes they also provide design services (Contract Design Manufacturers or CDMs). While some lead-firms manufacture their products in house, Sturgeon and Kawakami (2010) indicate that the use of CMs has been a strong trend since the 1980s. Platform leaders are companies that have been successful in implanting their technology (as hardware, software or a combination of both) in the products of other companies. Intel is a good example of a platform leader in the PC industry. Platform leaders have both technological capabilities and market

power to position the points on the value chain where open standards can start (Sturgeon and Kawakami 2010).

GVCs are important at the national level as a country's ability to prosper depends on its participation in the global economy, "*which is largely a story about their role in global supply chains*" (Gereffi and Lee 2012, p.24). Electronics firms can use the twin strategies of outsourcing and off-shoring quite easily (Sturgeon and Kawakami 2010). This is because there is less need for the engineers to co-locate than with other high technology sectors. Sourcing is often done globally and it is relatively easy to move and adapt electronics factories. This has resulted in the electronics industry being more geographically extended and more dynamic than any other sector producing goods. Sturgeon and Kawakami (2010) identify flexibility, resiliency, speed and economies of scale (which accrue at the industry level rather than the firm level) as the characteristics of value chain modularity. Producer driven chains occur in areas such as advanced electronics where production is controlled by trans-national manufacturers (Barrientos *et al.* 2011). According to Haugh (2013), the high level of FDI in Ireland is responsible for Ireland's involvement in GVCs.

Technology Roadmapping (TRM) includes both commercial and technological perspectives, along with the linkages and discontinuities between the various perspectives. According to Kostoff and Schaller (2001) roadmaps are used in industry, government, and academia to portray the structural relationships among science, technology, and applications.

To date, the published literature on roadmapping is sparse; however, Kostoff and Schaller (2001) have found a significant amount of industry based information (much from practitioners) in the broader literature (Carpenter *et al*. 1981; Kappel 1998). In reviewing the roadmapping literature, Carvalho *et al.* (2013) find that a roadmapping approach has two main components. These are

1) The application or roadmapping process
2) The result of the application or the roadmap produced.

They also note that roadmapping has been mostly used in qualitative studies due to the exploratory nature of the theme. The number and variation of definitions support both an emergent theme and also the flexibility of the approach (Carvahlo *et al.* 2013 Appendix II). The main levels of analysis are roughly equally split between strategy/business level and the innovation/new product development level of analyses. At a methodological level, 53 out of the 79 papers reviewed by Carvahlo *et al.* (2013) were case studies, indicating that this framework is suitable to apply with case study methods.

This research adapts Phaal *et al*.'s (2011) technology roadmap as the industry analytical framework for this study. Phaal *et al.* (2011) propose a framework for mapping technology-based industry development. They used TRM concepts to produce a map of industrial emergence with a three-dimensional approach

1. Establishment of industrial dynamic patterns which use time-based models with phases and transitions marked on the horizontal axis of the map
2. Focus on the principles of emergence and evolution in complex systems using key themes which provide the supply and demand side drivers

3. Mapping of industrial emergence with the TRM approach using significant events and milestones from R&D to industrial application and then to market.

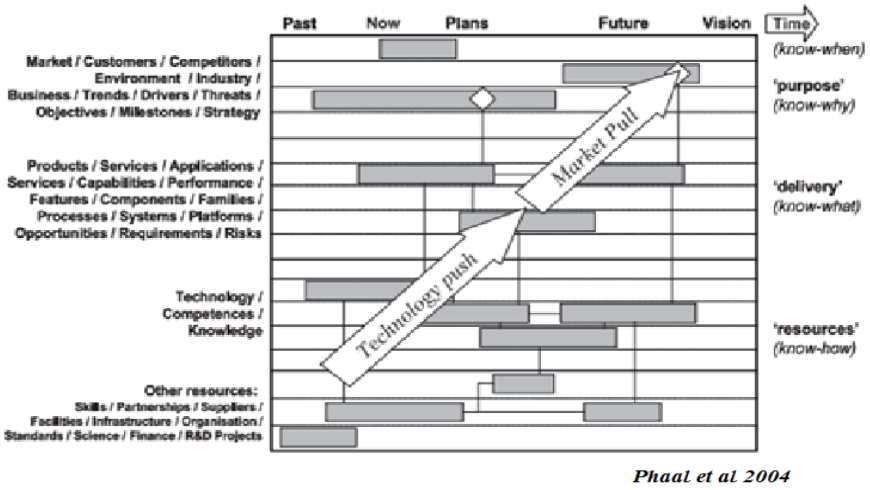

Figure 1 *A Generic Technology Roadmap*

From a temporal perspective, there are two major variants of analyses that have examined the science–technology–application evolution process: retrospective analysis and prospective analysis. The focus here is on the retrospective analysis. Technology Road-Mapping (TRM) is the chosen framework to deal with the complexity of the inter-related time-series for government policy, and the industrial sector development. This mapping of the change processes over time is consistent with the road-mapping technique. The Technology Roadmap can be seen as a flexible time-based chart. Where Phaal *et al.*'s (2011) generic roadmap, illustrated in figure 1 above, indicates industry and technology, this study adds the areas of government industrial policy and technical education. A retrospective road map analysis was chosen as the framework to explore the influence of government policy, education and technology development in the ICT sector in Ireland over this time period.

3.0 Methodology

Critical Realism (CR) is an integrative meta-theory based on the works of Roy Bhaskar. It takes a transcendental realist ontology, and argues for a world "composed of objects (generative mechanisms) existing *independently* of human interpretation, knowledge, enactment or discourse" (Hedlund-deWitt 2012, p.4). Objects (or Entities) and Structures are the basic theoretical building blocks used by critical realist explanations. They can be social or material, complex or simple, structured or unstructured. Examples of this are people, relationships, organisations, attitudes etc. (Easton 2010). These real entities have emergent powers to cause events under certain conditions. They also have liabilities or susceptibilities to the actions of other entities or mechanisms.

The unit of analysis is a social construct, an open system, consisting of the industry sector itself. It contains, embedded within it, other entities such as the ICT enterprises and individual actors. CR considers that reality is made up of many different objects which, by nature of their constitutive structures, have different powers and mechanisms. Structure indicates how the object or entity is constituted. Structures can be nested within other structures.

In CR, entities will usually be structured. For example the ICT sector, as defined, can be seen as an entity in its own right, consisting of a series of other objects or entities such as firms, associations, networks, people, processes, resources etc. all of which can have an effect on one another. Some of these structures are nested inside of one another. Each firm, for example, can have its own structure; can be a member of a network and a constituent of the ICT sector as a whole. And each entity had its own causal powers and liabilities.

The relations between these entities that comprise the ICT sector can be either necessary or contingent relations. Necessary relations mean that changes in one entity will by nature of the relation lead to changes in the other entity where contingent relations may cause changes but are themselves the product of other causal processes which have their own structures with causal powers and limitations. According to Ryan *et al.* (2012, p.300), "*Critical realism is well suited to addressing the central questions of structural change and transformation in industrial relationships and networks*." There is a match between the '*evolutionary processes'* (Porter 1980; deWit and Meyer 2010) and the critical realist (CR) view of underlying structures and driving mechanisms (Bhaskar 1997).

Empirical evidence in the form of fifteen semi-structured interviews was gathered, spanning the areas of government policy, technical education and the industrial sector itself. Kvale and Brinkmann (2009, p.2) call it "*an inter-view, where knowledge is constructed in the inter-action between interviewer and the interviewee*". A semi-structured research plan was developed which looked to address the areas of interest of government policy, technical education and industry development and this plan formed the basis for conducting interviews with all respondents. Three interviews took place with the government industrial support agencies and views of government policy from the perspective of industry experts was sought to allow triangulation of the points of view expressed.

A CR philosophical approach is chosen to deal with the time-frame and the subject area breadth. CR allowed the viewing of the Irish ICT sector as an 'open system' (Danermark *et al.* 2002, p.199) thus allowing the complex and dynamic and interactive nature of the government policy and the ICT sector to be explored.

A non-pre-specified within-case sampling (Miles and Hubermann 1994) or selection process was used to identify key "experienced and knowledgeable experts" (Lincoln and Guba 1985). Yin (2014) distinguishes between the unit of data collection and the unit of analysis. He points out that care needs to be taken that the unit of data collection does not distort the unit of analysis. Every attempt was made to maintain a wider context by also interviewing key people from as broad a spectrum as possible.

As the timescale covers five decades a spread of people with relevant experience who have joined the sector at different times was targeted. Sampling over the spectrum of implementers of government policy (development agencies), educational influencers (people currently actively involved in an educational capacity) and people with relevant industrial experience were chosen. Some of the people interviewed crossed two of the divides in that they had both relevant ICT industrial experience and also professional educational experience. Also, under the banner of industrial experience, attempts were made to represent the hardware and software sides, as well as indigenous industry and MNCs (multinational corporations). People with relevant industrial experience of ten or more years and who had top managerial experience were chosen. So it is *"working knowledge of the contexts of the individuals and settings that lead us to select them for initial inclusion in our study*" (Maykut and Morehouse 1994, p.57). Figure 2 shows the interview number and date and illustrates the areas of expertise of the respondents. The marker shown for each respondent illustrates their starting dates of taking up employment.

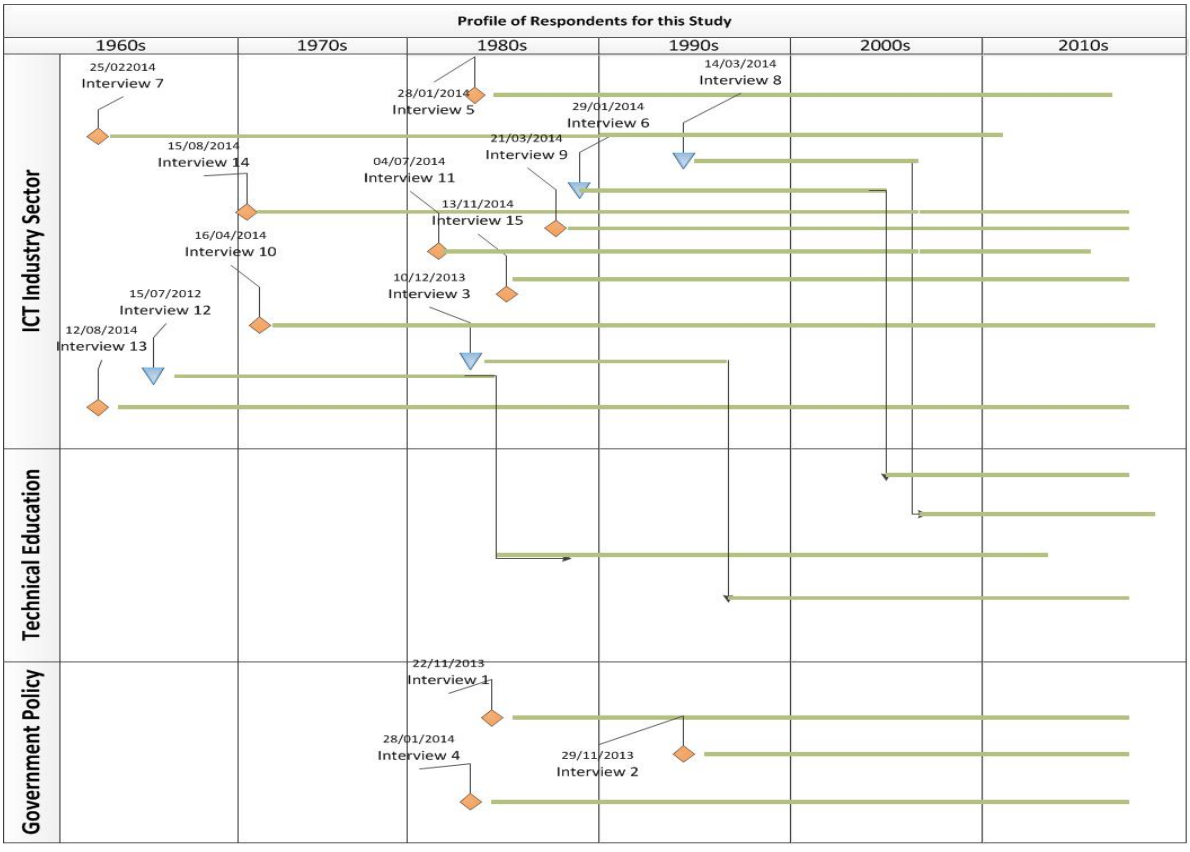

Figure 2 Representation of Respondent/Interviewee Selection

In terms of validation, the findings and conclusions of this research were reviewed by 3 respondents and 1 knowledgeable ICT expert who had not taken part in the research. All four concurred that the findings depicted the industry as they knew it and found it a good representation of the industry development.

Evidence for this case study research was collected from documents, archives and from interviews. Documents best provide corroboration and augment evidence collected from other sources (Yin 1989). Yin (2014, p.53) points out the suitability of a single longitudinal case study to "cover trends over an elongated period of time, following a developmental course of interest". Documents and Journals in the *Engineers Ireland* library and in The National Archives of Ireland in Dublin were also consulted to augment the evidence from semi-structured interviews.

3.1 How Industrial sector evolution matches to CR structures and mechanisms

Sayer (1992, p.26) cited in Danermark *et al.* (2002, p. 31) points out that objects of social science are both socially defined and socially produced in comparison with the objects of natural science which are socially defined but are naturally produced. Social phenomena always occur in open systems (Danermark *et al*. 2002, p.39). The process of change is an inherent process in the development of the ICT sector in Ireland and thus an open system view is justified. This open system with all its complexity and dynamism matches to a CR viewpoint.

The unit of analysis is a social construct consisting of the industry sector itself. It contains, embedded within it, other entities such as the ICT enterprises and individuals. There are so many variables interacting at any given time that control of any situation for testing is impossible in a positivistic, experimental sense. Also, the interactions of government policy, technical educational change and developments in the industry sector itself are of interest and, as per Ryan *et al.* (2012, p.300,) "*Critical realism is well suited to addressing the central questions of structural change and transformation in industrial relationships and networks."*

In CR studies, researchers are likely to rely on multiple sources of data consisting of different types of qualitative evidence, including observation, in-depth interview, historical and archival research, along with available quantitative evidence or industry statistics (Blundel cited in Neergaard and Ulhøi 2007) This study met the effort to address the complexity involved by using multiple sourced data with semi-structured interviews, archival research and available industry secondary sources. Matthyssens *et al*. (2013) indicate that semi-structured interviews are suitable to support the balance between "*open-endedness and scope*" of CR case research. Easton (2010, p.123) states that the events can *"exist in records of the past including the memories of those human actors who can attest to the events"* leading to the collection of interviews from people who had experience in the sector throughout the time period under study to identify drivers.

In CR, entities will usually be structured. For example the ICT sector, as defined, can be seen as an entity in its own right, consisting of a series of other objects or entities such as firms, associations, networks, people, processes, resources etc. all of which can have an effect on one another. Some of these structures are nested inside of one another. Each firm, for example, can have its own structure; can be a member of a network and a constituent of the ICT sector as a whole. And each entity had its own causal powers and liabilities. These relations between these entities that comprise the ICT sector can be either necessary or contingent relations. Necessary relations mean that changes in one entity will by nature of the relation lead to changes in the other entity where contingent relations may cause changes but are themselves the product of other causal processes which have their own structures with causal powers and limitations.

Danermark *et al.* (2002) advise that it is not sufficient to study just the events. They find that attention has to be switched from events themselves to the mechanisms that produce them. Easton (2010) also indicates that the outcome looked for is the identification of mechanisms that explain what caused event to occur. According to Sayer (1992) causal claims are not about finding regularities or rules but rather about "*the production, and prevention, of change*" In searching for these mechanisms or drivers, the research spiral path indicated by Ryan *et al.* (2012) was used to guide the process.

A representation of the critical realist view of causation is shown in Figure 3. This illustrates how events (which occur in the actual domain) are the starting point for critical realist investigations. When an event is experienced it becomes an empirical fact and comes under the empirical domain (Danermark *et al.* 2002).

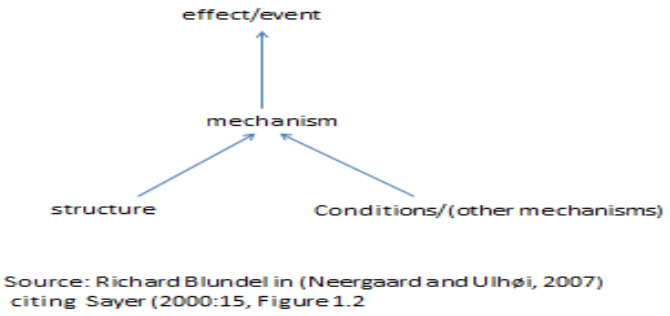

Figure 3 A Critical Realist View of Causation.

In this study, it is the mechanisms that caused change in the Irish Electronic and Software sector that are of interest and, this study seeks to equate drivers and inhibitors with CR generative 'mechanisms' or 'causal powers' in order to generate an understanding of the change process in the sector over time. The distinct time series developed are chronological sequences of events that occurred in technical education, government policy and industry and these events, along with the interview data collected, are the CR source to begin the process of looking for drivers or mechanisms in a critical realist methodology.

According to Smith (2006, p.522), change can be either revolutionary (rapid transformation) or evolutionary ("slower, longer term, fluid and directional") and sensitivity to both the temporal dimension and the spatial dimension is required. This requires the consideration of a variety of policy areas that may themselves be undergoing changes as well as staying true to the temporal dimension by the mapping of the change processes over time (Smith 2006). The time period for measurement is another challenge for strategic theory, where both exogenous and endogenous variables, as well as environmental factors, were and are subject to change over time. Porter (1991) indicates that when examining strategy over long periods, it is more appropriate to seek determinants earlier in the causality chain. This is compatible with the aims of this study which seeks to establish the

development of an industrial sector over a long time period and establish drivers and inhibitors for the electronics and software industry.

This use of the road-mapping framework allowed, in particular, the development of interlinking time series in the spatial areas of

1) Government policy,

2) Technological changes,

3) Technical educational developments, and

4) The ICT sector's industrial emergence

to be viewed alongside one another.

4.0 Findings and Discussion

CR and TRM have the flexibility and breadth to allow a wide lens to be used in studying the case of the ICT sector. Two roadmaps were developed from the findings of this research. Technology Roadmap 1, developed from the literature review, presents the data gathered in the actual CR stratum. This roadmap comprises key developments across the education, government policy, industry and technological development spheres.

Begley *et al.* (2005) review the phases in industrial development in Ireland and find five phases of multinational involvement. These five phases roughly correspond to the decade breakdown.

In the decade 1960-1970, they point to the liberalisation of the economy with low tax, low costs and generous grants as main advantages for attracting Foreign Direct Investment (FDI). General Electric subsidiaries EI and Ecco were examples of companies attracted to Ireland mainly as a low-value manufacturing site. In the seventies, IDA expertise and government flexibility were added to the above advantages resulting in the attraction of manufacturing in more capital-intensive sectors. Wang, Digital and Nortel were cited as examples of new enterprises that came to Ireland in the 1970s. Ireland became a member of the EEC and this access to the larger European market was a further attractor for FDI.

The eighties saw Lotus, Lucent, Microsoft, Intel, EMC and Apple arrive in Ireland. Begley *et al.* (2005) indicate that the arrival of these companies coincided with a technically educated workforce. By this stage, there was an accumulation of multinational management expertise, developed in the existing manufacturing base. There was some turn-over, in the form of arrivals and departures of firms, particularly in the low-tech sector. Also the focus shifted to attracting higher value manufacturing-related activities, such as supply chain management and customer services.

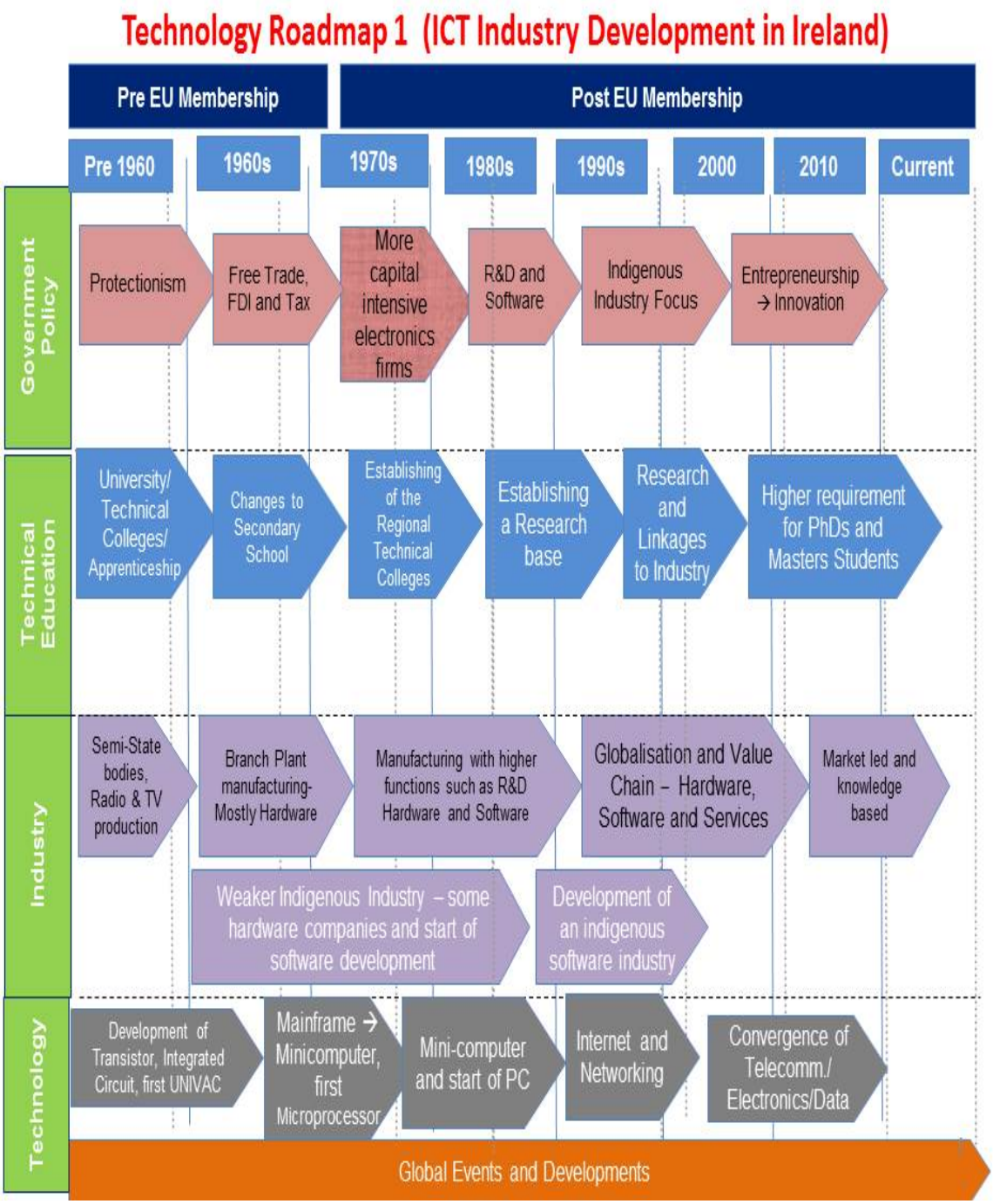

Figure 4 ***Technology Roadmap1*** *from the literature review (the actual stratum)*

In the nineties, the rising cost base, due to the success of the economy led to staff shortages in many sectors but particularly in the ICT sector. This decade, however, added the advantages of access to the university systems and greater co-operation between third- level institutions and industry.

Venture capital became more abundant for investment in start-ups. While many firms continued to exit, particularly in manufacturing, there were many successes, as companies such as Dell, Xerox, Xilinx and SAP started up in Ireland. This transitioned into the "Knowledge Economy" from 2000 onwards. Successes in FDI included Google, e-bay, Paypal, Cisco, Amazon and Facebook with customer service, supply-chain and HQ functions. The profile and type of company also emphasised the increased reliance on e-commerce and software development. Focus on R&D, Innovation and flexibility in the workforce increased in importance.

Alongside the five decades of multinational evolution and development, the indigenous Irish industry also took shape. Many Irish engineers in the1960s found work with the Electricity Supply Board (ESB), the Department of Posts and Telegraphs and the national broadcaster, RTÉ. In the 1970s and 1980s, O'Gorman *et al.* (1997) state that rapid growth was seen in the high technology areas of computers, pharmaceuticals and medical instruments. By 1990, the indigenous side of these industries employed only some hundreds of people in each of these sectors (O'Gorman *et al.* 1997). Ireland developed a high number of indigenous software companies and this is one area where Ireland was identified as having sufficient successful activity for the formation of clusters (O'Gorman *et al*. 1997; Sterne 2004). Also, the indigenous software industry grew as the multinational element grew.

Sterne (2004) divides software firms in Ireland into five separate generations. The first generation of companies began in the 1960s and early 1970s and focused on providing computer consultancy and services to support mainframe computers. This was followed by generation two, consisting of product development companies which coincided with the rise of mini-computer and PC industries. Sterne (2004, p.23) indicates that, by the second half of the 1980s, the third generation of "*technically elite"* software companies was developing niche products in specialist areas. They were followed by software companies who looked immediately for available external investment and to trade internationally. This, according to Sterne (2004), was the defining characteristic for generation four. Following the economic downturn around the year 2000, the ambitious companies, that had floated on the stock exchange or had accepted high venture capital investment, suffered badly(Sterne 2004). This led to generation five which focused again on vertically integrated products for specialist markets such as banking, insurance, regulation compliance and government applications. Success and development in the area of software had led to sufficient development in the sector for a successful clustering of software companies (Sterne 2004). In fact, development of software was one area where the Irish indigenous industry appeared to compete with the FDI software sector in terms of numbers employed.

In producing Technology Roadmap 1, four key economic reports that reflect the development of the electronics industry in Ireland were reviewed. These are The Second Programme for Economic Expansion (1963), the Telesis Report (NESC 1982), the Culliton Report (1992) and the Ahead of the Curve Report (Enterprise Strategy Group 2004). This earliest report (1963) reflected a simplified view that the industrial base could be expanded only by attracting FDI to Ireland. The statement of industrial policy in the 1960s was "*based on the understanding that such industry will supplement, but not supplant, Irish industry"* (Second Programme for Economic Expansion Part II 1964, p.154). The attraction method was based on simple expenditure supports such as tax relief and grants. Under

these policies, electronic hardware manufacturing was attracted, as illustrated by the arrival of two GE subsidiaries.

The Telesis Report (1982) recommended a shifting of public expenditure to support internationally trading indigenous industry and a building up of skilled sub-supply firms. It also recommended a reduction in the level of grants offered to newly investing foreign firms (NESC 1982). FDI was no longer viewed as the only way to expand the industrial base. A two-pronged approach was suggested, the continuation of FDI but with improvement sought in the areas of linkages with FDI firms and better supports to develop, indigenous industry. In the early 1990s, the City and County Enterprise Boards were established by the government to support indigenous industry and, particularly, start-up companies. Enterprise Ireland was established in 1998 to support the exporting indigenous sector. The indigenous support policy started with the aim of creating a climate favourable for start-ups and shifted, over time, to removing the barriers to growth and encouragement for upscaling by looking to meet each individual firm's specific requirements (Tiernan *et al.* 2006).

The Culliton Report (1992) identified that industry development drivers were not limited to public expenditure support of industries but also involved many macroeconomic factors such as education. This report found "serious gaps" in the Irish system for education and training which were considered to be "a most critical element of policy". The report called for a broadening of industrial strategy to include "*overall macroeconomic and fiscal policy, the level and structure of taxation, the effectiveness of education and training and the provision of adequate infrastructure*" (Culliton 1992). The Ahead of the Curve Report (2004) the changing nature of the industrial landscape which now includes globalisation and a requirement for networking or cohesive co-operative development across many areas. This report lists the four essential conditions for economic prosperity as: Cost Competitiveness, Infrastructure (both physical and communications), Innovation and Entrepreneurship, and Management Capability. Expertise in Markets, Technology (particularly in product service and development), and Education and Training to build world-class skills and effective, agile government were also required, on top of the four essential requirements, to build sustainable industry in the country.

The second roadmap, Technology Roadmap 2, was created using the interview data collected and is, thus, a roadmap from the CR empirical stratum. The findings from the two roadmaps illustrate a similarity between the actual domain roadmap and the empirical domain roadmap. The scarcity of jobs in electronics were described by the respondents who graduated from college in the 1960s.

The influence of technology development trends can be seen with a brief analysis at the predominant computer type and the types of foreign-owned companies operating in the country. This trend indicates that the story started with hardware manufacturing. Software development followed on and currently, services or a combination of hardware/software/services appear to dominate.

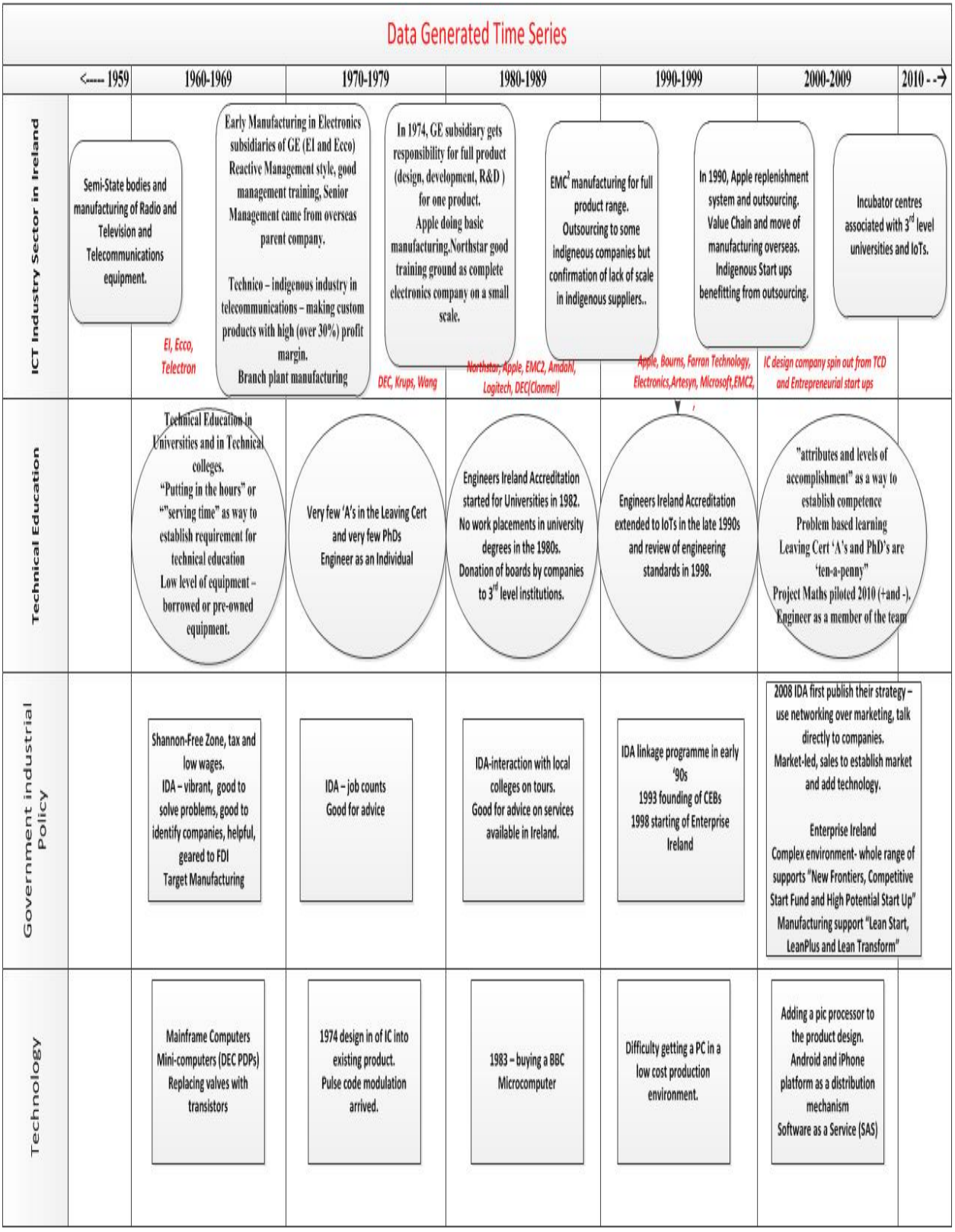

Figure 5 Technology Roadmap 2 from the interview data (the empirical stratum)

The Government policy focus shifted from protectionism in the 1960s to a strong focus on entrepreneurship and innovation towards 2010. The industrial sector began as a low cost manufacturing electronics location which corresponds to factor-based development; it moved to more advanced technological foreign direct investments (FDI) (such as DEC, Microsoft, Apple, EMC) and then moved to encourage venture capital investment and entrepreneurship as a successful indigenous software base developed. More recently, industrial policy has sought to drive innovation to further national economic development. On an industry level, the semi-state bodies played a key role in sector development in the 1960s, where the dominant industry players were in radio receiver and TV manufacturing. This is in stark contrast to the 2000s, where indigenous firms emerged and prospered from MNCs' outsourcing strategies and campus based incubators expanded and supported both spin-in and spin-out technology entrepreneurship activity.

On the education track, the shift from a focus on apprenticeships in the 1960s, to a requirement for masters and doctoral graduates is evident in recent decades. The process of change in education proceeds at a different pace from industry. There was little disruptive thinking in the educational area over the fifty years. The educational amendments were more in line with additions, and attempts to fit with the existing educational structures, rather than a fundamental re-alignment of the structure or an identification of a complete new model to meet the country's technical education needs.

Many adaptations in the areas of technical education or government industrial policy occurred to deal with duplication or optimisation of functionality. An example of this is the long time taken to develop a single framework for qualifications in the country. Another example is developments in management of apprenticeship training which switched from An Cheard-Chomhairle, to AnCO, to FÁS and now to Solas. Industry changes can happen quickly. Industry changes, in-turn, drive changes in the third-level technical education sector which leads to the entry points/requirements for courses varying widely and the number of applicants for some courses changing dramatically. This means that a flexible and adaptable system is needed.

4.1 Determinants (Drivers and Inhibitors)

Begley et al (2005) list five main reasons for investment in Ireland by multinationals, namely, corporate tax regime, government support, workforce characteristics, EU access and cost of operations. Grimes and Collins (2008) attribute the pro-business environment policy, adopted by successive governments and by government agencies, as a key driver leading to Ireland's attraction as a location for FDI. Barry and vanEgeraat (2005) cited Ireland's corporate tax regime as a major factor in the country's success in attracting FDI. They also note the trend for success in internationally traded services and shared services, rather than hardware, in the years post the dot-com collapse but state that the post millennium negative trends for ICT subsectors were more likely due to the global downturn rather than any particular shift out of Ireland. The exception, they claim, was the move of the computer assembly and peripherals operations.

Determinants (drivers and inhibitors) found in the interview data collected are subdivided into six categories, namely, Global, National, Industry, Firm, Individual and Technological.

4.1.1 Global Determinants

Many respondents mentioned global influences. Global events, such as the opening up of new developing countries and the dot.com boom, were mentioned as drivers that were outside of the nation's control but which had an influence. **Globalisation** as a process was mentioned in relation to the changes in education where modules were introduced and the change from terms to semesters in third-level education was viewed by one respondent as a form of globalisation. Globalisation and speed of globalisation were mentioned in the report Ahead of the Curve in 2004.

> "*Ireland cannot depend on the past drivers of growth to sustain and promote further development. These drivers will have to be replaced, modified or reinvigorated. Irish business leaders and policy-makers must be alert to these developments and create rapid response mechanisms to defend against new threats and to exploit new opportunities*"
>
> (Enterprise Strategy Group 2004, p.14).

The fact that we are **English speaking** was mentioned by many respondents and this is no doubt an important facet for FDI and for modern communications. The OECD (2006) reported that 32% of internet users are English speaking. English speaking as an advantage or driver was well referenced in the literature (Barry and vanEgeraat 2005, Grant 2013, Ryan and Giblin 2012). One respondent pointed to this as a declining advantage as "*people are less afraid of that*" (Interview 10). Foreign languages were also mentioned. Few Irish people had foreign language skills to a high enough level required for industry (localisation requires native-speaker language skills along with cultural knowledge). However, one respondent believed that our **attractive location** means that we can attract language-talent from Europe. He mentioned that many new start-ups in the software localisation space would look for a mix of nationalities but that in this type of start-up, a considerable percentage of the staff would be Irish. "*So you are pulling from Europe, you are not pulling from Ireland alone*" (Interview 2).

Membership of the **EU** and being in the **Eurozone** were also mentioned by many respondents as drivers and accessing the EU market was seen as offsetting the small scale of the Irish home market. This more global view of markets was also vitally important for expanding Irish companies, according to the Enterprise Ireland respondent.

Overseas experience was seen as a factor in development. Many of the people interviewed had overseas experience. The GE training schemes were initially carried out in the United States. Respondent 10 reported how multicultural the early Digital Equipment Corporation (DEC) experience was and how this had contrasted to his upbringing where he would have encountered very few foreigners. This openness to and acceptance of people from overseas was considered vital by the IDA respondent. Broadening of an individual by exposure to a multicultural industrial context was seen as a big positive by Respondent 6. Ireland benefitted from returned emigrants in DEC (Interview 10). A list of skilled qualified people, willing to return to Ireland, was also mentioned by White (in McSharry and White 2000) in the IDA's efforts to attract Intel. The IDA respondent mentioned this also: "*The cross-pollination is unreal at the moment. The number of people who have been over and back, that's really positive for Ireland."*

The **Irish-American connection** was also a positive driver in much of the FDI from the United States and was mentioned by two respondents in relation to the location of EMC in Cork. It was also mentioned by the IDA respondent who identified it as a driver, particularly in the early stages of encouraging FDI into Ireland in the 1960s and 1970s. Related to this, Respondent 5 argued that management training under the American systems made Irish companies familiar with the American style of doing business. Respondent 2 mentioned that Irish people are familiar with American culture from Television and that this means a cultural understanding exists when dealing with Americans. This cultural affinity was also mentioned by Grant (2013) and Begley *et al.* (2005).

4.1.2 National Determinants

Being a small peripheral island nation with a small home market was seen as negative or a limiting factor. In many respects, these negatives were somewhat offset by the technological changes of miniaturisation and improvements in communications and logistics. The small open economy, while vulnerable to global changes and increased competition, was also capable of the **flexibility** required to suit fast-paced industries, according to Respondent 13. Another advantage of this national characteristic was that there was good "crosspollination between companies" (Interview 15). This respondent saw Ireland as good for **networking** because of the small size. Scale and size were seen as reasons for a niche approach to manufacturing and for selectivity in research areas. Also, scaling for indigenous companies did not occur according to the data collected, but here, again, globalisation has meant that some successful Irish companies are now multinational in their own right.

Government policy was mentioned as a driver for the industry, particularly the policy of **foreign direct investment.** References were made to the supports of the **IDA and Enterprise Ireland** for the sector. **Tax** was mentioned by most respondents as a driver and was the first one that came to mind in many instances.

Time zone was a newer driver which came into play with the effects of globalisation and Ireland's location as a crossover time zone between the United States and Asia. This driver was mentioned by two respondents. The IDA respondent said it is currently a good selling point for the IDA, particularly as they look to broaden the FDI base.

Unions were mentioned as an inhibitor, particularly in respect of the early development of the industry in the 1960s and 1970s. The GE subsidiaries had serious difficulties when they refused to recognise the unions in the 1960s, as recounted by Respondents 13 and 14. Strikes were a regular feature on the Irish industrial arena in the 1970s. By the 1980s, Respondent 7 was informed that the factory would be shut if there was any hint of union involvement and he lived in fear of an employee demanding his rights to union representation. "*No unions*" was a comment by another respondent in relation to working in a multinational in the 1990s. Respondent 10, who currently resides in the United States, gave the outside view that "*With the software world Ireland has a very good reputation of being easy to deal with. In the hardware world, there was the reputation of being a little bit unionised and sometimes having a little bit of a problem.*"

Costs were initially a positive driver in the 1960s but this changed as Ireland became more prosperous. Where some of the electronic manufacturing had held out "longer than it should have", eventually cost became the reason for the move of much electronic manufacturing overseas. "It went

in the end for cost pressure" (Interview 6). Around the year 2000, government began to focus on competitiveness (Ryan and Giblin 2012). Wage agreements were not mentioned in the data gathered but featured in Collins and Grimes (2008).

Many workforce characteristics were mentioned as drivers - "*easy to get along with*", "*Good for bonding with customers*", "*Can-do attitude*", "*Willingness to travel*", "*the ability to network and create linkages*" and "*employee loyalty*". **Ireland's reputation** was particularly mentioned in the data as a positive driver and that in the area of technical abilities "*we are well perceived internationally*".

A more recent driver was the development of the investment infrastructure and venture capital availability. **Funding** was mentioned by the state agency respondents but also by some of the respondents with industrial experience, particularly the entrepreneurial respondent and a respondent who had worked in a technology spin out company. In the literature, O'Riain (2004) identifies the period around 1998 as a time when venture capital become more available in Ireland. This more entrepreneurial climate, with good start-up companies, was identified as a driver both to drive the domestic economy and as an attractor for foreign investment.

4.1.3 Industry Determinants

Some comments reflected the turbulent environment of the electronics and software industrial sectors. "*Speed to market*" was identified by some respondents; "*the only advantage in software is time*" and "*it is about getting your product to market first"*. Also, speed in responding to the market was mentioned "*so we can respond very quickly*". The sector was very much identified as being **market driven** in the interview data.

Respondent 14 indicated that they had survived only because they undertook continuous product development and research to continuously upgrade and adapt the product for the changes in technology and in the market. He also mentioned a unique product offering and the firm was continuously looking to add value to the product.

Vision and Ambition were identified by three respondents, one, at an industry level, one at a personal level and one, in the "Leadership for Growth programme". Respondent 14, in an indigenous Irish company, said "*There is no reason why we cannot become the next Glen Dimplex and that's the ambition"*. Respondent 13 reported that he had decided "*by the time I am 35 to be managing a factory… I made up my mind and that was on a piece of paper under my pillow*". Respondent 9 indicated that '*Aspiration*' was the first goal to be worked on in the Stanford 'Leadership for Growth' programme he attended.

The need to move up on the value chain became a driver as electronic manufacturing came under pressure and three respondents had experience of this within two large multinationals. Another respondent (Irish-owned company) felt that remaining vertically integrated was a strength. He would be reluctant to split the activities even though the company had expanded and had overseas subsidiaries.

Production and Operational developments were also seen as drivers. One respondent mentioned the adoption of world-class manufacturing and Japanese techniques as a reason for success. Another

mentioned Lean Manufacturing as a success driver and "Kaizen" had particularly "played a key role in" their continued success.

The types of company and **company culture** within the industry were also seen as drivers. 'Open' and 'developmental' were two words used. This was certainly the case with the Digital Equipment Corporation and Respondent 10 recalled that this openness contrasted with a more restricted and hierarchical structure in other existing industries in the country in the early 1970s. These companies had good training and management development. Digital was a "*very open company and I think those kinds of companies really made an enormous difference in Ireland. So it was very different than the traditional world. And Digital, the opportunity there was infinite"*. These new companies were then the source of management for further incoming investing companies and, in some cases, for starting up Irish technology companies. Respondent 13 commented that, during his time in GE subsidiary Ecco, "at least 50 CEOs in Ireland who had worked for me at one stage". This shows development of **a capable managerial cohort w**ho led or started up other companies.

4.1.4 Firm Level Determinants

Many firm level drivers were also identified in the data. Company culture was already mentioned in relation to DEC and Respondents 6 and 7 also found this to be the case with EMC. "Open" was the word chosen to describe these types of company. **Cost versus profit** was identified by Respondent 5 as the key in determining the culture of the firm. Where profit margins were high, the company culture tended to be open and progressive. Where cost was key and margins were low, the culture tended not to be so open or developmental. Respondents differentiated between consumer electronics and components, subassemblies and full products. Companies that were supplying a complete product to the customer tended to have more margin than the sub-assembly and component manufacturers.

"**Communication**" was mentioned by two respondents as an important company driver. Respondent 14 believed that it was important to communicate well with employees and particularly so, in difficult times, so that they are aware of what is happening. Respondent 6 attributed some of EMC's success to good communication, "*you had many functions but I think the walls between the functions,…the silos weren't that great. There was definitely a good flow of information across. You know, that was just the nature of it but being close to the customer was always seen as very important*".

This "**customer focus**" and closeness to the customer was mentioned as important by Respondents 1 and 15, also. Respondent 15 recalled that Telecom Éireann were flexible and looked to match the customers' expectations in small matters as well as big and he recalled "*If their customer was calling from Germany they got a German ring tone, not Irish, and they were the little things you needed to do."*

Other firm level drivers included "*hiring the right kind of **people***" as "*people are the most important asset*" and **product development**. Respondent 14 indicated that they had survived only because they undertook continuous product development and research to upgrade and adapt the product for the changes in technology and in the market. He also mentioned a unique product offering and the firm was continuously looking to add value to the product.

4.1.5 Individual Determinants

"**Personal relationships**" were identified as a key driver in many instances. Respondent 11 said "all business is personal". Respondent 6 felt that things "happen through people and through personal relationships". One respondent indicated that a CEO with Apple always looked for the key personal relationship within supplier companies and he asked other staff to do the same.

This personal relation benefit could percolate throughout an organisation.

*"I saw it more in Apple than anywhere else, where the supervisors on the floor would be asked their opinion on how to do something and they eventually had a level of personal vested interest … They still worked rigidly on their hours but they were more willing to give of their time for something once they were brought into it, so to speak, … it wasn't a them and us thing. Now we are all in this together and we have to make i*t" (Interview 11).

It is interesting here how a more personal relationship to the work then translated into a better team environment. This improved environment was also reported by Respondent 14 whose company *"is known as a very friendly company/place to work for and a nice place to work and that's because we treat the person, very much the full person"* When hiring engineers as an Operations Manager, Respondent 7 "*was always just look[ing] for more of a personality fit. So let's say the hiring manager or supervisor, I depended on them to make sure that technically the person was actually qualified to do the job they were hired to do and I was always more interested then in 'ok will this person fit in with the thing?'"*

In reviewing which start-ups to support in Enterprise Ireland, "*it just comes down to those two things the project and the person"*. This respondent saw a requirement for both to be evaluated because "*the project can change and adapt and then there are the people. And once you've got some sense of the person, you can tell fairly quickly if they have that dedication"*.

The **ability to take risks** was also identified. One respondent indicated that industry was, to his mind, the more exciting career choice. One CEO indicated that he had come through the multinational experience but, he had *"taken a chance and gone off and done something uncomfortable … It is easy to take the next easy shilling and go in and work"*

4.1.6 Technology Determinants

The **developments in communication** and the speed of communications were identified as a "huge enabler for industry" by Respondent 15. In the late sixties, one respondent "began doing this switching for ordinary telephones as well, using solid state instead of the …relays because relays began to cost a fortune because of the copper". He recalled working in a rural IDA start-up in the late 70s when the phone system still required an operator. Respondent 15 described adapting the telephone system in Telecom Éireann to adapt to the needs of incoming call-centres in the late 1990s. Respondent 9 indicated how business was global in the software space and that communications meant that overseas partners could be found without the need to travel and meet in person.

Alongside this, technology drove improvements in **logistics and delivery mechanisms.** This was an inhibitor for manufacturing but a driver for the more knowledge-intensive software and services which could make use of newer business delivery mechanisms.

Legislation and regulation were drivers for one company. The introduction of regulation in a particular area gave their product the means to avoid becoming a consumer electronic product, susceptible to cost competition from overseas. Alongside continuous upgrading of functionality in the product, to meet modern market needs, the product was also differentiated by quality and, by the service offered in supporting the product. As the product was a life-safety product, this combination turned out to be a winner for this company. Regulation and standardisation were notable features of the technology industries and had caused large effects in the PC industry, networking and telecommunications sectors.

High quality product was also identified as a driver. High **reliability** and stringent **testing** were mentioned as drivers. These were perceived as being more important in certain applications, and in hardware more than software. "*The cost of screwing up and being late is really, really bad. So the hardware people have built methodologies and, particularly, simulation and testing*" (Interview 10). The IDA respondent identified quality as an important driver for the Irish manufacturing space. One respondent compared the telecommunications sector with the computer sector and found that the difference was *"reliability was just way higher. You lift off the telephone, you get dial-tone –end of story"*. Reliability was also an issue for EMC who were competing against IBM in the electronic storage market and "*So, there was the performance of the product, that it had to be twice as good as IBMs product and then just quality and reliability had to be - that it wasn't going to break down at some critical time for that customer*" (Interview 7). To get this level of reliability "*the testing was extreme*" but eventually the move to outsource for cost savings came in here too. Cost overtook these drivers and resulted in the moves to off-shoring and the advent of the value chain approaches.

The incorporation of **research and development** in the industry was also seen as a driver. R&D "is in the blood" (Interview 14). This respondent saw it as a vital ongoing process without which they would not have survived. "*As our features are equalised, obviously the prices are eroding and that's where the pressure is on R&D to be ahead on the next feature. So we are constantly looking for the next thing to be ahead on and we have done a bloody good job of it over the years"*. Respondent 3 compared a research environment with the industrial environment. *"The Apple experience was completely different. I worked in a very small Irish research type company which, I only realised later on, didn't really grow people very well. [It] didn't give people responsibility and authority or didn't allow you to make mistakes".*

The Enterprise Ireland respondent reported that "*If you look at it from a research perspective, there has been a huge amount of funding gone into research over many years*". This indicated an ongoing *importance of R&D, as identified by the government. However, he pointed to a low starting-base here also "The debate sometimes about the research agenda and the research we have now is usually linked to spinouts. But we didn't actually have a research, a sufficient research environment/mass for an industrialised nation twenty years ago or thirty years ago"*. He pointed to spin-out companies being used as an indicator of successful use of research funding but also "*from the start-up perspective, it's important that that capability, that funding is in place, not only for the start-up but to facilitate IoTs and third-level generally to reach out to companies at all stages of development."*

5.0 Conclusion and Implications

TRM has been practiced by some organizations for decades (and much longer under other titles), but the broader adoption of road-mapping practices is still relatively new (Kostoff and Schaller, 2001; Carvalho *et al.* 2013). The approach is flexible and adaptable and other relevant data points can be inserted without negating the previous work. It would benefit greatly from a research team which would reduce any possible single-researcher bias and would mean that a greater volume of data could be gathered and analysed.

Despite the limitations of the framework, this study provides an initial retrospective ICT sectoral analysis work that subsequent research can build upon. Case studies that use retrospective TRM as a framework would be of benefit in further evaluating this as a suitable industry research method. As such, the findings of this study are not generalisable, but it is possible that this method of looking at industry development can be used to explore development of other industrial sectors. It may also be of benefit to newly industrialising countries looking to develop their ICT industry.

This research contributes to the body of knowledge of industry evolution and analysis by identifying the parallel development and interplay between education, government policy and technology. A limitation of this study is that the time frame ends in 2010. The industrial sector, technical education and government policy have experienced many changes since then and are continuing to undergo changes. This needs to be kept in mind when reviewing the findings.

We suggest that the evidence presented here can inform further policy development and a set of recommendations in this regard is put forward. For example, this study has highlighted a difference in opinions about the exit strategies of some of the successful indigenous ICT companies. All were agreed that successful entrepreneurs deserve reward for their success, but the question was posed as to whether some of these companies could be kept as Irish-owned companies and further developed under Irish management. While it would certainly not be suitable in all cases, there are perhaps some companies where there would be merit in seeing if more larger-scale internationally-trading Irish technology companies can be created. It may also improve the managerial cohort in larger scale companies in the indigenous ICT sector. Government needs to consider whether a layer of support could be put in place to examine if entrepreneurship policy can incorporate a means to maintain businesses (with long-term scalability prospects) in Irish ownership. Currently, there is no mechanism where this can even be considered.

From an education perspective, this study has revealed many changes in technical education over the course of the five decades reviewed. Throughout, matching of skills to what is required by the ICT sector at any given time was, and is, a particular challenge. From a simple requirement to drive the development of electronics industry by a policy of foreign direct investment, government policy evolved and developed to drive industry in a more holistic process. Government policy now seeks to drive industry using other macroeconomic change drivers, such as, education and entrepreneurship. In the 1960s and 1970s, government educational focus was on improving the educational base within the country. Free secondary school education was introduced in the 1960s and Regional Technical Colleges were built with the specific purpose of providing skilled workers for the industry attracted. The move to the 'knowledge economy' has upped the requirement for a greater number of PhDs and

Masters qualified jobs. Not everyone is suitable to undertake such high levels of academic study and the area of apprenticeship and the role of the technician also need to be advanced to match the 'knowledge economy'. This more democratic approach to technical education was echoed in the conclusions of a 2004 European Commission report,

> *"Certain policy-makers … advocate that the creation of élite higher education institutions in Europe should be the main policy objective. We do not agree with this view that, in our opinion, disregards the social and cultural context of scientific development in democratic societies, the need to reinforce and widen the social constituency able to support scientific and technological development and, notably, the very wish to study science and pursue science and technology careers. Such approaches also tend to disregard the importance of science literacy for all in democratic decision-making as well as the role of science learning in developing critical thinking skills"* (Gago, Parchmann, and Europäische Kommission 2004).

As the ICT industry is fast paced, many employers are no longer willing to do on-the-job training and want them *'oven-ready'* directly as they come out of college. This has led to a requirement in broadening technical education to produce such work-ready graduates. A key area of benefit would be identification of the best technical education model(s) to match engineering education and skills development to the needs of a dynamic and continuously changing industrial sector. The development of the Expert Group for Future Skills Needs (EGFSN) has certainly helped in this area but job churn and the associated job insecurity are difficult selling points for an industry to attract new 'talent'. In this area, establishment of lines of demarcation would perhaps be helpful. This demarcation was once an area of difficulty where barriers needed to be broken down to allow linkages and networking between educational institutions and industry. A framework to establish the duties of care of the various stakeholders in training and development would be beneficial. A clearer definition in areas of responsibility of education and training is needed. What are the responsibilities of the student, the third-level educational institution and the industrial sector?

Throughout the fifty years of ICT sector development considered in this study, a capable managerial cohort was developed. This cohort managed the next generation of industry, leading to a cumulative and continuous development. One of the side-effects of running a 'lean manufacturing' process, which is necessary to compete in the global manufacturing environment, is that the next generation of management tends not to be a priority. The 'self-destruct' employee also has implications in terms of employee loyalty and for management succession and future planning. Government policy should lead the way and provide exemplars of how to build a skills portfolio for individuals and find a means for evaluation and identification of requisite transferrable skills and how they can be developed. Ideally, a means to build these transferrable skills in co-operation with industry should be found.

In conclusion, retrospective roadmapping allowed a broad view of the sector development throughout the time period of this study. This maintaining of breadth allowed significant insight into the ICT sector development in Ireland and was successful in identification of many industry drivers. It has identified many other changes and trends which have implications for the present and the future. Emerging themes in the data pointed to some negative drivers which may act to the detriment of the sector such as weakness in mathematics for engineering, fluctuation in Leaving Certificate entry points to third level courses and parental influences on career choice. Development trends

identified were a change in the perception of education with time, a change from the 'job-for-life' to the 'tour-of duty' and a change of emphasis from the individual to teamwork in engineering working life. Emerging trends in the empirical data collected highlighted the issue of a lack of an engineering identity supported by the opposing discourses within engineering itself. These discourses are the generalist versus the specialist, the professional engineer versus the engineering manager and the academic versus the practical.

References

Barry, F., and C. vanEgeraat. 2005. "The Eastward Shift of Computer Hardware Production: How Ireland Adjusted." *National University of Ireland-Maynooth, National Institute for Regional and Spatial Analysis Working Paper 27*, 1–57.

Begley, T. M., E. Delany, and C. O'Gorman. 2005. "Ireland at a Crossroads: Still a Magnet for Corporate Investment." *Organizational Dynamics* 34 (3): 202–17.

Bhaskar, R. 1997. *A Realist Theory of Science*. London: Verso.

Carpenter, M.P., F. Narin, and P. Woolf. 1981. "Citation Rates to Technologically Important Patents." *World Patent Information* 3 (4).

Carvalho, M.M., A. Fleury, and A. Lopes. 2013. "An Overview of the Literature on Technology Roadmapping (TRM): Contributions and Trends." *Technological Forecasting and Social Change* 80: 1418–37.

Collins, P., and S. Grimes. 2008. "Ireland's Foreign-Owned Technology Sector: Evolving Towards Sustainability?" *Growth & Change* 39 (3): 436–63.

Culliton, J. 1992. "A Time for Change: Industrial Policy for the 1990s; Report of the Industrial Policy Review Group." Stationery Office, Dublin.

Danermark, B., M. Ekstrom, L. Jacobsen, and J. Ch. Karlsson. 2002. *Explaining Society: Critical Realism in the Social Sciences*. Psychology Press.

deWit, B., and R. Meyer. 2010. *Strategy Process, Content, Context ; an International Perspective*. Andover, Hampshire: Cengage Learning.

Easton, G. 2010. "Critical Realism in Case Study Research." *Industrial Marketing Management* 39 (1): 118–28. doi:10.1016/j.indmarman.2008.06.004.

Enterprise Strategy Group. 2004. "Ahead of the Curve. Ireland's Place in the Global Economy." Dublin: Forfás.

Gago, José Mariano, Ilka Parchmann, and Europäische Kommission, eds. 2004. *Increasing Human Resources for Science and Technology in Europe: Report of the High Level Group on Human Resources for Science and Technology in Europe, Chaired by Prof. José Mariano Gago*. Luxembourg: Office for Official Publications of the European Communities.

Gereffi, G., and J. Lee. 2012. "Why the World Suddenly Cares About Global Value Chains." *Journal of Supply Chain Management* 48 (3).

Grant, Noeleen. 2013. "A Taxonomy of Manufacturing Strategies in Manufacturing Companies in Ireland." *Journal of Manufacturing Technology Management* 24 (4): 488–510.

Hedlund-deWitt, N. H. 2012. "Critical Realism : A Synoptic Overview and Resource Guide for Integral Scholars." MetaIntegral Foundation, Integral Research Center, Resource Paper. https://foundation.metaintegral.org/sites/default/files/Critical%20Realism_4-12-2013.pdf.

Kappel, T.A. 1998. "Technology Roadmapping: An Evaluation." PhD dissertation, Evanston, Illinois: Northwestern University.

Kostoff, R.N., and R.R. Schaller. 2001. "Science and Technology Roadmaps." *IEEE Transactions on Engineering Management* 48 (2): 132–43.

Kvale, S., and S. Brinkmann. 2009. *Interviews - Learning the Craft of Qualitative Research Interviewing*. Second Edition. United States of America: SAGE Publications Inc.

Lincoln, Y.S., and E.G. Guba. 1985. *Naturalistic Inquiry*. Beverly Hills, Calif.: Sage Publications.

Matthyssens, P., K. Vandenbempt, and W. Van Bockhaven. 2013. "Structural Antecedents of Institutional Entrepreneurship in Industrial Networks: A Critical Realist Explanation." *Industrial Marketing Management* 42 (3): 405–20.

Maykut, P.S., and R. Morehouse. 1994. *Beginning Qualitative Research: A Philosophic and Practical Guide*. London; Washington, D.C.: Falmer Press.

McSharry, R., and P.A. White. 2000. *The Making of the Celtic Tiger: The inside Story of Ireland's Boom Economy*. Cork: Mercier Press.

Miles, M.B., and A. M. Huberman. 1994. *Qualitative Data Analysis: An Expanded Sourcebook*. 2nd ed. Thousand Oaks: Sage Publications.

Neergaard, H., and J.P. Ulhøi. 2007. *Handbook of Qualitative Research Methods in Entrepreneurship*. Cheltenham, UK; Northampton, MA: Edward Elgar.

NESC. 1982. "A Review of Industrial Policy: A Report Prepared by the Telesis Consultancy Group." Dublin: National Economic and Social Council.

O'Gorman, C., E. O'Malley, and J. Fahy. 1997. *The Irish Indigenous Software Industry: An Application of Porter's Cluster Analysis.* Vol. 3. Research Series. NESC (National and Economic Social Council).

O'Riain, Seán. 2004. "State, Competition and Industrial Change in Ireland 1991-1999." *The Economic and Social Review*, Spring 2004, 35 (1): 27–53.

Phaal, R., C.J.P. Farrukh, and D.R. Probert. 2004. "Technology roadmapping—A Planning Framework for Evolution and Revolution." *Technological Forecasting and Social Change* 71 (1-2): 5–26.

Phaal, R., E. O'Sullivan, M. Routley, S. Ford, and D. Probert. 2011. "A Framework for Mapping Industrial Emergence." *Technological Forecasting and Social Change* 78 (2): 217–30.

Porter, M.E. 1980. *Competitive Strategy: Techniques for Analyzing Industries and Competitors*. New York: Free Press.

———. 1991. "Towards a Dynamic Theory of Strategy." *Strategic Management Journal* 12: 95–117.

———. 2004. *Competitive Advantage*. New York; London: Free Press.

Ryan, A., J. Tähtinen, M. Vanharanta, and T. Mainela. 2012. "Putting Critical Realism to Work in the Study of Business Relationship Processes." *Industrial Marketing Management* 41 (2): 300–311. doi:10.1016/j.indmarman.2012.01.011.

Ryan, P., and M. Giblin. 2012. "High-Tech Clusters, Innovation Capabilities and Technological Entrepreneurship: Evidence from Ireland." *The World Economy* 35 (10): 1322–39.

Sayer, R. A. 1992. *Method in Social Science: A Realist Approach*. London; New York: Routledge.

Second Programme for Economic Expansion Part II. 1964. Dublin: The Stationery Office.

Smith, N.J. 2006. "Mapping Processes of Policy Change in Contemporary European Political Economies: The Irish Case." *The British Journal of Politics and International Relations* 8 (4): 519–38.

Sterne, J. 2004. *Adventures in Code: The Story of the Irish Software Industry*. Dublin: Liffey Press.

Sturgeon, T.J., and M. Kawakami. 2010. "Global Value Chains in the Electronics Industry : Was the Crisis a Window of Opportunity for Developing Countries ?" Policy Research working paper ; WPS 5417. No. WPS 5417. : World Bank. Washington, DC: The World Bank.

http://documents.worldbank.org/curated/en/2010/09/12753375/global-value-chains-electronics-industry-crisis-window-opportunity-developing-countries.
Tiernan, S., M. Morley, and E. Foley. 2006. *Modern Management: Theory and Practice for Irish Students*. Dublin: Gill & Macmillan.
Yin, Robert K. 1989. *Case Study Research: Design and Methods*. Newbury Park, Calif.: Sage.
Yin, Robert K. 2014. *Case Study Research: Design and Methods*. 5th ed. Library of Congress Cataloging-in-Publication Data, USA: Sage.