Capabilities & Competitiveness:

A Methodological Approach for Understanding Irish Economic Transformation

THE LUCERNA PROJECT REPORT - 2010

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Executive Summary

Ireland has achieved significant economic growth that has been characterised by rising high-tech exports and knowledge-based employment. This growth was driven primarily by the presence of foreign-owned multinational corporations in high-tech sectors and its sustainability has always remained a basis for debate. A deeper understanding of industrial change and the technological capabilities that underscore the Irish economy at present is essential to resolve the debate. The Government has ambitious plans for moving toward the 'smart economy' with high levels of R&D. But does the Government have partners in the private sector in the form of fast growing companies with the organisational and technological capabilities to drive growth and create tens of thousands of jobs? While many Irish government reports describe the post Celtic Tiger growth challenge and set ambitious targets for employment growth in new sectors (such as renewable energy) and increased private sector R&D, they suffer from a common weakness: very little 'coalface' data on business organisation including evolving production and technological capabilities.

Public data on industrial sectors is aggregated at a level that means researchers on industrial enterprise evolution and technological change are unable to track the firms or account for changing product boundaries. Companies are anonymous and company product mix data is not recorded in such public data. The anonymity of companies involved obscures growth dynamics and the neglect of product information cloaks cluster boundaries and dynamics. Therefore, the picture of industrial activity is incomplete. Therefore, crucial policy questions go unanswered with available public data, as currently structured, such as whether the capabilities are in place in Irish industry to allow a transition to a new business model based on endogenous development; whether there is potential for an enhancement of these capabilities through technological convergence that occurs at the intersection of two or more of the technology-based clusters that presently exist; whether expanded funding of HEI research can be an engine of high-tech growth; and whether new sectors can have large employment impact.

To address this data deficit the 'Lucerna' database has been developed at the Centre for Innovation and Structural Change (CISC) at NUI Galway. The project is funded under the EU's Marie Curie Transfer of Knowledge programme and reflects a partnership between NUI Galway and the University of Massachusetts, USA, where a similar study was conducted for high-tech industry in the 'Greater Boston' region. The Lucerna database provides detailed information on high-tech companies designed to characterise evolving technological capabilities, deep craft skills, emerging industry dynamics and churn. As the database will assist policy makers and academics to answer the identified key questions we propose to make it open access to those interested parties that may wish to interrogate it.

In essence, the Lucerna dataset serves as a metaphorical laboratory to study the emergence of high-tech industrial sectors. It is composed of firms and the products they make – single or multiple – and the sectors they operate in. Many firms, particularly large ones, operate in more than one sector. Companies that straddle industry boundaries are most important in understanding industrial change and renewal as firms transition into new industries and products. Lucerna includes rapidly growing companies, those in transition and foreign MNC subsidiaries that drive industrial growth and, as such, are the carriers, developers and consolidators of regionally distinctive technological capabilities. To demonstrate the power of the Lucerna database we have undertaken preliminary data analysis exercises in two key areas:

1. An examination of the historic emergence, growth, dynamics, and distinctive capabilities of the successful Medical Technology sector in Ireland.
2. An assessment of the future for Renewable Energy, examining the potential and barriers for this emerging sector of the Irish economy.

The report suggests that from a capabilities perspective, Ireland has assimilated certain technological, manufacturing and managerial capabilities primarily from the presence of multinationals and supported by HEI investment that can be the drivers of economic growth.

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1 A Methodological Perspective on Irish Industrial Capabilities and Competitiveness

1.1 Introduction

The project LUCERNA—Latin for ‘a lamp’—is a means to shed light on highly disaggregated industry data, particularly in the contexts characterised by rapid technological change, where the challenges of measurement are especially acute. The Lucerna project integrates competitiveness and innovation scholarship with database techniques in data gathering and economic development analysis. Micro enterprise level data are employed to populate a virtual laboratory of high-tech companies and then to ‘interrogate’ this population of companies and conduct experiments designed to understand the sources of industrial development and to enrich the concept of industrial dynamics. The database provides a research capacity to gather, analyse, and disseminate finely detailed business demographics in emergent and fast-changing high-technology clusters. It facilitates the determination of the competences of firms in a technology cluster and accordant distinctive regional capabilities.

1.2 The Capabilities Perspective

Business organisation and technological advance are central to the story of industrial development and change. Capabilities are organisational accomplishments that take time and teamwork to develop. According to Teece et al., (2000) capabilities are the ability to reconfigure, redirect, transform, and appropriately shape and integrate existing core competences with external resources, strategic and complementary assets to meet the challenges of a time-pressured, rapidly changing world of competition and imitation. The concept to some extent combines both the hard part of technology in the form of science and engineering and the softer aspect such as the processes enabling its effective application (Phaal et al., 2004). It is evident from many empirical studies that micro-level organisational capabilities within specific firms can be related to macro level regional capabilities. From this perspective technology is seen as cumulative and differentiated. As a result the present industrial capabilities (industrial composition of innovation activities and growth) in a given location reflects past technological accumulation (Boschma & Frenken, 2006).

Closely related to production capabilities and business organisation, technology (and its close associate, technology management) is a specific form of organisational capability. However, technology differs from the other forms in two related ways. First, technological capabilities are inherently dynamic: they are continuously reshaped with every iteration of the ‘capability and market opportunity’ cycle. Sometimes, the change is to a ‘next generation technology’; other times it involves the integration or re-integration of two or more technologies as part of new product development. Second, technology capabilities are unique: they impart distinctive industrial signatures or fingerprints. Thus, technological capabilities are marked by both change and continuity. Their evolution is regionally path dependent. Best (2001; 2005) argues that regional core competence is about distinctive regional technological capabilities that have been cumulatively and collectively developed across enterprises over time.

Successful regions, like successful firms, have core competences or distinctive capabilities that impart competitive advantage. Like all capabilities, the regional variant takes time and teamwork to develop, is not easily imitated, and cannot be purchased in the marketplace. Such regional technological capabilities are intangible; they are embedded in the production processes and deep craft skills of a region's inhabitants, and are manifest in distinctive industrial sectors, or technology-based clusters. The underlying distinctive capabilities give a regional organisational advantage. At the same time, participants can easily take distinctive capabilities and associated skills for granted. The empirical challenge is to audit and characterise a region's technological capabilities.

Best (2006) relates how regions such as Massachusetts differ from less successful regions in sectors such as medical devices. He states that part of the answer lay in Massachusetts long history of precision engineering and instrument making dating back to weaponry production centuries earlier through defence and more recently, mini-computers and ICT. Ireland, with its agrarian-based economy over centuries of colonisation has no comparable industrial heritage and legacy. Pockets of regional capabilities such as glass-blowing in Waterford existed. But these did not provide a basis for high-tech development. However, in recent decades multinational companies based in Ireland have transplanted capabilities in critical areas such as precision engineering in Galway for medical device production (and lately design). Higher education institutes have also targeted high-technologies for capability development, such as regenerative medicine and nanotechnology.

The high-tech companies that thrive today do so as members of specialised groups that both leverage and renew a long-established heritage of regionally distinctive technological capabilities and skills. They combine the region's technology capability and skills heritage with an 'open systems' business model to contribute to a vibrant regional innovation system. A regional innovation system successfully builds on and leverages a region's distinctive technological heritage (Best, 2005). The described 'capabilities perspective' underpins much of the analysis of the Irish high-tech real economy in this report. The next section sets out the current situation for the Irish high-tech economy.

1.3 Ireland in the Global Context

It is a time of industrial and economic transition globally and in Ireland. While the news is filled with accounts of imbalances in the property and financial markets, the 'real' economy has structural imbalances that demand attention as well. It is in the real economy that a nation's wealth is created and innovation is concentrated. Ireland, as a small nation, will never be immune from disruptive forces of globalisation but the constructive forces can offer great opportunities. During the 1980s and 1990s Ireland successfully rode waves of technological change generated particularly in America. The marriage of business and technology in post war America was accompanied by the emergence and rapid growth of new high tech sectors driven by technology-intensive business models.

In post war America and in the technologically stable industries, the multi-divisional model prevailed in which corporate R&D labs were financed by oligopoly profits. Subsequently, a new, continuous improvement model of innovation made the Japanese business system a competitive force in mass production industries. But in recent decades yet a third model of innovation emerged. This involved an inter-institutional assemblage of government, universities, and business which fostered a new interactive model of industrial innovation with powerful locational effects. Greater Boston's 'Route 128' and California's 'Silicon Valley' became the archetypal regional innovation systems. Greater Boston is populated by some 3000 high tech enterprises and Silicon Valley by twice that number.

Ireland never has had and will not likely soon be an independent source of industrial innovation and technology development at least on the scale of the three models of business organisation mentioned here. A small economy simply will not have the range of infrastructures required to sustain an innovation ecosystem like that of greater Boston or Silicon Valley. But at the same time, many of the success stories of small economy, high-tech sectors such as Taiwan, Israel, Singapore, and Ireland have developed business models that are closely inter-related with America's high tech industrial districts.

What these small nation success stories illustrate is that the forces of rapid technological development can be tapped not only within the regions in which they are centred but by distant locations which develop complementary capabilities. In the case of Ireland, affiliates of fast growing high tech enterprises were attracted by the availability of world-class production and remote-management capabilities for routine activities. These capabilities became the means for the transfer of technologies and business practices developed elsewhere.

A critical mass of affiliates with positive feedback loops was quickly established in several rapidly growing sectors including computers, software, bio-pharma, medical devices followed by internationally tradable services. Along the way Ireland developed national capabilities in the rapid ramp up of production facilities for the world's leading high tech companies combined with management capabilities for the marketing, sales, logistics and related activities for US companies seeking a platform to grow market share in Europe.

However, over time imbalances and barriers have arisen. Growth was concentrated in production and management activities that can be imitated by other regions with similar government policies. Growth was also concentrated in rapidly growing sectors with high tradable content. While the latter is not undesirable on its own, it meant that little attention went to a number of key infrastructural sectors such as energy and transportation. These sectors have proven intractable to development by invitation strategies. They are huge sectors of the economy that have been highly resistant to innovation and technological change. And, as in the case of renewable energy demonstrated in section 3 of this report, Ireland has huge and untapped natural resources. This is a case of organisational failure.

Second, Ireland's economic success, driven by affiliates of large foreign global companies, has not, to date, been accompanied by the indigenous 'industrial districts' of networked groups of differentiated and specialised small firms. This model of business organisation, common to high income regions of Italy, Denmark, and Germany, does not seem to have taken hold in Ireland. Its best example may be in the continuing evolution of the medical technology cluster in Galway, as shown in section 2 of this report.

With the global downturn in the last half of the present decade new queries are raised about the sources and dynamics of growth in the past and the potential drivers of growth as Ireland enters a new era. The last 20 years have seen the emergence of a substantial body of comparative historical research on the foundations for industrial development (Chandler, 1990; Lazonick, 1990; Porter, 1990; Freeman & Soete 1997; Best, 2001). What emerges from this literature is the interplay of Industry, Technology, and Innovation. How do the last couple of decades of industrial development in Ireland fit into this literature? What can we learn about Ireland's evolving capabilities from this interplay - its industrial dynamics? Addressing these matters depends upon the availability of enterprise (firm)-level data.

In a comprehensive search for information on business enterprises and industrial growth in Ireland we found a serious lack of availability of reliable and complete enterprise-level data required to investigate these issues. In an attempt to overcome these limitations the Lucerna research team developed a new dataset that provides insight into industrial dynamics[1] of Irish high-tech industry. This next section of the report describes a systematic approach to identify key technology sectors in the Irish economy. The shortcomings of existing datasets are discussed in more detail in the next subsection and the construction of the new database described. We outline the advantages of the dataset and broad implications for the utility of this methodology for researchers and policy makers. Some examples of analytical exercises are conducted for illustrative purposes of the utility and potential power of the Lucerna database.

1.4 Shortcomings of Existing Data

Many studies have shown that a certain amount of insight into industry dynamics can be gleaned from disaggregating all Irish industrial activity by 2 digit NACE codes. At the same time, we have found a number of shortcomings in addressing this issue using available official data.

a. The data on business enterprises is lacking and incomplete. Even at a relatively basic level it has been noted that gathering data on firms in Ireland is

[1] There are four main facets to industrial dynamics: 1) the nature of economic activity in the firm and its connection to the dynamics of supply and therefore economic growth, particularly the role of knowledge; 2) how the boundaries of the firm (degree of vertical integration) and the degree of interdependence among firms change over time and what role this interdependence plays in economic growth; 3) the role of technological change and the institutional framework conducive to technological progress at both macro and micro levels; and 4) the role of economic policy in facilitating or obstructing adjustment of the economy to changing circumstances (domestically as well as internationally) at both micro and macro levels of industrial policy.

problematic. As O'Sullivan and Giangrande (2002) stated, "In the Irish case …trade associations, development agencies and similar organisations were extremely disappointing as sources for company lists. In most cases, these organisations could not provide us with a list of companies and when the information was available it was typically limited." In many cases, companies are anonymous in official data or subject to confidentiality clauses making large-scale company-based analysis nearly impossible. Critically important, longitudinal examination of individual companies and sectors is not possible.

b. The current statistical datasets on industrial sectors provided either commercially or by state agencies, such as, the Central Statistical Office, are constructed according to standard industry classification systems such as NACE, SIC or NAICS, which are too broad and static to capture the location, source and extent of technological change and industrial transition. The data conflates growing and declining subsectors and companies within sectors. In addition, multi-product technology-driven companies often operate in more than one NACE code but are recorded in only one. Furthermore, as technology has evolved so too have industry categories which introduce additional ambiguity into published industry aggregates. Many services sectors, for example, are excluded which create big holes in the data when technology-driven companies shift from, for example, packaged software, to down-loadable software as in the case of Microsoft in recent years.

c. The compilation of public datasets organises industrial sectors according to the share of value-added of firm activities carried out. However, this leaves researchers and policymakers with little insight into the development of specific activities and capabilities within particular sectors in Ireland as it does not comprehensively capture the particular products developed or services offered by firms and how they are evolving. We conclude that without more firm-level and finely granulated empirical information it is difficult to critically assess the fundamental challenges to the next stage of industrial development in Ireland. Therefore, the next section describes a unique approach to addressing these issues.

1.5 Lucerna Database Methodology Approach

At the firm level the process of product development capability (and corollary engineering design skills) can be accessed from product data. The assumption here is that product range is a suitable proxy of product development capabilities and, furthermore, potentially a 'measureable' indicator of advance in capabilities and underlying technology. Mapping product development change requires a finely granulated classification system that captures the firm's product portfolio and technology and can be aggregated to the level of region to address the issues related to innovation and industrial change.

This project develops a company dataset informed by a finely granulated and technologically-informed product classification system designed to identify key technology-based industrial clusters. The objective is to understand and monitor innovation and its economic impact through growth and changes in the key technology sectors that are critical to the nation's economy. Without the application of a technology-based classification system it is nearly impossible to assess dynamic, knowledge-intensive sources of growth or to compare business and technology development in Ireland with other regions.

To determine the key technology sectors we initially took as influence a number of American public studies (e.g. Index of the Massachusetts Innovation Economy, 2008; The 2008 State New Economy Index; and vTHREAD developed by the Centre for Industrial Competitiveness, University of Massachusetts, Lowell) to index and benchmark state technology and innovation performance. Many US states pursue technology-based economic development initiatives and deploy benchmark comparisons not only with leading states but with small technology leading nations such as Finland, Denmark, Israel and Taiwan. While every state and nation has a distinctive industrial portfolio, a number of key technology-based or knowledge-intensive clusters can be identified. We have characterised technology-based sectors in ways that draw upon these so that one can distinguish Irish technology sectors and at the same time make comparisons and develop historical performance measures.

Four steps were undertaken to construct the Lucerna database:

I. First, official, aggregative data was analysed to derive first approximations of industry composition for the purposes of focusing on significant sectors in terms of size, growth, and technology intensity.
II. Second, we searched an extensive product and service nomenclature for these significant industrial sectors using a comprehensive product classification system.
III. Third, a set of key technology-based clusters were derived from this high tech product and service list to facilitate international and inter-regional monitoring and comparisons of industrial performance.
IV. Fourth, the dataset of companies was used to populate these key technology-based-clusters.

We employ the term 'Technology Based Cluster (TBC)' to denote these aggregated industrial sectors that comprise the present Irish competitive high-tech sector. The procedures and limitation of these steps are described in the following sub-sections.

1.6 Identification of competitive sectors using official-data sources

Step 1: Identification of significant high-tech sectors

As noted, before turning to the development of the new company database, various exercises are performed on readily available industry data. Our purpose is to focus on significant sectors in terms of growth, size and technology intensity. By using publicly available data key sectors in Ireland are identified by the following indicators:

A. Industries with competitive advantage
    a. Revealed comparative advantage[2]
    b. Significant amount of export revenue
B. Industries with a significant amount of employment
C. Demonstrated growth or identified by government agencies as potential growth sectors
D. Both science-based and specialised supply sectors that are characterised by substantial organised R&D, strongly linked to science, display capabilities in engineering
E. Includes both manufacturing and service sectors[3]

As the present study is confined to high value export sectors based on capabilities in engineering and science, some of the traditional trade categories were excluded in the analysis[4]. This resulted in the identification of the following set of globally competitive industries: Organic chemicals; Medicinal and pharmaceutical products; Chemical materials and products; Office machinery and computers; Medical, precision and optical equipment; Radio, television and communications equipment; and Professional, scientific and controlling apparatus

Step 2: Product classification for the dataset

In the first step of developing the new dataset, an industry-product concordance was sketched using the Kompass Product Classification System. The Kompass Product Classification System consists of three levels: the first level (2 digit code) represents the broad industries, the second level (5 digit code) represents major product groups, and the third level (7 digit code) represents the individual products. Kompass's technical team in France updates this classification regularly and new products are continuously added to the classification system. We used the most recently published version of this classification (2008) that comprised 71 industry groups at 2-digit level which is further broken down into 1808 product and service groups. These 1808 product and service groups consists of 57335 individual products. The classification is organised in three parts: Industry Section [01 to 54 -manufacturers and traders who specialise in the products listed]; Trading Section [61 to 68 -only traders are listed in this section]; and

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[2] These examine the proportion of a good produced or exported, or the numbers employed in each industry, relative to other countries' international trade data. In an exercise Addison-Smyth (2005) used 'Balassa indices' to determine Ireland's comparative advantage for 2002. We extended this exercise to 2005 data.

[3] The detailed exercise to identify key industrial sectors is available in a CISC working paper: 'Competitive Irish Clusters – The application of the capability perspective to the study of cluster dynamics'.

[4] These sectors are: 'Food and Live Animals (SITC 0)', 'Beverages and Tobacco(SITC 1)', Crude materials, inedible, except fuels (SITC 2), Mineral fuels, lubricants and related materials (SITC 3), Animal and vegetable oils, fats and waxes (SITC 4).

Service Section [69 to 89 - only service providers]. Kompass groups firms by process or technology, independent of material. The 2-digit correspondence of Kompass product classification was searched to match the industries that we have identified as key competitive technologies in Ireland in the previous exercise. A high-tech product pool was constructed by thoroughly searching the product and service groups for correspondence with the 5 digit Kompass classification system.

Step 3: Creation of Technology-Based Clusters

The next step was to organise the product groups into technology- and process-related industrial categories for the purposes of indexing and conducting internationally comparative analyses of Ireland's industrial performance that is anchored in the development or lack of development of capabilities at the enterprise level. Initially, ten key technology-based clusters (TBCs) emerged from this exercise. An additional 'Renewable Energy' technology was added to our database because of its emerging significance.

Table 1-1: Competitive Technology-based clusters of Ireland and associated business units

Name of TBCs	Population*
Computer and Communication Hardware (CCH)	341
Software and Communication services (SCS)	865
Medical Devices (MEDEV)[5]	67
Pharmaceuticals (PHARMA)	107
Test, Measurement, & Instrumentation (TMI)	105
Processed Chemicals & Materials (PCM)	341
Diversified Manufacturing & Processing (DMP)	116
Renewable Energy (RE)	208
Scientific, Technical, Engineering, & Consultancy Services (STECS)	987
Business & Management Services (BMS)	6758
Finance and Insurance Services (FIS)	2402

*Note: Population as per Lucerna data set-1: 2008

Taxonomies have been created for the purpose of classifying product groups and establishments in the Irish context. They are based on the assessments of specific engineering intensity, technological know-how involved in the critical production processes, and proximity to closely-related technologies in the underlying scientific

[5] This TBC includes medical product/device manufacturing firms only. Service and support firms to the medical device sector are included in the Scientific, Technical, Engineering, & Consultancy Services (STECS) category. A comprehensive analysis of the medical device sector should include the MEDEV cluster along with the relevant service and support firms that are included in the STECS category (see Section 2 of the report; 'Case Study: Ireland's Medical Technology Sector').

discipline[6]. The resulting 11 key technology-based clusters and the number of associated business units in Ireland are shown in Table 1-1. The detailed composition of these technology based clusters in terms of the constituent 5-digit product and service groups from the Kompass classification are provided in annex-1.

Of the 11 key technology-based clusters, which include both manufacturing and service, our attention is focused on the manufacturing-based clusters. While the distinction is somewhat arbitrary, the business units in these clusters are predominantly where advances in business organisation capabilities in new product development and technology management are made operational. These are the practical sites at which innovation is translated into increases in productivity. This does not take away from the critical contribution of the three professional service dominated key industry clusters (the last three TBCs in Table 1-1) and particularly their employment impact, but these three industry clusters are primarily technology-using.

Step 4: Populating the technology-based clusters

Populating the eight TBCs involved the following steps. First company data, including company name, product code and description, employment and location information were pulled from the Data Ireland Kompass 2007 directory[7]. Second, after due data cleaning and validation; the company/business registration number assigned by the CRO (Company Registration Office) was identified for each company record. The CRO number is unique to each business unit and is used as the main identifier for our records and also used as a key to merge further micro-level data from different sources. For instance, company data from the FAME 2007 database was merged with the Kompass database by using the CRO numbers, and were individually matched to avoid duplication or record mismatch. In many cases, FAME provides more enhanced company demographic, profile and financial information than Kompass or any other dataset found in Ireland. However, companies in FAME are grouped according to the existing conventional industry classifications such as NACE and UK SIC and thus fail to allow users to identify product development capability and emerging technologies.

This practice of constructing bridges between multiple datasets by using a unique company identifier, i.e. the CRO number, allows flexibility within the Lucerna database by enabling users to further enrich the dataset as needed. Furthermore, in longitudinal series, the unique identifier allows users to monitor the development of individual companies as their demographics, production or organisational structures change over time. It also pinpoints the records in a panel and indicates operational time (exit from

[6] We removed some of the products (also product groups) that are not a part of Irish production and in some cases do not fit to the existing technology-sector group. Some products are also removed from the pool if they are not part of knowledge intensive industries but only a part of industry group e.g. cotton and bandage in medical device industry, CD level in software and communication services industries etc.

[7] Kompass used a systematic method to collect this data but there is a time lag in updating all the records. Therefore, the information in the 2007 directory which is available in early 2008 contains demographics for the period 2006 and 2007. This is currently being updated by the Lucerna research team with 2009 Kompass data.

production) of the company in Ireland. Each individual company record in the Lucerna database has the following information presented in the following table.

Table 1-2: Information on individual companies in Lucerna data

1. Identifier
    a. KOMPASS registration number
    b. Company registration number by Company Registration Office – Ireland
2. Name as registered in Company Registration Office (CRO)
3. Location Information
    a. Postal Address (Industrial Site, Street, Town, County)
    b. Telephone and Fax
    c. Geo coordinate
4. Product and Activity Information
    a. Industry (2 digits) Product Group (5 digits) Product (7 digits)-for KOMPASS Product Classification System with description
    b. UK SIC and US SIC Classification Code with Description
5. Incorporation Year
6. Last year of Operation (Exit Year)
7. KOMPASS Employment Figure
8. Country of Origin

1.7 Advantages of the new dataset

The new database consists of up-to-date business demographics for the key tradable sectors of Ireland. The key sectors are demarcated at the product code level. As individual companies are not anonymous in the database it allows case-by-case study and allows greater flexibility to add or verify information. It also includes business unit incorporation and exit year illustrating industrial evolution and churn. As the TBCs are constructed by taking account of cluster studies developed elsewhere it provides a basis to compare clusters internationally. Locational information for each record allows us to integrate it to GIS-based analysis and mapping. It also provides flexibility to conduct studies on various regional levels of aggregation (city, county, and region). Finally, product-based classification for data-building allows the examination of technological activities, engineering/science base of the industry and most importantly emerging technologies and technology management capabilities.

The following sections outline some descriptive statistics and analytical exercises that utilise the Lucerna dataset for illustrative purposes of its utility and potential power.

1.8 Description of Irish Technology Clusters

Descriptive statistics from the database, as presently constituted, can be used to summarise different indicators of business enterprise demographics, including employment size, incorporation period, geographic concentration and indigenous-versus foreign-owned activity. Table 1-3 provides a standardised index for start-ups in each TBC over time. The index indicates the relative start-up activity in each sector for each period. For example, Table 1-3 shows the relatively early business development of the processed chemical and materials (PCM) and pharmaceutical (PHARMA) TBCs in Ireland. In fact, PCM has an index value greater than 1 for all but the last decade of the twentieth century. Perhaps this is linked to the early arrival of pharmaceutical business units well before the Celtic Tiger period. Likewise the relatively large number of start-ups in test, measurement, and instrument (TMI) and diverse manufacturing and processing (DMP) in mid-century Ireland created the conditions for the rapid growth of medical device (MEDEV) start-ups between 1970 and 1990. The enormous burst of activity in software and communication services (SCS) start-ups only began in 1995. The point here is not that the database proves any such connections but it does allow the researcher to pull out the specific companies and explore more deeply the activities involved and the capabilities and skills being developed.

As this business unit entry date index only considers the number of start-ups it tells merely a part of the story of industrial growth. To supplement, Table 1-4 uses employment data to calculate location quotients for each TBC by county. The logic is that a region with an employment share in any given TBC greater than the national average is judged to be relatively specialised in the production of the output of that particular sector. Share of employment as a percentage of total employment in each TBC is presented in the maps in figure 1-1.

These applications of the database are examples of a range of background ‘quantitative’ exercises to guide qualitative, case studies of industrial transition, capability development, and emerging sub-sectors in Ireland. As the dataset is updated annually an additional range of longitudinal-oriented exercises can be deployed to more accurately characterise the underlying organisational and technological capabilities that drive industrial growth and development. Examples include:

- Fast growing firms and clusters by technology and region
- Changing composition of technology-based companies by region
- Industry churn charts, assessing enterprise entries and exits
- Company and technology genealogies by region
- Company family trees indicated by changes in executive employment
- Exit and entry rates of firms by industry, region, and year
- Maps of high tech companies illustrating size and growth. [8]

[8] Detailed descriptions of some of these types of exercises are available in various CISC working papers linked to the Lucerna project (see www.nuigalway.ie/cisc).

Table 1-3: Standardised index of Entry of Establishments in Ireland

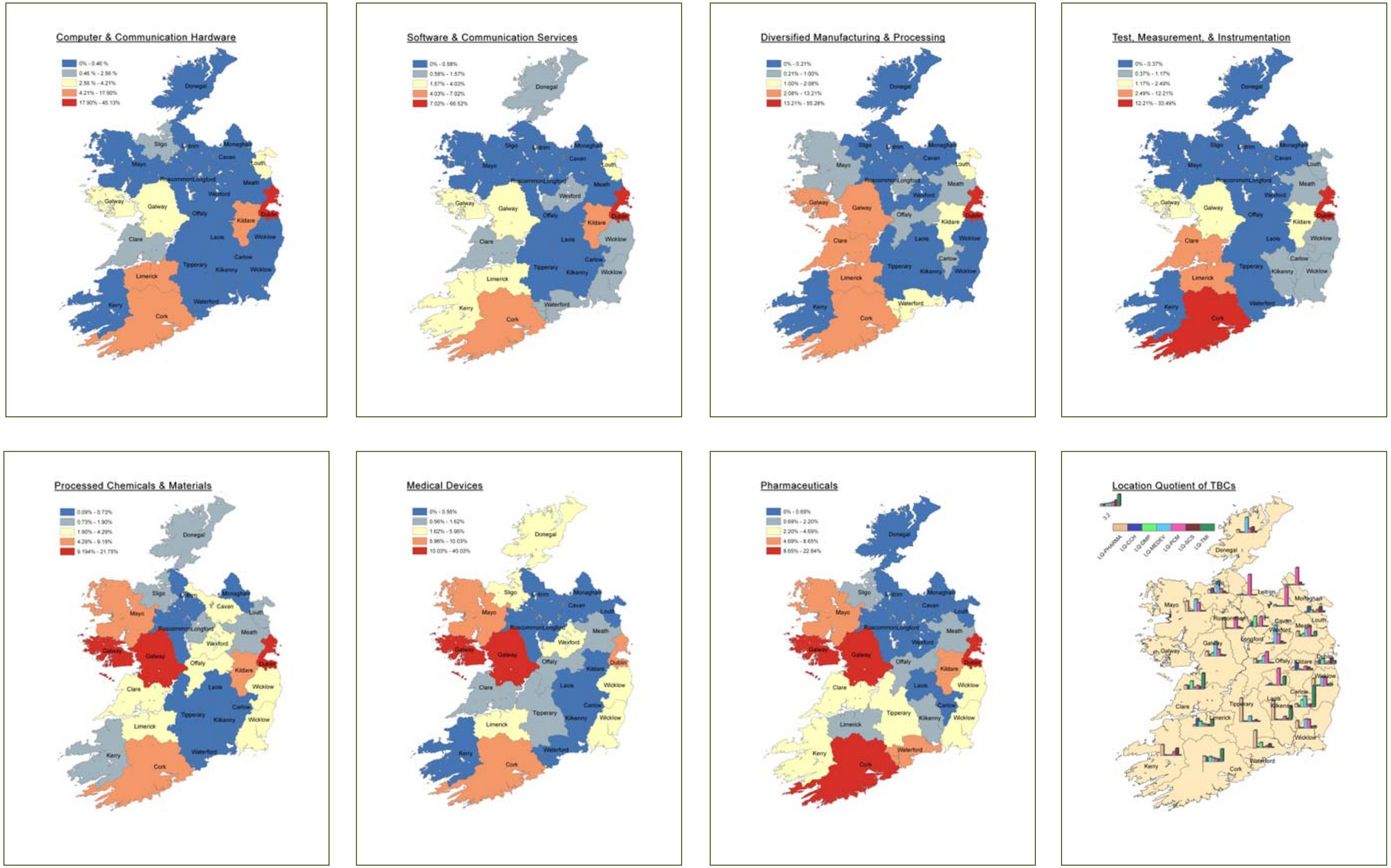
$$\textbf{example : Index of Entry} = \frac{\text{Number of startups in SCS}^{1991-1995} / \text{Total numbers of start ups in all TBCs}^{1991-1995}}{\text{Total numbers of start ups in SCS}^{\text{all entries}} / \text{Total numbers of start up in all TBC}^{\text{all entries}}} = \mathbf{1.091}$$

	<1900	1901-1925	1926-1950	1951-1955	1956-1960	1961-1965	1966-1970	1971-1975	1976-1980	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005	>2005
CCH	0.00	0.68	0.61	0.00	1.67	0.61	0.98	0.71	1.35	0.68	1.25	0.91	1.04	1.13	0.73	0.70
DMP	0.00	1.83	0.82	1.27	1.50	1.65	1.50	2.11	1.32	2.20	1.48	1.64	0.81	0.53	0.34	0.75
MEDEV	0.00	0.00	2.86	0.00	0.00	0.00	0.00	1.66	1.43	0.00	1.56	1.06	0.75	0.87	0.82	2.60
PCM	5.61	1.87	2.52	3.88	1.53	1.68	2.55	1.89	2.02	2.37	1.42	1.07	0.79	0.36	0.51	0.89
PHARMA	0.00	0.00	1.79	2.75	1.63	3.58	2.84	2.91	1.43	1.19	0.62	0.66	1.23	0.58	0.74	0.81
RE	Data is not available for majority of companies.															
SCS	0.00	0.98	0.22	0.00	0.40	0.33	0.10	0.26	0.24	0.29	0.65	0.89	1.09	1.40	1.47	1.21
TMI	0.00	0.00	1.82	1.40	1.66	2.73	1.66	1.48	1.82	2.43	1.27	1.58	0.95	0.38	0.67	0.00

Table 1-4: Location Quotient of TBCs in different counties of Ireland

County	Carlow	Cavan	Clare	Cork	Donegal	Dublin	Galway	Kerry	Kildare	Kilkenny	Laois	Leitrim	Limerick	Longford	Louth	Mayo	Meath	Monaghan	Offaly	Roscommon	Sligo	Tipperary	Waterford	Westmeath	Wexford	Wicklow
CCH	0.29	0.00	0.90	1.04	0.08	1.07	0.32	0.00	1.93	0.08	0.37	0.00	2.10	1.09	1.57	0.01	0.33	0.00	0.50	0.06	1.27	0.06	0.10	0.80	0.09	0.09
DMP	1.94	0.00	2.18	1.35	0.00	1.33	0.81	0.00	0.23	0.00	0.00	0.00	1.32	2.80	0.56	0.16	0.69	0.00	0.52	0.00	0.00	0.05	1.36	0.00	0.16	0.12
MEDEV	2.96	0.00	0.40	0.98	4.19	0.21	3.99	0.00	0.01	0.00	0.00	0.00	0.64	0.00	0.06	3.29	2.09	0.00	1.88	0.00	3.27	1.41	0.06	0.15	5.05	2.48
PCM	0.55	5.43	0.92	0.74	1.08	0.52	1.83	0.92	1.00	0.92	4.67	5.72	0.46	2.71	0.70	2.30	2.74	4.78	3.06	3.12	1.14	0.13	0.38	2.68	2.52	2.38
PHARMA	0.82	0.35	1.02	1.42	0.73	0.56	1.30	2.92	0.78	5.27	0.00	0.00	0.38	0.00	0.08	2.76	1.36	0.00	1.14	2.94	0.95	6.47	4.72	1.31	0.00	2.02
RE	Employment figures not available for majority of companies.																									
SCS	0.72	0.03	0.56	0.57	1.49	1.59	0.30	1.92	0.76	0.36	0.05	0.00	0.43	0.03	1.52	0.06	0.10	0.63	0.07	0.37	0.44	0.38	0.92	0.60	0.56	0.45
TMI	5.90	0.00	4.40	3.44	0.28	0.79	0.18	0.00	0.27	3.79	2.45	0.00	1.83	0.00	0.28	0.06	1.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.53

Figure 1-1: Employment in different Technology based Clusters in Ireland



1.9 Network Analysis of the Technology based Clusters

The Network approach is a useful heuristic tool that enables us to focus on the network structure, inter-linkages of TBCs, industries, firms and products and determine how networks change over time. Mark Granovetter's (1985) notions of connectivity and embeddedness establish the degree to which TBCs, industries, firms and products are enmeshed and linked in a network. Zaheer and Bell (2005) identified 'network-enabled capabilities' in that firms are better able to exploit their capabilities to enhance their performance via superior network position in the network structure.

We used standard network analysis software to identify a set of actors that may have relationships with one another. The networks created illustrate the industries connected to a technology-cluster that have greatest interaction and exchange of knowledge, people and trade. Potentially one can identify other non-tradable links and exchange of externalities and spillovers of social capital.

1.9.1 Basic properties of Industry-Technology Net

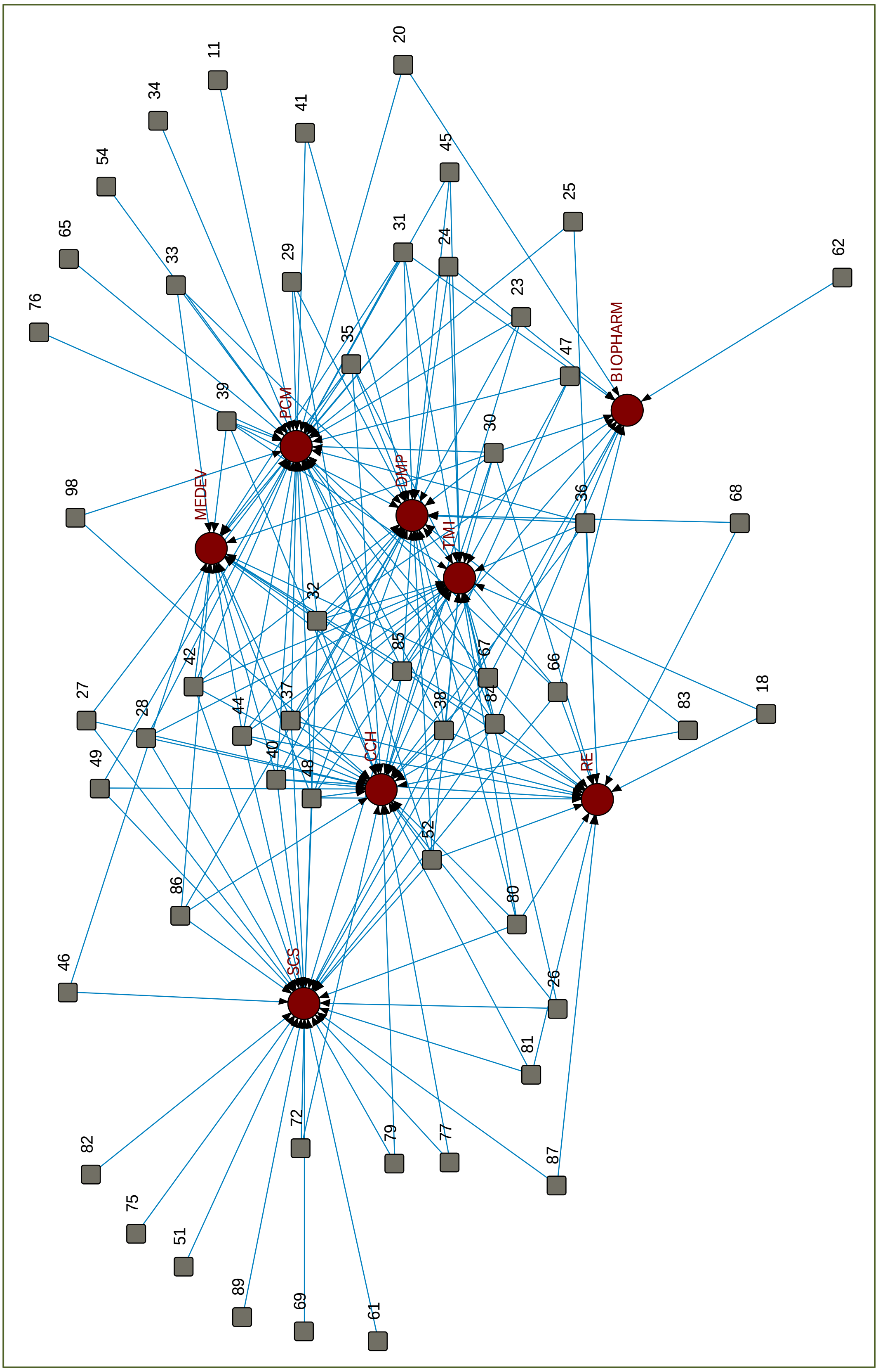
Figure 1-2 illustrates the connection between industries[9] and technology-based clusters for the entire database. A careful interpretation of this graph can be very useful in getting an intuitive grasp of the important features and structure of high-tech industrial organisation in Ireland. The number and kind of ties that actors have are keys to determine how much their embeddedness in the network determines their behaviour, and the range of opportunities, influence, and power that they have. We examine whether capabilities are transferrable across TBCs and industries in an evolutionary manner through technological convergence.

The density of a network is simply the totality of all possible ties that are actually present. This overall measure provides insight into the extent to which actors have high levels of relational capital and/or constraint. This is 0.652 (SD = 14.652) for this net. The density value of 0.652 indicates the entire industry-technology cluster net is well connected. Connectivity is central to the facilitation of an open innovation model. Further analysis could be conducted on the mechanisms through which new technology start-ups become embeddeded in innovation and manufacturing networks.

Network theory contributes a number of important insights about the power of the actors in a network. The network approach emphasises that power is inherently relational. Actors that face fewer constraints, and have more opportunities than others are in favourable structural positions. In industry-technology net having a favoured position affords more opportunity to extract better bargains in exchanges, have greater influence, and be a focus of attention for future growth and competitiveness. Lucerna facilitates analysis of the elements and meaning of power and position as well as the roles of brokers, technology gatekeepers, connectors and the natures of structural holes and path-dependency.

[9] Description of each 2-digit industry is provided in annex 2.

Figure 1-2: Network indicating Industry-Technology Cluster interaction in Lucerna database.



1.10 Conclusion

Existing official data sources provide valuable insights into industrial composition in Ireland. For example, official data sources can be used to 'reveal' comparative advantage and estimate industrial location quotients within Ireland. We have developed a complementary, business-enterprise-centred research methodology to go inside the existing aggregative indicators of industrial dynamics.

No classification system can predict in advance the twists and turns of industry fortunes consequent upon innovation and technological change. Uncertainty will always prevail. The virtue of the Lucerna research methodology is that the site where these changes impact on the economy is the business enterprise; consequently, the macro level of industrial change can be examined in terms of the technologies, processes, products and services that enterprises design, develop, produce and market at the micro level.

We deployed a product classification system to assist in the identification of eleven key technology-based clusters (eight in manufacturing predominantly). A consistent methodology is developed so that key industry clusters do not overlap and are mutually exclusive in terms of data. Each year the data can be updated so that emerging trends can be anticipated and benchmarked internationally. Thus the Lucerna database methodology provides a general framework for investigating and understanding the evolving Irish economy.

Nevertheless, the interaction of business organisation, technological change and innovation is inherently complex. To more fully understand the dynamics of emerging, rapidly growing, and maturing clusters requires a considerable amount of qualitative investigation using case study and other research techniques. Nanotechnology and renewable energy, for example, may be emerging technologies that operate at the intersection of two or more of the technology-based clusters that presently exist in Ireland. For another example, as the next section of the report illustrates, the rapid growth of medical devices in the 1990s has led to the repositioning of companies once classified in simple instruments manufacturing and to the convergence of medical delivery devices, life sciences, pharma and information systems to result in the emergence of a complex medical technology sector.

2 Case Study: Ireland's Medical Technology Sector

2.1 Introduction

The development of the medical technology sector in Ireland typifies the nature of economic growth that the country has experienced over the past two decades. Led by the presence of significant operations by top foreign-owned multinational corporations in the field, the Irish medical technology sector has contributed to rising high-tech exports and knowledge-based employment. The purpose of this section is to undertake a data analysis exercise utilising the Lucerna database and methodology to understand the development and dynamics of this sector. In particular, the study provides an understanding of the underlying capabilities and skills of the sector by analysing the prevailing industrial dynamics. Based on this analysis, the main argument presented is that the distinct capabilities are in place to allow a transition to a new business model based on endogenous development. However a caveat is the danger of lock-in to a technology through over-specialisation. Cognisant of the specialisation of activity at a regional level, we examined more closely the medical technology sector in the Galway city region. A description of the emergence and development of this regional cluster is provided, the interplay between university and industry outlined, and emerging and converging technologies identified. Finally, certain conclusions are drawn.

2.2 Medical Technology sector in Ireland

The successful development of the Irish medical technology sector is a consequence of the policy drive to attract high-tech FDI. The presence of significant operations by the world's top companies such as Boston Scientific, Abbott, Johnson & Johnson, Medtronic, Stryker, Merit Medical, Baxter and Tyco Healthcare has resulted in the Irish sector being compared to leading global medical centres: Massachusetts and Minneapolis. The initial investments by foreign-owned MNCs (multinational corporations) in the country were predominantly low-cost assembly manufacturing sites, whereby the corporation was attracted by the low corporate tax rate and special grant aid incentives. The presence of these firms has stimulated the growth of an indigenous base of small companies providing mainly sub-supply and support services. The indigenous base of enterprises involved in producing medical devices or diagnostics is relatively small and has developed mainly as a result of ex-employees of foreign MNCs establishing local enterprises or start-ups from universities. This is an export-oriented sector with the US as a major export destination for the products manufactured in Ireland. The US companies based in Ireland carry out major manufacturing activities with an aim to export products to US and European destinations.

To understand the capabilities that underscore this TBC we use the methodology described in the previous section of this report. The cluster as presently constituted includes 657 individual products that, according to Kompass, can potentially be produced in the medical diagnostics and testing areas. Our objective was to see what proportion of these 657 products was manufactured in the Irish medical technology sector. Kompass updates the list of products each year so longitudinal study of the sector's evolution is possible.

We identified a core group of 67 establishments that belong to this technology cluster which are composed from 18 different industries. Apart from manufacturing, a substantial number of firms in the medical technology sector belong to 'science technology engineering consultancy services' (STECS) in the Lucerna database. We arrived at a list of 137 establishments that includes the 67 core manufacturers and 70 service providers but excludes medical textile and medical glassware manufacturers. The entire product portfolio of this technology-based cluster is regrouped into 16 medical device sub-groups (MD Sub-Groups) as presented in table 2-1. Each subgroup consists of number of a 'related variety of products'. This generally denotes common technology and engineering platforms, production process or medical specialisation.

Table 2-1: Sub-groups of Medical Devices and Services

Medical Device Sub-Groups	No of Available Products
Surgical & Medical Equipment - Specialised (SME-Spl)	87
Surgical & Medical Equipments - Basic (SME-B)	21
Surgical & Medical Equipment - Support System (SME-S)	15
Surgical & Medical Equipment - Sterilisation & Preservation (SME-SPs)	40
Surgical & Medical Equipments - Monitoring(SME-Mn)	33
Basic Surgical & Medical Instruments (SMI-B)	91
Dental Equipments (DENT)	82
Medical Reproduction Equipments (MDRE)	65
Orthopedics & Prostheses (ORPR)	49
Medical Products - Basic (MDPD-B)	43
Veterinary Equipments (VET)	37
Electro-medical and electro-biological equipment (EMBE)	33
Diagnostics Equipments & Testing Devices (DETD)	28
Rehabilitation Device & Equipment (REDE)	24
Medical Services (MDSV)	6
Medical Products - Other (MDP-O)	3
TOTAL	657

Data mining methods are employed to discern the pattern and structure of clusters and sub-clusters. Information on which firms produce which product(s) is illustrated on scatter plots in figures 2-1 to 2-4. The procedure behind this data mining technique is that the product portfolio of this TBC in Ireland are scattered in a matrix format in which the system specifies each product produced in Ireland. All the potential products that can be produced in medical technology (ref our methodology and Kompass classification) are organised into the technology sub-groups and represented on the x-axis, while all the existing firms in this TBC in Ireland are represented on the y-axis.

Figure 2-1: Product Landscape of the Irish Medical Device Sector by Employment

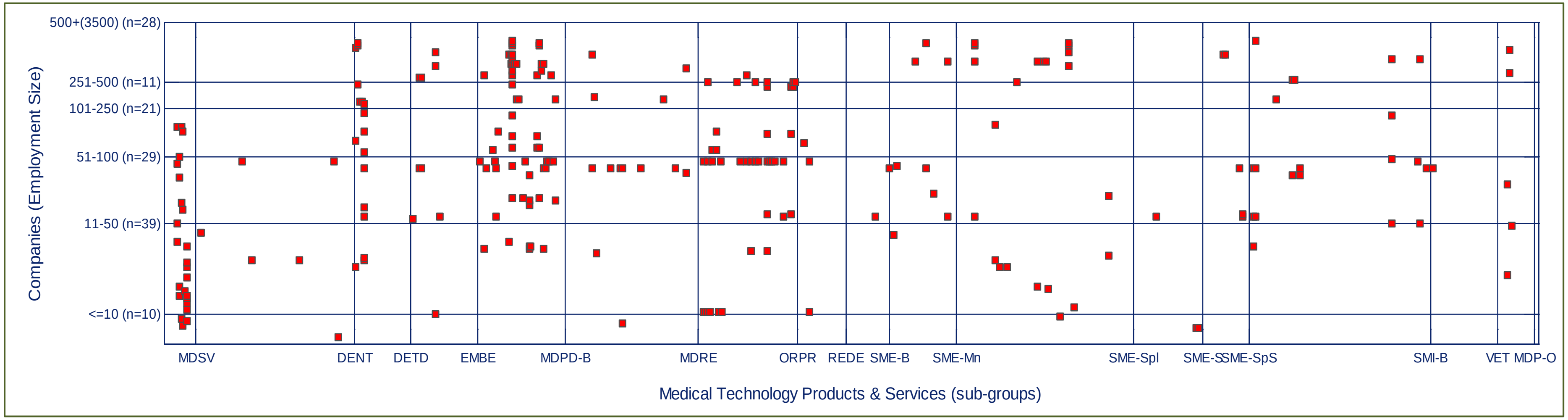


Figure 2-2: Product Landscape of the Irish Medical Device Sector by Incorporation year

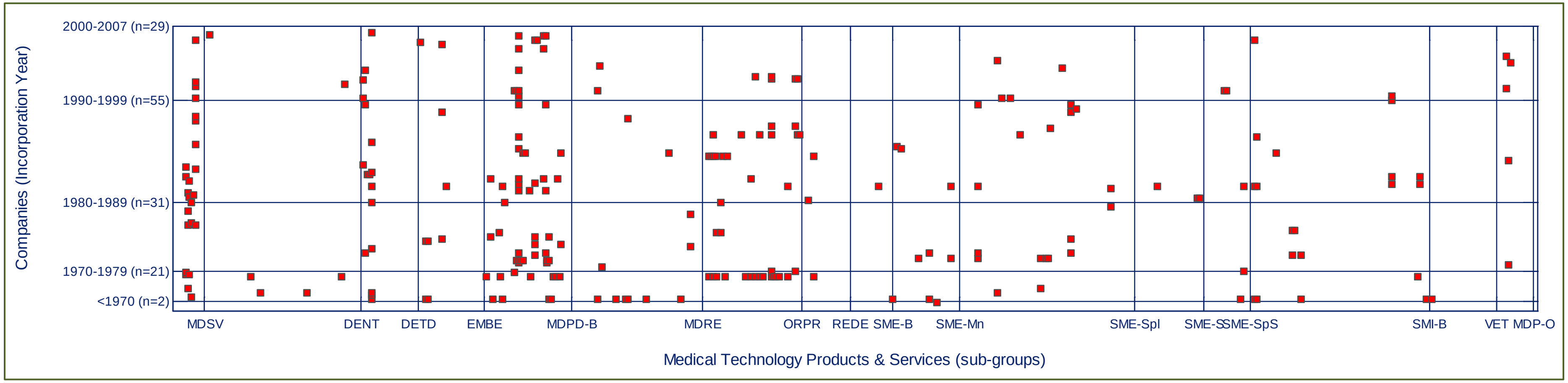


Figure 2-3: Product Landscape of the Irish Medical Device Sector by Origin

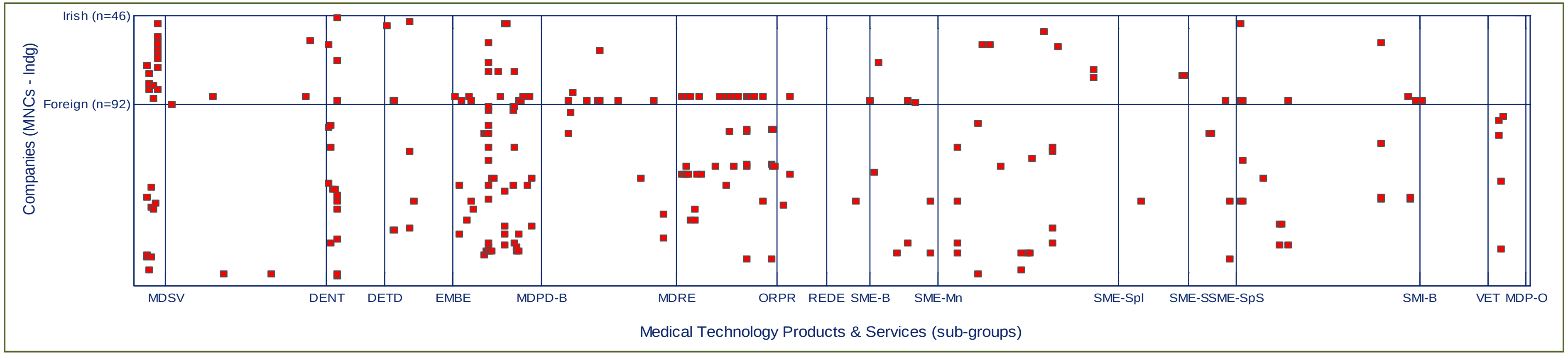
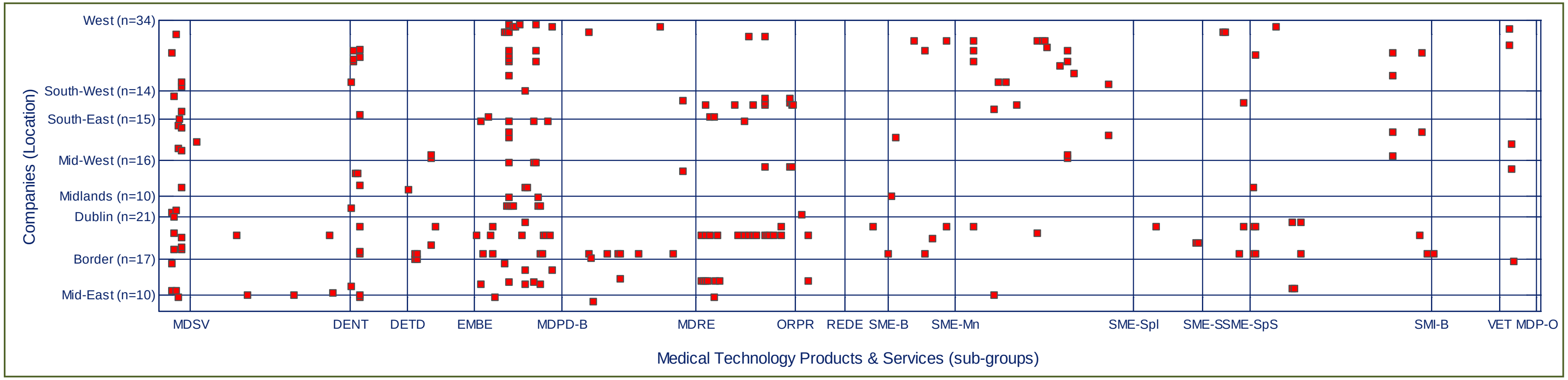


Figure 2-4: Product Landscape of the Irish Medical Device Sector by Region



The scatter plot in Figure 2-1 shows that there are concentrations of product and services in a few subgroups, that is, MDSV (Medical Service), MDPD-B (Medical Products – Basic). The concentration of activity in these particular sub-groups indicates capabilities in precision engineering and plastics. These sub-groups also exhibit unique employment patterns. For example, the MDSV sub-group consists of firms that have less than 250 employees with the majority employing 10 to 49 employees; MDPD-B (Medical Products – Basic) and ORPR (Orthopedics & Prostheses) groups have sizable employment. This may be linked to the nature of their investment, that is, foreign or indigenous. Overall, in this TBC in Ireland, firms are involved in the production of a few related varieties and complementary products around a few medical speciality groups, irrespective of their size of employment.

Young and old firms as well as indigenous and foreign-owned firms operate within the same MD sub-groups and activities are related as illustrated in figures 2-2 and 2-3. suggesting transfer and learning of capabilities. Figure 2-3 illustrates a typical concentration of indigenous activities mostly confined to those specialised MD sub-groups where foreign owned MNCs also operate. This is particularly true in MDSV (Medical Services), DETD (Diagnostics Equipments & Testing Devices), MDPD-B (Medical Products – Basic) and SME-Sp (Surgical & Medical Equipment - Sterilisation & Preservation) sub-groups. An in-depth analysis of the product portfolio indicates indigenous firms are mostly involved in the production of related and complementary products to MNCs or produce niche products in the same medical specialisation of MNCs subsidiaries in Ireland. This is true irrespective of employment size and age.

Figure 2-4 shows the distribution of product by region. Eight administrative regions are considered for this purpose. Analysis indicates some regional specialisations of capabilities, (e.g. the West is specialised in SME-sp and ORPR in the South). We conducted similar profiling exercise for Galway and the resulting product landscapes are presented later in this section in Figures 2-5 to 2-7. The results again indicate young and old, MNCs and indigenous operate in the same MD sub-group and are involved in related activities.

The summaries of these findings that shed light on industrial dynamics and evolving capabilities in this TBC are listed as follows:

- There is an inherent specialisation around a few medical speciality products and services, and technology and engineering platform.
- Production in most of the MD sub-groups is distributed around related varieties and is complementary to MNCs activities.
- The profiling exercise suggest significant organisational learning but also reveal the exposure and potential vulnerability of the medical technology cluster to technological lock-in.

These summary findings can act as ‘triggers’ for further more detailed empirical studies, particularly qualitative analyses. Indeed based on these points a more detailed empirical study of the cluster in Galway was carried out and is presented in the next sub-section.

Indigenous start-ups principally lack the state of the art process management capabilities of the MNCs. MNCs also commonly acquire the indigenous start-ups after a successful product development as part of their asset augmentation strategies. These indigenous firms (innovation gap fillers) use specific niche strategies (particularly development of products with shorter regulatory paths) to maximise potential success through commercialisation. The other original indigenous manufacturers also use MNCs as the source of knowledge. After a successful product development they connect to value added resellers, other MNCs and distributors, both inside and outside of clusters, for their global connections. This dynamic is conceptualised in a capability framework and presented in table 2-2. Being the main source of knowledge in-house MNCs substantially influence the organisational learning and routines of the cluster. On the one hand it leads to a technological trajectory where new product development is concentrated on a few medical speciality product(s) (e.g. intravenal cardiology in Galway). On the other hand, the cluster can get locked-in to too few routine activities.

Table 2-2: Conceptual frame work for Understanding MEDEV Cluster Capabilities

		Product Development Capability	
		High	**Low**
Process Management Capability	**High**	First Follower - Innovation Mode ***Cluster Strategy*** **Original Manufacturer** (Innovator – Cluster Enhancer)	Process Capability - Pioneering Mode ***Niche Strategy*** **Original Equipment Manufacturer** (High end component manufacturer/suppliers)
	Low	Product Technology Innovation /Pioneering Mode ***Niche Strategy*** **Original Design Manufacturer** (Innovator-gap fillers)	Application Specialist Mode ***Free-Riding Strategy*** **Supply and Service Provider** (Low end component suppliers)

Adapted from Yang, 2008

2.3 A Regional Case: Galway's Medical Device Cluster

2.3.1 Cluster emergence and development

The first major investments in technology-related activities in the Galway region were the establishment of a manufacturing facility by DEC (Digital Equipment Corporation) in 1971 and the Canadian telecommunications corporation, Nortel Networks in 1973. Digital in Galway was set up as a computer hardware assembly and distribution centre for the European market (Wijnekus, 1997). Software, which was imported primarily from the US and used to support the hardware business, was assembled into kits and distributed with the hardware from the facility in Galway (Wijnekus, 1997). The facility originally opened with 109 employees but the number employed grew consistently to over 1000 workers by 1981 (Wijnekus, 1997). The software side of the facility also developed quite rapidly and within the first three years of the operation a software entity, distinct from hardware manufacturing, had emerged, namely the European Software Distribution Centre (ESDC) (Wijnekus, 1997). This reflected the growing knowledge-intensity of the activities being undertaken at the Digital facility (Wijnekus, 1997). Similarly, while Nortel Networks initially established a Galway-based manufacturing site in the telecommunications domain, it subsequently invested in and expanded activities at the site to include considerable research and software development responsibilities.

In line with the growing electronics and software sector, medical technology activity in Galway was initiated with the CR Bard investment in 1982. CR Bard's facility involved the development and manufacture of products in the area of coronary and vascular disease. CR Bard continued to make significant investment in the facility in Galway through the 1980s and 1990s across various functions, including research, development, manufacturing and marketing (Murphy, 1998). Ireland provided corporations like CR Bard, Digital and Nortel Networks access to the European market, tax incentives and an English speaking and educated workforce (Wijnekus, 1997).

The closure in 1993 of the Digital manufacturing facility in Galway resulted in a number of initiatives being undertaken by Digital, the Government and local business groups that resulted in the foundation of start-up enterprises in the region (Needham, 1999). Digital itself offered internal services to redundant staff that included job search facilities, career change programmes and an enterprise development/start your own business programme (Needham, 1999). In addition, the Government along with national industrial development agencies and local business support groups formed an inter-agency task force from which the most significant outcomes were the provision of funding for start-up enterprises, access to advisory services and the establishment of the Galway Technology Centre (Green et al., 2001). The Centre provides workspace for early stage and developing high-technology enterprises.

As a result of these initiatives, many ex-Digital staff used their acquired managerial skills to form businesses in various areas including, electronics, software, manufacturing and services (Needham, 1999). In addition, existing foreign investments in technology were encouraged to remain in the region while new foreign investment was sought (Green et al., 2001). In particular, one of the world's leading medical technology corporations, Boston Scientific, established a facility in 1994, occupying some of the redundant Digital space. Whilst initially it was a relatively low-value added manufacturing facility, over the 1990s and early 2000s the MNC opened an R&D facility to develop as well as manufacture medical devices particularly drug-eluting stents within the field of cardiology. Furthermore, in 1998 the cardiovascular division of CR Bard was acquired by AVE (Arterial Vascular Engineering), which was subsequently acquired by Medtronic the following year. Both AVE and Medtronic retained this division in Galway and the facility concentrates on the development and manufacture of drug-eluting stents and their components.

While Medtronic and Boston Scientific are presently by far the largest employers (employing over 4000 people between them in the region), a number of smaller-sized indigenous and foreign-owned companies have been established in the past decade adding to the vibrancy of the cluster (Giblin & Ryan, 2010). The establishment of these new firms as well as the frequent mergers, acquisitions and management buy-outs taking place underscores the cluster's dynamism. However, foreign investments from world-renowned corporations, including Tyco Healthcare (renamed Covidien and formally Nellcor Puriten Bennett in the region), Beckman Coulter and Merit Medical as well as Boston Scientific and Medtronic drive the cluster (Giblin, 2007; Giblin & Ryan, 2010). While divestments from the region, most notably Abbott in 2007 also mark its landscape and accentuate the vulnerability attached to a dependence on foreign investors, it is the upgrading of many of these investments from initial manufacturing sites to product development facilities that has resulted in a transfer of knowledge, skills and capabilities to the locality (Giblin, 2007; Giblin & Ryan, 2010). The next subsection explores these capabilities and skills in more detail using explicitly the Lucerna dataset.

2.3.2 Cluster capabilities and skills

The influential presence of Boston Scientific and Medtronic has resulted in many of the companies being involved in cardiology-related devices, particularly drug-eluting stents and their components, such as guide wires, balloon catheters, hypo-tubes and filters. As a result the Galway region has been recognised for its specialisation in coronary devices. This point is emphasised in Figure 2-5 that shows a specialisation in the Specialised Surgical and Medical Equipment (SME-Special) technology sub-group in Galway. The products within this sub-group are mostly minimally invasive cardiovascular interventional products. Figure 2-5 also displays the distribution of the products within each MD sub-groups in relation to the employment size of the firms. It is not surprising to observe that Diagnostics Equipment and Testing Devices (DETD), Basic Medical Products (MDPD-B) and Surgical and Medical Equipment Monitoring (SME-Monitor) and Specialised (SME-Special) products are manufactured by the firms that have 500 or more employees considering the fact that some of the top global medical device companies have manufacturing plants in Galway.

In terms of origin, products in DETD, MDPD-B, SME-Monitor, SME-Special and SMI-B technology sub-groups are produced heavily by foreign owned companies in Galway (see Figure 2-6). Figure 2-7 maps medical device products distribution by the year of establishment of firms in Galway. What this figure suggests is that the establishment of the CR Bard cardiovascular products plant in the early 1980s was followed by many other Galway plant openings in the 1980s and 1990s. The scatter plots demonstrate the region's specialisation and capabilities in tackling design and production challenges of complex medical products.

Figure 2-8 is a schematic illustration of industrial dynamics for the Galway medical device cluster. This sector is highly regulated and successful product development heavily depends upon critical management skills, knowhow and contacts specific to this sector. That includes access to top clinician and R&D centres; understanding of the regulatory standards; accreditation and regulatory approval by the FDA, marketing expertise; and connection to government agencies, industry bodies, suppliers and distributors. The MNCs play a pivotal role as they are the main sources of 'managerial knowhow' in the cluster. Required international connections are often made through MNCs. Knowledge transfer occurs through the movement of people between firms. New indigenous start-ups by previous MNCs employees emerge as different forms of knowledge, both tacit and codified, get circulated among cluster members. MNCs also act as the most important source of 'technological knowhow' for indigenous firms. Indigenous entrepreneurs avail of the gaps in the innovation value chain of the MNCs activities which provide opportunities for new product developments.

Figure 2-5: Product Landscape of the Medical Device Sector in Galway by Employment

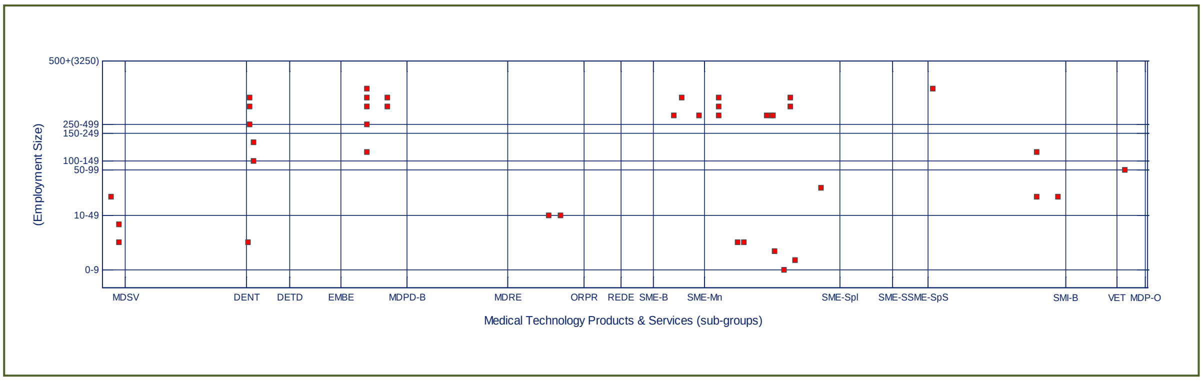


Figure 2-6: Product Landscape of the Medical Device Sector in Galway by Origin

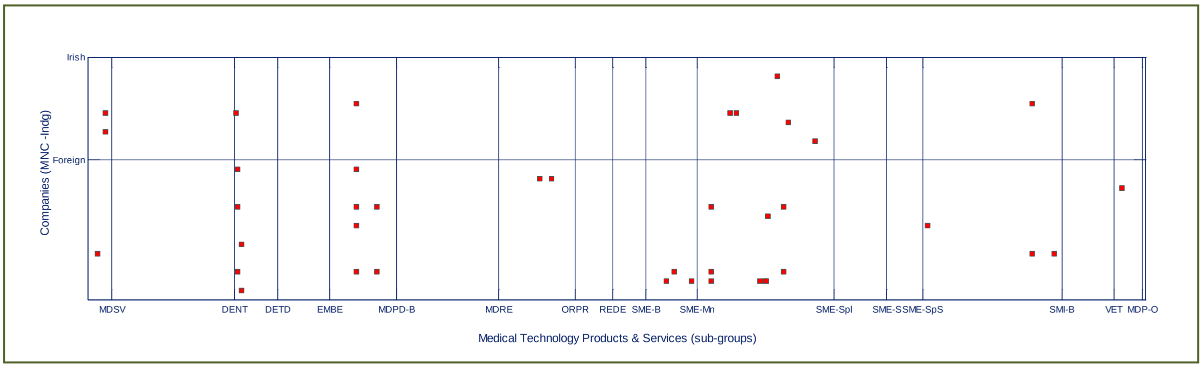


Figure 2-7: Product Landscape of the Medical Device Sector in Galway by Incorporation Year

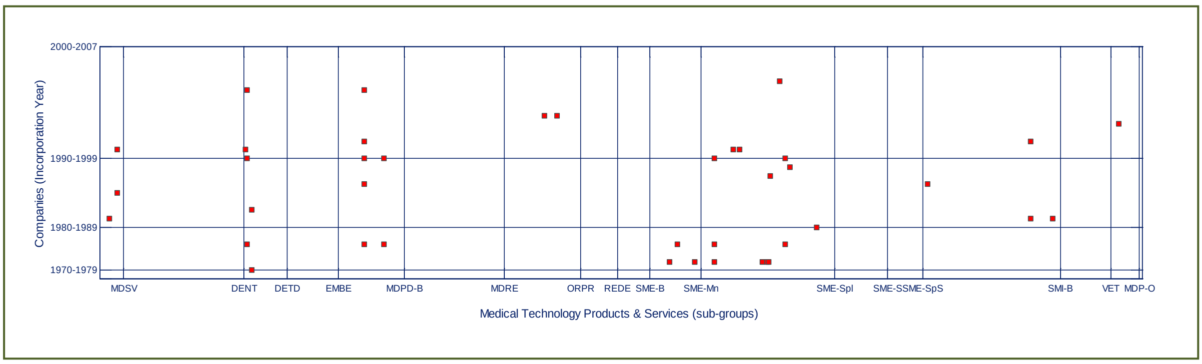
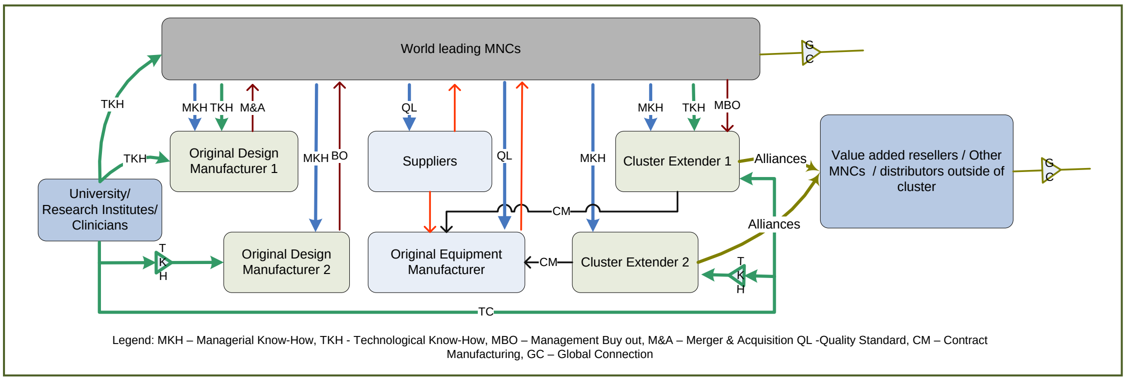


Figure 2-8: Galway medical device cluster: Actors and flow of information



In the absence of a strong third level education/research institutes and industry interplay, developing an internal technical infrastructure to challenge complex design and product development tasks is not feasible. The next section addresses the historic interplay dynamics in the Galway region.

2.3.3 Third-level institutes and industry interplay

The Government establishment of Centres of Science Engineering and Technology (CSETs) through Science Foundation Ireland (SFI) at Irish Universities facilitated the creation of partnerships between academic researchers and industry to conduct leading-edge research. Within Galway, the Regenerative Medicine Institute (REMEDI) CSET was established in 2004 at NUI Galway. REMEDI is involved in stem cell biology and manufacturing, gene therapy, orthobiologics, immunology, cardiovascular, socio-economic and bioethical research (REMEDI 2009). One of its main industrial partners is the local foreign-owned medical technology corporation, Medtronic, which invests funding in the institute and has people working on the Insitute's research activities. The collaboration with Medtronic builds a reputation for REMEDI, opens opportunities for students and further funding, and from Medtronic's perspective, provides the possibility for the development of a beneficial licensing arrangement from the research (Brady 2006). REMEDI is also embedded within the activities of the National Centre for Biomedical Engineering Science (NCBES) based at NUI Galway. In conjunction with the growing local medical technology sector, the Centre was established in 1999 and undertakes research activities under four main themes; biomedical engineering, cancer, neuroscience and regenerative medicine through REMEDI. Since its establishment the NCBES has engaged in numerous formal research contracts with the medical technology sector and participates in Enterprise Ireland Innovation Partnership projects that provides funding for research projects involving third level institutes and Irish-based companies.

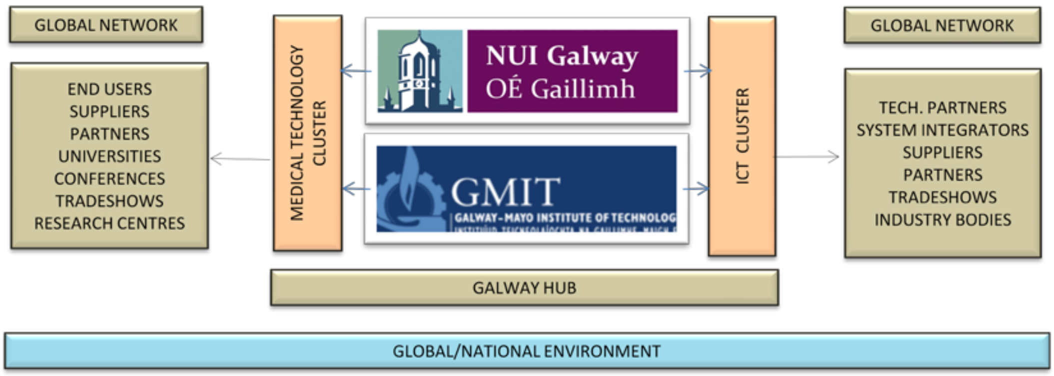
In addition to these collaborative research activities, NUI Galway has also participated in meeting the labour skill requirements of the medical technology sector. The University introduced a new degree programme in Biomedical Engineering in 1998, the first students of which graduated in 2002. The degree programme was established under the

Department of Mechanical Engineering, which changed its name in 2002 to the Department of Mechanical and Biomedical Engineering. This reflected its focus on biomedical research and education activities. On average, twenty-two students have graduated each year since 2003 and it was the first biomedical engineering degree programme to be accredited by the IEI (Institution of Engineers of Ireland).

Such developments at NUI Galway and GMIT, which are embedded within the overall policy context, have been significant for building the capabilities of the medical technology sector in Galway (see figure 2.9).

Given that the local sector is driven by foreign-owned MNCs, the need for the cluster to develop endogenously-based capabilities is significant, particularly for its sustainability. In this respect, and as argued in the literature on clusters and regional growth (e.g. Feldman & Braunerhjelm, 2006; Feldman, 2008; Giblin & Ryan, 2010), the development of local research and entrepreneurial activity is essential. Therefore, the following section concentrates on cases of entrepreneurship in the region and examines the potential for the convergence of technologies that may underscore the future of the cluster.

Figure 2-9: Galway Technology Cluster



Source: Giblin, 2007

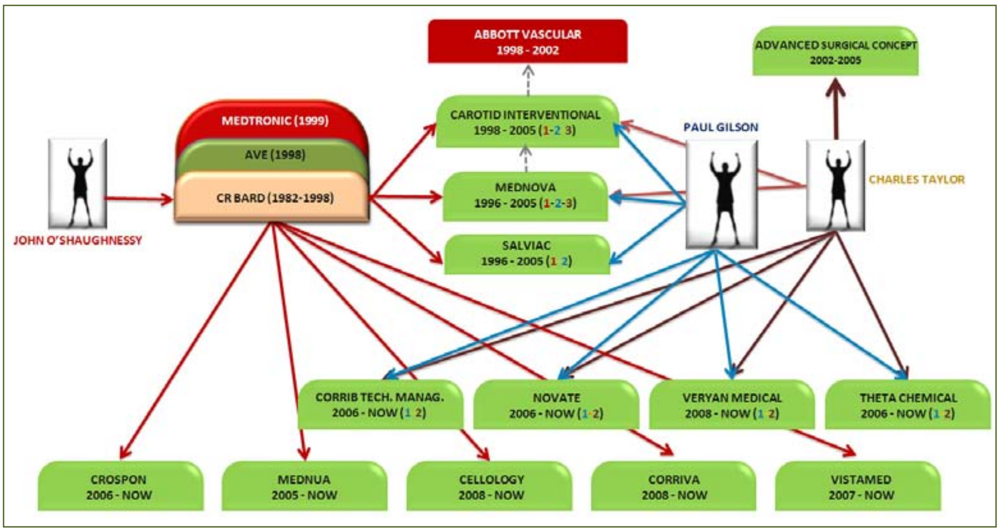
2.3.4 Indigenous Growth, Emerging Technologies and Convergence

The effects of the DEC closure on the formation of start-ups in newly developing subsectors within ICT such as integrated-circuit design and software are highly visible (Sheridan, 2008; Giblin, 2007; Needham, 1999). Medical device start-ups, in the Galway region in particular, were also emerging as a result of indigenous-focused policies that have been implemented through various government agencies. Post-DEC era policies, as discussed previously, created incentives for redundant but skilled DEC employees (Needham, 1999) and ex-vendors to link with the globally emerging new sectors. Figure 2-10 provides an initial attempt to identify links amongst affiliates of foreign-owned and local start-up medical technology companies as well as key serial entrepreneurs in the Galway region. The core data for the map is acquired from the Lucerna database and supplemented with data from internet content and archive searches. The Galway region has become home to a small number of serial entrepreneurs who have prior MNC managerial experience.

As Figure 2-10 illustrates, John O'Shaughnessy, Charles Taylor and Paul Gilson were originally senior executives of CR Bard[10], the first US medical device firm to locate in the region. The CR Bard acquisition was followed by the first wave of start-ups by the O'Shaughnessy, Taylor and Gilson trio. The first series of start-ups, Salviac, Carotid Interventional Systems (CIS) and MedNova, were successful. CIS and its parent company MedNova were acquired by the vascular division of Abbott, the US life science company. Another successful Irish Start-up, Crospon Technologies, was also a team effort this time by John O'Dea, John O'Shaughnessy, and Conor McNamara. Prior to Crospon, John O'Dea set up the R&D facility for Puritan Bennett before starting Caradyne in 1997, which was acquired by Respironics, a US company, in 2004 (Daly, 2007).

Figure 2-10 indicates the family tree of the current medical technology cluster and emphasises the importance of the juxtaposition of different technological spheres in the region. Most importantly, the development of capabilities in electronics through the presence of companies like Digital in the region provided an initial platform from which medical technology activities have grown. The Galway-based company, Creganna provides a case in point. This company, established in 1980, was involved in contract manufacturing to the electronics industry but by 2003 it had divested interests in electronics to focus solely on the medical device market. It is now one of the largest indigenous employers in medical technologies in Ireland with over 520 employees across its Irish and US bases (Corrigan, 2008a). With Boston Scientific and Medtronic both involved in the production of drug-eluting stents in the region and the growth of companies like Creganna around this activity the convergence of pharmaceutical and medical technologies has also been at the core of the cluster's development.

Figure 2-10: A subset of entrepreneur network in indigenous start-ups



As companies look for new opportunities, the potential for product development in the convergence of particularly ICT and medical technologies has received attention recently

[10] CR Bard was later acquired by Arterial Vascular Engineering (AVE) which was later acquired by Medtronic.

(Allen, 2008) and is one in which Galway is ideally placed to exploit. Along with the growing medical technology cluster in the 1990s, the closure of Digital signalled the growth of an ICT cluster in Galway (Green et al., 2001), particularly in the area of software (Giblin, 2007). Although it entails a smaller concentration of firms than in Dublin, the software industry in Galway is characterised by the presence of foreign-owned affiliates, such as Hewlett Packard and Nortel creating most of the employment and a larger number of small and medium sized enterprises. Many of the firms are involved in software product development, particularly bespoke software, systems software and application software development as opposed to lower value-added localisation activities (Giblin, 2007). With clusters of software and medical technology firms in Galway, the potential for using local expertise in the convergence of these technologies is significant but has not as yet been greatly exploited.

The endeavour to integrate IT and medical technology has been undertaken by one medical company in the region by collaborating with Hewlett Packard in the US. Through a license agreement with HP the indigenous company Crospon will produce and commercialise a drug-delivery patch applied to the skin, which enables “precise control of dosage timing, access to dosage history, patient activation mechanisms and inherent safety protocols for preventing adverse drug interactions” (Crospon, 2007). The skin patch, developed by HP Labs based on the core technologies of their thermal inkjet printer (Brown, 2008), will involve a three-way convergence of IT, medical technology and pharmaceuticals. While Hewlett Packard initially foresaw regulatory barriers in bringing the concept to market but were considering it as a potential business partnering project, the bringing together of the corporation with Crospon through Enterprise Ireland led to the licensing out of the intellectual property (Brown, 2008). Hewlett Packard runs an IP licensing programme and Enterprise Ireland approached the corporation in Palo Alto, California to encourage them to consider Irish companies for licensing agreements. From this, the relationship with the Galway-based medical technology company developed.

Another company in the region, Vysera, which is involved in the design of anti-reflux valves based on biomimetic material and used for the digestive tract, has recently undertaken a “software modelling project that will add value to future product design” (Corrigan, 2008b). Although, perhaps not a direct use of software for the functioning of a medical device, the increased awareness of companies of the use of software to add value in different ways is significant for the industry and local economy. Indeed, John O’Dea of Crospon states that “the proximity between the IT and medical device sectors could be harnessed here with Ireland playing a key role in the emerging technological space” (Allen, 2008). The opportunities of using IT technologies to develop systems that communicate with implantable medical devices (Allen, 2008) or to control and manage the delivery of drugs as in the case of the HP-Crospon skin patch are considerable.

However, there are challenges to the development of this technological convergence whether at a local or national level. It requires a collaborative environment (Allen, 2008) with connectivity linkages between various actors; including firms from different technological domains, regulatory bodies, end-users (e.g. clinicians), legal bodies, funding agencies and research centres. Industrial development authorities, like Enterprise Ireland and IDA Ireland can be used as a means for opening and building communication linkages between these various actors. Most significantly however, such a collaborative environment necessitates inter-organisational trust (Allen, 2008) and long-term commitment to capitalise on local technological expertise in the highly competitive industries of IT and medical technology.

2.4 Summary and conclusions

As one of the success stories of the Irish economy over the past two decades, the Irish medical technology cluster is examined in this section using the Lucerna database. It shows the evolution of the industry from low value-added branch plant manufacturing to upgraded product development and world-class manufacturing capabilities. Three main results from the data analysis are identified. First, there are significant clusters of product activity around basic medical products, medical services and orthopaedics and prostheses in this sector in Ireland. Secondly, foreign-owned and indigenous companies tend to engage in the same product activity bands, which is indicative of a competency transfer effect. Finally, a spatial effect is also occurring in this sector as the data shows concentrations of activity in orthopaedics and prostheses in the South-West and Dublin region, while specialised surgical and medical equipment is clustered primarily in the West of Ireland.

The data has then been filtered to examine the product composition of the Galway medical technology cluster. An examination of the evolution of this regional cluster shows the early stage establishment of manufacturing sites by foreign-owned multinational corporations and the increase in indigenous start-up activity, primarily since the mid-1990s. Furthermore, the convergence of technologies around electronics, medical technology and pharmaceuticals has been a key factor in the evolution of the regional cluster and its future development will depend on the exploitation of local opportunities for new technological convergences.

Overall, this analysis provides a systematic understanding of the internal dynamics of the medical technology industry in Ireland. As the economic model of attracting FDI based on cost competitiveness and grant incentives has now become relatively inadequate in Ireland, the challenge is to make the successful transition to a new model based on endogenous development. The argument made here, substantiated by an analysis of the medical technology sector using data mining techniques, is that the skills and capability legacy can be leveraged to make this transition. The old model has been successful in establishing a global and vibrant high-tech industry within a few decades. However, to advance such an industry to a level comparable, and complementary, with other high-tech regions internationally, like Massachusetts, requires encouraging skill transformation processes, exploiting new skill formation in the form of indigenous enterprises and entrepreneurship, and most significantly promoting the convergence of technologies to lead the way in the development of next-generation technologies and products.

3 Case Study: Ireland's Renewable Energy Industry

3.1 Introduction: The Challenge and Opportunity

For reasons of energy security, climate change obligations, and cost, pressure is building for Ireland to establish a renewable energy (RE) industry with the capacity to address security, climate change, and competitiveness goals. The Government has set goals of 15% of electricity from renewable by 2010 and 33% by 2020[11]. The barrier to the achievement of RE goals is not the lack of natural resources. While Ireland does not have appreciable fossil fuels, it has vast wind, wave, and tidal energy resources. Presently, wind energy is Ireland's lowest cost source of electricity with low environmental externalities. Besides wind power, the west coast of Ireland is the site of Europe's most abundant source of accessible wave power with at least as much potential as off-shore wind energy (SEI 2004 p. xvi; Staudt, 2007 p. 7)[12].

Ireland therefore is in the enviable position that it has the natural resources which, combined with proven wind turbine technology, can supply its total electricity energy needs with renewables. Sustainable Energy Ireland's Brian Motherway states that "Ireland has 13% of Europe's coastline. In terms of wave and wind energy that is the equivalent of a natural gas oilfield". Similarly, Harvey Appelbe of Tonn Energy comments that "Because the country has such a vast natural energy resource, and as the technology becomes proven, and the government policy and supports take effect, Ireland can really be the 'Texas of Europe' exporting large quantities of green electricity" (Knowledge Ireland, Winter 2009).

It is unlikely the contours of a future industry have ever been as predictable as that of renewable energy. Only the timing and trajectory are in doubt. While technological breakthroughs will alter the composition of energy sources and the fate of individual companies, the broad industrial outlines of the post-carbon technology age are coming into focus. As Eoin O'Driscoll of Forfas stated "We understand the underlying science principles involved in solar, tidal, bio-fuels, wind. What we don't know is how to harness the sun, wind, waves and crops to produce energy in a cost-efficient manner. ..Its more of the engineering challenges and the deployment challenges and the cost-conversion challenges than it is around basic science". The timing and trajectory, however, are important. Regions and nations that lead the way in the transition will enjoy the economic advantages of leadership in that industry.

Ireland has engineered the development of new industries in the past but none as complex as this RE sector. In the case of the Information and Communication Technology (Computer & Communication hardware and Software & Communication services) and Medical technology (Medical Devices, Equipments, and Services) the Irish Development Agency (IDA) attracted affiliates of foreign headquartered companies with a range of government supports. This included fostering close industry and education partnerships in the creation of a curriculum to educate a labour force that matched both

[11] The Government's *Energy White Paper* published March 12, 2007.
[12] This section of the Lucerna report on renewable energy will therefore focus principally on wind and wave energy potential and challenges.

the technical skills and the size to rapidly ramp up production. The end result was the development of a competitive advantage in complementary capabilities to foreign headquartered technology-leaders. These capabilities evolved from the rapid establishment to scale of world class manufacturing plants with an educated, low cost labour force to the remote management of a range of other routine business processes.

Because of changes in both Ireland and the rest of the world, this model will not drive the creation of a renewable energy industry. Its success created imitators abroad and increased costs at home. Inviting large numbers of rapidly growing foreign firms to establish Irish affiliates to deliver world class manufacturing capabilities is no longer sufficient to drive the creation of a new industrial sector in Ireland. To establish a new and rapidly growing RE industry in Ireland, the Government needs to do more than offer services and facilities that keep costs low. The challenge is multi-faceted.

Growing an indigenous RE industry will depend upon mutual interactions amongst growing enterprises across a set of technologically inter-dependent and inter-related sub sectors as well as with civic bodies. That demands a structural change in the existing Irish innovation system to a scale that the entire country will act as a full scale laboratory for these sectors (as Denmark[13] did for wind industry). An entirely different business model will be required and needs to be supported.

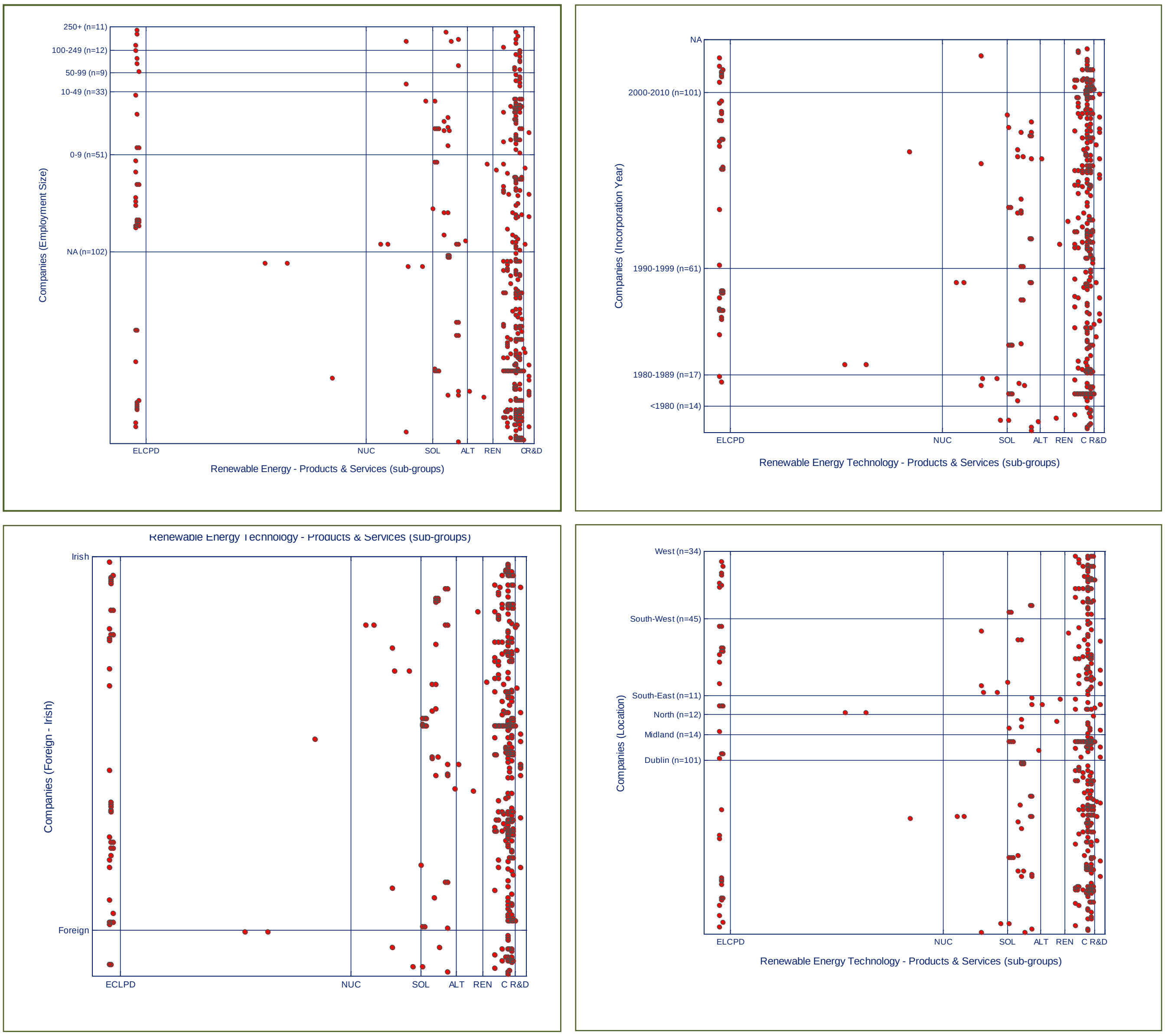
In recent years considerable attention has been paid to the lack of and potential for development of the renewable energy industry. In addressing these challenges a plethora of reports have been produced on the sector and its opportunities and challenges[14]. However missing from these governmental and advocate reports and elsewhere within Ireland is a rigorous discussion of the population of enterprises that currently or potentially constitute the RE industry within Ireland, both indigenous and foreign headquartered, their strategies, and how the existing business organisation capabilities and projects compare to an endpoint of an established RE industry. While no simple mapping can be done from RE clusters elsewhere such as in Massachusetts or Denmark, we can identify a number of inter related sub-sectors that will constitute such an industry. Within each sub-sector potential industry drivers can be identified and emerging technological capabilities can be characterised. The research methodology is, in part, to characterise emerging distinctive national competitive advantages by interrogating the product concepts and emerging technology capabilities of rapidly growing companies, of companies that have successfully attracted finance and forged technology development alliances with global leaders. Such an exercise of technology capability characterisation is subject to ongoing reassessment as real-world events unfold. At the same time it offers a starting point for developing a strategy for business organisation development and the interdependent roles of government, foreign

[13] Denmark particularly began the transition to a RE industry in the 1970s when a rapid rise in oil prices brought the issue of energy security to the attention of the public and government for the first time. While no country has completed the transition to a post-carbon age industrial system, they have made important advances.

[14] See especially the excellent work of Sustainable Energy Ireland and its extensive range of RE reports at www.seai.ie/publications.

headquartered companies, indigenous ventures, business alliances, university programs and research centres.

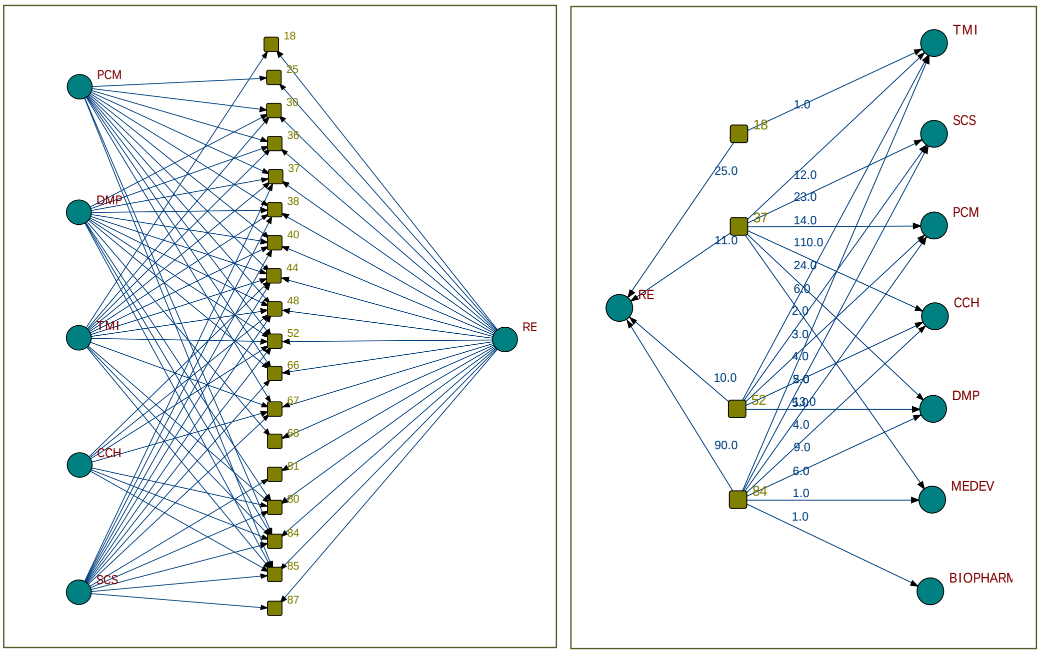
Figure 3-1: Scatter plot of Energy TBC: Product and Services



In this connection a sample of RE industry companies is drawn from the Lucerna database. A product pool was constructed of the product groups (5 digit correspondence at Kompass classification) and products at 7-digit level at Kompass, for the RE TBC (Annex 1). There are 227 engineering products and service categories that are defined by using Kompass 7-digit product classification. Scatter plots (see figure 3-1) were created by Lucerna researchers in which the companies that provide services or products are represented on the Y-axis and the actual products are represented on the X-axis. In the resulting figure 3-1, 208 RE firms which were sorted in terms of employment size, origin, incorporation year, and by region are represented on the Y-axis. Each of the 236 red marks on the figures indicates products that are produced by corresponding companies on the X-axis. By taking products as a proxy for firm capability, the red marks in the figures indicate certain clusters of activity. This exercise allows us to better understand the industry segments in which Irish production capability lies.

There are a number of key messages that can be discerned from the scatter plot figure 3-1. First, this is obviously a relatively new sector as indicated by the recent incorporation years of the member firms. The employment structure shows most are small firms. This is due to the newness of the sector and the fact that most firms are in the consultants (C) band. There is a further concentration of small firms in the R&D band. Electrical production and distribution ELCPD) has most large firms. There is a wide distribution of firms in alternative (Alt) and renewable (REN) energy bands. Most of the firms in all bands are indigenous. The next round of Kompass data, which is now available, will facilitate us to track the growth and evolution of sectors and firms across bands. [15]

Figure 3-2: Network of connectivity of Renewable Energy TBC



The network analyses show that the RE TBC is connected to 18 different sub-industries in the Lucerna high-tech database (figure 3-2). Figure 3-2 shows the strengths of the principal connections. The four major ones are 18 (electrical production and distribution), 37 (electrical and electronic equipment), 52 (building and construction) and 84 (science, technology and engineering services and consultancies). The TBCs most closely linked are CCH (computer hardware), SSC (software) and DMP (diversified manufacturing processing). Those least connected are unsurprisingly MEDEV (medical devices) and BIOPHARM (biopharmaceuticals).

[15] We left the nuclear (NUC) band in as it shows up the small level of activity in this broadest of bands according to Kompass list of potential products. This reflects Ireland's non-nuclear policy.

Three lessons can be drawn from this initial audit of RE companies in Ireland with respect to the goals of carbon emissions reduction, energy independence, and economic growth.

First, the RE sector as currently constituted is small. Even stretching to include very small wind farm developers and consultancies the total is closer to 50 than to 100 firms. Airtricity aside, there are no large employers. In contrast to emerging RE clusters, such as Denmark's wind energy cluster with over 200 firms, many of which are technology-driven and some of which are large employers, RE in Ireland is far short of a critical mass of enterprises to suggest the realisation of the climate change and energy independence goals.

Second, a number of indigenous RE technology development companies have attracted foreign partnerships and funding in ocean energy technologies. This reflects both the success that Ireland has achieved in wind farm projects and the promise of wind, waves and tides as sources of energy generation in Ireland. In fact, it confirms meteorological findings that Ireland has a natural advantage in a resource that can potentially not only supply all of Ireland's electricity needs but be an export earner.

Third, most if not all of the energy technology companies in Ireland are organised in terms of an open-systems business model. Here we find a similarity with the business model at the centre of the emergence and success of both high-tech sectors and design-led sectors elsewhere in the world. In both variants, the open-systems business model has fostered industrial innovation.

New business models tend to be introduced to a region or nation in the same process as the introduction or creation of new industrial sectors. The success of the new business model is not lost on new companies in pre-existing sectors and they become diffusion vehicles. The leading business model in Ireland today is that of an affiliate of a foreign headquartered company. The local units are networked, as noted before, but along global production chains. The open-system business model is a vehicle for a different form of networking in which companies specialise on core capabilities and partner for complementary capabilities. This alters the prevailing model of innovation within the economy and creates growth potential from cluster dynamic processes (Best, 2001).

3.2 Recommendation for a Business Model for Renewables

3.2.1 Inter-Organisational Relationships and Cluster Formation

Our initial interrogation of Lucerna found a small population of innovative enterprises in an industry in which Ireland has a natural competitive advantage (2007 Kompass data)[16]. To date, the gap between the actual and the potential realisation of the natural advantage in RE is wide. What would it take to create a dynamic RE cluster capable of turning the country's natural advantage into a competitive advantage? Put simply, it requires the emergence and rapid growth of not a few but a large number of business

[16] This is currently being updated with recently available Kompass data. This will show areas where evolution and growth is occurring.

enterprises. And while the understanding of cluster formation is not a hard science, history does reveal a few key relationships.

i. First, we find firms do not grow alone, but as members of groups of enterprises, mutually adjusting one to the other. For this reason, amongst others, the open-systems business model is a building block.
ii. Second, we find inter-sector feedback loops: the PC and semiconductor industries; furniture making and woodworking machines; the combustion engine and the car body industry.
iii. Third, we find interactions between emerging industries and government funded physical infrastructure: the car and the highway system; ICT and the fiber-optic Internet backbone; electrical appliances and the national grid.
iv. Fourth, we find interplay between technology driven enterprises and university conducted basic research. In fact, from an innovation perspective we can see technology management as cutting across universities and enterprises to link basic, technological, developmental, and applied research with new product development.
v. Fifth, we find government funding of a basic research and a science and technology infrastructure centred in research-intensive universities. While this is most pronounced in high tech sectors, the interplay of specialist technology education and product-led business strategies is universal.

In all of these cases we are not simply looking at the existence of a list of activities in the industrial, governmental and educational spheres. We are looking for interactive, cross-institutional processes by which the activities in each institutional sphere mutually adjust to one another to establish an innovative system.

3.2.2 Tapping the technological capabilities of affiliates of technology leaders headquartered in Ireland

MNEs currently located in Ireland may amend their business models to employ their capabilities in the RE arena. There is great scope to utilise capabilities of MNEs in materials, machining, engineering, hardware and software, electronics and S&T knowhow in the RE arenas. Several major IT companies with a major presence in Ireland are entering into the smart grid space with investments and acquisitions elsewhere. Gary O'Callaghan, of Siemens Ireland, makes the point: "Renewable energy would form the bedrock of a smart grid in Ireland...If the government is going to invest heavily in the national infrastructure to achieve its target of 33 percent of renewable energy, it would get additional savings by deploying smart grid technologies" (Siliconrepublic.com).

While the details need to be worked out, we do know this: achieving climate change and energy independence goals is about reinventing the grid to take full advantage of both the IT revolution and renewable energy technology advances. Only then will the RE industry come of age in a self-reinforcing and self-organising set of inter-industry dynamics to become the foundation of a post- carbon age, knowledge-intensive industrial economy.

3.2.3 Building an Industry-embedded Science and Technology Infrastructure

Companies need to do more than make products; they need to have new product development and technology management capabilities if they are to contribute to the growth of an indigenous, innovative RE industry. Important as these enterprise capabilities are, the creation of a RE industry will require the industrial innovation capabilities that are rooted in interactions amongst a critical mass of flexibly specialised enterprises.

Building a dynamic renewable energy industry exposes many of the shortcomings of the Irish high-tech economy as presently constituted. While Ireland's economy grew rapidly over a two decade period, it was not based on the development of an indigenous S&T infrastructure and technology development within Ireland. Strikingly, there was under-investment by the Irish government in science, technology, and innovation in the period 1994-1999. It did fund education and ramped up the output of science and engineering graduates in sync with the needs of the affiliates of foreign-based high tech companies. This did not leave Ireland with an independent direction to technology and future industrial development. It was passive in technology priorities. It worked until costs rose. But the seeds for RE and clean technology and transportation were not planted in the education and research system and the transition will accordingly be that much harder.

Despite improvements in public investment in S&T since 1995, Ireland is not well prepared for technology-led transitions at least in terms of R&D capability. A report by the Irish Energy Research Council stated the following: "A review of the current status of energy research in Ireland reflects the historically low levels of investment [c. Euro 6 million in 2005] with fragmented research effort on a wide range of topics" (IERC, 2008 p. 18). For 2005, Ireland spent 0.07% of GDP on energy R&D and this is in contrast to Denmark (0.30% of GDP); Netherlands (0.27%); Norway (0.30%); and Switzerland (0.40%). (IERC,2008 p. 13; European Commission, 2007).

Government leadership will be required to oversee the establishment of both the smart grid and a S&T infrastructure in which 'third-mission' R&D capabilities of university labs foster the growth of a critical mass of firms which both benefit from and contribute to advancing and shaping Ireland's S&T infrastructure.

The troika model of interplay amongst industry, government, and university was not lost on economic policymakers elsewhere. The Nordic countries, more so than anywhere else, have institutionalised just such a complex to foster the emergence and growth of high tech sectors. In Denmark, Sweden, Finland and Norway, the government has funded basic research, fostered industry and university research partnerships, and sought to leverage emerging 'indicators' of competitive advantage and turn them into clusters with a critical mass of companies. They have thought and acted long term.

We might call the troika a framework for government technology management (TM) policymaking. As for the Nordic countries, TM is not a government add-on to policymaking; it is about effectively administering the interplay of business organisation, production capabilities and skill formation, the capability triad.

Ireland simply does not have the critical mass of resources to compete with a Route 128's 3000 plus high tech companies, or Silicon Valley's 6000 plus high tech companies. But both of these regional innovation systems began with industry and university partnership capabilities and government funding of basic research. Long term partnerships can be an organisational means to link basic research, technological research, developmental research, applied research and new product development into a single system. This is a common feature of the most successful high tech industrial districts.

In this regard, the Shannon Energy Valley project was initiated by partners from NUI, Galway, University of Limerick, Shannon Development and the Irish Technology Leadership Group (which is based in silicon Valley). The aim is to harness the resources of the Western Irish seaboard region as well as the research and development expertise at the two universities. Professor Terry Smith of NUI, Galway stated that "the Shannon Energy Valley concept seeks to provide a big-picture coherent ecosystem relating to energy" (Irish Examiner, March 16, 2010)

3.3 Renewable Energy Sub-sectors and Companies: A Strategic Audit

Wind energy is the most advanced of the renewable electricity generating technologies. Ireland is currently one of the world's leading countries in the use of wind energy for electricity generation (Irish Times, 27 May, 2010). A recent SEAI report reveals the share of electricity generated from renewable resources in 2009 was 14.4%, two-thirds of which was wind. Perhaps not surprisingly however, given the lack of renewable energy R&D, Ireland has no wind energy technology making companies. History, too, has a role. Turbine technology development goes back at least to the early days of water-powered textile mills. Many generations later, military funded jet engine companies invested heavily in R&D in turbine technology. Wind turbine development began in earnest in the 1980s in northern Europe and more recently advances have been made in the U.S. as well. Innovations in advanced materials are continuously upgrading turbine efficiencies. Consequently, given the head start, regions with wind energy clusters such as Denmark have a well established competitive advantage.

Nonetheless, Ireland has a number of companies, most notably Airtricity and SWS Energy, that operate large wind farm systems. The ability to store wind energy is the key to success for wind energy. Gaelectric is a pioneer in wind energy storage using a compressed air technology and the firm is planning to invest more than €2 billion in America over the next six years (Irish Examiner, 29 March, 2010). Another complementary technological capability is the software solution developed by Servesnet which provides a real-time picture of how wind installations are performing. This software capability can be extended to wave and solar power installations. Consultant services further pad out the RE sector. AirEn Services, for example, provides site assessment, wind measurement and grid application services for wind energy to both domestic and commercial clients.

Wave and tidal technologies, however, are not dominated by established companies elsewhere. Ocean wave energy technology lags some way behind wind energy technology. Ireland has at least 3 companies that are engaged in ocean energy technology development and production with the potential, in the long run, to play important roles in the development of the industry globally.

OpenHydro Group was formed in 2004 following a “technology trawl” by two Irish businessmen that identified the open center turbines designed by Irish-American Herbert Williams who had been working on the technology since 1995. The three became controlling owners in the new company and have since raised over Euro 50 million for development, including Euro 15 million from Imera. In 2008, after 18 months of testing, it became the first tidal energy company to connect a tidal turbine to the U.K. national grid from a testing site at the European Marine Energy Centre off Orkney, Scotland, which illustrates how Ireland currently lags behind Scotland in marine energy. OpenHydro designs, produces, and manufactures both 250kW Open-Centre turbines and is beginning the production of a new generation 1MW Open-Centre Turbine. Although early days in tidal wave technology, the potential for scale is considerable. Presently, OpenHydro turbines are being installed for utilities at tidal sites in Nova Scotia and the Channel Islands.

WAVEBOB is a first generation wave energy technology developer and operates an open system business development model. Wavebob has entered into a joint venture with the Swedish company Vattenfall, the fourth largest energy producer in Europe to develop a 250MW wave farm off the west coast of Ireland. Chevron’s Technology Ventures subsidiary is also an investor in Wavebob. Wavebob has established a US location near Annapolis, Maryland and the largest wave tank in the world at the US Navy Academy.

Another emerging wave power company OCEAN ENERGY is trialling its ‘OE Buoy’ at the Marine Institute/SEI test centre in Galway Bay. The west coast of Ireland is an attractive test site because it offers testing in one of the most vigorous wave regimes in the world. Furthermore, the demonstration test centre allows wave energy developers an advantage over developers in the US which are forced to negotiate inter-departmental jurisdictions before getting permission for ocean testing.

Both OpenHydro ($2.36 million) and Ocean Energy ($1.16 million) received marine energy funding from the Scottish government in 2007 for testing their devices near Orkney where it plans to build the world’s largest commercial wave energy farm. In 2008, Ireland announced an investment of €2 million for a grid-connected test site for full scale prototypes to be located in northwest Ireland. This will complement a sub-scale test facility in the Bay of Galway. Nevertheless, it appears that there are less than five wave energy converters worldwide that have moved beyond the concept phase to demonstrate a capacity to generate electricity in a real-life, sea environment.

3.4 Two Barriers to a Renewal Energy Industry

What has kept RE from becoming a major industry in Ireland given the country's unique natural advantage? The reasons are partly general but also specific to Ireland. Two stand out. First, the renewable energy industry everywhere has been held back, perhaps strangled at birth by national grids designed, constructed, and laid out geographically to electrify economies around centralised fossil fuel and nuclear technologies. This is not to underestimate the positive effects on industrial growth of the creation of the grid in its time. The electrification of the economy was driven by a hugely successful electric power industry which ushered in a new phase of industrial development that impacted everything including product and process design, plant layout, and the geographical location of industries and cities.

At the same time, the structural links between the grid and fossil fuels unintentionally erected a barrier to the emergence and growth of a dynamic RE industry. This is illustrated by Ireland. Ireland's RE natural resources are most pronounced along the west coast which is not connected to the grid except for 'light end' household usage. The existing grid is like a one-way highway system from a place, in this case 24 large fossil fuel power stations, to companies and households. It is not organised to flow from the west, where RE sources are abundant, to population centres and it is not organised for two-way flow of electricity and information. Consequently, if an RE industry had begun to emerge as even a minor source of national energy supply, the grid would have choked it.

The intermittent nature of renewable energies has been a second major obstacle to the growth of renewable energy. This has changed. Innovations in long distance transmission technology and convergence of IT and energy technology in the form of the "smart grid" have greatly reduced the intermittency barrier. We turn next to two "game changing" technological and organisational changes in the electric power industry infrastructure both of which attenuate the intermittency challenge of renewable energies.

3.5 Unshackling Renewable Energy: Reinventing the Physical Infrastructure

Globally, technological advances in the transmission and distribution of electric power are moving fast. Innovations in transmission technology have greatly reduced the loss energy in long distance power transmission. High voltage, direct current transmission (HVDC) lines enable efficient transfer of power over hundreds of miles. This technology is critically important to the economics of wind energy. It involves converting AC current from renewable sources to DC current for long distance shipment before reconversion at the point of application. Denmark exports up to half its wind energy during peak periods and uses the same transmission lines for imports as required. At present projects in India and China to transmit power over much greater distances are underway. Investments in nanotechnology and superconductivity technology in the U.S. are being undertaken to tap market opportunities and enhance the economics of sending wind and solar generated industry from mid-west and south-west regions to the east coast (Pernick & Wilder, 2007).

These technological advances are not lost on Irish entrepreneurs. Imera Power, headquartered in Dublin, is using advanced HVDC long distance technology to link Ireland's grid to mainland UK and later to the North Sea.20 Once completed, Imera's three cable lines linking Ireland with mainland UK have the capacity to transmit nearly 15% of Ireland's energy generating capacity.21 The project is part of a bigger drive to create a pan-European offshore electricity network, the EuropaGrid. The project includes schemes to integrate the offshore wind farms in the North Sea region with the existing main power grid. Offshore wind energy potential in the region is estimated to be 68,000 megawatts (Irish Examiner).

As important as advances in long-distance electricity transmission is to fostering the growth the REs, the idea of the "smart grid" has complementary and even greater long term effects. In fact, the "smart grid" has been likened to the interstate highway and the internet highway in terms of its revolutionary impact on business and industrial structure. A smart grid is 'an electricity network that can intelligently integrate the actions of all connected to it - consumers, suppliers and those who do both (Eamon McKeogh of UCC).' The 'smart grid' approach involves a two-way flow of power and information. It enables a combination of central power stations and small and widely distributed power suppliers. A smart grid can attenuate the natural fluctuations of wind, wave, tides, and sun with real time analysis of, and response to, supply from sources scattered throughout the country and off-shore, and demands both locally and nationally.

The convergence of IT and energy technology is not new. But the smart grid, an Internet-enabled two-way conversation between the source and use of electricity, is creating new market opportunities involving an emerging network of devices connected by switches, routers, and software. It will require sensors to anticipate disruptions, circuits to redirect spiking currents, automated meter readers, and intelligent control systems that will automatically power down non-critical appliances such as daytime lighting during periods of peak demand. CleanEdge (2009) comments that "these devices, from commercial refrigeration units to residential washing machines, will have a unique identifier—an Internet Protocol, or IP address—that will allow the integration of buildings, vehicles, cell phones" (p. 8).

A smart grid which connects disparate sources of renewable energy sources will act as a standardising force by open-system interface protocols. Intel's public interface rules sparked the rapid growth of the PC industry by diffusing experiments and design activities across thousands of specialist firms linked by the public interface rules. Network economies were established by numerous specialists, niche producers that set the standard for their link in the value chain.

Like the two previous "highways" the "smart grid" will rely on government funding and industry standards to flourish. But the potential is huge. Consequently, many IT leaders are entering into the smart-grid space: Cisco, GE, Google, HP, IBM, Analogy Devices. First generation smart-grids are being developed by IT and utility partnerships. For example, the Pecan Street Project in Austin, Texas, includes Cisco, Dell, GE, IBM, Intel, Microsoft, and Oracle to create a showcase next generation grid.

3.6 Summary and conclusions

Of particular importance to Ireland, the technical challenges to the transition to a RE industry are largely resolved in the case of wind energy but ocean power technologies are still in the developmental stages. The technological challenges posed by the intermittency of RE are being addressed by R&D projects elsewhere and rapid advances are underway. Perhaps most relevant, the concept of the 'smart grid' is integrating IT and energy tech in ways that promise step-change improvements in energy efficiency and the application of diffused energy storage capacity.

Globally, the confluence of IT and energy technology is creating a huge opportunity in the form of the reinvention of the electric utility grid. The smart grid has the opportunity to incorporate many of the leading innovations of high tech in the production and delivery of energy. Many argue that the smart grid will be to the electric power industry what the Interstate Highway program was to the transportation industry in America and fibre optics and packet switching to the Internet-driven communications industry.

Could renewable energy play a role in driving growth in the Irish economy like the IT or medical devices industry in the 1980s and 1990s? Not on its own. The emergence and growth of a dynamic RE industry will require government leadership in establishing three inter-related infrastructures. First, designing and building a smart grid takes advantage of the latest developments in digital information technology to better manage and deliver a range of centralised and distributed energy sources. But it has pervasive public good characteristics and will not be built without government funding.

Second, as is the case in all high-tech industries, establishing a science and technology infrastructure involves close partnering between technology-driven enterprises and scientific and technological research in independent, university departments and laboratories. The IDA's challenge was to attract affiliates of fast growing companies headquartered elsewhere in which the technology was crystallised to create an industry where one had not existed. It did not require the development of an indigenous S&T infrastructure; the basic research was conducted elsewhere. A certain S&T infrastructure has been created in IT and medical devices over the past decade.

Third, the emergence of a critical mass of rapidly growing, technology-driven companies will depend upon a business organisation development infrastructure. In the past Ireland has relied upon the attraction of affiliates of rapidly growing foreign headquartered enterprises to establish a foothold in a new industry. Establishing, for the first time, cluster dynamic processes will require financial institutions regulated to foster long-term commitment to company development as well as liquidity requirements. Both the leading technology development states in the U.S. and the Nordic countries offer models for support systems and institutions that encourage and enable the transition of technology development companies from basic research to proof of concept to early stage technology development to product development to production and marketing.

The consequences of fostering the emergence and growth of an innovative renewable energy industry in Ireland extend beyond the benefits of the industry itself. They would include the transition to a model of industrial development that would establish a national technology management capability that could enhance performance in all sectors.

There is certainly some cause for optimism. Brian Motherway of SEAI reports that “the level of entrepreneurial activity is staggering, the amount of people with ideas is staggering and established companies such as Kingspan and Glen Dimplex have reoriented themselves to capitalise on this opportunity” (Knowledge Ireland, Winter 2009). The history of industrial evolution based on capabilities tells us that from these seeds of entrepreneurial activity and existing firms’ reorientation grow the most successful of modern industries. The necessary capabilities and skills will be a blend of the old, such as those in electrical and engineering, and newer, such as marine energy and green software development.

4 Conclusion: Industrial Transition Processes in Ireland

The Lucerna database was created to permit researchers and policy analysts to characterise, measure and monitor emerging technology-oriented business activities that can become drivers of industrial transition processes in Ireland. There is no single, universal model of business organisation that fosters innovation and drives economic growth. Close examination of successful national and regional economies reveals that success in fostering technological change and innovation involves the development of business models and a business system that has unique organisational features. The Lucerna company database research methodology is to facilitate a deeper understanding and analysis of business organisation within Ireland and how it can be a force for fostering innovation and economic development. The Lucerna database complements and extends existing industrial datasets. It can be employed to trace the origins and evolutions of technologies, product groupings and industrial clusters in high-tech sectors. It facilitates examination of fast growth sectors and sub-sectors in the Irish economy. It can assist in the identification of 'green shoot' technologies and sectors that might fruitfully be nourished into fast growth sectors. While application of the Lucerna database is still in the early stages the following overarching themes have emerged:

Technology clusters and industrial dynamics

At the level of analysis and policy a focus on technology clusters as distinct from industrial sectors can be rewarding. Our research shows that the juxtaposition and co-evolution of different technological spheres has been an important feature in the growth of industrial activity in Ireland. For example, the presence of electronics firms, such as Digital in Galway in the 1970s and 80's provided the initial platform from which medical technology and software has grown in the region. The future development of industry is not around individual sectors but rather the intersection of technologies, which is evident in the merging of medical devices, pharmaceuticals and ICT, and the newly emerging area of renewable energy that transcends sectoral boundaries. Technological convergence is the key to the evolution of cluster dynamic processes and future development requires the exploitation of local opportunities for new technological convergences.

Business organisation development infrastructure

The economic model of attracting FDI based on cost competitiveness and grant incentives and subsequently relying on such investment to establish an industry in Ireland is now largely inadequate. The need to make the successful transition to a new model based on endogenous development is paramount. Our research suggests that in certain TBCs the seeds to make the transition are in place. An analysis of the medical technology sector in Ireland shows evidence of a competency transfer effect taking place from the foreign-owned to indigenous sector, as companies from both sectors tend to engage in the same product activity. It is suggested that the formation of skills from the presence of the multinational corporation has, to a degree, translated into the establishment of start-up enterprises. But start-up enterprises are only the beginning of a long and difficult process of business organisation development (Best 2009).Both the leading technology development states in the U.S. and the Nordic countries offer models for support systems and institutions that encourage and enable the transition of technology development companies from basic research to proof of concept to early stage technology development to product development to production and marketing. This requires enhanced connectivity, long-term commitment and inter-organisational trust among various actors, including firms from different technological domains, regulatory bodies, end-users, legal bodies, financial providers and research centres.

Regional specialisation within Ireland

While Ireland is a small country, there are regional effects taking place with regards to the development of technologies and industries which should be promoted through public policy. An analysis of the Lucerna database shows concentrations of technological activity in particular regions across the country. For example, within medical devices, a specialisation in orthopaedics and prostheses was demonstrated in the South-West and Dublin region, while specialised surgical and medical equipment was revealed to be clustered primarily in the West of Ireland. Further investigation of the relevance of such concentrations of activity reveals the significance of 'lead' or 'anchor' organisations in a region as they influence the technological development of a region. Research on the Galway medical technology cluster in particular shows the influence that large MNCs can have in a region as they can result in the formation of start-up enterprises, the development of labour skills and the growth of suppliers in the locality.

5 Final Comment

From a capabilities perspective Ireland has not failed as an economy. It has assimilated capabilities, technological, manufacturing and managerial from multinationals, principally American. It has belatedly invested in the higher education sector that should, with proper management, further develop technological capabilities. Whilst the short–term economic outlook for Ireland is bleak the longer term prospects are more promising in areas of high-tech expertise and knowhow such as IT, pharma and medical technology. These can underpin green technology and nanotechnology as exemplars of future growth. The capabilities perspective can also be the foundation for projects such as the 'Green Collar economy' programme recently proposed which will provide a stimulus package for 'technology actions' to generate 30,000 new jobs in the 'smart economy'. So the Lucerna project is an exhortation for economic growth via evidence-based capabilities development, guided evolution and enhancement. Chris Horn stated in the Irish Times (8th August 2009) that "I have been surprised by the absence of public discussion on just how we now expect to drive growth in our economy". He asks "what can now be the engine of growth to create sustainable jobs?". Lucerna can contribute to this required public discussion as an evidential database to illustrate potential engines of growth.

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ANNEX 1 : LUCERNA TECHNOLOGY-BASED CLUSTER LISTING (Page 1 of 2)

Computer & Communication Hardware

KOMPASS CODE	Product & Service Descriptions	TBC
37300	Telecommunication system exchanges & network equipment	CCH
37310	Telecommunication transmission & reception equipment	CCH
37311	Telecommunication transmission & reception equipment	CCH
37320	Telecommunication equipment accessories	CCH
37350	Remote controls, electric & electronic	CCH
37360	Radar systems & equipment	CCH
37361	Radar systems & equipment	CCH
37390	Radio equipment, professional	CCH
37391	Radio equipment, professional	CCH
37400	Television & video equipment, professional	CCH
37401	Television & video equipment, professional	CCH
37410	Radios, tape recorders, CD players & high fidelity (hi-fi) equip.	CCH
37420	Television receivers, video recorders & camcorders	CCH
37430	Audio-visual (AV) & simultaneous interpreting equipment	CCH
37440	Loudspeakers & headphones	CCH
37460	Aerials, wave radiators & collectors	CCH
37480	Microphones	CCH
37490	Recording equipment for industrial use	CCH
37500	Automation systems & servomechanisms	CCH
37510	Electronic equipment & components, industrial	CCH
37511	Electronic equipment & components, industrial	CCH
37600	Capacitors & power factor correction systems	CCH
37601	Capacitors & power factor correction systems	CCH
37610	Resistors & rheostats	CCH
37620	Passive electronic components: coils, chokes & power transformers	CCH
37650	Complex electronic components. Passive microstructures	CCH
37660	Tubes & valves, electronic	CCH
37661	Tubes & valves, electronic	CCH
37690	Semiconductors	CCH
37700	Transistors, thyristors & metal rectifiers	CCH
37710	Integrated circuits (ICs) & printed circuits	CCH
37720	Components for semiconductor devices & micro-electric circuits	CCH
37730	Electric & electronic relays, classified by type	CCH
37731	Electric & electronic relays, classified by type	CCH
37740	Electric & electronic relays, classified by use	CCH
37750	Amplifiers	CCH
37751	Amplifiers	CCH
37760	Oscillators	CCH
37770	Microwave systems	CCH
37810	Wires & cables for telecommunications & electronics	CCH
37820	Fibre optic cables, systems & equipment	CCH
37850	Lasers & masers	CCH
37860	Electrical & electronic equipment for military use	CCH
44140	Printing machinery & equipment	CCH
44141	Printing machinery & equipment	CCH
44160	Printing machinery & equipment, special purpose	CCH
44180	Typesetting & phototypesetting/photocomposing mach. & equip.	CCH
44200	Lithographic, offset & photolithographic machinery & equipment	CCH
44220	Colour separation & scanning equipment	CCH
44240	Screen printing equipment	CCH
44260	Laser & ink jet printing machinery	CCH
44300	Block making & stereotyping equipment	CCH
44320	Type & typesetting supplies	CCH
44340	Printers' ancillary equipment & supplies	CCH
44341	Printers' ancillary equipment & supplies	CCH
44360	Bookbinding & folding machinery & equipment	CCH
44400	Typewriters	CCH
44420	Calculating machines	CCH
44440	Accounting & invoicing machines. Cash registers	CCH
44460	Duplicators & addressing machines	CCH
44480	Photocopiers	CCH
44500	Office machinery & equipment NES	CCH
44501	Office machinery & equipment NES	CCH
44520	Mailing & postal machinery & equipment	CCH
44560	Servers & large scale computers	CCH
44580	Desktop computers, portable computers & related devices	CCH
44620	Industrial computers. Special purpose computers NES	CCH
44640	Simulators	CCH
44660	Data storage devices for computing	CCH
44680	Circuit boards & microprocessors for computers	CCH
44720	Terminals, monitors/display screens	CCH
44740	Network equipment, switches & terminators	CCH
44760	Computer keyboards & other input devices NES	CCH
44780	Printers, plotters	CCH
44800	Document scanners, bar code scanners/readers	CCH
44820	Local area network (LAN) equipment NES	CCH
44830	Computer cable assemblies & connectors	CCH
44840	Computer consumables & accessories. Components for computers NES	CCH
44841	Computer consumables & accessories. Components for computers NES	CCH
44860	Integrated computer systems	CCH

Software & Communication Services

KOMPASS CODE	Product & Service Descriptions	TBC
28730	Publishing: Compact discs, records, audio & video cassettes	SCS
44880	Operating systems. System & development software	SCS
44890	Software, database management system (DBMS)	SCS
44900	Application software packages, business, office, professional & financial	SCS
44901	Applic. softw. packages, business, office, profes. & financial	SCS
44920	Application software packages, industrial, technical & scientific	SCS
44930	Software NES	SCS
44940	Software, multimedia	SCS
44950	Software to customer specification, software houses	SCS
44951	Software to customer specification, software houses	SCS
44952	Software to customer specification, software houses	SCS
44960	Computer & computer peripheral maintenance services	SCS
44970	Computer maintenance accessories	SCS
44980	Electronic data processing (EDP) & data input services	SCS
44990	Computer & Internet related services NES	SCS
61860	Internet portals	SCS

Medical Devices

KOMPASS CODE	Product & Service Descriptions	TBC
38890	Medical & surgical instruments	MEDEV
38891	Medical & surgical instruments	MEDEV
38900	Equipment & instruments for medical laboratories	MEDEV
38910	Medical & surgical equipment	MEDEV
38911	Medical & surgical equipment	MEDEV
38912	Medical & surgical equipment	MEDEV
38913	Medical & surgical equipment	MEDEV
38914	Medical & surgical equipment	MEDEV
38915	Medical & surgical equipment	MEDEV
38920	Ophthalmic equipment	MEDEV
38930	Orthopaedic equipment	MEDEV
38940	Prostheses	MEDEV
38950	Physiotherapy & spa equipment	MEDEV
38960	Dental equipment & instruments	MEDEV
38970	Dental laboratory equipment & supplies	MEDEV
38980	Dental prostheses	MEDEV
38990	Medical & surgical equipment, veterinary	MEDEV
37550	Electro-medical & electro-biological equipment	MEDEV
37560	Hearing aids	MEDEV
37630	Optoelectronic systems & equipment	MEDEV
42650	Laboratory equipment, microbiological	MEDEV

Pharmaceuticals

KOMPASS CODE	Product & Service Descriptions	TBC
31310	Organic acids, their anhydrides & acid halides	BIOPHRM
31311	Organic acids, their anhydrides & acid halides	BIOPHRM
31312	Organic acids, their anhydrides & acid halides	BIOPHRM
31313	Organic acids, their anhydrides & acid halides	BIOPHRM
31314	Organic acids, their anhydrides & acid halides	BIOPHRM
31315	Organic acids, their anhydrides & acid halides	BIOPHRM
31510	Raw materials for pharmaceuticals	BIOPHRM
31511	Raw materials for pharmaceuticals	BIOPHRM
31512	Raw materials for pharmaceuticals	BIOPHRM
31513	Raw materials for pharmaceuticals	BIOPHRM
31610	Carbohydrates, proteins & enzymes	BIOPHRM
31611	Carbohydrates, proteins & enzymes	BIOPHRM
31620	Vitamins, hormones & organ extracts	BIOPHRM
31621	Vitamins, hormones & organ extracts	BIOPHRM
31630	Barbiturates, sulphonamides, glycosides, alkaloids & antibiotics	BIOPHRM
31631	Barbiturates, sulphonamides, glycosides, alkaloids & antibiotics	BIOPHRM
31632	Barbiturates, sulphonamides, glycosides, alkaloids & antibiotics	BIOPHRM
31640	Pharmaceutical preparations for the cardiovascular system, central & autonomic nervous system. Anaesthetics	BIOPHRM
31650	Pharmaceutical preparations for ophthalmology, ear, nose & throat & dent.	BIOPHRM
31660	Pharmaceutical preparations for metabolism, nutrition, alimentary systems. Pharmaceutical preparations for urology, dermatology, gynaecology & obstetrics	BIOPHRM
31670	Pharmaceutical preparations NES	BIOPHRM
31680	Pharmaceutical veterinary preparations	BIOPHRM
31690	Chemotherapeutic agents, endocrines, antiseptics, immunological prep.	BIOPHRM
31691	Chemotherapeutic agents, endocrines, antiseptics, immunological prep.	BIOPHRM
31710	Parapharmaceutical preparations	BIOPHRM
31720	Medical preparations, oriental	BIOPHRM

Renewable Energy Technology

KOMPASS CODE	Product & Service Descriptions	TBC
18100	Electricity Production & Distribution	RE
37890	Nuclear engineering Plant, installation & equipments	RE
37900	Nuclear Fuel, isotopes, compounds, related equipment	RE
37910	Measuring & control instruments for nuclear installations	RE
37920	Nuclear engineering Contractors	RE
37950	Solar energy systems & equipments	RE
37960	Alternative energy equipments, NES	RE
37980	Renewable energy equipments, Parts & accessories	RE
4495117	Software, energy network management & services, to customer specification	RE
84720	Nuclear engineering consultants	RE
84740	Alternative energy engineering consultants	RE
85510034	Heat & energy technology Research & Development	RE
85600	Nuclear Energy research	RE
85620	Renewable energy research	RE

ANNEX 1 : LUCERNA TECHNOLOGY-BASED CLUSTER LISTING (Page 2 of 2)

KOMPASS CODE	Product & Service Descriptions	TBC
	Test, Measurement, & Instrumentation	
37530	Ultrasonic, ultraviolet, infrared & radiolog. equip. for indust. & scientific use	TMI
37540	Ultrasonic, ultraviolet (UV), infrared & radiological equipment for biological & medical apps.	TMI
38010	Electrical & electronic instrum. & apparatus for measur. electrical quantities	TMI
38030	Electrical & electronic test equipment	TMI
38040	Electrical measuring & control instruments for electric circuits & networks	TMI
38060	Electrical, electromechanical, electrochemical, electrophysical measuring equipment for non-electric values	TMI
38100	Electrical & electronic measur. & controlling instruments for nuclear	TMI
38120	Electronic measuring instruments & meters for laboratory & research. Oscilloscopes, wavemeters	TMI
38130	Electronic measuring, testing & controlling instruments for vibration & electro-aco ustics. Filters, signal generators	TMI
38160	Magnetic & electromagnetic measuring instruments	TMI
38180	Static & tensile testing equipment	TMI
38190	Dynamic testing equipment	TMI
38200	Structural testing equipment	TMI
38210	Industrial testing equipment for internal combustion engines & motor	TMI
38220	Hydraulic & thermal test equipment	TMI
38230	Testing equipment for building materials	TMI
38240	Testing equipment for paper & paper pulp	TMI
38250	Testing equipment for the rubber, plastic & leather industries	TMI
38260	Testing equipment for textiles	TMI
38270	Testing equipment for colours, paints & varnishes	TMI
38280	Testing equipment for precious stones	TMI
38300	Testing equipment for metals	TMI
38320	Physical measur. equip., chromatographic analy., X & gamma-ray	TMI
38410	Microscopes	TMI
38440	Refractometers & other optical instruments	TMI
38450	Astronomy equipment	TMI
38460	Optical instruments for military use	TMI
38550	Photographic processing equipment	TMI
38590	Surveying & geodetic instruments	TMI
38600	Underwater testing & measuring instruments	TMI
38830	Telecommunication measuring & testing equipment	TMI
38840	Measuring & testing instruments, electric & electronic NES	TMI
38880	Precision measuring instrument components & accessories	TMI
39180	Control & navigational instruments for ships	TMI
39750	Aircraft cockpit equipment	TMI
39780	Aircraft cabin equipment & appliances	TMI
39790	Aircraft electrical equipment	TMI
39830	Flight training equipment	TMI
39950	Airport equipment	TMI
47740	Machinery & equipment for the electrical industry	TMI
47760	Machinery & equipment for the electronics industry	TMI
38150, - 51	Electrical & electronic measuring, monitor. & controlling instru. for various	TMI
38170, - 71	Test equipment for the electrical & electronics industries	TMI
38290, - 91	Testing equipment for materials & products NES	TMI
38310, - 11	Testing & analysing equip. for the chemical, pharmaceutical & cosmetic	TMI
38430, - 31	Spectrophotometric & photometric instruments	TMI
39810, - 11	Aircraft control & navigational equipment	TMI
	Processed Chemicals & Materials	
29100	Processed rubber, rubber solutions & adhesives	PCM
29360, -61	Rubber products for industrial use	PCM
29560	Rubber products for medical, veterinary & laboratory use	PCM
29750	Cellular/foam rubber products	PCM
29800, -01	Ebonite & gutta-percha products	PCM
30180, -81	Glass fibre reinforced plastic (GRP) products	PCM
30590, -91, -92, -93	Plastic products, miscellaneous	PCM
30680	Plastic products for the chemical, pharmaceutical & cosmetic industries	PCM
30700	Plastic products for the mechanical engineering industry	PCM
30720, -21	Plastic products for the electrical & electronics industries	PCM
30820	Plastic products for the optical, photographic & cinematographic industry	PCM
30870	Plastic products for hospital & medical use	PCM
30880	Plastic products for surgical, orthopaedic & dental use	PCM
30890	Plastic products for veterinary use	PCM
30900, -01	Thermoplastics processing contractors	PCM
30950	Thermosetting plastic contractors	PCM
31120, -21, -22	Iron & steel alloy compounds	PCM
31140, - 41, - 42	Non-ferrous heavy metal compounds	PCM
31160, -61, -62	Light metal compounds	PCM
31180, -81	High-melting point & noble metal compounds	PCM
31200, -01, -02	Metal compounds NES	PCM
31250	Inorganic chemicals NES	PCM
31260	Compressed & liquefied gases. Chemicals for refrigeration	PCM
31270	Rocket propellants	PCM
31330, -31	Hydrocarbons & halocarbons	PCM
31730	Culture media, fresh cell culture solutions. Bacteria	PCM
31810, -11	Petroleum based fuels, fluids, industrial oils, lubricants, greases & gases	PCM
31940, -41, -42, -43	Synthetic rubbers, resins, latices & other precursors	PCM
32020, -21	Fertilisers	PCM
32040, -41, -42	Fungicides, insecticides, bactericides, vermin destroyers	PCM
32060	Herbicides, plant growth control substances, chemical spray prods, fumigants	PCM
32440, -41	Paints & primers	PCM
32480	Vitreous colours, enamels & glazes	PCM
32500	Anti-corrosion, anti-foaming, antioxidant, antistatic & antifreeze products	PCM
32510, -11	Adhesives, synthetic	PCM
32610, -11	Explosives, gunpowders & detonators	PCM
32640	Pyrotechnical products	PCM
34040	Ferro-alloys	PCM
34050, -51	Refined, special & tool steels & their semi-finished products	PCM
34210	Light metals & alloys	PCM
34250	Precious & rare metals & their alloys	PCM
34260	Precious & rare metal semi-manufactured products	PCM
34290	Pure metals	PCM
34310, -11, -12	Non-ferrous metals & alloys NES	PCM
	Diversified Manufacturing & Processing	
37780	Electrical & electronics industries contractors	DMP
37830	Electrical insulators	DMP
37840	Electrical insulating & dielectric materials	DMP
37890	Nuclear engineering plant, installations & equipment	DMP
37900	Nuclear fuels, isotopes, compounds & related equipment	DMP
37910	Measuring & control instruments for nuclear installations	DMP
37920	Nuclear engineering contractors	DMP
37950	Solar energy systems & equipment	DMP
37960	Alternative energy equipment NES	DMP
37980	Renewable energy equipment, parts & accessories	DMP
38510, -11	Cameras, photographic equipment & projectors	DMP
38530	Cine-cameras, cine projectors & related equipment	DMP
38560	Cine film processing equipment	DMP
38570	Microfilm equipment	DMP
38850	Photoelectric control systems & devices	DMP
39010	Ocean-going ships	DMP
39060	Submersible vessels & equipment	DMP
39120	Marine propulsion, transmission & steering units. Boilers	DMP
39210	Locomotives, railcars, & trams	DMP
39250	Railway & tram carriages & wagons	DMP
39310	Motor cars & vans	DMP
39330	Buses & motor coaches	DMP
39340	Lorries/trucks & tractor units	DMP
39350	Motor vehicles, special purpose	DMP
39700	Aircraft	DMP
39710	Missiles, rockets & satellites. Launching platforms	DMP
39730	Aircraft engines & components	DMP
39740, -41	Aircraft structural equipment & components	DMP
40010	Water turbines & engines	DMP
40030	Steam & gas turbines & engines	DMP
40050	Internal combustion engines	DMP
41950, -51	Food industry plant & equipment NES	DMP

ANNEX 2: INDUSTRY CLASSIFICATION – 2 DIGIT KOMPASS CLASSIFICATION	
Kompass Code	**Kompas Industry Groups Desciptions**
01	Live animals
02	Agricultural, horticultural and floricultural prod.
07	Agricultural and animal services
08	Forestry
09	Fish and other marine and freshwater prod.
11	Coal and peat
12	Ores
13	Crude oil (petroleum) and natural gases
14	Quarried stone
17	Minerals, non-metallic
18	Electricity, gas and water
20	Food and tobacco
21	Beverages
22	Leathers, skins, furs and their prod.. Travel goods. Footwear
23	Textiles
24	Clothing and textile prod.
25	Wood and cork prod.
26	Furniture
27	Cellulose, paper, board and their prod.
28	Printing and publishing
29	Rubber and synthetic rubber prod.
30	Plastic prod.
31	Acids, alkalis, chemical base materials, alcohols, petroleum prod., pharmaceuticals, resins
32	Agricultural chemicals, insecticides. Detergents, soaps, perfumes, cosmetics, waxes and polishes. 33 Non-metallic mineral prod.
34	Basic metal prod.
35	Metal constructions for the building industry. Metal tanks, containers, cables, ropes, wires and fabrics. Chains, screws, bolts, nuts and rivets. Fasteners and springs. Metal turned articles. Bearings, pulleys, couplings and gearwheels. Industrial power transmission equipment
36	Metal pipes, tubes, hoses, taps, valves, cocks, packings and gaskets. Metal sanitary and household articles. Knives, scissors, shears
37	Electrical, electronic and nuclear equipment
38	Measuring and testing equipment. Optical, photographic equipment. Medical, surgical, dental and veterinary equipment
39	Means of transport. Transport infrastructure equipment
40	Turbines, engines, steam machines, pumps, pneumatic and hydraulic equipment, boilers, ovens, kilns, furnaces and burners. Heating, ventilation, air conditioning (HVAC), cleaning, catering, cooking and refrigeration equipment. Fire-fighting, protection and safety equipment
41	Agricultural and forestry machinery and equipment. Food, drink and tobacco industry machinery and equipment
42	Plant, machinery and equipment for chemicals, rubber, plastic, refuse and water. Packaging machinery and equipment
43	Textile, clothing, leather and shoemaking machinery and equipment
44	Pulp, paper machinery and equipment. Printing and office machinery and equipment. Electronic data processing (EDP) equipment
45	Machinery and equipment for mining, quarrying and stoneworking, oil and gas extraction, cement, clay, ceramics and glass industries machinery and equipment. Road making, building. Mechanical handling machinery and equipment. Industrial robots
46	Plant, machinery and equipment for metalworking
47	Plant, machinery and equipment for wood and cork. Machinery and equipment for the precious stone, optical and watchmaking industries.
48	Forging, stamping, hot pressing, surface treatment and machining contractors. Mechanical construction and assembly contractors. Industrial packaging contractors. Mould, foundry core and pattern making contractors.
51	Civil and marine engineering contractors
52	Building industry
54	Environmental services
61	Importers and exporters, general. General traders and commodity merchants. Department and chain stores
62	Wholesalers and distributors, importers and exporters of consumer goods: animals, agricultural prod., plants, food, drink and tobacco
63	Wholesalers and distributors, importers and exporters of consumer goods: textiles, clothing, domestic furniture, toiletries, cosmetics
64	Wholesalers and distributors, importers and exporters of consumer goods: publications, stationery and office requisites
66	Wholesalers and distributors, importers and exporters of industrial and commercial prod.: base materials and their prod..
67	Wholesalers, distributors, importers and exporters of industrial and commercial prod.: machinery and equipment, hospital and medical equipment, electrical and electronic prod., telecommunication equipment, computers, office machinery
68	Wholesalers, distributors, importers and exporters: means of transport and related spare parts and accessories
69	Hospitality and tourism, hotels, motels, catering services. Conference centres.
71	Transport infrastructure administration
77	Warehousing and storage services
79	Postal services, telecommunications, radio and television
80	Administrative, personnel and property services
81	Commercial services
82	Financial and insurance services
83	Hire and rental services
84	Technical offices and engineering consultancies, architects
85	Research and testing
86	Education and training
87	International and national organisations. Public administration
88	Medical care, social services

ANNEX 3: EXAMPLE - LOCATING MEDEV AND STENT RELATED TECHNOLOGIES IN KOMPASS CLASSIFICATION (2, 5 & 7 DIGITS)

	2, 5 & 7 Digit Kompass Codes	Kompass Product Group/Product Description
	2 DIGIT - 38	Measuring and testing equipment. Optical, photographic and cinematographic equipment. Medical, surgical, dental and veterinary equip.
5 DIGIT KOMPASS	38010	Electrical and electronic instruments and apparatus for measuring electrical quantities
	38030	Electrical and electronic test equipment
	38040	Electrical measuring and control instruments for electric circuits and networks
	38060	Electrical, electromechanical, electrochemical, electrophysical measuring equipment for non-electric values
	38100	Electrical and electronic measuring and controlling instruments for nuclear engineering
	38120	Electronic measuring instruments and meters for laboratory and research. Oscilloscopes, wavemeters
	38130	Electronic measuring, testing and controlling instruments for vibration and electro-acoustics. Filters, signal generators
	38150	Electrical and electronic measuring, monitoring and controlling instruments for various applications
	38151	Electrical and electronic measuring, monitoring and controlling instruments for various applications
	38160	Magnetic and electromagnetic measuring instruments
	38170	Test equipment for the electrical and electronics industries
	38171	Test equipment for the electrical and electronics industries
	38180	Static and tensile testing equipment
	38190	Dynamic testing equipment
	38200	Structural testing equipment
	38210	Industrial testing equipment for internal combustion engines and motor vehicles
	38220	Hydraulic and thermal test equipment
	38230	Testing equipment for building materials
	38240	Testing equipment for paper and paper pulp
	38250	Testing equipment for the rubber, plastic and leather industries
	38260	Testing equipment for textiles
	38270	Testing equipment for colours, paints and varnishes
	38280	Testing equipment for precious stones
	38290	Testing equipment for materials and products NES
	38291	Testing equipment for materials and products NES
	38300	Testing equipment for metals
	38310	Testing and analysing equipment for the chemical, pharmaceutical and cosmetic industries
	38311	Testing and analysing equipment for the chemical, pharmaceutical and cosmetic industries
	38320	Physical measuring equipment, chromatographic analysers, X-ray and gamma-ray spectrographs
	38330	Mechanical measuring instruments for laboratories
	38350	Instrument recorders for research and industry
	38370	Optical lenses and glasses. Optical mirrors
	38371	Optical lenses and glasses. Optical mirrors
	38380	Spectacles and spectacle frames
	38390	Magnifiers, eyepieces and objectives
	38400	Binoculars, telescopes and periscopes
	38410	Microscopes
	38420	Optical projectors
	38430	Spectrophotometric and photometric instruments
	38431	Spectrophotometric and photometric instruments
	38440	Refractometers and other optical instruments
	38450	Astronomy equipment
	38460	Optical instruments for military use
	38500	Compasses
	38510	Cameras, photographic equipment and projectors
	38511	Cameras, photographic equipment and projectors
	38530	Cine-cameras, cine projectors and related equipment
	38550	Photographic processing equipment
	38560	Cine film processing equipment
	38570	Microfilm equipment
	38580	Meteorological equipment
	38590	Surveying and geodetic instruments
	38600	Underwater testing and measuring instruments
	38630	Drawing and mathematical instruments
	38650	Length, surface and volume measuring instruments
	38660	Measuring instruments, mechanical and optical NES
	38670	Checking instruments, mechanical
	38680	Mechanical measuring and controlling instruments for pressure. Manometers
	38681	Mechanical measuring and controlling instruments for pressure. Manometers
	38690	Mechanical counters and tachometers, industrial
	38720	Mechanical scales, weigh batching and dosing equipment
	38730	Automatic scales, weigh batching and dosing equipment
	38731	Automatic scales, weigh batching and dosing equipment
	38750	Optoelectronic, electronic and special scales, weigh batching and dosing equipment
	38760	Accessories and weights for scales
	38780	Temperature measuring instruments
	38781	Temperature measuring instruments
	38790	Flow measuring and control equipment
	38791	Flow measuring and control equipment
	38800	Level measuring and control equipment for liquids
	38810	Moisture, specific gravity, pH, fluid conductivity and viscosity measuring instruments
	38811	Moisture, specific gravity, pH, fluid conductivity and viscosity measuring instruments
	38820	Temperature regulating and control equipment
	38830	Telecommunication measuring and testing equipment
	38840	Measuring and testing instruments, electric and electronic NES
	38850	Photoelectric control systems and devices
	38860	Regulating and control systems and equipment NES
	38861	Regulating and control systems and equipment NES
	38862	Regulating and control systems and equipment NES
	38870	Components and accessories for regulating and controlling systems and equipment
	38880	Precision measuring instrument components and accessories
	38890	Medical and surgical instruments
	38891	Medical and surgical instruments
	38900	Equipment and instruments for medical laboratories
	38910	Medical and surgical equipment
	38911	Medical and surgical equipment
7 DIGIT KOMPASS	3891100	Medical and surgical equipment (cont'd)
	3891101	X-ray room equipment
	3891102	Production equipment, automatic, for radiotherapy beam shaping filters
	3891103	Dosimeters for radiotherapy
	3891104	Kymographic tubal insufflation apparatus
	3891105	Injection equipment for radiological contrast media, medical
	3891108	Anaesthesia apparatus and accessories
	3891109	Epidural anaesthetic apparatus
	3891110	Anaesthetic and cardio-respiratory monitoring apparatus
	3891112	Electro-surgical equipment
	3891113	Microsurgery equipment
	3891114	Cryosurgery systems and equipment
	3891116	Surgical diathermy apparatus
	3891117	Surgical equipment, laser
	3891118	Surgical equipment, ultrasonic
	3891119	Surgical equipment, water jet
	3891120	Blood loss measurement apparatus (haemorrhometers)
	3891122	Stereotactic equipment, medical
	3891123	Ophthalmic surgery equipment
	3891124	Vascular surgery equipment
	3891125	Cardio-surgery equipment
	3891126	Coronary stents
	3891127	Lithotrity and lithotomy apparatus and equipment