Selling Circuits Short

EMBARGO: 00.01 hrs, Tuesday 28 August

Electronics is a strategic capability that any modern country must maintain and develop to play a major role in future growth markets and industries. Hence industry and government should work together in ensuring this vital, but often invisible sector is well equipped to compete and grow in the long-term.

Marco Pisano, Electronics Programme Manager at Intellect, voice of the UK's technology industry

I congratulate Civitas on a well-researched look at the UK electronics industry. It highlights many of the things we care about at NMI and are working-on to develop an Action Plan through the ESCO Report.

Derek Boyd, Chief Executive at the National Microelectronics Institute, trade association for Electronics Systems, Microelectronics and Semiconductors in the UK

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Improving the prospects of the British electronics industry

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Summary

- Using qualitative and quantitative analysis this paper is a wide-ranging assessment of the British electronics industry. The sector was last subjected to comprehensive scrutiny in 2004.

- International electronics production is dominated by China, USA and Japan, which account for approximately 50 per cent of global production. The UK is the 13th largest producer of electronics, with output totalling £15.3 billion in 2011. The British electronics market is worth approximately £28.2 billion.

- The electronics industry, in Britain and abroad, is extremely fragmented. Large vertically-integrated companies are becoming rarer as new business models that separate design, production and assembly become more important.

- The UK's strength lies in the production of high-end and complex electronics products produced in relatively low quantities. Britain is an important producer of electronics in the health and industrial sectors, as well as control and instrumentation electronics and radio communication electronics. The UK has largely exited the consumer electronics market in terms of production but is an important player in design.

- Although in some respects not geographically cohesive, there are three broad electronics clusters in Britain. The 'M4 corridor' is home to the headquarters of many international companies and also hosts important research and development (R&D) centres. 'Silicon Fen', or the Cambridge cluster, emerged in the 1970s and today continues to boast leading edge firms with links to the University. 'Silicon Glen', located in a central area of Scotland between the cities

of Dundee, Inverclyde and Edinburgh, was once a hub for mass electronics production by multinationals but is now a location for low-volume, high-end electronics manufacturing and design.

Four case studies each examining a different electronics industry

- Taiwan, recipient of significant electronics foreign direct investment (FDI) in the 1970s and 1980s, developed the 'pure-play' foundry model whereby companies manufacture microchips for others. As a result the country is one of the largest producers of microchips in the world.

- Japan was once on the brink of domination in the electronics industry, but today the struggles of many of the country's large vertically-integrated firms demonstrate the dangers of failing to adapt in an industry that evolves incredibly quickly.

- Silicon Valley, the most famous industrial cluster in the world, highlights the importance of marrying technical and business skills, as well as the facilitating role that government can play in a complex, fast-moving industry.

- In twenty years China has become the largest producer of electronics but wishes to produce more cutting edge technology; its success in doing so will depend on the country producing, and retaining, more highly skilled individuals.

Government action is required if Britain's electronics sector is to prosper

- More needs to be done to attract state-of-the-art manufacturing facilities, in particular large semiconductor foundries, to the UK. The government should also support the development of a 450mm semiconductor foundry in Europe, even if it is not located in the UK, as British firms would benefit from the presence of such a facility.

- The government needs to address the shortage of skills in the industry. In the future the electronics sector will require more engineers as well as those able to combine technical and business skills. Promising headway has been made in this regard with the creation of the UK Electronics Skills Foundation for which support should continue.

- Being able to obtain affordable credit for a sufficient period of time is important in any industry. However, the electronics sector struggles because many firms are small, lack security, and produce products that financiers find difficult to understand. More needs to be done to ensure that banks, venture capitalists and public equity markets support the industry.

- Access to credit and talented employees is necessary if Britain is to develop more multinational electronics companies. It is worrying that acquisitions of UK firms by foreign competitors occur regularly.

- The government needs to reconsider how it engages with the sector. Electronics is unlike other manufacturing industries due to its pervasiveness and low visibility. A more disaggregated approach whereby government works with sub-sectors of the industry is required. More cooperation by trade bodies could help, and could also enable more comprehensive statistics and data on the industry to be produced.

- The government should seriously consider building another runway at Heathrow. There is a clear need to expand airport capacity in the South East; doing so at Heathrow would allow the M4 electronics corridor to continue to flourish. Plans to expand airport capacity in other locations fail to appreciate Heathrow's position within a broader industrial ecosystem.

Introduction

The transistor, the basis of modern electronics, is often described as one of the greatest inventions of all time. Its importance is evident when one considers the ubiquity of electronic products today.

It is therefore no wonder that since the 1950s developed and developing countries have recognised the importance of a successful electronics industry, with China the largest and most recent example of a country placing huge faith in the sector. It is perhaps surprising then that Britain's electronics industry is rarely discussed in political or popular circles, despite the fact that concerns over its future prosperity have been voiced since the 1980s.[1]

This paper is a comprehensive assessment of an industry often neglected by policy-makers, and one, despite its importance, that is notoriously difficult to capture accurately in official statistics. The last comprehensive examination of the British electronics industry by the government was in 2004,[2] although reports on sub-sectors of the industry have been published since then.[3] In spring 2012 a group of trade associations launched ESCO (Electronic Systems – Challenges and Opportunities), an investigation of the sector involving trade bodies, businesses and the government. It is hoped that this paper, and the work of projects such as ESCO, will help boost awareness and understanding of the sector and the challenges it faces.

The paper combines qualitative and quantitative analysis. Statistics produced by leading market research firms help capture industry trends and provide an indication of where Britain's strengths will lie in the future. A number of detailed case studies complement this analysis. The first set of case studies examines three pivotal British electronics clusters. The second set of studies takes a look at four important electronics industries, those of China, Japan and Taiwan and the electronics cluster in the San Francisco Bay Area known as 'Silicon Valley'. These case studies are necessary to appreciate the competitive challenges facing Britain's electronic industry. They also illuminate factors that have affected the success of electronics companies across the globe. The report goes on to investigate a number of issues that policy-makers need to address if Britain's electronics industry is to remain competitive and prosperous in the future.

It is important to note that the paper examines electronics hardware and does not address software. In some respects the distinction between these two sectors is increasingly unclear: large software companies such as Microsoft and Amazon produce hardware and hardware firms are increasingly designing embedded software for their products. Nevertheless the distinction is drawn in this report because it still exists and while government is often quick to support software and services it tends to neglect manufacturing and hardware. Furthermore a focus on the hardware industry, including design and production, allows the particular challenges facing this industry to be examined in detail.

1

The international electronics industry

International electronics production

Total production in the international electronics industry in 2010 was $ 1.7 trillion.[4] Production by the top five countries, China, USA, Japan, South Korea and Singapore accounted for 65.8 per cent and production by the top three countries, China, USA and Japan, accounted for 55.5 per cent of global production. This gives some indication of the way in which the top three countries dominate the industry, at least in terms of the volume of output.

Table 1: Summary of global electronics production 2010 ($ billions)

Rank	Country	Production
1	China	489.8
2	USA	269.1
3	Japan	199
4	South Korea	114.8
5	Singapore	64.3
6	Germany	64.2
7	Taiwan	60.7
8	Malaysia	56.7
9	Mexico	53
10	Brazil	37.2

Source: Reed Electronics Research, www.rer.co.uk

Table 1 presents 2010 production figures for the top ten producers of electronics. The UK was the 13th largest producer in 2010 with output totalling $21.8 billion.

International electronics consumption

Table 2: Summary of global electronics markets 2010 ($ billions)

Rank	Country	Market
1	USA	405.9
2	China	327.4
3	Japan	174.4
4	Germany	85.1
5	Brazil	51.6
6	South Korea	51.6
7	**UK**	**44**
8	France	42.5
9	Mexico	38
10	Italy	35.8

Source: Reed Electronics Research, www.rer.co.uk

Table 2 presents the top ten markets for electronics in 2010. The UK is the 7th largest market. It is worth noting how the rankings for production and markets diverge. The USA, China and Japan are all big producers and consumers of electronics, while Brazil, Britain, France and Italy are larger consumers. At the other end of the spectrum Singapore and Malaysia are large producers but are not included in the top ten consumers. The divergence between production and consumption reflects developments in the industry over time: some countries have reduced production or moved up the value chain while increasing their consumption of simpler electronics products, others have increased exporting capabilities, which now outstrip their domestic consumption.

The shape of the international electronics industry

Describing an industry by categorising its businesses often results in gross simplifications as to what firms actually do. Nevertheless it is worth outlining some of the types of businesses that operate in the electronics industry to provide an overview of how the production chain is divided up. In general businesses can be placed into one of the following categories.

Original Equipment Manufacturers (OEMs)

When one thinks of the electronics industry, large, multinational companies, such as Apple, IBM or Samsung come to mind. However these companies, often described as OEMs, are just the tip of the iceberg; below them is a raft of other firms who help produce the OEMs' products. OEMs form a distinct group only in as much as it is their name on the product the end consumer is using. In almost every other way OEMs vary: whilst some such as IBM and Samsung are large producers of microchips, others including Apple do not fabricate (manufacture) their own chips. Apple uses Foxconn, a company specialising in electronics manufacturing, to assemble many of its products, while some other OEMs continue to assemble their products. Those OEMs that continue to manufacture their own microchips to be used in their own products are often described as integrated device manufacturers (IDMs). IDMs such as IBM and Samsung may also outsource microchip production on occasion but differ from companies that no longer possess the capacity to fabricate their own chips.

Outsourcing by OEMs has stimulated the growth of a number of other business models located at specific parts of the electronics production chain.

Pure-play foundries

The key components in electronic products are integrated circuits or microchips. Microchips are produced in a semiconductor fabrication plant, often referred to as a 'fab' or foundry. When mass production of the microchip began in the 1970s OEMs such as IBM produced microchips for their products in-house. In-house production continues to have many advantages with many companies fabricating their own microchips. However there are drawbacks to in-house production, most importantly the substantial capital costs involved. Building a semiconductor foundry costs more than £1 billion and there are significant running costs. When demand for microchips falls and output is reduced the deadweight capital costs of maintaining a foundry eats into revenues. To remove this source of financial risk microchip manufactures began to outsource fabrication in the 1980s. This stimulated the development of companies such as Taiwan Semiconductor Manufacturing Corporation (TSMC), the first 'pure-play' foundry set up in 1987, and United Microelectronics Corporation (UMC), another Taiwanese firm, which began to turn Taiwan into an important country for electronics production. Taiwanese firms still dominate the pure-play foundry market although America, China and South Korea all boast important foundry firms and large semiconductor foundries can be found across Asia, North America and Europe.

Table 3: Regional semiconductor foundry capacity and ownership 1980 – 2001 (%)

Year		Asia (not including Japan)	Europe and Middle East	Japan	North America
1980	Location	4	16	38	42
	Ownership	**3**	**15**	**37**	**44**
1990	Location	12	13	45	30
	Ownership	**12**	**9**	**45**	**36**
2001	Location	38	13	20	29
	Ownership	**39**	**8**	**24**	**38**

Source: Brown, C. & Linden, G., 'Offshoring in the Semiconductor Industry: A Historical Perspective', Brookings Trade Forum on Offshoring of White-Collar Work, May 2005.

Table 3 shows the effect that the emergence of the pure-play foundry business model had on the distribution of global fabrication capacity. In 1980 Japan and North America dominated fabrication both in terms of ownership and location. By 1990 this dominance had begun to be eroded as firms such as TSMC emerged; by 2001 Asian countries, including Taiwan but also South Korea and Singapore, and increasingly China, had emerged as important locations for semiconductor fabrication. Pure-play foundries accounted for some of the growing fabrication capacity in the emerging countries, but non-Japanese Asian OEMs such as South Korean Samsung also developed their fabrication capacity.

Fabless and chipless companies

The growth of pure-play foundries encouraged the development of fabless chip companies. 'Fabless' companies are those that do not possess fabrication facilities but design and sell microchips to OEMs or other users. A variation on the fabless model are 'chipless' companies: these companies do not fabricate or even sell microchips but rather design microchips and then sell licences for the use of their designs to other companies. The majority of the largest fabless companies are American; in terms of sales they are on a par with some OEMs, although still dwarfed by the largest. Qualcomm, the world's leading fabless company, had revenues of $10.9 billion in 2010,[5] whereas IBM had revenues of $99.8 billion.[6] The chipless sector is far smaller — the market leader ARM, had revenues of $785 million in 2011.[7]

Electronics Manufacturing Services (EMS) companies

EMS firms began to emerge in the late 1970s and early 1980s as OEMs looked to outsource the assembly of their products. Up until this point, OEMs like IBM would usually source components from other companies before assembling the final product. EMS firms took on the assembly of the product but often also the distribution and after-sale services. EMS firms originally arose to serve American OEMs and tended to be based close to them. Many of these early US EMS firms remain market leaders today. In one of the first, and most notable, instances of outsourcing to an EMS firm, IBM used SCI Systems to assemble the mother boards for its first personal computer in 1981.[8] EMS firms expanded in the 1980s and 1990s by acquiring production facilities from OEMs, giving them access to a global network of manufacturing sites with which they could serve different markets. Assembling products, which initially made up the majority of work carried out by EMS firms, is labour intensive and as a result they were quick to expand manufacturing operations in countries with low labour costs. The bursting of the tech bubble in 2000 and the recession in the US economy in 2002 prompted many EMS firms to move manufacturing facilities out of developed countries and into countries with lower labour costs. In 2001 Celestica, a multinational EMS firm, had 81 per cent of its facilities in higher cost locations; by 2005 80 per cent of its employees were based in low-cost locations.[9] At the same time the company's sales in Asia increased from 9 per cent to 47 per cent.[10] Celestica's experience is indicative of the industry in general.

Despite a general trend towards moving assembly to low-cost countries, other tasks such as prototyping and product development continue to be carried out in higher-wage countries where the workforce possess the necessary skills. The result is that at present the largest EMS firms operate global production networks marked by a division of labour with, for example, assembly work in Mexico and development work in California, or similarly, assembly work in Eastern Europe and prototyping in Western Europe. However, it should be noted that this strict dichotomy between more and less developed economies is being eroded as the skills of employees in developing countries improve.

As a result of the logistical and operational challenges of producing and distributing electronics in enormous quantities the EMS industry is very concentrated. The revenue of the market leader, Foxconn Electronics, in 2010 was $77.4 billion, three times that of the second largest company Flextronics and over 10 times that of Celestica, the fourth largest firm.[11] Foxconn's revenues are of a similar magnitude to some of the largest electronics OEMs. The industry has also become more concentrated over time. The ten largest EMS firms held 42 per cent of the market in 1999 and 70 per cent in 2003[12] and in 2009 the largest firm, Foxconn, controlled 44.2 per of the market due to the rapid growth of its largest customer Apple.[13] Despite the dominance of Foxconn and the few other multi-billion dollar firms in the industry, smaller EMS companies continue to play an important role, especially in producing complex electronics in smaller production runs.

Original Design Manufacturers (ODMs)

ODMs followed on from EMS firms as the next stage in the development of outsourcing in the electronics industry. In the 1990s some contract manufacturers began to develop design capabilities, designing and manufacturing products that could be bought by OEMs and sold on under their own brand. It is fair to say that the ODM model was born in Taiwan, and only one of the top ten ODM firms by revenue in 2010 was not Taiwanese.[14] It is too simplistic to argue that the ODM model emerged just because OEMs wished to outsource design. One important spur was the fact that contract manufacturers recognised the increased revenue and market influence that could be grasped by developing design capabilities and producing their own intellectual property (IP). Another spur was the growth of consumer electronics, such as laptops and mobile telephones, with shorter product life-cycles, some of which demanded that new models be launched every couple of months. This created design and development costs that could not be borne solely by OEMs.

2

The British electronics industry

British electronics production

Production data in official studies on the electronics industry by the government, or associated public bodies varies and is out of date. In 2004 the Department of Trade and Industry carried out an extensive examination of the electronics sector, titled 'Electronics 2015: Making a Visible Difference'.[15] The report estimated that the industry was worth £21 billion, although it stated that the sector had sales of £37 billion in 2002 and also quoted figures produced by Reed Electronics Research (RER) that sales of British electronics products exceeded £29 billion in 2003. Four years later, in a report on the British electronics design sector, the Department for Business, Enterprise and Regulatory Reform (BERR) estimated that the entire electronics industry was worth £23 billion a year.[16]

The government admitted in 2004 that official statistics fail to accurately capture the industry because many electronics firms class themselves using the Standard Industrial Classification (SIC) code of the industry they supply. Figures from the Office for National Statistics (ONS) support this: according to ONS statistics, two industries; 'computer, electronic and optical products' and 'electrical equipment', were worth £13.8 billion in 2010, lower than any other estimate.

To produce a more accurate picture of the British electronics industry and to put it into an international context, this report primarily uses data from leading market research firm, Reed Electronics Research (RER).

Table 4: Summary of global electronics production 2010 ($ billions)

Rank	Country	Production
1	China	489.8
2	USA	269.1
3	Japan	199
4	South Korea	114.8
5	Singapore	64.3
6	Germany	64.2
7	Taiwan	60.7
8	Malaysia	56.7
9	Mexico	53
10	Brazil	37.2
11	Thailand	32.1
12	France	27.5
13	**UK**	**21.8**
14	India	19.4
15	Hungary	16.8
16	Philippines	16.1
17	Italy	15.4
18	Czech	14.5
19	Poland	13.1
20	Switzerland	11.9

Source: Reed Electronics Research www.rer.co.uk

Table 4 ranks countries in terms of production in 2010, with the UK in 13th place. This gives some indication of the size of the British electronics industry relative to those of other countries. ONS data* gives an indication of the size of the electronics industry relative to other sectors of the British economy. The electronics industry, including electrical equipment had a gross value added (GVA) of

* Although ONS figures do not accurately capture the electronics industry they are used here in order to fairly compare different sectors of the British economy. Figures give an approximate indication of the size of different

£13.8 billion in 2010 and employed 204,300 people, the automotive industry had a GVA of approximately £5.6 billion and employed 124,600 people and the pharmaceutical industry had a GVA of £11.9 billion and employed 39,800 people.[17] Looking a little closer at the UK's strengths and weaknesses, Reed Electronics Research produces data on the sub-sectors of the electronics industry.

Table 5: Medical and industrial electronics production 2010 ($ billions)

Rank	Country	Production
1	USA	28.5
2	Japan	7.6
3	Germany	6.8
4	China	6
5	Taiwan	5.2
6	Netherlands	2.5
7	Ireland	2.2
8	Switzerland	1.9
9	**UK**	1.8

Source: Reed Electronics Research, www.rer.co.uk

Table 6: Control and instrumentation electronics production 2010 ($ billions)

Rank	Country	Production
1	USA	39
2	Germany	20.3
3	Japan	10.4
4	China	7.7
5	**UK**	**4.7**

Source: Reed Electronics Research, www.rer.co.uk

Tables 5 and 6 reveal two areas of particular strength for the British electronics industry: medical and industrial electronics and control and instrumentation electronics. Production in both these sub-sectors is described as high mix/low volume meaning that very complex products are produced in relatively small quantities. The UK excels in these areas because of its strong automotive, aerospace and healthcare industries. Power electronics, a further sub-sector which falls into the two categories of medical and industrial electronics and control and instrumentation electronics, is another area where the UK has significant capabilities. The country boasts some world-leading indigenous power electronics firms such as Rolls-Royce, IQE Group and Dynex Semiconductor.[18] Alongside these two sectors the UK is also the 8th largest producer of radio communications electronics in the world.

Table 7: Consumer electronics production 2010 ($ billions)

Rank	Country	Production
1	China	55
2	Japan	25.1
3	Mexico	20.6
4	Poland	7.4
5	Malaysia	7.2
17	USA	1.6
34	**UK**	**0.065**

Source: Reed Electronics Research, www.rer.co.uk

Table 7 draws attention to one of the key aspects of the global electronics industry. Whereas in all other sectors examined the United States places near the top in global rankings, in consumer electronics the country places 17th and the UK 34th. It is noticeable that China is the largest producer of consumer electronics by some margin, this helps to explain why it leads the rankings for total production. China is the workshop of the world when it comes to electronics and especially consumer products. The country's production accounted for 35 per cent of global electronics hardware revenue in 2008.[19] China's Pearl River Delta, home to huge assembly plants including the 300,000 person factory of EMS firm Foxconn, has become the largest location for the production of electronics.[20]

RER's figures provide a more nuanced picture of the British electronics industry, indicating areas of strength and weakness. However the data does not shed light on a particular area of success for Britain; its electronics design sector. This sector, which includes fabless and chipless firms, will be examined in greater detail below but is worth briefly drawing attention to it here.

Table 8: Semiconductor sales for connected devices 2006 - 2011 ($ millions)

Country	2006	2007	2008	2009	2010	2011
China	N/A	N/A	N/A	20	23	19
Europe	378	550	612	453	401	263
Other	253	196	171	124	169	224
Taiwan	94	134	177	179	267	303
UK	**704**	**847**	**696**	**663**	**782**	**715**
USA	2,111	2,360	3,004	3,281	5,244	5,911
Total	3,540	4,087	4,660	4,720	6,886	7,435

Source: iSuppli, Connected Devices Database, www.isuppli.com

Table 8 shows how the UK is one of the leading producers of semiconductors for connected devices with annual sales greater than Taiwan, China and all other European countries combined. Connected devices are any internet connected electronic device such as smartphones, tablets and laptops, and increasingly products like set-top boxes and digital cameras. The semiconductors and microchips for such devices are particularly complex and require significant design expertise.

Table 9: Spend on semiconductor design tools 2011 - 2013 ($ billions)

Rank	Country	2011	2012	2013
1	US	88	90.8	93.9
2	Japan	53.3	53.5	54.6
3	China/HK	20.5	22.5	24.3
4	S. Korea	20.3	21.6	23.1
5	Taiwan	19.6	20.4	21.7
6	Germany	10.1	10.7	11.3
7	France	5.2	5.2	5.4
8	**UK**	**4.3**	**4.4**	**4.5**
9	Finland	4.2	3.6	3.8
10	Sweden	3.8	3.9	4

Source: iSuppli Design Activity Tool, www.isuppli.com

Table 9 ranks the top ten countries by semiconductor design tool spend in 2011 and predicted spending in 2012 and 2013. The UK places 8th. These figures should not lead one to conclude that the UK ranks 8th in terms of design expertise in the world; the data in table eight suggests otherwise and it is worth noting that Israel, a country with a world-class electronics industry, places 16th in global design tool spend. A better indication of design strength would be to look at the size of design spend relative to the size of the economy and the size of the electronics industry. With the exception of France, all the countries ranked higher than the UK in terms of semiconductor design tool spend have larger electronics industries.

Britain's design prowess and success in low volume, high value sub-sectors explains the high value added of the electronics industry. In 2010 GVA per employee in the electronics industry, including electrical equipment was £67,547 of which employees received two-thirds. Compare this to other sectors, such as the automotive sector with a GVA per employee of £44,975 and the aerospace industry with a GVA per employee of £54,773 and it is clear that the electronics sector is an extremely productive part of the British economy.[21]

Britain's electronics market

Britain is the 7th largest market for electronics products in the world. Its demand, however, varies across different electronics sectors. The UK is the 5th largest market for office equipment, radio and communications, and consumer electronics. The country is the 6th largest market for electronic data processing devices, and medical and industrial products. By contrast, Britain is the 9th largest market for control and instrumentation electronics and telecommunications products and the 16th largest for components.[22]

Britain is a large consumer of office equipment and consumer electronics due to the relative affluence of its population and the fact that the majority of businesses use information technology in some form. It is also a large consumer of medical and industrial, communications and of control and instrumentation products because of the relatively large amount of technologically intense production that occurs in the UK compared to less developed countries. Britain is a far smaller consumer of components because it is not a large manufacturer of electronics products produced in high volumes.

The shape of the British electronics industry

To analyse the British electronics industry effectively it is useful to examine companies using the categorisation employed in the previous section. Once again this should not be taken to mean that companies always neatly fit into one of these categories, but does allow the UK's specific strengths and weaknesses to be evaluated.

Electronics Manufacturing Services (EMS) firms

Three of the ten largest EMS firms in the world have a manufacturing presence in the UK and a further three of the largest EMS firms have non-manufacturing facilities in the UK. Two of the top fifty EMS companies in Europe as ranked by Reed Electronics Research are UK firms. Including these, six of the top fifty have a manufacturing presence in the UK and a further two have non-manufacturing facilities in Britain.[23] In terms of market share, Germany and the Scandinavian countries are home to a disproportionate number of EMS firms, with France also boasting a number of companies in the top 50.

Table 10: Top British EMS firms in 2011

Employees				Σ	Turnover (£ million)			Σ
0 - 100	100 - 250	250 - 500	500 +		0 - 20	20 - 100	100 - 1000	
4	9	3	6	**22**	10	7	5	**22**

Source: Reed Electronics Research, www.rer.co.uk

Table 10 examines twenty two leading domestically-owned EMS companies in the UK by turnover and employee number.[24] It is worth noting that of these companies, five have the facilities to carry out high-volume manufacturing and thirteen have facilities abroad. The majority of EMS firms in the UK are medium-sized businesses with a turnover of less than £100 million, specialising in complex products produced in small to medium volumes. Relatively few firms carry out volume manufacturing. UK EMS firms tend to manufacture products for the aerospace, medical, and general industrial electronics markets or carry out prototyping and development work.

UK EMS firms cannot rely on competing on cost, except when they use facilities based abroad, and so many have attempted to develop design and development skills. This is reflective of the EMS industry in general where more companies are looking to expand their services to compete with ODMs and capture more of the value-added of the final product.

Despite a number of the world's leading EMS firms possessing manufacturing facilities in the UK and Britain boasting a number of extremely successful indigenous firms, the country could improve its EMS capabilities. This is clear when one reflects upon EMS industries in a number of other European countries, notably the Scandinavian countries and Germany. The success of EMS firms in these countries and indeed in Britain itself undermines the argument that all electronic assembly work will inevitably move towards low-cost countries. Importantly EMS firms in the UK and other higher-cost countries serve different industries and supply different types of products than their competitors or subsidiaries based in low-cost locations. The retention of manufacturing capability is important to serve those industries that require specialist or niche electronics products such as aerospace, medical and telecommunications. Manufacturing facilities are also important for young electronics firms looking to manufacture products in small batches before ramping up production.

Fabless, chipless and design companies

The British government has conducted a number of studies into Britain's electronics design sector, its chipless, fabless and contract design companies. In February 2008 BERR published 'Competitiveness and Productivity of the UK Design Engineering Sector' and September the same year saw the release of 'Electronics System Design: A Guide to UK Capability 2009/10 Edition'. Both reports drew attention to Britain's success in this area; the country boasts world-class chipless and fabless firms that have enabled the UK to control 40 per cent of the European independent electronics system design market.[25]

The BERR report of February 2008 identified the UK as one of the world's leading countries for chipless companies. This continues to be the case with ARM Holdings dominating the industry. In 2011 ARM had revenues of $785 million, double that of its closest competitor, Rambus.[26] Another British firm, Imagination Technologies is also one of the world's leading chipless firms with sales of $155 million in 2011, the fourth largest in the industry.[27] Another British firm, ARC International was also included in the top ten chipless firms until it was acquired by Virage Logic, another chipless firm, in 2009. Virage Logic was itself acquired by Synopsys in 2010, a US firm mainly involved in designing software tools for electronic system design.

British firms do not dominate the fabless as they do the chipless sector. This is perhaps unsurprising given the fact that the fabless business model emerged before the chipless model and is a far larger industry, with total sales of $59 billion in 2009[28] compared with just over $1 billion in the chipless sector.[29] Nevertheless the UK is home to a number of the world's leading fabless firms, and because of this the British fabless sector is one of the most productive globally.

According to 'Competitiveness and Productivity of the UK Design Engineering Sector', in 2005 the top five British fabless firms accounted for 1.8 per cent of global fabless revenue.[30] This figure fell to 1.3 per cent in 2009. Oxford Semiconductor, the fourth largest British fabless firm in 2005, was acquired by the American firm PLX Technology in 2009. The fall in market share for British firms is representative of their mixed success since 2005. Cambridge Silicon Radio (CSR), with revenues of $600 million in 2009 and $845 million in 2011, dominates the British fabless sector and is close to becoming one of the top ten fabless companies in the world. CSR has experienced impressive growth in the last couple of years despite posting a loss in the third quarter of 2011. In contrast Wolfson Microelectronics, the second largest British fabless firm, has seen its revenues fall from $231 million in 2007 to $157 million in 2010. Two smaller firms Frontier Silicon and CML Microsystems, the third and fourth largest UK fabless firms respectively, have seen revenue growth since 2005, partially making up for the fall in sales by Wolfson Microelectronics. Although the impressive success of the British fabless sector since 2001 has stalled somewhat recently, the sector is still highly successful. The US fabless firms that dominate the industry have had a mixed couple of years with eight of the eleven top US companies posting double digit declines in sales in 2009.[31] In spite of this the industry continues to grow and there is no reason why British firms cannot reap the benefits of this.

Foundries

The UK has no state-of-the-art, large scale foundry for semiconductor manufacture, although the country does possess approximately twenty mid-sized commercial foundries for mid to low range production volumes and a further thirty to forty smaller foundries for prototyping and development work.[32] Some of the UK's foundries operate leading edge technology, some of which is the most advanced in the world; however these foundries do not manufacture on a large scale. While the UK does retain some fabrication facilities a number of foreign firms, including Freescale Semiconductor and Atmel, have recently closed British facilities.[33] However, other international semiconductor manufacturers, such as Diodes Incorporated and International Rectifier, continue to operate cutting edge fabrication plants in the UK. They exist alongside domestic firms such as Semefab, a Scottish company with three fabrication plants in Glenrothes.

The vast majority of pure-play foundry firms are Taiwanese, South Korean or Chinese and the Far East, including Japan, hosts the largest share of high-volume foundries. None of the top 15 foundries, based on sales in 2011, have a manufacturing presence in the UK, and only two, GlobalFoundries and the German firm X-Fab, have facilities in Europe.[34] Outside of America and the Far East, Israel boasts two high-volume foundries operated by the Israeli firm TowerJazz (along with others run by OEMs such as IBM). X-Fab used to operate a facility in the UK but this was sold to the British firm Plessy Semiconductors in 2010.

As discussed above, producing microchips is a capital-intensive activity. GlobalFoundries is building a new large scale fabrication plant in Saratoga, New York at a cost of approximately $4.6

billion.[35] This creates obvious entry barriers to the industry and as a result many of the market leaders, such as TSMC and UMC, have dominated for decades. The existence of pure-play foundries makes the fabless chip company possible, and allows British firms such as CSR to be competitive in the global marketplace. Nevertheless, it is worth noting that the majority of countries with long-running, successful electronics industries possess significant fabrication capacity.

A horizontal sector

It has been mentioned above that many British electronics firms define themselves by the industry they serve rather than describing themselves as belonging to the electronics sector. British electronics firms play an important part in leading manufacturing sectors such as automotive, aerospace and oil and gas. In this respect the electronics industry runs horizontally across a range of British industries as many of its products are sold to other firms rather than directly to consumers. This has important ramifications, particularly regarding the way in which the government works with the sector, which will be discussed below. For now, however, it is important to understand that the size and importance of the electronics sector is often underestimated.

3

Three British electronics clusters

Having taken a broad sweep of the British electronics industry, this section takes a closer look at three important electronics clusters. Electronics firms tend to agglomerate; the archetypal electronics cluster in Silicon Valley, despite being the most impressive, is not unique. Britain itself hosts three important electronics clusters, though the term 'cluster' is used loosely to describe a region that sustains a disproportionate number of electronics firms. The three clusters examined are the M4 corridor, Cambridge or 'Silicon Fen' and 'Silicon Glen' in Scotland. These clusters developed at different times and are examined below in chronological order.

Describing a concentration of firms as a 'cluster' is somewhat misleading in that it imposes a false sense of order or limit on a group of firms. By focusing on just three clusters, and failing to examine other areas in more detail, this report is partly guilty of this. One important area for the electronics industry is sometimes described as the 'Silicon South West' cluster; a grouping of approximately 100 microelectronics companies operating in Bath, Bristol, Exeter, Plymouth, Southampton and Swindon. Some of the cluster may fall within the M4 corridor but it is notable that in the south west there are a disproportionate number of semiconductor firms.[36] Although it is not examined as a distinct cluster in this report it is clear that the area is incredibly important for the UK electronics industry.

Another high-tech cluster that has received a great deal of political and popular interest recently is 'Silicon Roundabout' located in Inner East London. It is not strictly a cluster of electronics firms but is rather a mix of information technology and digital content firms.

As one recent report put it: 'manufacturing and wholesale of ICT equipment form a pretty small slice' of the cluster.[37] Given this, and the fact that it has received a great deal of scrutiny and political support, this cluster is also not examined below.

The M4 corridor

The M4 corridor, an area stretching from London to South Wales, is often described as an electronics cluster. However the idea of a fixed electronics corridor abutting the M4 motorway does not reflect reality; it is better to see the M4 corridor as a fluid phenomenon. Beginning in the 1920s 'high-tech' firms increasingly located outside the capital and to the west of London,[38] although firms were not grouped in a corridor, but more of an arc, framing the capital. Later the counties of Berkshire and Hampshire saw the most stable concentrations of high-tech and electronics firms, creating a 'corridor'. At times this corridor was extended by firms, often more concerned with manufacturing, located further along the M4 and in Wales, but this manufacturing activity began to shrink in the 1960s and new areas, such as the cluster around Bristol, emerged. The result has been a crescent of high-tech businesses framing London to the west, with a pronounced corridor encompassing Reading, Bracknell, Slough and Swindon.

History of the M4 corridor

The M4 corridor, although it has altered dramatically, is the area in the UK with the longest history of hosting technology and electronics firms. After World War One towns to the north and west of London, and counties such as Berkshire, Hampshire and Hertfordshire saw an increase in investment. Some towns experienced significant population growth: Slough, host to one of the first private industrial trading estates, saw its population increase from 27,000 in 1921 to 63,000 in 1939.[39] Many firms evacuated London during World War Two and post-war development rules meant that businesses had to build facilities outside the capital and were often limited to certain locations. As a result towns and regions bordering London grew; areas to the west of the capital were often chosen by the government for development (although development was guided by planning constraints), shaping the location of industrial growth. Evidence of this change is provided by employment figures for the 'high-tech' industries, including electrical engineering, scientific instrument production and manufacture of aircraft. In 1921 27.1 per cent of employment in these industries was found in central London, but by 1951 this figure had fallen to 10 per cent and by 1971 to 4.1 per cent. During the same period there was a concomitant increase in high-tech employment, firstly in greater London and Middlesex and then in the counties surrounding London, particularly those to the west.[40]

The general move out of London by high-tech companies was largely the result of space and cost constraints encouraging firms to look outside the city. Planning decisions, the result of conflicts between central and local governments, did encourage development to the west of the capital. However, this was not the main reason why the region to the west of London saw disproportionate investment by electronics firms in the 1950s and 1960s.

Links to the defence industry, and to defence research institutes in particular, were important in this regard. After WWII the British defence industry increased R&D expenditure and created new, or expanded existing, research institutes. The government also increased defence spending. The majority of research institutes were to the west and south west of London, with Slough, Farnborough and Teddington hosting significant facilities. Procurement by these research institutes and by defence firms were an important part of business for many electronics firms. Firms chose to locate near their customers because collaboration was often required on defence projects involving advanced technology. In 1953 it was estimated that one third of total output in the electronics sector went to the defence industry;[41] even in the 1980s approximately 20 per cent of the electronics industry's output continued to go to the Ministry of Defence.[42] As well as procurement, the government and the defence research institutes also funded R&D carried out by electronics firms. A Parliamentary Select Committee was told in 1968 by the Ministry of Defence that 72 per cent of R&D in the electronics and aircraft industries was publicly funded.[43] Ensuring that the government got value for money often meant working closely with firms, something made easier when firms and research institutes were located near to one another.

Developments in infrastructure added to the advantages of locating in the region. The development of Heathrow after WWII and the construction of the M4 motorway, the majority of which took place in the 1960s, provided businesses with easy access to other firms in the corridor, to London and to export markets. Heathrow was not constructed with industrial development to the west of London in mind but its presence facilitated it. The M4, although its construction occurred after growth in the corridor had already begun, helped to promote further development. Originally the M4 was supposed to run directly between Swindon and London, north of Reading; however, due to lobbying by councils it was eventually decided that the road would run north of Newbury and south of Reading, serving Bracknell and Slough in the process. This connected the main urban areas in the corridor and made the area an attractive one to firms and their employees. In a 1984 survey of 44 electronics firms based in Berkshire, the area with the highest concentration of electronics firms during the 1970s and 1980s, 75 per cent cited proximity to London and Heathrow as an important factor in their decision to locate in the area and 63 per cent said that the M4 motorway was important.[44] A precursor to the M4 and Heathrow, which made Reading and Bristol attractive places to do business, was the Great Western Railway. The upgrading of the line which connected Slough, Swindon and Bath in the 1970s, helped to improve connectivity to the West of London, and contributed to the corridor's development.

The M4 corridor offered many of the benefits of London, including a good pool of skilled labour and international transport links, but with the added benefits of lower overheads and more room to construct new facilities. Such factors were especially important to foreign firms. In an article on the corridor in 1983 The Times newspaper argued that American multinationals such as Hewlett Packard, Fairchild Semiconductor and IBM looked for business conditions similar to those found in North America. The M4 corridor provided landscaped greenfield sites with skilled workers and good international transport links.[45]

Over time some of the factors that attracted firms to the corridor, including links to the defence industry and the cheaper labour which was found further along the corridor and into South Wales, have faded. Nevertheless some, such as proximity to Heathrow, London and the M4, have remained important, and help to explain the continued attractiveness of the area. Another factor, important in all industrial clusters, is proximity to existing firms; businesses like to locate near their customers and suppliers, and near other firms in their industry. The 1984 survey of firms in Berkshire indicated that a large part of the cluster's development could be explained by new firms setting up within commuting distance of where their founders used to work.[46] This meant that new firms spun-out of, or started by employees of, existing firms often set-up nearby. This extended the cluster westwards where rents were cheaper.

Different types of firms which came to the M4 corridor were motivated to do so for different reasons. Smaller, start-up firms often chose to locate near to where their founders lived or used to work. Larger firms, especially international ones, were attracted by the infrastructure, particularly Heathrow and the M4. All firms valued the access to skilled labour.[47]

The M4 corridor today

One of the interesting aspects of the development of the electronics industry in the M4 corridor is that many companies chose to base their national offices, R&D facilities, sales and service activities relatively close to Heathrow and London. Production facilities were often located further along the corridor, in Wales or another part of the country. This division of labour began to emerge in the 1980s. One study found that only one in five new firms in Slough and Bracknell set up in the early 1980s were engaged in manufacturing.[48] This was particularly the case with foreign firms; in the 1980s Hewlett Packard had four sites in Berkshire engaged in administration, R&D work, sales and servicing. The company's production facilities were located near Bristol and Edinburgh.[49] This geographical division of labour was partly due to the benefits of having office functions near Heathrow and London, with production work carried out in areas with smaller overheads and cheaper labour costs.

This improved the resilience of the corridor; unlike Silicon Glen (discussed below) the M4 corridor did not witness the wave of closures that affected low-cost assembly in the UK. The cluster is home to many electronics, IT and technology multinationals. Hardware companies have been joined by software firms and companies, such as life science firms, that often require niche electronic products. The output of the British electronics industry has fallen in the last couple of decades as assembly work has moved from West to Eastern Europe. This negatively affected Silicon Glen and continues to affect production facilities across the UK. Panasonic closed a manufacturing facility in Newport in 2012 and a facility in Cardiff in 2009 but continues to run its British headquarters from Bracknell. Similarly, Pioneer has an R&D centre in Slough but closed its manufacturing facility in Yorkshire in 2009. Both companies have been negatively affected by trying to sustain loss-making TV businesses but the M4 corridor has proven resilient because it hosts the facilities, such as R&D centres, head offices, sales and service, that multinationals are less likely to close in a downturn. LG, Huawei, Lexmark and Intel are just some of the foreign firms with facilities in the region.

The M4 corridor is an important location for electronics multinationals, yet it is also home to a number of innovative British firms. Icera and Picochip are two fabless microchip companies whose hardware is used across the world. Icera produces baseband processors that power the radio functions of mobile phones. Picochip produces the chips used in cellular femtocell base stations, which transmit broadband connections. As with many other innovative British firms both have recently been acquired by larger American firms; nevertheless they provide two further examples of the innovative electronics firms the UK is adept at producing.

Silicon Fen

Silicon Fen, as the Cambridge cluster is known, covers a twenty mile radius extending from the city out to the towns of Huntingdon, Newmarket, Royston and Ely. In the cluster 48,000 people are currently employed by high-tech industries, of whom around 25 per cent work in R&D and another 11 per cent as technology researchers in academic institutions.[50] Cambridge's electronics firms tend to excel in those areas which require the most sophisticated engineering and scientific capabilities, such as chip design. Services collectively account for more than 69 per cent of high-tech employment with computer services accounting for just below 15 per cent and technical services, including consultancy and microchip design, 6 per cent.[51]

By 2008 electronics manufacturing and production provided only 4,100 jobs across Cambridgeshire. These jobs are mostly in high value manufacturing with EMS firms, such as Prism, offering small to medium volume production to clients, as well as prototyping and product development services. What manufacturing remains is concentrated in South Cambridgeshire. By contrast, the city of Cambridge itself accounted for 4,200 jobs in R&D and 14,700 jobs in high-tech services. However these figures should be treated with caution. The line between manufacturing and service activities has become increasingly blurred, nowhere more so than amongst Cambridge's electronics firms, many of whom offer design and related services to their customers alongside or independent of production.

Cambridge and its environs host between fifty and eighty new start-ups annually, of which more than three-quarters are launched in Cambridge (rather than re-locating from outside the area).[52]

A false start

High-tech industry in Cambridge experienced something of a false start. In the 1950s city authorities, anxious to preserve its market town atmosphere, made a conscious policy of discouraging industrial development, even though this meant missing out on the opportunity to host IBM's European research and development centre. This hostile attitude to high-tech industry contrasts sharply with that of the city managers of Silicon Valley's San Jose (discussed at greater length below). Only in the late 1960s did Cambridge City Council change its tune after the University of Cambridge Senate published the Mott report, which recommended the easing of planning restrictions and development of a science park. The Cambridge Science Park opened in 1973, but five years on housed only seven tenants.[53]

The 1980s saw an upturn in the fortunes of Cambridge as an electronics hub, with an increase in new high-tech firms from the late 1970s.[54] In 1978 the local managers of Barclays bank offered start-ups business advice and assistance in raising finance.[55] This initiative proved short-lived but invigorated the industry at a critical juncture. Other contributing factors included the altering of the science park's leasing policy to offer smaller units on shorter terms, which made it more attractive to start-ups. The 1980s saw the emergence of leading microcomputer manufacturers, including Acorn, Torch Computers and Sinclair Research.

Another false dawn

Founded in 1978, Acorn Computers quickly adopted a strategy of providing a broad range of products. Its founders, Hermann Hauser and Chris Curry, wanted to design microcomputers for the home, educational establishments and businesses, as well as local area networks and associated hardware and software. Early on, they made the decision to focus on the development of in-house R&D and design capabilities, outsourcing manufacturing and assembly to companies based elsewhere in the UK.

The company began by selling home computer kits by mail order and quickly won contracts from the BBC and then the Indian government. It developed IBM-compatible products for the business computing market and established joint ventures with hardware and software companies including International Computers Limited.

Like many companies founded in Cambridge, Acorn developed impressive research capabilities, but failed to develop similar business talents. Senior managers tended to be more interested in technological developments than business management. A crucial management failure was Acorn's decision not to pursue the worldwide adoption of its products as the industry standard, rejecting offers to license its technology. In 1999, Acorn was broken up into ARM and Element 14.[56]

Acorn was not alone in its failure to maintain commercial success as an electronics manufacturer. During the 1980s Sinclair Research, Amstrad and Apricot were all unable to compete effectively with IBM and Apple (both at home and overseas). These British companies were handicapped by the small home market for computers and related high-tech products, as well as a lack of managers with manufacturing and business experience.

Renewed fortunes

Nevertheless, the 1990s also witnessed the genesis of new firms that would revive the fortunes of the cluster. Cambridge Silicon Radio is one of the companies whose emergence heralded the renewed fortunes of Silicon Fen. The company originated as an internal project at Cambridge Consultants to develop single-chip radio devices that would enable appliances to communicate with each other over short distances. When CSR set out on its own in 1998 it focused narrowly on its strength in design and on developing its marketing skills. Within a year it was able to raise large sums of money from venture capitalists and corporate investors: Amadeus, Gilde and 3i each contributed £2 million in April 1999 with Intel following suit early in 2000.[57] CSR rapidly made the transition from Cambridge R&D firm into a global concern with manufacturing in Europe and Asia supervised from the US; and sales, marketing and applications development in the US and Asia. Nevertheless, Cambridge has held onto CSR’s headquarters and R&D activity.

In contrast Virata, another successful fabless semiconductor company founded in Cambridge five years earlier than CSR, moved its headquarters to California in 1999 and subsequently merged with US firms Globespan and then Conexant Systems. Its Cambridge operations were closed down in 2005.

ARM is one of the best known success stories of the Cambridge cluster. Acorn Computers was dissolved in 1999, but before its closure it spawned (directly or indirectly) more than 30 start-ups including ARM. ARM learnt from the mistakes of its forebear: rather than subcontracting the manufacturing of its chips and selling products, it sold its technology through licensing. ARM design reduced instruction set computing (RISC) processors, which can be embedded in any high-tech product and the largest market for which is found in the US. ARM tapped external markets by establishing subsidiary operations overseas, which helped them to gain credibility with foreign customers. ARM is now the world's leading supplier of semiconductor intellectual property (IP) and has sold 800 processor licenses to more than 250 companies to date.[58]

A British Silicon Valley?

In many ways Cambridge resembles a youthful Silicon Valley, boasting strikingly similar educational infrastructure. Institutional linkages between high-tech industry and the University of Cambridge strengthened from the late 1980s. Collaboration with large firms, both national and international, led to the funding of new research laboratories. The first of these was the Olivetti and Oracle research lab, set up by former Cambridge student Dr. Andy Hopper, which subsequently span out firms including Virata, Telemedia and Adaptive Broadband.[59] This success was followed by other research collaborations, most notably with Bill Gates and Marconi.[60] In 2000 the Cambridge-MIT Institute was founded to address the difficulties that Cambridge University has experienced in trying to get its IP into the commercial arena.[61]

Like Stanford, Cambridge has been a source of new companies. According to a Centre for Business Research (CBR) survey carried out in 1996, one in five spin-offs originated with the efforts of academics to commercialize technological inventions, although only four per cent of firms established with this aim credited the university as the source of innovation.[62] In 2000 SQW Consulting estimated the proportion of university spin-offs to be higher at 31 per cent.[63] The university also functions as an indirect source of knowledge transfer, providing free technological advice through multifarious formal and informal links. 42 out of 50 companies in the CBR survey reported such connections, with 14 of these firms believing these connections to be critical to their success.[64]

Despite boasting strong university-industry links, Cambridge has struggled to develop an equally strong financial infrastructure. A venture capital industry did begin to develop in the 1980s when technology consultants such as Cambridge Consultants Limited (CCL) began to offer venture capital services. CCL offered its spin-outs funding and assistance in commercializing innovations in return for license fees, equity or royalties. Many of the venture capital funds subsequently established were managed by employees of Cambridge firms or entrepreneurs from Cambridge's first high-tech wave. The directors of CCL quickly established other successful funds: Robert Hook founded Prelude Technology Investments in 1984 and Gordon Edge set up Generics Asset Management Limited in 1987. Hermann Hauser, one of the founders of Acorn, was involved in the setting up of Amadeus, which subsequently funded Cambridge Silicon Radio.[65]

However, many among the UK's first-generation of venture capital funds abandoned seed stage investment. For example, in 1981 Apax Partners modelled its first fund on Silicon Valley financiers, but by 1990 put as much as two thirds of its capital into later stage investments.[66] The 1996 CBR survey reported that only 20 per cent of firms had used local venture capital, whilst in 1999 only four per cent of the applications made to Cambridge funds received financial backing.[67] Further, since the financial crisis began in 2008 much of the venture capital sector has retreated from Cambridge, with the region's strong business angel community failing to plug the gap. Despite the continued activity of major fund Amadeus, the consensus among Silicon Fen start-ups is that the scale of venture capital available within the cluster is insufficient.

Silicon Fen today

Despite a number of ups and downs the cluster prospers today, benefitting from strong design and R&D skills and a wave of innovative companies that emerged in the 1990s. However, the cluster's future prosperity is not assured.

The Cambridge region does not possess a large number of outstandingly successful firms that have grown to large sizes. True, there are firms that have a high stock market capitalization. Four $1 billion electronics companies have been created in Cambridge over last 15 years — CSR, Virata, ARM and Sentec. Business strategies which focus on design and R&D have helped these firms to avoid the obstacle which defeated Acorn, Torch and Sinclair Research: the need to carve out large product markets in order to compete effectively with IBM and Apple. But playing to its strengths has been a double-edged sword for Cambridge. This very absence of large-scale product markets at home means that it is relatively easy for successful start-ups to follow the example set by Virata, by moving to Silicon Valley to be close to the US firms who are often their biggest customers.

The lure of larger markets, and the resources of Silicon Valley, will always affect British firms. The challenge for Cambridge is mitigating this pull by addressing weaknesses, most notably the insufficient availability of venture capital, that inhibit the city's ability to become one of the pre-eminent global locations for electronics firms.

Silicon Glen

The term 'Silicon Glen' is often used to described the cluster of electronics firms based in a central area of Scotland between the cities of Dundee, Inverclyde and Edinburgh. Today it is best known for companies such as Wolfson Microelectronics that specialise in designing advanced microchips. However, the area rose to prominence in the 1960s and 1970s as a place where electronic products were manufactured in high volumes, usually by foreign multinationals.

The development of Silicon Glen

The electronics industry began in Scotland in 1943 when Ferranti Limited moved near Edinburgh to escape the bombing during the Second World War. Indigenous firms were soon joined by American multinationals with a number of large firms, including IBM and NCR Corporation, investing in the area in the late 1940s and early 1950s. Between the 1940s and 1970s US companies made up the majority of external investment into the area; by 1981 22 per cent of firms in Silicon Glen were US companies and they accounted for 40 per cent of employment in the area.[68]

In a survey of a number of prominent multinational firms in 1986 it was recorded that US firms clustered in Silicon Glen for a number of reasons including access to semi-skilled and skilled labour, favourable business conditions including subsidies by the Scottish government and the fact that Britain provided access into the European market.[69] Initially the companies were not particularly concerned with accessing highly skilled labour because the early investments were mainly in assembly plants used to serve the British and European markets. The early growth of Silicon Glen coincided with the beginning of offshoring in the semiconductor and electronics industries. Scotland benefitted from the decision by US multinationals to offshore some production to reduce costs and to avoid tariff barriers.

In the 1960s the manufacture of semiconductors began in Scotland.[70] American firms, Motorola, National Semiconductor and then later Japanese firms such as NEC began employing more skilled labour and moving beyond assembly operations in their Scottish facilities. The increase in fabrication work in Scotland meant that the industry moved up the value chain, although there was still a significant amount of lower value-added assembly work being carried out in Silicon Glen until the beginning of the twenty first century.

One reason that foreign firms chose to increase R&D activity and higher value added production in Scotland is that their products increasingly required greater engineering skills in final assembly and later production stages. Another was that new products were increasingly being developed specifically for the British and European markets.

Despite an increase in R&D work in Scotland the R&D intensity of foreign multinationals lagged behind that of their indigenous operations and those of Scottish electronics firms. US multinationals employed 10 per cent of staff in R&D roles in their Scottish subsidiaries; this figure was approximately 30 per cent for domestic firms.[71]

It would be misleading to characterise all foreign firms as 'R&D-light' but it is striking that although output increased significantly in the 1980s, gross value added, a better measure of how much Scottish operations were adding to a final product, actually fell from 39 per cent in 1983 to 24 per cent in 1989. Reflecting on this development, Ivan Turok in a study of Silicon Glen in 1993 estimated that 75 per cent of the income generated through sales went on payments outside the Scottish industry to component suppliers abroad or to parent companies outside of Scotland.

Not all domestic firms had higher R&D intensities than their foreign counterparts but in general they employed more skilled employees and conducted more R&D. However, they failed to match foreign firms in terms of productivity and output and tended to concentrate on niche sectors, leaving foreign firms to serve the largest growth markets of the time, consumer electronics, data processing and components. Despite the simple distinction made above between foreign and domestic firms, foreign firms made a large contribution to R&D in Scotland because of their size. Foreign affiliated electronics firms accounted for 40 per cent of all R&D spending by Scottish businesses in 2000.[72]

The decline of Silicon Glen

The 1980s and 1990s witnessed significant growth for electronics production in Scotland. From the late 1970s the industry grew rapidly while other manufacturing industries in Scotland saw little growth or contraction.[73] In the early 1990s electronics accounted for one in seven of all manufacturing jobs and nearly half of all manufactured exports.[74] Nevertheless the growth of the electronics industry masked a number of important weaknesses.

The major weakness was that the sector was in many respects dominated by foreign multinationals that responded to changes in global production systems by reducing investment in Scotland in the early 2000s. Foreign direct investment (FDI) in the Scottish electronics sector in 1999 was £650 million, in 2000 it was £1.7

billion but by 2001 it had fallen to £271 million.[75] This was important because in 2001 60 per cent of manufacturing in the Scottish electronics industry was carried out by foreign firms.[76] The benefits those foreign firms had brought to Scotland over the course of the previous four decades, including stability, employment growth and increased exports were somewhat negated by the fact that many were quick to relocate production when a sharp fall in purchases of IT hardware occurred in the early 2000s.

In one sense the 1990s and early 2000s was the period in which the Scottish electronics industry, as embodied by Silicon Glen, reached its peak, yet it also saw the industry fall into terminal decline. In 2000 Keith Vaz, Minister for Europe, boasted that Silicon Glen accounted for 15 per cent of European semiconductor capacity, 32 per cent of the continent's branded PC production, 65 per cent of automated teller machines production and approximately 80 per cent of workstation production.[77] Unfortunately Vaz's praise came just as the industry was collapsing. The fall in FDI manifested itself in factory closures and job losses: in 2001 Motorola cut 3,100 jobs, Hewlett Packard 650 jobs, Inventec 600 jobs, Sanmina SCI 750 jobs and Fullarton Computer Industries 500 jobs. It has been estimated that between 1998 and 2006 at least 20,000 jobs were lost in the industry, though this appears a conservative estimate when one reflects that in 2003 alone an estimated 15,000 jobs were lost.[78] The sharp reversal of Silicon Glen's fortunes led one journalist to describe its previous success as 'a mirage, a trompe l'œil that would disappear as dramatically as it arrived'.[79]

The rebirth of Silicon Glen?

It is somewhat misleading to talk about the 'rebirth' of Silicon Glen.[80] In many respects the decline of the area's electronics industry has been overplayed. It is more accurate to say that Silicon Glen transformed in the mid-2000s: jobs were lost and certain forms of production shut down but new companies emerged, multinationals remained and new forms of competitive advantage were cultivated.

Although output and employment fell in the early 2000s, the number of electronics firms and the gross value added of the industry did not fall as significantly, whilst R&D output grew. Exports of electronic goods fell by 67 per cent between 1999 and 2005 and employment fell by 43 per cent between 1999 and 2004.[81] Yet the number of electronic firms only fell from 1017 to 890 and the gross value added of the industry fell by only 20 per cent.[82]

This is not to suggest that there was not a decline, but the information on R&D suggests that this decline had a transformative character. From 1999 to 2005 R&D expenditure in the office machinery and computer industry fell by £8.5 million and in the electrical machinery and apparatus industry by £57 million. In contrast R&D expenditure rose in the radio, television and communication equipment industry by £37.7 million and in the precision instruments industry by £80.9 million. The result is that R&D expenditure across the whole electronics industry increased by £53.1 million.[83] It is particularly interesting that R&D expenditure increased in the radio, television and communication equipment industry despite the fact that exports fell by £2.3 billion between 1999 and 2004.[84]

This data, despite only covering the period 1999 to 2005, sheds light on the important transformations that occurred within the Scottish electronics industry during, and shortly after, the period of restructuring. The picture that begins to emerge in 2005 is of an industry focused more on R&D work and less on industries such as computing and consumer electronics.

Scottish Development International calculates that the ICT and electronic technology industry is worth 14 per cent of GDP.[85] The Scottish Council for Development and Industry estimated that the electronics industry was worth 4 per cent of GDP in 1990. The two official figures are not directly comparable, as the Scottish Development International figure includes a far wider spectrum of sub-sectors such as software, nanotechnology and clean technologies that would not have been included in the 1990 figure.

Nevertheless the figures show that the electronics industry and its current sub-sectors are still an important part of the Scottish economy.

The electronics industry today is a far more diverse sector than previously. Silicon Glen and the Scottish electronics industry were dominated by foreign multinationals from 1970 to the beginning of the twenty first century. Today multinationals still occupy an important place in the industry but they have been joined by a number of very successful indigenous firms including a raft of smaller businesses.

The type of multinational and the activity carried out has changed since the 1990s. Consumer electronics companies such as Motorola have withdrawn operations from Scotland and others such as Hewlett Packard have closed manufacturing facilities but retained servicing jobs. IBM closed its manufacturing facilities but retains software support and other service functions in the country. Those multinationals that have retained manufacturing sites tend to concentrate on producing high-end products for more niche markets. Agilent, a biological and chemical analysis equipment company, Honeywell, a firm selling control and instrumentation electronics to a wide array of sectors, and National Semiconductor, now owned by Texas Instruments, all retain manufacturing facilities. These companies and others such as Dialog Semiconductor, Freescale Semiconductor and NCR Corporation all continue to conduct R&D work in Scotland.

The picture is fairly similar for indigenous firms. Wolfson Microelectronics, a world-leading fabless company has its chips manufactured abroad but conducts its other operations in Scotland. Optos, a multinational based in Fife that saw its revenues grow by 35 per cent in 2011, produces retinal imaging machines in the country. Firms that produce high-value products in relatively low volumes continue to manufacture in Scotland. Firms that require high-volume production sometimes choose to outsource or manufacture abroad. Advanced manufacturing, such as that carried out by semiconductor fabrication plants, continues in Scotland, although production is not of the scale achieved by fabs in the US or Asia.

Having examined Britain's three major electronics clusters, the report will now inspect some of their competitors.

4

Taiwan: climbing the value chain

The trajectory of Taiwan's economic development has been defined by the export-oriented boom in cheap manufactures that it enjoyed in the 1960s and 1970s. Manufacturing lies at the heart of the island's economic success, with exports generating roughly 70 per cent of Taiwan's GDP growth in 2009.[86] As wages rose and its currency strengthened in the 1980s, it began to focus on capital and technology-intensive industries, and became one of the world's largest producers of computer-related products. In recent years Taiwan has become an increasingly important producer of semiconductors and liquid crystal display (LCD) units. The historical development of the Taiwanese electronics industry provides intriguing examples of firms which have been able to insert themselves into a global value chain, at the level of contract manufacturer, and subsequently succeeded in 'upgrading' their position within that chain. Today, Taiwan's electronics firms are key players in not only the production systems, but also the innovation systems, of the global electronics industry. To what or whom should their success be attributed?

The shape of the Taiwanese electronics industry

Taiwan's entry point into the global electronics industry was as a hub of contract manufacturers and pure-play foundries, both of which make products or components according to designs and plans provided by other companies. Traditionally their largest customers have been US OEMs such as Apple, IBM and Hewlett-Packard. Taiwan Semiconductor Manufacturing Corporation (TSMC), founded in 1987, was the first pure-play foundry. TSMC responded to a growing division of labour between IC design companies and foundry companies. The development of the pure-play foundry model enabled Taiwan's semiconductor industry to break the monopoly that had previously been held by the US, Japan and South Korea, and to establish the country as one of the leading semiconductor producers.[87] Today, Taiwanese firms continue to dominate the foundry market. Taiwan is also home to Foxconn Electronics (also known as Hon Hai), the world's leading EMS firm.

Since the 1990s Taiwanese electronics firms have tried to move away from a model of production based solely on contract manufacturing and foundry services towards one involving product design. Today, examples of breakthrough Taiwanese innovation in the electronics industry abound. Acer Inc. (producer of electronic devices including PCs, tablets and smartphones) is perhaps the best known example of a Taiwanese electronics firm which has succeeded in shifting from manufacturing to the design, marketing and distribution of products. Asustek Computer Corporation, Taiwan's leading producer of motherboards (the central printed circuit board within most personal computers), provides another example of successful innovation. The company began primarily as a contract manufacturer but in recent years has become successful in selling products under its own brand name (as an original equipment manufacturer), spinning off its contract manufacturing unit in 2010. The improvements which Asustek made to the quality of motherboards led them to win the trust of US platform leader Intel, with whom they established a close partnership. Consequently, Asustek secured the specifications for new Intel microprocessors far earlier than other companies, enabling the company to launch new generation motherboards before their competitors, giving them important 'first mover' advantages. Other contract manufacturers have developed into original design manufacturers (ODMs) who design and manufacture products which they then sell on to original equipment manufacturers (OEMs). One such ODM is Taiwan's Quanta Computer, the world's largest manufacturer of notebook computers, whose customers include Apple, Hewlett-Packard, Compaq and Sony.

Given this shift towards the development of design capabilities, recent years have seen the rapid growth, in both size and number, of research and development facilities. An OECD study has demonstrated that not only are there more high-tech researchers in Taiwan than in Britain, but Taiwanese technology companies also spend more on R&D than British ones.[88] As a result, a workforce previously dominated by semi-skilled assembly line workers now accommodates large numbers of highly-qualified and experienced engineers and managers, many of whom possess invaluable experience of working for US electronics designers and manufacturers.

Largely as a consequence of outsourcing, the industrial sector's share of GDP fell from a peak of 44.8 per cent in 1986 to 27.5 per cent in 2007. In the same period the service sector's share of GDP has climbed from 49.8 to 71.1 per cent.[89] This relative decline in the importance of domestic manufacturing seems set to continue. Nevertheless, Taiwan remains an important centre for the manufacturing and assembly of electronics products. Fears about China's inferior business environment have meant that, for the most part, the production of higher-end goods, such as semiconductors and LCD panels, has remained in Taiwan. In terms of volume, Taiwan was the world's seventh largest producer of electronics in 2010, with its output totalling $60.7 billion.

Foreign investment

Prior to the late 1990s, explanations of industrial development in middle-income countries tended to develop state-based theses centring on governments' promotion or compulsion of nationally-owned firms. However, if the case of South Korea, for example, supports such arguments, the experience of Taiwan does not. In Taiwan, where the electronics industry is both the largest manufacturing sector and largest export industry, it was foreign investment and not state intervention which first stimulated growth.[90]

Foreign investment had a three-fold impact in Taiwan giving electronics firms access to stable markets, enabling them to insert themselves into a global production chain, and allowing for the transfer and adoption of new technologies. After WWII and from the early 1960s especially, Taiwanese firms became the beneficiaries of newly mobile Japanese consumer electronics firms. These firms chose to invest in Taiwan because they sought access to its growing consumer market and to its cheap labour, and because its physical proximity and colonial heritage appealed to them.[91] Japanese components makers established joint ventures with Taiwanese entrepreneurs as a means of gaining access to the highly protected Taiwanese market. As a result of Japanese investment, local Taiwanese firms were able to acquire knowledge about new technologies, adopt new production processes and participate increasingly in the international electronics industry.

In the mid-1960s US consumer electronics firms began to establish manufacturing sites in Taiwan. They were initially attracted by the prospect of cheap labour, but soon began procuring Taiwanese-made components owing to their quality. New US customers gave local firms the leverage to dissolve Japanese joint ventures and set up wholly-owned Taiwanese facilities; as a result exports of locally produced components grew from 10 per cent in 1972 to over 30 per cent by 1979.[92] US firms continued to source components from Taiwanese manufacturers after closing some Asian operations in the late 1970s and early 1980s. In this way foreign investment eventually opened up new markets to Taiwanese companies. The heterogeneity of its foreign investors also greatly benefited the Taiwanese electronics industry. Foreign investment and exports created important backward linkages and channels for the transfer and implementation of new technologies and manufacturing processes.[93]These channels made it possible for Taiwanese electronics firms to develop their capacity in R&D with limited financial resources. This transfer of technological capabilities was facilitated by migration flows and the return of experienced engineers and managers to Taiwan from the US.

Therefore, foreign investment made possible what the state could not: investors enabled local firms to gain access to global production chains and to implement new technologies. It was Taiwan's linkages with Japanese and US multinational firms which provided the catalyst for the development of a successful Taiwanese electronics industry.

The role of government

Foreign investment catalysed the development of the Taiwanese electronics industry, but the government also shaped its growth, often in unintended ways. Most notably it inadvertently stimulated the development of a vibrant SME sector during the 1960s and 1970s and more recently has supported high-tech innovation.

SMEs

Taiwan's industrialization has been unique in that small and medium-sized enterprises (SMEs) have been the major contributors to exports. SMEs employed more than 50 per cent of all workers during the late 1970s and early 1980s. They accounted for 44.9 per cent in 1976 and 47.6 per cent in 1984 of the total value of production. Between 1981 and 1985 more than 60 per cent of exports were produced by SMEs.[94] In 1996 SMEs had 96.5 per cent of Taiwan's market share of the global electronics industry.[95] In contrast, in South Korea conglomerates provided most of the final products for export in the electronics industry.

Why were SMEs the driving force of the Taiwanese electronics industry? According to Yongping Wu, the proliferation of SMEs in the 1960s should be understood not as a state-led development, but rather as a 'politically inspired industrial success'. That is to say, Taiwan's SMEs were the product of a unique industrial structure, not shaped by industrial policy but as an unintended consequence of public policy. Universally-applied state reforms such as land reform, repressed labour costs, the promotion of education and the devaluation of currency and export tax rebates, certainly benefited Taiwan's exporting SMEs but are not sufficient to account for their unique success. Rather the Kuomingtang (KMT) regime's political goals had an indirect effect on the shape of Taiwan's industrial structure, which allowed SMEs to flourish.

It has already been mentioned that, especially from the 1960s, smaller Japanese components makers established ventures with Taiwanese entrepreneurs in order to access Taiwan's highly protected consumer market (as the government imposed restrictions on foreign ownership and used local contents requirements extensively). These protectionist tendencies were born of political motives and had far-reaching consequences for Taiwan's SMEs. The Taiwanese state's relationship with business was shaped by the regime's anti-business ideology as a quasi-Leninist party, its authoritarian nature and its distrust of locals owing to its position as an émigré regime. Whereas in South Korea the state forged an alliance with business groups (*chaebols*) for industrialization, the KMT was economically vigilant against large enterprises (LEs) to prevent the emergence of political rivals. The KMT tended to ignore SMEs whilst protecting and restricting LEs in order to prevent the growth of powerful multinationals. The unanticipated outcome of this strategy was that LEs (proving unwilling to face foreign competition in international markets without government protection) became entrenched in the domestic market whilst SMEs, to whom access to the domestic markets was largely denied, focused on the export market. Here, the absence of LE competitors meant that they benefited from opportunities for robust inter-SME competition. A two-tier economy developed, wherein LEs dominated the domestic economy and SMEs concentrated on exports. Only when the political strategies of the state changed — as in the mid-1970s the regime sought new legitimacy in response to America's recognition of the People's Republic of China — did the state begin to make a concerted effort to support the success of the SMEs.

Although Taiwanese policy towards SMEs before the 1970s is best described as one of 'benign neglect', they did benefit from the government's policy of export promotion. In the early 1960s, under pressure from the US, Taiwanese policy shifted from a commitment to import substitution towards export promotion. However, as we have seen, LEs were discouraged from exporting; therefore it was SMEs that grew rapidly as a result of the government's export promotion policy. The shift from import substitution to export-oriented industrialization was accompanied by a series of reforms that improved the environment for the private sector and foreign capital. The most important of these, for SMEs at least, was the establishment of a strengthened central bank to regulate interest rates, control the money supply and supervise commercial banks. The SME sector benefited considerably from reduced interest rates.[96] An unanticipated outcome of the state's efforts to reduce interest rates in order to safeguard and regulate the market was the improvement of the financial resources available to SMEs.

Innovation

Taiwanese banks, and to a lesser extent the government, had an indirect effect on the products that Taiwanese firms specialised in. Fuller, Akindwande and Sodini examined Taiwan's successful CMOS logic fabrication industry[97], the struggling DRAM industry[98], and the AMLCD industry, which experienced mixed success,[99] and found that the ability to innovate within a specific sub-industry is largely determined by one key institutional characteristic: the availability of long-term or patient capital.[100] The financial policies of the Kuomingtang regime meant that banks and the state could and would not allocate credit 'patiently', and government subsidies failed to provide a remedy for this. The lack of long-term capital limited the ability of firms to expand production capacities and R&D capabilities. As a result, prospects for innovation were more positive in those industries with no requirement for significant long-term capital; for example, in the AMLCD industry where there is little need to invest in continuous product R&D. A second consequence of this institutional characteristic is that Taiwanese firms are more likely to succeed in becoming innovators where production processes can be broken down into smaller segments or 'modules'. A modular production process, whereby certain parts of a manufacturing process are outsourced to suppliers with specific capabilities, enables firms to develop technological competence with limited funds by focusing on specific aspects of production.[101]

Government interventions also played a more positive role in high-tech innovation. As we have seen, Taiwan's electronics industry is comprised predominantly of SMEs. From the late 1970s the government began to make concerted efforts to support this sector. As smaller firms may be deterred from investing in innovation by the costs, particularly for high-tech products, the Taiwanese government implemented a number of policy measures designed to encourage innovation, one of which was publicly-funded research.

Taiwan's incredibly successful semiconductor industry was born of government-funded research, carried out by the Industrial Technology Research Institute (ITRI) which was founded in 1973. Taiwan's two most important microchip companies, United Microelectronics and Taiwan Semiconductor Manufacturing Company, began as spin-offs from ITRI. The National Science and Technology Projects (NSTPs) provide financial support to ensure that the research institute has a stable budget to undertake long-term R&D activities; since 1979 more than 60 per cent of the NSTPs' budget has been entrusted to ITRI, representing annual funding of over NT$10 billion ($334 million). Today, the ITRI employs 5,728 personnel, of whom 1,163 possess PhDs and 3,152 Master's degrees. The institute was established to provide support for private sector 'upgrading', particularly amongst the many smaller firms lacking the necessary funds to undertake R&D activities, and is tasked with 'diffusing' the results of its research to the private sector. To date, ITRI holds more than 14,500 patents and played a role in the creation of more than 160 start-ups and spin-offs. The process of technology diffusion has been facilitated by the movement of personnel from ITRI into the private sector. For example, in the semiconductor industry, a very high proportion of the staff of United Microelectronics and Taiwan Semiconductor Manufacturing Company, from researchers up to the company chairman, were previously employees of ITRI.

Beginning in the late 1980s the government worked through research institutes to form innovation alliances to encourage industrial upgrading. The Notebook PC Joint Development Alliance ranks among the most successful of these. The Computer and Communications Laboratories of ITRI and the Taiwan Area Electrical Equipment Manufacturers Association invited 46 companies to form this alliance in the early 1990s. The alliance pooled group resources, enabling them to complete the development of a motherboard in only three months. As a result the alliance could legitimately claim that Taiwanese companies had the capability to produce notebook computers, allowing Taiwanese firms to secure 'first mover' advantages and obtain overseas orders. By 1998, Taiwan had overtaken Japan to become the world's largest producer of notebook computers and by 2000 accounted for almost 50 per cent of total global notebook computer output.[102]

The government also sought to encourage the diffusion of technology by establishing a 'cluster' modelled on Silicon Valley in the US. In 1980 the government established the Hsin-Chu Science-based Industrial Park (HSIP) to create a base for nurturing high-tech industries. The park was set up on government land near to the National Tsing-Hua and National Chiao-Tung Universities and received NT$18 billion in government investment between 1980 and 2000. It has become the main centre for Taiwanese industrial development. The number of employees at the Park increased from 8,275 in 1986 to 102,775 in 2000, whilst the total sales of Park-based companies increased from US$450 million to US$29.8 billion during the same period. In 2000, companies located within the HSIP spent an average of 5.94 per cent of their sales revenue on R&D.[103] HSIP has also been influential in importing technology from overseas and encouraging the repatriation of Taiwanese technical specialists. Between 1980 and 1989 14,880 people who had been studying overseas subsequently returned to Taiwan to work and between 1990 and 1995 another 30,238 people did likewise. A survey of companies based within the HSIP found that amongst their main sources of innovation 'technology brought back by people who had studied abroad' ranked a close second to their 'own research and development work'.[104]

These R&D support networks were supplemented by tax incentives. The Statute for Industrial Upgrading and Promotion, in force over a period of 19 years from 1991 to 2009, used tax incentives to encourage SMEs to undertake R&D, automation and personnel training. Most notably, companies in high-tech industries were offered investment tax credits. The statute achieved impressive results in terms of stimulating expenditure and boosting the economy. The provision of an additional NT$1 tax credit for R&D resulted in manufacturers increasing expenditure on R&D by 16.6 per cent. In 1993, for every NT$1 invested in R&D, real GDP increased by NT$1.14. During the statute's lifetime average labour output increased by NT$25,800 and the export value of technologically-intensive products increased by NT$2.57 billion.[105]

Conclusions

In the case of the Taiwanese electronics industry, foreign investment constituted the initial catalyst of growth, enabling firms to insert themselves into global production chains while creating important backward linkages for the transfer of new technology. This is not to underplay the importance (both direct and indirect) of institutional factors in the development of the island's electronics industry. In the 1960s and 1970s the political goals of the Kuomingtang regime shaped a Taiwanese industrial structure in which SMEs would come to dominate (albeit that this was not the regime's intention). However, in more recent years, the Taiwanese government has, with great success, implemented a range of pro-SME initiatives: funding research institutes, establishing clusters, forming innovation alliances and creating tax incentives, all of which encouraged innovation.

The success of Taiwan's electronics firms in consolidating their position as critical actors in global production chains suggests that once firms have become established in a chain, opportunities for technology transfer enable them to retain and strengthen their position within that chain — in Taiwan's case, through industrial 'upgrading' from contract manufacturing to design. Of course, as the market leader in foundries, Taiwan has retained a large stake in manufacturing. Nevertheless, the historical development of the Taiwanese electronics industry demonstrates that the global electronics industry is characterised by continuous change and opportunity. As academics Sturgeon and Kawakami put it: 'Assumptions about industry life cycles, where product segments stabilize as the industry matures, do not seem to apply to the electronics industry'.[106] Perhaps the most useful question for burgeoning electronics industries in other parts of the world is not how to replicate Taiwan's success, but rather which roles might offer points of entry to growing global production chains.

5

Japan: how have the mighty fallen?

From the early 1970s through to the mid-1980s Japanese manufacturers were world leaders in the burgeoning electronics industry. Japanese firms dominated consumer electronics, had gained leading market shares in semiconductor chips and looked set to replicate these successes in computers, telecommunications and office systems. So concerned were US industrialists and policy-makers that the Reagan administration adopted an interventionist industrial policy in a bid to support the US microelectronics industry and wrench the lead from their East Asian competitor.

Today, the outlook for Japanese electronics firms seems far more uncertain. In the 2011 financial year, Japan's electronics giants lost a combined $17 billion. Panasonic alone reported losses of $10 billion. By contrast, South Korea's Samsung reported profits of $15 billion and America's Apple made $22 billion. Since 2000, Japan's big five (Nippon Electric Company, Hitachi, Fujitsu, Mitsubishi Electric, Toshiba) have decreased in value by two-thirds.[107] The global recession and subsequent collapse of demand for commoditised consumer electronics (such as household items and liquid crystal displays) has highlighted deep-seated structural problems within Japan's electronics industry; it is in the main these structural problems, coupled with managerial reluctance to reform, which Japan's electronics giants have to thank for their relative decline.

The shape of the Japanese electronics industry

Many of Japan's biggest electronics companies, including Sony, were established in the aftermath of WWII and built their success on creating and selling products under their own brand name.

Unlike US Original Equipment Manufacturers (OEMs) such as IBM and Apple, Japanese companies have been slow to embrace outsourcing and offshoring strategies. The 'fabless' or foundry business model has not significantly caught on in Japan, despite the fact that 'fabless' companies now represent 23 per cent of the global semiconductor market. According to semiconductor market research company IC Insights, in 2009 only one Japanese firm, MegaChips, made it into the top 25 in a ranking of 'fabless' firms by sales (placing nineteenth and lagging behind Taiwan's MediaTek in fourth place).[108] Nor do any Japanese firms make it into Manufacturing Market Insider's top ten electronics manufacturing services (EMS) firms based on 2010 revenue, although Sumitronics, SIIX and UMC Electronics all feature within the top twenty.[109]

In terms of volume, Japan was the world's third largest producer of electronics in 2010, with its output totalling $199 billion. However, although Japan's electronics companies boast global reputations, from the early 1990s they have rapidly lost ground to US and Asian competitors. Today, most remain overwhelmingly dependent on the domestic market, having failed to capture a sizeable share of dynamic emerging markets. Research undertaken by McKinsey & Company in 2011 revealed that, as a group, Japan's high-tech companies (of which electronics firms form a sizeable part) still generate more than 50 per cent of their sales in the domestic market, which in recent years has grown only 1 per cent annually, in comparison to growth of 2 to 3 per cent in other developed markets and 5 to 10 per cent in the developing world.[110] Having failed to tap into growth markets, even if Japan's electronics firms were successful in defending their current market shares they would still see their share of the global market diminish. Worse still, the market shares of Japanese firms in key geographic markets are dwindling. Between 2005 and 2009, Japan's share of liquid crystal display (LCD) television unit shipments grew from 96 to 100 per cent in Japan but fell from 40 to 30 per cent in North America.[111] For Japan, this pattern of success in the home market but failure overseas is an all too common one. In 2004 Japanese firms held three of the top five positions in the global PC market, but only one in 2008. Similarly, Japanese companies occupied the number one and two spots in LCD televisions in 2004, but had lost them to South Korea's LG and Samsung by 2009.[112]

Identifying causes of decline in the Japanese electronics industry

In the short-term, the dramatic appreciation of the yen has disadvantaged Japanese and benefited South Korean exporters. The won has lost roughly 50 per cent in value against the yen since the global financial crisis began in mid-2008, enabling South Korean companies to undercut Japanese exporters.[113] In February this year Elpida, Japanese manufacturer of dynamic random-access memory (DRAM) chips, filed one of the largest bankruptcy claims made by a Japanese firm. South Korea's Samsung stands to gain the most from its failure. Of course, the relative performances of Elpida and Samsung cannot be attributed to exchange rates alone. Between the mid-1990s and 2008 the yen's real exchange rate generally followed a depreciating trend. Furthermore, the success of many new Asian firms must in large part be attributed to their boldness and agility (characteristics which set them apart from most of their Japanese competitors).

Other short-term factors that have had a detrimental effect on Japan's electronics industry include natural disasters. Factories were destroyed and supply chains disrupted by the earthquake and Tsunami of March 2011. Flooding in Thailand halted imports of electronics components and car parts. These set-backs were exacerbated by corporate-governance scandals, most notably at Olympus,[114] which undermined trust in the big electronics companies.

Overcrowded markets

However, these recent misfortunes alone do not account for the dramatic losses reported by Japan's electronics giants at the end of last year. These firms are feeling the adverse effects of more profound, structural problems. Japan's consumer electronics market is overcrowded; there are too many companies selling a very broad range of products which overlap with one another. Nine Japanese companies manufacture mobile phones, six make televisions, and ten produce rice-cookers.[115] During Japan's economic boom, from the 1960s through to 1990, this 'supermarket' strategy, whereby single companies sought to produce as many different electronic devices as possible, was effective. But today Japan's electronics giants, having prided themselves not on profits but rather on the range of products they offer, have grown into overblown and unwieldy conglomerates. Japan's biggest electronics conglomerates can each boast over 500 affiliates; the Hitachi 'umbrella' shelters an astounding 1,069 companies. Large numbers of firms with small market shares means that profit margins are meagre; as a result, firms struggles to raise capital to invest in efficient R&D that would enable them to outstrip overseas competitors.

Nowhere is the problem of overcrowding more apparent than in the market for liquid crystal display (LCD) flat-panel screens, used in televisions, computers and mobile phones. In 2004 firms like Japan's Sharp could boast annual profit margins of 10-15 per cent on flat-panel televisions.[116] But today no single firm worldwide makes money by producing LCD panels. Since 2004 global sales of LCDs by volume have increased tenfold, whilst their prices have fallen by 75 per cent.[117] Between 2004 and 2010, LCD manufacturers worldwide lost a combined $13 billion. In 2011 Sony made losses on its television business for the eighth consecutive year; indeed, every set sold cost Sony $45.[118] The LCD industry serves as a convincing example of the severity of the problem of market overcrowding, a phenomenon which is especially pronounced in Japan and exacerbated by outdated conglomerate structures. The global recession, falling demand and short-term difficulties already outlined have laid bare these structural problems, forcing firms to consider reform.

The 'Galapagos effect'

Nippon Electric Company (NEC) highlights how state intervention has played a role in the formation of saturated Japanese electronics markets. This has shielded Japanese firms from healthy international competition, their technology evolving in an isolated environment: the 'Galapagos effect'. NEC was once one of the largest IT and telecoms firms globally. However, in the last decade its shares have fallen by 90 per cent, whilst in January this year it forecasted losses of a ¥100 billion ($1.28 billion) for the fiscal year.[119] For most of the time since its foundation in 1899 the state has been its main customer. In 1985 NEC's customer, monopoly government-owned, Nippon Telegraph and Telephone Public Corporation (NTT) was privatised, forcing NEC to compete. However, NTT (with the government still owning around one third of its shares) demanded highly specialised technical specifications from its suppliers, effectively protecting NEC's monopoly as these technical demands acted as a barrier to entry for rivals. In the long-run this convenient arrangement became NEC's downfall. It struggled to modify the complex technology it produced for NTT for other clients. NTT even threatened to cut orders should NEC make too many sales to domestic rivals, viewing competition as disloyal. Further, working for NTT has meant that NEC gained little experience of how to operate its telecoms and IT equipment; as a result it has found it difficult to succeed overseas, where operators prefer vendors who can help with the running of equipment and will pay handsomely for these services. NEC's trade is solely in hardware which today yields only low margins. The difficulties experienced by NEC are symptomatic of far broader problems in Japan's electronics markets, caused by monopolistic tendencies.

As mentioned above, Japan's electronics giants have traditionally been characterised by 'vertically-integrated' corporate structures, wherein a single company owns all of the firms which make up its supply chains. Elsewhere electronics companies have benefited from shifts towards modular production, whereby certain processes are outsourced or offshored to suppliers possessing specific capabilities. The 1980s saw a dramatic increase in the number of US firms working with suppliers in the China Circle (the People's Republic of China, Hong Kong and Taiwan) and Singapore. Modular production helped lower production costs and decreased turnaround times, enabling US firms to pioneer strategies of continuous innovation and outperform their Japanese competitors, who, by contrast, have been extremely slow to relinquish more insular modes of production. The development of modular production was doubly damaging for Japan, as it also encouraged the growth of Asian-based direct competitors in several of the markets in which Japan had been most successful — consumer electronics, memory chips and LCD displays. Many Japanese manufacturers have responded to Asian competition by moving low value-added production and assembly overseas, whilst keeping core and high-end technologies at home as jealously guarded secrets. Though for many this decision should have been made some time ago.

The Japanese government must also accept some responsibility for the failings of many electronics firms. Japanese authorities have been anxious about the prospect of electronics manufacturing going overseas and have acted to prevent this. Hidetaka Fukuda, who oversees information technology for the Ministry of Economy, Trade and Industry (METI), reported in 2004 that the ministry had intervened to persuade NEC to sell its plasma-display business to local competitor Pioneer, rather than to a foreign investor, in order to keep its technology in Japan. Unfortunately by preventing outsourcing, the government prevented many Japanese firms from staying abreast of their competitors.

Canon and Nikon are two such firms. Both produce steppers, the tools used to make microchips. In 1990 the Netherlands' ASML had less than 10 per cent of the market, while Japan's Canon and Nikon dominated it. By 2009, however, ASML controlled 65 per cent.[120] Too small to compete directly with the Japanese firms (who had more resources and undertook all aspects of manufacturing in-house), ASML redesigned their stepper so that its production process could be modularized — that is, different stages of production could be undertaken by different manufacturers. For example, they outsourced the creation of precision lenses to Carl Zeiss, a German specialist. This modular production process enabled ASML to innovate more quickly and make more technologically advanced products than its vertically-integrated Japanese competitors.

Reluctant Reform

Since the early 2000s Japan's giants have been forced to implement reform. But is it a case of too little, too late? Japan's business culture is notoriously resistant to change. In 2001, the president of Fujitsu, Naoyuki Akikusa, rejected calls for Fujitsu to break up its 517 companies, pledging instead to implement a 'Japanese new-business model'.[121] In the same year the president of Toshiba, Tadashi Okamura, made vague statements which promised to create 'synergy effects' among the 323 group companies.[122] And in 2005, Sir Howard Stringer, CEO of Sony, insisted that reshaping the company would not involve separating its electronics and media divisions, citing Japan's consensual business environment and strong internal resistance.[123] Unfortunately, the markets were not so sympathetic to Japan's corporate philosophies — within a week of Sir Howard's announcement Sony's shares had fallen by 6 per cent.[124]

Under pressure to provide investors with evidence of reform, Japan's struggling electronics firms initially avoided restructuring in favour of laying-off staff. Despite long-held principles that firing long-serving workers was taboo, in 2001 Toshiba and Fujitsu announced job cuts of 19,000 and 16,000 respectively. NEC increased its planned workforce reduction from 15,000 to 19,000 jobs. Kyocera cut 10,000 and Oki Electric 2,200.[125] However, these timid efforts at reform were both controversial and ineffective and skirted the central issue of the need for restructuring and consolidation amongst Japan's large electronics firms.

Restructuring

Japanese firms have traditionally resisted mergers and acquisitions. The closed approach of Japanese firms contrasts sharply with that of firms in the US and Europe, where takeovers are viewed as a natural business process. Nevertheless, during the past five years Japan's electronics giants have found themselves reconsidering this position. In 2009 Fujitsu sold its loss-making hard disk drive business to Toshiba. However, perhaps the best example of this kind of restructuring is in the semiconductor industry. Many Western technology firms, including Philips and Hewlett-Packard, have long-since shed their chip-making units, owing to the impossibility of achieving consistently high margins as new types of chips quickly become commoditised and the need to build expensive new fabrication plants (at $3 - 5 billion each time). Only in recent years have Japan's technology conglomerates begun to come round to this 'fab-lite' strategy. In 2007, Sony, choosing to concentrate on its media technology, put its processor-chip division into a joint venture with Toshiba and also sold its chip-making facilities to its rival.[126] Toshiba stood to gain economies of scale whilst Sony would still have a reliable supply of processors for its PlayStation 3 games consoles without having to make large investments in chip technology. Sony's chip business had lost ¥10 billion ($127 million) the previous year. Again the worry is that such decisions have been made too late.

Last year even saw moves towards mergers amongst some of Japan's most well-known electronics giants. Sony, Toshiba and Hitachi are merging their small and mid-size LCD-panel operations, accepting at long last that, in an overcrowded Japanese market, consolidation makes sense if firms are to compete against rivals in Taiwan and South Korea. All have been making losses on small panels, so the merger will enable them to focus on their main operations. The merged company, Japan Display, will be listed by the financial year ending March 2016, by which time it is hoped that annual revenues will have increased to ¥750 billion from ¥570 billion this year. The merger is costing $2.6 billion of government-backed funds, giving the state a 70 per cent stake in the business. Unfortunately it is far from clear that the Japanese tax payer is getting value for money: Shigeo Sugawara, a senior investment manager at Sompo Japan Nippon Koa Asset Management, has argued that 'it's not a business that will likely provide stable profits in the mid to long term'.

Success of medium-sized firms

The failings of Japan's lumbering electronics conglomerates contrasts sharply with the success of its medium-sized firms. Japan's *chuken kigyo* (strong, medium-sized firms) dominate specialised global markets but their success has tended to be underappreciated in a culture which has valued size over profitability. The products made by these companies are usually invisible to the consumer, but firms hold outsized market shares because they are necessary for making particular final products. Nidec make roughly 75 per cent of motors in computer hard-disk drives. Mabuchi make 90 per cent of the micro-motors used to adjust rear-view mirrors in cars. Covalent produces 60 per cent of the containers that hold silicon wafers during the process of turning them into computer chips.[127] According to METI, Japanese firms serve more than 70 per cent of the worldwide market in at least 30 technology sectors, each worth more than $1 billion.[128] Whereas Japan's electronics giants have lost market shares to Chinese, South Korean and Taiwanese competitors, the country's smaller, less well known firms have, thus far, continued to dominate niches which support the global technology industry. As Alberto Moel, of consultants Monitor Group, puts it: "They may not be the sexiest products, but you can't make a semiconductor chip…without them".[129]

Capacitors provide the best example of the technical strength of Japan's medium-sized enterprises. So small that magnifying glasses are needed to see them, they store electricity in a circuit and are the basic building blocks of all manner of electronic devices. A mobile phone may need 100 of them, a PC 1000. Murata, a Japanese company, controls 40 per cent of the global market. Investment bank Macquarie estimates that Murata has overall margins of roughly 50 per cent. Once other suppliers such as TDK and Taiyo Yuden are taken into account, Japan's total market share is around 80 per cent.[130] Often the only real competitors of leading Japanese medium-sized firms are other *chuken kigyo*. For example, 50 per cent of the market for the photomask substrate, which is used to place patterns on semiconductors, is held by Shin Etsu, but all of the other producers — AGC, NSG, Covalent and Toosh — are also Japanese.[131] Japan remains indispensable even when more than one supplier exists.

Of course, the success of Japan's medium-sized enterprises is not unique. British firm ARM Holdings dominates the market for application processors, which run software on smart phones. The closest Western equivalent to Japan's *chuken kigyo* is Germany's *Mittlestand* which contains a host of relatively small world-beating firms. Just as with the *Mittelstand*, the *chuken kigyo* are not merely a part of the national economy, but its industrial core.

Why do Japan's medium-sized electronics firms succeed whilst its giants flounder? The high quality and reliability of components is important; no manufacturer would be happy if its final products malfunctioned because of a problem with a tiny part. The Chairman of Covalent, Susumu Kohyama has emphasised that the components produced by successful *chuken kigyo* are highly customised: only by working very closely with clients over a long period of time are suppliers able to gain an insight into clients' future technical plans and are sufficiently trusted for clients to consult them on tricky technical problems. For this reason, once firms achieve a leading position in a particular technology, it becomes difficult to depose them. Whilst many electronic products have become commodities, components such as capacitors have not because they require constant innovation. As a result, entry barriers remain high, as do margins (in contrast with the low entry barriers and shrinking margins in the production of LCD panels). Japan's *chuken kigyo* owe their success, in part, to changes in the industry that have hurt Japan's large electronics firms; lower entry barriers to final goods manufacturing has reduced the market shares of the likes of Sharp and Hitachi, whilst increasing demand for components produced by firms such as Murata where entry barriers are high.

Conclusions

The relative decline of the Japanese electronics industry owes most to ineffective industrial and corporate structures. For the past two decades Japan's electronics giants have been held back by outdated conglomerate structures which have valued breadth over profitability, leading to market overcrowding. In terms of efficiency, insular Japanese approaches to production have lagged behind the modular processes adopted by their US and Asian counterparts, whilst near-monopolies have undermined the ability of Japan's electronics firms to compete in global markets. The relative success of Japan's medium-sized electronics firms speaks to the benefits of focus, modular production and quality of product and innovation; all of these characteristics of Japan's *chuken kigyo* contrast with those of their overblown conglomerate siblings.

The global financial crisis laid bare the structural defects of Japan's electronics giants and forced managers to implement change. But reform has been excruciatingly cautious and, as a result, often ineffective. Managers have tended to skirt the most controversial measures when streamlining workforces and axing poorly performing business units. The most prominent government interventions, most notably, the provision of public funds to back mergers, seem ill-advised and could have been avoided with more timely reforms. Sickeningly for Japan's struggling electronics conglomerates it is their Asian rivals who now offer them a way out from capital-intensive, low-margin businesses. If Japan's large electronics firms are to recover, managers must not shy from implementing bolder structural reforms; they must cut costs by offshoring certain functions, increase efficiency and shift corporate focus to the global markets with the strongest opportunities for growth. If Japan's companies are to regain their position as leaders of innovation, they will need to adopt a narrower focus and seek cross-organisational and cross-border collaboration.

6

Silicon Valley: cluster capital

Silicon Valley is *the* textbook example of a successful high-technology cluster. Home to Intel, Google and Apple, this expanse of suburban sprawl accommodates more than 8,000 firms and provides 500,000 jobs in high-tech industries.[132] The Silicon Valley model — a technological nursery which brings together technical expertise, entrepreneurial people with strong personal networks, university and industrial research facilities, experienced venture capitalists and good market access — has been imitated in places as far afield as Helsinki, Cambridge, Tel Aviv, Bangalore and Taipei.

But to what should the phenomenal success of Silicon Valley be attributed? Popular mythology surrounding the genesis of Silicon Valley tends to identify a number of key factors. These include physical and financial infrastructure, university links, an influx of government funding, and even California's pleasant climate. Unfortunately such accounts merely provide a 'checklist' of background factors and overlook the committed entrepreneurial efforts made by key firms and individuals: the birth and growth of the cluster has been characterised, above all, by responsive and forward-thinking business practices and management. That is not to downplay the importance of a range of auxiliary factors, geographical, cultural, educational, financial, but these all mean very little to a firm without the insight and skill to recognize and seize the opportunities before it.

According to local lore, the birthplace of Silicon Valley was a garage at 367 Addison Avenue in Palo Alto. It was here in autumn 1938 that Stanford graduates Bill Hewlett and Dave Packard built an audio oscillator (an electronic test instrument used by sound engineers) which would become the first product of one of Silicon Valley's most successful technology firms. Hewlett-Packard (HP) went on to become a corporation of more than 88,000 staff, with annual revenues of nearly $60 billion.[133]

Although the audio oscillator was one of the first inventions of the Valley, it was the semiconductor industry which gave the area its name (semiconductor materials are used to make microprocessor chips and transistors, meaning that all computerized equipment relies on them). In 1955 William Shockley, co-inventor of the transistor, founded Shockley Semiconductor to commercialise semiconductor devices. However, his domineering and paranoid management style quickly drove eight of his best electronics engineers, nicknamed the 'Traitorous Eight', to leave the company and found their own firm, Fairchild Semiconductor. Fairchild, established in 1957, went on to spawn an entire industry; today a whole host of semiconductor firms, including National Semiconductor, Intel and Advanced Micro Devices (AMD), can trace their roots back to Fairchild. It was these firms — HP, Fairchild and Intel — which pioneered the 'Silicon Valley' strategy of growth based on innovation and flexible modes of business and entrepreneurship (although the term 'Silicon Valley' itself did not gain currency until the 1970s).

A snapshot of Silicon Valley

What sets Silicon Valley apart is its structure. Elsewhere firms often operate in close proximity to one another, but they remain autarkies, valuing proprietary knowledge and self-sufficiency in product development. Not so in Silicon Valley where a complex web of relationships connect firms to universities, government research facilities, venture capitalists and each other. These networks carry out many of the same functions as a formally incorporated body, but with far greater flexibility and resources. IP is widely shared, whether in strategic alliances between firms or between employees in informal social settings. Employee mobility makes for the constant movement of knowledge and expertise.

University research laboratories innovate for the commercial sector. Investors are not passive onlookers but co-managers in start-ups.[134]

The importance of networking necessitates physical proximity; no technology has yet displaced the benefits of regular face-to-face contact. Silicon Valley is a relatively compact area. The distance between San Jose at the southern extreme of the Valley and Marin County in the North is roughly a two-hour drive, which, as Israeli venture capital fund manager Jon Medved points out, is around the amount of time the region's venture capitalists are willing to spend travelling to a portfolio company or investment partner: 'In Silicon Valley for a long time people said they wouldn't invest in anything they couldn't drive to — many still don't. For something to explode entrepreneurially, you have to have a community, a geographically compact entity'.[135] While this unwillingness to travel has dissipated in recent years, it remains the case that physical proximity facilitates the kind of face-to-face networking which enables firms to build effective alliances and partnerships. A second corollary of the geographically compact Silicon Valley network is the speed at which business is conducted. Strategic alliances, mergers and acquisitions, venture capital financing, public offerings and product roll-outs all happen at a remarkable pace.

Silicon Valley firms tend to be characterized by disintegration — that is, 'the segmenting of various operations between companies horizontally and vertically'.[136] Vertical disintegration enables firms to concentrate on a single segment of a supply chain, usually R&D, by assigning other functions to allied firms. The complexity of the Silicon Valley network is, in part, the result of disintegration and the proliferation of spin-offs. The founders of Fairchild Semiconductor set a powerful precedent when they absconded from Shockley Semiconductor in 1957. In sharp contrast with Japan's vertically-integrated electronics giants, Silicon Valley firms have tended to spin-off suppliers in order to avoid excess diversification and inefficiency. However, spin-offs also become competitors, challenging established firms. As Gordon Moore (co-founder of both Fairchild Semiconductor and Intel) and academic Kevin Davis put it:

> … successful start-ups almost always begin with an idea that has ripened in the research organisation of a large company (or university), causing a fundamental tension between what is ideal for the individual technology firm and creating a phenomenon that builds a dynamic high-tech region.[137]

A key structural feature of Silicon Valley is its mixture of large and small high-tech companies. Discoveries made in the R&D facilities of well-established companies can lead to the founding of new independent enterprises. These start-ups are able to take more risks than larger, better established firms, who have a reputation to protect and ongoing projects to maintain, meaning that they can only dedicate a small portion of their total resources to new enterprises. This pattern has been facilitated by American cultural values. The US has long esteemed the maverick self-made millionaire and tolerated failure, in stark contrast to many other cultures. Such cultural factors are difficult to understand in terms of causality and are not, of course, subject to rapid change.

The role of Stanford

One particularly important structural characteristic of Silicon Valley is the porous relationship between high-tech firms and Stanford University. A number of imitative high-tech clusters (including that in Cambridge, discussed above) have come to view universities as producers of path-breaking intellectual property which companies cannot match owing to their short-term, market-driven horizons. But Stanford's contribution to the birth and development of Silicon Valley was more substantial than the development of IP alone (although this function was clearly important). Certain key individuals at the university also played pivotal roles in creating regional conditions conducive to commercial entrepreneurship.

Fred Terman, Head of Stanford's Department of Electrical Engineering from 1937, stands out. After WWII he endeavoured to improve Stanford's level of government funding; his first success was a contract from the US Navy financing three projects for basic research in chemistry, physics and electrical engineering. Terman created a series of follow-ups to the government-funded electrical engineering project, which resulted in the development of two leading research facilities, Stanford's Electronics Research Laboratories (ERL) and the Stanford Linear Accelerator.[138] The former facility soon formed strong bonds with local, young technology firms, including Varian Associates and Hewlett-Packard. Together with their own R&D these firms were able to transform much of the ERL's basic research into product applications which could be successfully marketed. Terman was also instrumental in the 1951 creation of the Stanford Industrial Park (later the Stanford Research Park); he made personal efforts to secure estimable early tenants including Varian, HP, General Electric and Lockheed Space and Missile Division. Over a period of fifty years the Park grew into a 700 acre development boasting 150 high-tech firms, R&D institutes and professional services companies.[139] Terman also implemented a number of cultural innovations with the aim of increasing ties between business and academia; most notably, the Honors Cooperation Program which got industry engineers back into education.[140]

For many in the Valley Stanford's main contribution has been its provision of human capital in the form of outstanding M.Sc. and Ph.D. graduates. Terman dramatically improved the quality of Stanford's electronics curriculum and research. He was also personally committed to the careers of graduates of his department. Terman persuaded Stanford graduates Bill Hewlett and Dave Packard to return from their respective careers in Chicago and New York to found a start-up in the Bay Area, offering various incentives including the opportunity to gain a postgraduate degree for Hewlett and a list of potential customers for their first product. In 1960 Stanford created departments in chemical engineering and materials science, core areas of semiconductor research. Between 1988 and 2004 the revenue of firms formed by Stanford research teams and graduates composed roughly half of the total revenue of Silicon Valley firms.[141]

Terman laid vital groundwork for the growth of Silicon Valley, establishing at Stanford University an acceptance of close cooperation with both government and industry. This principle of collaboration represented a major innovation in its own right.[142] Today, Stanford continues to aggressively license its IP and grant faculty time to consult in the corporate sector. It is an institution responsive to the needs of the industrial community and marketplace.

Entrepreneurial management

Despite the important role played by Stanford, it alone cannot account for the success of Silicon Valley. Indeed, the university's first spin-out failed. The Federal Telegraph Corporation (FTC) was founded in 1909 by a Stanford engineering graduate, Cyril Elwell, to produce wireless telegraph systems. In its early years it failed to capitalise on technical breakthroughs and so struggled to expand its market position. Company scientist Lee de Forest detected the possibility for regenerative circuits (which allow electronic signals to be amplified many times and would be used in radio receivers from the 1920s) but did not recognise the implications of his discovery; no efforts were made to commercialise his discovery, nor were his findings patented (Edwin Armstrong would beat him to it in 1914). In 1931, Federal Telegraph's Palo Alto operations shut down and relocated to New Jersey after the firm was bought out by International Telephone & Telegraph (ITT).[143] Promising managerial and technical talent and a high-potential technology firm had few qualms about abandoning the Bay Area, which throughout the first half on the twentieth century did not build up and sustain a critical mass of technologically-intensive firms. The development of a thriving high-tech cluster required 'people who could perceive and respond to opportunities and effectively marshal the resources to capitalize on them'.[144] Fred Terman was the first of these individuals. He was followed by a whole host of managerially skilled innovators and entrepreneurs who pioneered the flexible modes of business which still characterise Silicon Valley today.

According to Gordon Moore, the cluster's economic growth depended upon the evolution of what he calls 'technologist-managers'; individuals with both technical insight and business capability, able to transform scientific developments into viable commercial enterprises. Detailing his own experience as a co-founder of Fairchild Semiconductor, Moore describes how he and his fellow scientists, devoid of business experience, advertised for a general manager. Their choice, Ed Baldwin, educated this group of technologist-managers about writing annual reports, capital asset and inventory management and how approaches to distribution and accounting impact upon profits. As a result, Fairchild's next business manager, Bob Noyce, was recruited internally. While Stanford produces many of the highly-skilled technical graduates that establish and work in Valley firms, existing firms provide on-the-job business training.

A technology firm's success, as the case of Federal Telegraph suggests, depends upon the ability of technologist-managers to recognize and exploit commercial opportunities. At Fairchild, Bob Noyce presided over a transition to commercial, product-driven science. His principle of 'minimum information' for 'efficient engineering' was intended to orient scientific discovery towards profits, by demanding that something worked in practice (not necessarily optimally) and at an acceptable cost.[145] This replaced an academic approach whereby complicated and costly research was undertaken in order to understand every facet of an effect as fully as possible. Fairchild's success, as well as that of its various spin-offs, grew out of a perception of the huge commercial opportunity offered by semiconductor technology. Similarly, Intel's phenomenal success in microprocessors would never have come about had Ted Hoff (their inventor) not recognised that the product had far broader applications than the calculator he had initially designed the chips for.[146]

In Silicon Valley non-hierarchical management structures are the norm. Work is organised in teams rather than through command chains, whilst informal working environments are attested to by laid-back dress codes and a porous division between work and leisure activities. Employee loyalty is secured through stock options rather than the promise of a steady career path. This management style works especially well for younger firms and was pioneered by Hewlett and Packard who, as their company began to grow from the 1940s, made a priority of developing a leadership style that would foster an organisation with a creative, motivated workforce. This set of management principles became known as 'the HP Way'.[147] Hewlett-Packard encouraged the development of an inclusive firm culture in which managers were appraised on how close a rapport they kept with frontline workers, as well as their ability to keep abreast of customer expectations.

Many Silicon Valley firms also benefitted from bold management decisions at key junctures. In 1999 HP's board of directors made the decision to jettison the firm's original (measurement and testing) instruments business and focus solely on computer-related products and services. HP's instruments group was spun-off as an independent firm, Agilent Technologies, which still has $11 billion annual sales.[148] Similar decisions have been pivotal for Intel's development. By the 1980s a formerly high margin market for memories (the firm's main product) had declined into a commodity market in which Japanese makers dominated. The easy option would have been to continue to compete, increasingly ineffectively, in this market. Instead Intel's managers opted to continue as a semiconductor manufacturer but as a producer of microprocessors rather than memory devices. These self-reinventions emphasise the centrality of innovative, entrepreneurial management in Silicon Valley's economic development.

Finance and business support networks

University research laboratories and industrial parks ultimately mean little to a company lacking the insight and skill to capitalize on commercial opportunities. Nevertheless, supporting infrastructures can and do critically affect the opportunities that a cluster offers businesses.

For HP, Shockley Semiconductor and Fairchild Semiconductor financial assistance came from personal acquaintances and corporate backers. However, angel investors, private individuals who provide capital to start-ups in exchange for equity, can usually provide only a limited supply of funds and management attention. While banks often neglect high-technology start-ups, due to the risks involved, venture capital can offer the combination of funds and strategic management that new firms need. Not until the 1960s did a significantly large, local body of professional financiers emerge in Silicon Valley. This first generation of the Bay Area's venture capital firms were located in San Francisco's financial district. The Bay Area did not have its own financial hub until 1969 when property developer Thomas Ford built four office complexes at 3000 Sand Hill Road, Menlo Park, on a remote corner of Stanford's campus. Ford's extensive personal network enabled him to draw into his offices Silicon Valley's most promising young venture capital (VC) firms: Kleiner & Perkins, Mayfield, Sequoia and Institutional Venture Associates. Other VC firms and professional services providers quickly followed suit. VC firms within the mini-cluster were able to keep abreast of investment activity, share information and coordinate on co-investments, while Silicon Valley start-ups now had a central location for shopping around their business plans. By 1998, within a half-mile radius of 3000 Sand Hill were the offices of more than forty VC firms, nine law firms, seven investment advisory companies, six consultancies, five executive search firms, four investment banks and three accountancies.[149]

The only institution crucial to the Valley's success which is not located in the region is the Nasdaq Stock Market. It was founded in 1971 as a market for small-capitalization stocks (companies with low market value) and soon became the home of high-tech companies. The Nasdaq is important because it provides early-stage investors, entrepreneurs and employees with a means of realizing the value of investments they make in terms of money, time and labour. It offers companies easier listing requirements than other stock exchanges, most notably lower capitalization and profitability, which suit Silicon Valley start-ups with rapidly developing and capital-intensive business plans. Further, investors on Nasdaq tend to accept larger risks in technology shares than with more established firms listed elsewhere (although, of course, in return they expect higher growth in revenue and profits).

Government interventions

The City Manager of San Jose between 1950 and 1969, Anthony P. 'Dutch' Hamann, led a city government which made considerable efforts to build up the Bay Area's physical infrastructure. During his time in office, 1400 neighbouring communities were annexed and the population of San Jose grew from 100,000 people occupying 17 square miles to 450,000 living across 150 square miles.[150] Between 1950 and 1965 the Chamber of Commerce spent $1 million promoting San Jose, subsidised by the city and county governments.[151] Local government improved infrastructure and changed planning laws to help high-tech firms. For example, when IBM made plans to expand to the south of the city, San Jose officials simply annexed the area for the company's convenience. This determination to bring in high-tech business was tied in with a push for the construction of new housing developments.

Prevailing wisdom in the Valley holds that high-tech industries are too dynamic to benefit very much from government interventions or incentives. Nevertheless, it is clear that the federal government played a supportive, and influential, role in the economic growth of Silicon Valley. During the early Cold War years Silicon Valley was bolstered by Defense Department spending, with Stanford benefiting from a large increase in federal funds. The primary market for silicon transistors in the late 1950s and early 1960s was for Air Force avionics and missile guidance and control systems.

Defence projects provided volume markets for companies. The military not only provided lucrative early contracts but also encouraged technological developments which could be put to broader commercial use. Most notable were R&D activities (both academic and industrial) for the 1960s space programme. Work undertaken for the Minuteman I missile hurried Fairchild Semiconductor's refinement of the planar transistor, which made possible the mass production of integrated circuits.[152] By the late 1960s the direct influence of defence contracts on the direction of Valley research or product programmes had become more limited,[153] although in later years the National Security Agency and the nuclear weapons laboratories became major purchasers of supercomputers.

The history of the internet provides an impressive example of the role of the federal government as a financier of innovation. In the mid-1960s the Defense Department's Advanced Research Project Agency (formerly ARPA, renamed DARPA in 1972) envisioned the creation of a network of computers. By the 1970s ARPA had helped fund ARPANET which connected some university computers. ARPANET was originally intended to function as a tool to support scientific research but other applications, including the ability to move files and send emails, developed rapidly. Although various other public and private actors were involved in expanding the network, initial financing by the government was vital, and by the early 1990s the internet had been born.[154]

Despite a move away from direct involvement, the federal government has continued to provide an important source of funding at Stanford; in 1994 the University received $528 million, or 40 per cent of its total income, from the government through its agencies and institutions.[155] DARPA has tended to allocate most of its computer science funding to MIT, Carnegie-Mellon and Stanford. Across America since the 1970s government finance has funded roughly 70 per cent of total university research in electrical engineering, semiconductor and communications technologies.[156] In

1997, 27 per cent of graduate students, including 50 to 60 per cent of Ph.D. students, in electrical engineering and computer science received federal funds.[157].

The government also played an important part in the Valley as a financier. In 1958, Congress established the Small Business Investment Company (SBIC) programme to provide long-term funding to growth-oriented small businesses. SBICs, federally guaranteed risk-capital funds, could borrow up to half of their capital from the government and received a variety of favourable tax incentives.[158] Although the SBIC programme came under extensive congressional criticism for low financial return, fraud and waste,[159] as Joshua Lerner (Professor of Investment Banking at Harvard Business School) argues, the SBIC programme resulted in the formation of the infrastructure for much of today's venture capital industry.[160] Many institutions, including law and accounting firms oriented towards the needs of entrepreneurial firms, which emerged in the 1960s and early 1970s began as organisations concerned primarily with SBIC funds. A number of the US' most dynamic high-tech firms, including Intel, Compaq (now part of HP) and Apple Computer, benefited from SBIC support before going public.

For advocates of free enterprise, the federal government's greatest contributions to high-tech industry were the reductions in capital gains tax rate from 49 per cent to 28 per cent in 1978 and then to 20 per cent in 1981 (which made risky investments more attractive) and the more favourable tax treatment of stock options (by taxing options only when exercised, not when granted).[161] The phenomenal growth of VC funds in the late 1970s and early 1980s was facilitated by government legislation. In 1979 the U.S. Department of Labor altered the Employee Retirement Income Security Act's 'prudent man' rule which now explicitly allowed pension fund managers to make large investments in high-risk asset classes including venture capital.[162] Other government regulations that have facilitated the growth of Silicon Valley firms include:

permitting general partners of venture firms to sit on the boards of their portfolio firms; restricting the liability of limited partners to the money they invest; and the non-taxation of partnerships.[163] Entrepreneurship is encouraged by bankruptcy laws that do not overly burden failed entrepreneurs.

But for Gordon Moore, the government's most significant intervention — one which he believes constituted the 'true birth of the [semiconductor] industry' — was in the field of intellectual property.[164] As part of an antitrust settlement, the government forced the American Telephone and Telegraph Company Corporation (now AT&T) to share freely its findings on semiconductors. Sprague Electric, Motorola and Shockley Semiconductor, three of the 'big four' early producers of semiconductors (the fourth would be Fairchild), were all formed by key personnel who attended a government-funded Bell Laboratories symposium in 1951, where Bell disclosed its entire collected knowledge of semiconductors.[165] This information sharing prefigured the porous quality of Silicon Valley's inter-firm relationships with their continuous exchange of knowledge and expertise. Here a tension exists between the benefits of knowledge-sharing and the importance to firms of protecting IP. IP law is a difficult area for governments. The US government have recently altered the patent system with the 2011 America Invents Act (the most significant change to the US patent system since 1952). This legislative change is intended to simplify patent law, thereby making the awarding of patents more efficient, and improving IP protection by shifting from the present 'first-to-invent' system, whereby applicants must present a series of proofs, to a 'first-to-file' system for patent applications filed from 16 March 2013. Only time will tell if the changes help encourage innovation.

Conclusions

The birth and development of Silicon Valley suggests that the key to a successful cluster is the attitudes of the people who work in them. No amount of cheap finance, tax incentives or targeted advice will turn someone who likes to be an employee into a risk-taker. It is, however, possible to establish a supportive framework for those who are entrepreneurial. The birth and extraordinary economic growth of Silicon Valley has been supported by a basic technical infrastructure (phone, internet, transport), a wealth of local finance, and a strong educational infrastructure providing a fount of intellectual property as well as highly skilled designers and technicians - all of which have, at some point, benefited from government intervention. The cluster has also enjoyed a sound legal infrastructure in which firms are able to enforce contracts and protect intellectual property, as well as stable tax laws which aid planning.

However, these institutional foundations alone are not sufficient to account for the Valley's phenomenal success. If some of the catalysts have been within the power of policy-makers to implement, many others rely on social and cultural factors which cannot be manipulated in any straightforward manner. The successes of Fairchild Semiconductor, Hewlett-Packard and Intel all point to the overriding importance of fostering business-minded managerial talent, a role performed most effectively not by academic institutions but well-established firms. Entrepreneurial management has been the key to the development of a product-driven approach to science, bold managerial decisions and, most importantly, the perception and exploitation of commercial opportunities. And the development of Silicon Valley's entrepreneurial management styles has been moulded by a local culture that places an extremely high value on creativity, imagination and entrepreneurship.

Nevertheless, it is important to recognise — though the Valley's firms are loath to admit it — the pivotal role played by the federal government during the Valley's formative years, as a customer, a financier and an early-stage developer. These key interventions were made when it mattered most; as the foundations for the

Valley's spectacular growth were being laid and key aspects of its distinctive business culture developed and refined.

7

China: workshop of the world

China is a hub of electronics production. Approximately a third of global electronics hardware revenue is generated by products made in China.[166] However in 1995 Chinese production accounted for only 3 per cent of the global total. How was it that the country managed to climb so rapidly up the global pecking order in such a short space of time?

The size and shape of the Chinese electronics industry

In 2010 total production in the Chinese electronics industry was worth $489 billion.[167] China dominates the production of electronic data processing devices, consumer electronics, and telecommunications. It is also a leading producer of components, radio communications and radar products and office equipment.

Table 11: Chinese electronics production by sector 2010 ($ billions)

Type of electronic product	Production in 2009	Rank
Electronic Data Processing	235.8	1
Components	85.3	2
Radio Communications and Radar	72.5	2
Consumer	55	1
Control and Instrumentation	7.7	4
Telecommunications	24.4	1
Medical and Industrial	6	4
Office Equipment	3	1
Total	489.8	1

Source: Reed Electronics Research, www.rer.co.uk

China is no longer just an assembly shop where cheap labour operates at the end of the electronics production chain. The data above demonstrates that the country is increasingly producing complex electronics and carrying out design and development work alongside production and assembly. Nevertheless the industry is still disproportionately weighted towards the manufacture, rather than the design or development parts of the production chain. This is clear when one examines the type of companies populating the industry.

Connectors, cable assemblies and backplane producers

Starting at the bottom of the production chain, China dominates the manufacture of relatively simple electronics components such as connectors, cable assemblies and backplanes. The country accounts for about 50 per cent of global production and is also the largest destination for these components. There are 24,193 companies producing these components in China compared with 3,013 in

America and 973 in Europe.[168] The sheer number of companies supplying these simple, yet fundamentally important, components means that China's supply chain is one of the best in the world and explains why the country has become the number one location for electronics assembly.

Only 20 per cent of companies producing connectors, cable assemblies and backplanes are Chinese; 39 per cent are Taiwanese and the rest are other foreign-owned firms.[†] This dominance by foreign companies is the legacy of China as an export hub; in the 1980s and 1990s foreign electronics firms moved to China to supply the region and the world.

Electronic manufacturing services firms

Approximately half the output of firms producing connectors, cable assemblies and backplanes is purchased by EMS firms. China's Pearl River Delta hosts the largest number of EMS plants in the world.[169]

EMS firms work further along the production chain than the producers of simple components but the majority of the work they carry out is labour intensive. 80 per cent of employees in a typical EMS firm in China will be unskilled and relatively low paid, 10 per cent will have an engineering degree and another 10 per cent will likely possess an engineering degree from a world-class higher education institution.[170] Many of the world's leading EMS firms have developed design capabilities and also provide distribution, logistics and after-sale services; however, the majority of their activity in China is labour intensive. An EMS factory in China could employ tens or even hundreds of thousands of people.

[†] The majority of 'foreign-owned' companies in China are joint-ventures with domestic firms due to the Chinese government's previous prohibition of wholly-foreign-owned firms. This prohibition has been relaxed but foreign firms still face issues when serving the domestic market so joint-ventures rather than independent companies are still a popular choice for foreign companies looking to invest in the country.

The majority of EMS firms are foreign-owned with 60 to 70 per cent of the Chinese EMS market being made up of foreign firms in 2007,[171] with the exceptional growth of Taiwanese firm Foxconn this proportion is likely to have grown since then.

Chinese semiconductor firms and foundries

It has been one of the priorities of the Chinese government to increase domestic semiconductor design and production and it is having some success in this regard. In 2004 China produced less than 10 per cent of its demand for microchips, in 2008 this figure had increased to 22 per cent.[172]

Those that believe that China is moving inexorably up the value chain point to successes such as Vimicro Corporation, a Chinese firm that created a cutting-edge digital imaging microchip currently used in approximately half of the world's PCs.[173] However Vimicro Corporation is an unusually successful company. The vast majority of the increase in Chinese semiconductor production is in simpler discrete semiconductors rather than complex 'system on chip' (SOC) or 'system in package' (SIP) integrated circuits. Furthermore, domestic demand appears to be outstripping the growth in supply. In 2005 China accounted for 24 per cent of global semiconductor demand, by 2008 the country accounted for 32 per cent of global demand. During the same period domestic production only increased by 1 to 2 per cent per year.[174]

Chinese demand for semiconductors may slow as low-value assembly of electronics moves to countries with lower labour costs. However, self-sufficiency in terms of semiconductors is less of an issue for the Chinese government than producing more advanced microchips. Vimicro Corporation demonstrates that there has been some success in this regard but a look at the leading semiconductor firms in China reveals the extent to which further progress needs to be made. The largest Chinese semiconductor firms are pure-play foundries with limited design capabilities. 12 per cent of the world's pure-play foundry capacity is located in the country and the largest

Chinese firm, Semiconductor Manufacturing International Corporation (SMIC), had revenues of $1.5 billion in 2010. In contrast the largest semiconductor design firm, China Huada IC (integrated circuit) Design had revenues of $203 million in 2008. The Chinese electronics industry needs to develop its design skills if it is to move up the value chain. It was calculated that there were 45,000 chip designers in the United States in 2008, compared to China's 5,000 and American designers are generally of a higher standard.[175]

Chinese OEMs

In much the same way that the Chinese government is determined to increase the country's semiconductor capabilities, it has supported domestic electronics firms in an attempt to produce world-class multinationals.

Firms like Lenovo Group Limited, Haier Group and Huawei Technologies Limited Company are all leading firms in their sectors. Huawei in particular can claim to operate at the top of the electronics value chain. The company spends over $1 billion on R&D annually and is one of the few firms capable of constructing a fourth generation (4G) cellular mobile network. Huawei won a contract to build a 4G network in London; operated by UK Broadband the service went live in February 2012.[176]

Despite the impressive success of firms such as Huawei, there are still relatively few leading Chinese electronics firms. When, in 2006, Electronics Design News ranked the top 300 electronics firms in the world, there were 24 Chinese firms on the list, with the highest, Lenovo, ranked 42nd. Following Lenovo was Haier, ranked 45th, and then Huawei at 78th.[177] It is worth bearing in mind that Electronics Design News' ranking is somewhat dated now, and should it be redone today undoubtedly these three firms would be ranked higher.

Nevertheless, leading multinational firms are still in the minority in China. The Chinese Ministry of Industry and Information

Technology (MIIT) listed the top 100 electronics firms in 2007. These 100 firms generated combined revenue of $185.9 billion. However, they only accounted for 22.7 per cent of the total revenue of the industry that year, indicating that the Chinese electronics industry is still dominated by smaller, less technologically advanced firms.[178]

Understanding China's rise

The rapid expansion of China's electronics industry is remarkable, but perhaps not unparalleled. Japan, Taiwan and Korea provide similar examples of rapid expansion, though the scale of China's industry is exceptional.

It is tempting to view China as unique; leaving the electronics industry to one side for the moment, the country's economic development since the beginning of economic liberalisation in 1978 has been dramatic. Since 1978 the country has experienced an average annual GDP growth rate of 9.9 per cent.[179] As a result of this the World Bank estimated in 2004 that in twenty years China had lifted approximately 400 million people out of poverty.[180]

Economic development on this scale is unparalleled in human history and partly explains the rise of China's electronics industry. The country's rapid expansion has provided three things that have contributed to the sector's development.

Labour

China's Eastern Coast is full of factories producing electronic goods on a huge scale and with impressive levels of speed. The majority of consumer electronics have incredibly short product life-cycles and the speed at which firms can get new products to market is vital. Chinese labour is plentiful and flexible, even if it is not as cheap as it used to be. The following account, from a former executive at Apple, of the speed at which the manufacturer Foxconn put its Chinese staff to work on a modification to the iPhone illustrates China's labour advantage:

> A foreman immediately roused 8,000 workers inside the company's dormitories… Each employee was given a biscuit and a cup of tea, guided to a workstation and within half an hour started a 12-hour shift fitting glass screens into beveled frames. Within 96 hours, the plant was producing over 10,000 iPhones a day.[181]

China's huge pool of labour is a natural advantage that helps explain why manufacturing activity, in electronics as well as other industries, has migrated to the country in the last twenty years. Furthermore, there is not just a huge amount of labour to draw on in China but it is also more productive, at least compared with comparatively priced labour in other markets. A Chinese worker is 54 per cent more productive than a worker in a similar low-cost location such as Mexico, where a significant amount of electronics assembly work is carried out for the North American Market.[182]

Capital

An increasingly wealthy population has allowed China to increase investment. Since 1978 fixed capital formation increased by an average of 8.7 per cent per year. Vastly improved infrastructure has made China an increasingly good place to do business and invest in. The large increase in domestic savings and investment also allowed the government to carry out an active industrial policy.

Large domestic market

Leaving differences in wealth aside for a moment, China, with 1.3 billion people, is the largest potential single market in the world. Although at present the wealth of American and European consumers means that these are larger markets, it is clear that should China's economic development continue at its current pace it will not be too long until the Chinese market is the biggest in the world. Since the beginning of liberalisation multinational firms have been keen to supply goods and services, including electrical goods, to the Chinese population. With imports of many electrical goods banned or covered by prohibitively high tariffs multinational firms had little choice but to base production in China to serve domestic demand. Even without tariffs many firms may have chosen to reduce shipping costs by setting up facilities in China.

The growth of labour, capital and the domestic market can explain some of China's economic success over the course of the last thirty years, and as a result partly explains the development of the electronics industry. However, these are general economic factors and it is notable that the growth of the electronics industry has outpaced GDP growth. In 1995 the electronics industry constituted only 1 per cent of GDP but by 2005 the industry's share of the economy had grown to 3.2 per cent.[183]

To understand the particular success of the electronics industry it is important to appreciate how changes in the international electronics industry over the course of the last three decades have benefitted China.

China's liberalisation in the 1980s coincided with the emergence of the EMS firm and an acceleration of the move away from a vertically-integrated production system for OEMs. Outsourcing in the industry began in the 1960s but the 1980s and 1990s saw the industry becoming increasingly fragmented as EMS firms began to capture an increasing share of the manufacturing market and pure-play foundries and fabless firms an increasing share of the fabrication and design markets respectively.

China also benefitted from technological developments. The 1990s saw the growth of the consumer electronics industry. The rise of the portable music player industry in the 1980s and 1990s, and the growth of the mobile phone industry in the latter decade meant that products with increasingly short product life-cycles were beginning to be made in larger quantities. As companies looked to meet this demand both at home and in rapidly growing emerging markets China provided favourable conditions for the mass production of electronics.

So far the explanation has excluded the role that the Chinese government played in the development of the electronics industry. Two broad areas of government policy are important in regard to the electronics industry: encouragement, yet control of foreign direct investment and public spending to aid technological development.

Foreign direct investment

After liberalisation China encouraged FDI but foreign firms were only offered limited access to the domestic market in exchange for the transfer of important technology. They were encouraged to use China as an export base but controls were put in place to stop foreign firms dominating the domestic market. The government declared electronics a 'pillar' industry in 1994. As well as receiving financial support and protection from imports, the government encouraged foreign direct investment in the pillar industries to stimulate technology transfers. As a result, FDI in the electronics industry as a proportion of the national total grew from less than 5 per cent in 1995 to approximately 15 per cent in 2005.[184]

It is worth marking the growth of FDI from 1995 because it was also around this time that the Chinese government began to relax some of the rules it had created to protect the domestic electronics industry from foreign competition. Up until 1995 the government had sought to enforce a strict separation between the export side of the economy and the domestic market. Foreign firms were invited, through setting up joint ventures in which they had to hold a minority stake, to use China as an export base, but export ratios meant that foreign firms had to dedicate a certain amount of production, usually more than 70 per cent, to export. This limited technology transfer. A partial liberalisation of the domestic market in the mid-1990s increased technology transfer. It also forced some domestic firms out of business but some, such as Lenovo, reacted well to competition, capturing a growing share of domestic and export markets.

Despite liberalisation in the mid-1990s the government still kept a firm grip on the domestic economy. Discriminatory technical standards in the telecommunications and mobile telephone markets prevented foreign firms from capturing a significant market share. This was particularly effective in the telecommunications industry and stimulated the initial success of joint-venture Shanghai Bell (now Alcatel-Lucent Shanghai Bell) and later that of domestic firm Huawei. However, the success of such discriminatory policies in other areas is far from clear. As described above, China continues to lack world-leading electronics firms and foreign-funded enterprises and joint-ventures controlled 83.7 per cent of the domestic electronics market in 2005.[185] There is little indication that their dominance has been significantly eroded since.

Public Spending

The Chinese government sought to help domestic firms improve their competitiveness by funding research and development. The Electronics Industry Development Fund was set up in 1986. Only state-owned firms with high-local content in their products could apply for funding. Between 1986 and 2004 $4.9 billion was disbursed through the fund. One successful recipient was the Vimicro Corporation, discussed above. A government priority, the microchip sector received $7.5 billion in government funding between 2000 and 2003, nearly double all previous investment in the sector.[186]

Alternative forms of public spending were also used by the Chinese government to develop the country's R&D capabilities and to help commercialise R&D. Improving the country's science and technology base was a priority for Deng Xiaoping's Government in the 1980s, this was not just a case of increasing public spending, but trying to build greater links between academia and industry that had been virtually non-existent. Universities and public research institutes such as the Chinese Academy of Sciences (CAS) were encouraged to generate a greater amount of funding through commercial ventures. Today CAS, Tsinghua University and Peking

University all have significant commercial operations and all three have produced multinational firms that the universities retain financial stakes in.[187] Other Chinese universities have also developed commercial operations.

Although Chinese public R&D spending has grown since the 1980s, as a share of total R&D spending public spending has fallen. In 1991 public spending constituted 60 per cent of R&D spending, by 2001 this figure had fallen to 40 per cent[188] and by 2008 to 25 per cent.[189] This is the result of increased spending by the corporate sector, including state-owned enterprises, other domestic firms and foreign firms.

If the electronics sector were not as important to the Chinese economy as it is currently, the money poured into the industry by the government and its protection of domestic firms would represent a huge failure. However it is fair to question how far some of the government's actions helped rather than hindered the industry. It is noticeable that it was the alteration of governmental policy in the mid-1990s and the opening up, albeit partially, of the domestic market that stimulated greater technology transfer. Furthermore, despite restrictions on complete foreign ownership and export quotas it is still the case that foreign-funded firms and joint-ventures dominate both the export and domestic markets. On the other hand, protecting domestic producers during their fledgling growth in the 1980s may have helped firms like Lenovo and Huawei fend off competition when it increased in the 1990s.

The future of the Chinese electronics industry: a world-class industry needs world-class minds

Scholars disagree as to the extent to which China will dominate the global electronics industry in the future. Clearly in terms of scale China's current success indicates that it will continue to lead volume production of electronics. A more disputed assumption is that China will continue to move up the electronics value chain until it dominates cutting-edge electronics in the manner of the United States, and to a lesser extent Japan.

Those who are bullish about China's future prospects point to the success of firms such as Huawei, Hisense and Haier. The argument runs as follows: although China may be underrepresented in terms of world-leading electronics companies at present, more Huaweis, Hisenses and Haiers will emerge over time. Given the success of these and other domestic firms over the course of the last decade, it will not take long before more firms achieve similar success.

However, development in the electronics industry is not a linear process. Rather, the further away an industry is from the cutting-edge of technology the easier it is to advance; as an industry approaches this point then further gains become more difficult and expensive. The state and the industry has realised this and is pouring greater amounts of money into R&D and innovation as one of the goals of the government's current five year plan. To support this goal the country is increasing its R&D spend; China's gross R&D spending is now second only to that of the United States. The country accounts for 12.8 per cent of total global R&D spending behind America at 33.4 per cent.[190] However in terms of R&D spending as a percentage of GDP, China, with spending of 1.44 per cent, still falls behind Japan, America, Israel, Germany, Britain and South Korea, as well as many other developed economies.[191] This perhaps illustrates an important issue facing China: the need for quality as well as quantity.

In terms of technological capability China is not too far behind the most advanced economies in terms of microchip production. SMIC's fabrication facilities are nearly up to the standard of the most advanced facilities in the US and Japan and SMIC dominates the fabrication industry in China. The Chinese government is determined to develop and retain cutting-edge fabrication facilities, and in this it has been largely successful. Where the industry is weak is in human skills.

China produces 777,000 science and technology graduates a year compared to America's 239,000.[192] However American graduates are better trained and industry observers have noted that quality is perhaps failing to keep up with quantity in China,[193] a problem exacerbated by the tendency for the brightest Chinese students to study abroad and not return.[194] At the end of 2010 only 135,000 Chinese students had returned home after studying abroad, a drop in the ocean when one considers the millions that have studied abroad since the 1980s.[195] The Chinese government is concerned by this and in 2008 the 'Thousand Talents Program' was set up to entice pre-eminent Chinese academics or business people to return to work in China. The program offers returnees 1 million RNB or £100,000 along with a leading position in their field; local government and businesses are also free to offer their own incentives.

It has already been discussed above that China lags behind other countries in terms of semiconductor design capabilities and it will need skilled engineers to bridge this gap. At present the US and Japan continue to dominate semiconductor design and industry analysts have estimated that Chinese companies, with a few exceptions, are still a generation behind the leading companies in the world.[196] To a large extent China's future success will depend on its ability to educate, train and retain highly skilled employees in the electronics industry.

8

Issues that must be addressed if the UK is to sustain a world-class electronics industry in the future

Governments should always be wary about placing too much faith in policy interventions aimed at stimulating specific industries. This is especially true for electronics, a fast-moving, intensely competitive and extremely technical sector. However, having taken a close look at the UK's electronics industry and those of other prominent countries, there are clearly some policy interventions that need to be made. Some of these are general, creating the right environment for firms to flourish; others are specific, addressing particular issues. This section discusses five areas where political intervention is required.

First however, it is worth briefly reflecting on what the case studies tell us about the dangers of government intervention. Japan provides the most evidence in this regard. In the case of NEC the Japanese government, as near monopoly purchaser of the firms' products, shielded the firm from international, and even domestic, competition. In the case of Canon and Nikon, the Japanese government's fear of outsourcing contributed to these two firms losing control of the international steppers market to Dutch firm ASML. The Japanese government has also spent public money facilitating mergers that may prove misguided.

The errors committed by the Japanese government came from a country trying to remain at the pinnacle of the global electronics industry. Fearful of losing market share even in areas where Japan could no longer effectively compete, such as the manufacture of simple consumer products, the government may have contributed to the weakening of some firms that were previously world-beaters in innovation. The UK government faces a different situation, but parallels do exist. Britain does not possess many companies with large market shares, but it does, like Japan, possess firms at the cutting edge of technology. In some respects, the Japanese government may have jeopardised its industry's technological advantage and the UK government must be wary of doing the same. Equally however, the government must be alive to the fact that innovation needs to be nurtured and the state has a role to play in this regard, as the evidence from Silicon Valley demonstrates.

Creating the right conditions for the high-tech electronics industry to flourish is important, but more than this the government must be willing to invest in infrastructure and skills and should be willing to spend money attracting cutting-edge R&D and production to the UK. To do so it must develop more effective working relations with the industry.

State-of-the-art manufacturing facilities

As discussed in section three, the UK has no state-of-the-art, large scale semiconductor foundry. The ramifications of this are not entirely clear; although a number of foundry facilities operated by foreign firms have closed recently, the UK has continued to produce world-leading semiconductor design companies. The UK does possess semiconductor fabrication facilities using leading edge processes, some of which are not found anywhere else in the world. However these facilities do not produce in large volumes.

Unfortunately the case studies and international evidence indicate that policy-makers should be concerned with the UK's foundry capacity. China, Taiwan and Japan all possess significant foundry capacity, as does the United States. Furthermore there is concern in Japan and America that their previous dominance in this area has been undermined. There is also significant concern in Europe that the European semiconductor industry is under threat owing to a lack of advanced manufacturing capacity. At present only Ireland and Germany possess large foundries that are being upgraded with the most recent technological developments.[197] Taiwan and China are keen to develop and expand foundry capacity as both countries look to improve their design capabilities; they do not feel that shedding manufacturing is prudent. In short the evidence suggests that there is a strong relationship between advanced manufacturing and innovation.

The internationalisation of electronics production, and the segmented business models that this has given rise to, has led some to believe that all parts of the production process can take place in distinct locations. The problem with this belief is that it is not shared by those working in the leading electronics industries. In 2004 the President's Council of Advisors on Science and Technology submitted a report to US President George W. Bush in which they canvassed industry opinion on the challenges facing information technology manufacturing in America.[198] One important conclusion of the report was that 'the proximity of research, development and manufacturing is very important to leading edge manufacturers' and that 'design, product development and process evolution all benefit from proximity to manufacturing'.[199] Although the report accepted that a significant amount of manufacturing employment would decrease in the future owing to productivity gains and that some manufacturing activities would continue to migrate to lower-cost locations, the authors were keen to stress the importance of cutting edge manufacturing. They dismissed the idea that R&D could be effective if divorced from manufacturing. This conclusion has led other industry analysts to believe that R&D and design activity will increasingly relocate from developed countries to those in East Asia, where the majority of new semiconductor fabrication capacity is being built. Dieter Ernst emphasizes the 'extraordinary' amount of coordination 'required between SoC [system on chip] designers, mask makers, foundries and third party SIP [semiconductor intellectual property] providers'.[200] The British government has itself recognised the threat that decoupling design from manufacture poses. In a 2011 report on the power electronics sector the Department for Business, Innovation and Skills, recognised that 'there are tangible benefits of manufacture being located close to design'.[201] The UK should rejuvenate its commitment to retaining and developing cutting edge manufacturing capabilities.

As well as the linkages between R&D and manufacturing, cutting edge manufacturing also acts as a stimulus for the agglomeration of firms in an area. A study of the economic impact of GlobalFoundries' decision to locate its new semiconductor plant in Saratoga found that the site would create 1,465 permanent manufacturing jobs, 550 service jobs, and 4,300 jobs in the construction of the facility.[202] In addition, the study estimated that the site would create a further 4,500 jobs in businesses linked to the facility. The report found that other companies were moving to the area in anticipation of production at the site.[203] The study concluded that this cluster-building was 'a reason why semiconductor fabs are sought after by nations from around the world'.[204]

International evidence suggests that the link between advanced manufacturing facilities and the clustering of technology firms is a self-reinforcing process: suppliers and customers locate near manufacturers and manufacturers often choose to locate near customers and R&D facilities. Once companies choose to invest huge amounts of money in constructing state-of-the-art facilities they are likely to continue investing in the future. Samsung plans to invest a further $1 billion in its facility in Austin, Texas this year, adding to the area's vibrant technology industry, which boasts over 2000 companies.[205] In the Middle East, Israel is a prime location for semiconductor manufacturing and has a vibrant electronics industry. The country is host to IBM's second largest facility and last year the company announced that it was investing nearly $2 billion in the country to develop its existing plants and to build an additional foundry.[206]

Having established the benefits of state-of-the-art manufacturing facilities, how can the UK develop or attract such facilities? And perhaps just as importantly: what are the chances of success?

In addressing the second of these questions a number of industry trends indicate that further investments in semiconductor manufacturing capacity are likely in the future. iSuppli predict that annual semiconductor revenue will increase at a compound annual growth rate (CAGR) of 5.8 per cent between 2011 and 2016.[207] This will only be possible if companies increase capacity, either by investing in existing facilities or by opening new ones. The recent evidence is that companies are doing both, even in the precarious economic climate. This suggests that investment is likely to continue or even increase in the future as demand in developed countries picks up and continues to grow in emerging markets.

One of the challenges currently facing the UK is that the country will have to attract new investment. Companies often choose to increase investment in an existing facility, owing to the sunken capital costs, but there also comes a time when it may make more sense to invest in a new production site. The industry will arrive at such a juncture in the near future as it looks to develop the technology to make microchips on a 450mm wafer (300mm is the current max wafer size). In September 2011 five firms, IBM, Intel, GlobalFoundries, Samsung and TSMC, agreed to work together to develop 450mm wafer technology.[208] Moving to a 450mm wafer, which industry analysts expect to happen around 2018,[209] will require new machines and a reconfiguration of factories, thus increasing the attraction of building a new fabrication plant.[210] Industry analysts recognise that the development of this fabrication technology puts electronics industries across Europe at a critical juncture:

> … it is crucially important to establish a 450mm manufacturing presence in Europe as a necessary condition for keeping and further developing such clusters in Europe.[211]

Given the size of the investment that could be required to help develop 450mm wafer technology or attract a company to invest in a 450mm facility, it has been suggested that a pan-European strategy is necessary.[212] The US and Japan are backing their firms in the development of the new technology, suggesting that there is a need for European governments to consider collaboration to achieve a similar scale of investment. The UK government, however, has not shown that it realises the importance of this technological change, failing to participate in a recent European study on the development of 450mm wafer technology.[213] One reason for the government's lack of engagement could be that the UK, unlike Ireland or Germany, does not have a significant amount of fabrication capacity. The UK's electronics industry and the government may be resigned to this; the British electronics industry has remained successful without such capacity and it may be able to continue to do so in future. Nevertheless, given that there is a consensus in the industry about the importance of retaining advanced semiconductor manufacturing capacity, the UK government should support this goal. This should involve attracting foreign investment to increase foundry capacity in the UK as well as supporting the development of a 450mm manufacturing presence in Europe, even if not in the UK, due to the benefits this will bring to British firms.

The job of attracting foreign investment does not just fall to the national government. A recurring theme in analyses of successful electronics clusters is the commitment of the local government to support and attract business.[214] The local government in Saratoga County and more broadly the various local governments of Upstate New York began their efforts to attract semiconductor and microchip manufacturers to the area in the mid-1990s. Education programmes at both full degree and associate degree level were put in place in local universities and community colleges. Sites for a fabrication facility were pre-approved, providing prospective businesses with the confidence that the construction of any facility would not face opposition. A generous subsidy regime was also created, which eventually totalled $1.4 billion. Grants and tax incentives are always provided to microchip manufacturers that decide to construct new facilities or significantly develop existing ones. This partly reflects the risks involved in making such a large investment and is partly the result of numerous countries and regions bidding for the facilities. In the case of GlobalFoundries, China, Russia and Brazil, as well as Saratoga, all wished to attract the company and offered comparable incentive packages.[215]

The efforts made by the governments and business groups of Upstate New York are broadly representative of the efforts made by similar institutions in clusters such as Austin, Texas and Silicon Valley, California. They indicate the concerted effort that governments and trade bodies need to make if they wish to attract investment. In Britain local governments have less power and so must work with the national government, but the principle is the same. Although important in the case of volume semiconductor foundries, the incentive scheme offered is only one element in attracting business. Furthermore, any financial incentive offered by government should reflect the need to create patient capital, so low-interest loans could be more beneficial than grants.

Semiconductor manufacturing is also a relatively energy intensive activity and as such energy costs are something governments must consider. UK fabrication facilities often raise the issue of electricity costs. Writing recently in the 'NMI Yearbook 2011-2012' representatives of three semiconductor manufacturers, Diodes Incorporated, Bourns Limited and International Rectifier all declared that energy costs were a significant concern for the industry. Tim Monaghan, Head of UK Operations at Diodes Incorporated, a multinational, discussed the international dimension:

> It's hard to explain a 15% cost increase in energy when your sister fab on another continent already has half the price/KWh.[216]

Energy costs are often an issue for manufacturing firms and those in the electronics industry are no different. To attract, and retain, state-of-the-art semiconductor manufacturing in the UK, the British government must ensure that the country's energy costs are competitive. The UK's currently very strong power electronics sector is under threat from high energy costs:

> Energy costs are a very significant consideration for power semiconductor manufacturing. Today the UK is at a significant disadvantage in this respect.[217]

Plans to increase energy generation from renewable and nuclear sources should be welcomed if they reduce costs in the long-run, but damaging price increases in the short-run should be mitigated for manufacturing firms for which energy is a large and unavoidable cost.

The government has shown how effective it can be in attracting large scale manufacturing investment by foreign companies, particularly in the automotive industry. Recent success in this sector suggests that the Government has recognised that investment grants or loans are necessary but must be accompanied by more important support for skills, the supply chain and research and development. There is no reason why the government should not seek to achieve similar inward investment in electronics, while ensuring that this does not come at the expense of supporting indigenous firms.

Skills

Skilled employees are, in many respects, the most important asset of any electronics firm. The vast majority of studies examining electronics or other 'high-tech' clusters emphasize the availability of skilled employees as the most, or one of the most, important factors in a cluster's success. In the electronics industry there are broadly two sorts of skills that are important: technical skills and business skills. There are issues that the government needs to address in both areas but technical skills will be examined first.

Table 12: Electronic and electrical engineering students and engineering and technology students 1996 - 2011

	Electronic and Electrical Engineering	Engineering & Technology
1996/97	29,717	134,041
2004/05	34,590	137,825
2006/07	32,345	140,580
2010/11	33,255	160,885

Source: Higher Education Statistics Agency

The 2008 BERR report 'Competitiveness and Productivity of the UK Design Engineering Sector' surveyed fabless and chipless semiconductor firms asking whether or not they had difficulty recruiting design engineers and other science and technology professionals. 100 per cent of fabless and chipless companies said that they found it 'moderately or very difficult' to recruit experienced professionals and nearly 70 per cent said they found it 'moderately or very difficult' to recruit appropriately skilled graduates.[218] Skill shortages were also mentioned as an issue in a 2004 report by the National Microelectronics Institute (NMI), a trade body for the industry, and in a governmental report on the power electronics industry in 2011.[219]

The data presented in table 12 suggests that recruitment is still likely to be a problem for fabless and chipless firms. The table displays the total number of students, undergraduates and postgraduates enrolled at British higher education institutions in four academic years. The number of electronic and electrical engineering students is lower than it was in 2004. Looking at annual enrolment figures rather than total students enrolled, a government report noted that in 2010 the number of UK students accepting a place to study electronics and electronics engineering was 41 per cent lower than in 2002; annual enrolment dropped from over 5000 a year in 2002 to below 3000 in 2010.[220] Germany already produces three times as many electronics engineering graduates and has increased graduate numbers by 15 per cent in five years.[221] In contrast, the UK is not producing more engineers with an electronics specialism or many more engineering graduates in general than it was at the time the BERR report identified a shortage of skills in the sector.‡

Various other reports have also identified the falling or stagnant numbers of engineering and electrical engineering graduates. The NMI refers to a number of these reports that all drew on HESA and UCAS statistics.[222] One report referenced by NMI, 'Engineering UK 2007', looks at the numbers of engineering graduates from a range of disciplines that move into professional engineering after graduation. Of concern for the electronics industry is the fact that just over 30 per cent of electronics engineering graduates in 2007 moved into the industry, a figure far lower than that for other engineering disciplines.[223]

The data on the numbers of electronic engineering and general engineering graduates grows more worrying as it is examined in more detail.

‡ In 2010/11 HESA instituted a change in data recording, but the effect of this change is likely to be small and does not affect the general picture presented by these figures.

Table 13: Electronic and electrical engineering and engineering and technology, UK and overseas students 1996 - 2011

	Electronic and Electrical Engineering		Engineering & Technology	
	UK	**Overseas**	UK	**Overseas**
1996/97	22,393	**7,324**	103,199	**30,842**
2004/05	20,980	**13,605**	97,545	**40,275**
2006/07	19,310	**13,035**	97,430	**43,150**
2008/09	18,090	**12,990**	102,005	**46,065**

Source: Higher Education Statistics Agency

Firms interviewed as part of 'Electronics Systems Design: A Guide to UK Capability 2009/10 Edition' found that 'suitably qualified engineers from the UK were hard to find.'[224] Managers in the industry found that many of the best candidates for jobs were of Chinese or Indian origin and were either educated in the UK or had been educated abroad before finding employment that allowed them to move to Britain.[225] Table 13 provides evidence that such anecdotes may be representative of a general trend. While the numbers of British electronic and electrical engineering students has decreased since 1996 the number of overseas students has dramatically increased. It is the same for engineering and technology students. The evidence suggests that it is a trend found across the science, engineering, maths and technology (STEM) subjects.[226] The concern is not just that British universities aren't producing enough skilled STEM students, but that increasingly it is overseas students taking these subjects. These students may be less likely to choose to remain in Britain, or be allowed to remain, and find employment in our technical industries.

As well as the general problem of ensuring an ample supply of highly skilled graduates, the electronics industry faces peculiar problems relating to the demography of its workforce. The Department for Trade and Industry's 2004 report drew attention to the fact that the electronics industry's workforce was disproportionately composed of older male workers.[227] The report argued that the industry needed to try and attract more young workers and female employees. The concern was that in the future women will increasingly make up a larger share of the UK's workforce, and so the electronics industry would need to draw more from this pool of talent. The ability to attract younger workers is also necessary if the industry wishes to attract new generations of talented individuals.

Table 14: Age of workers in the electronics industry 2003 – 2011 (%)

	15/16-24	25-34	35-44	45-64	65+
2003 (DTI report)[§]	7.5	25	28	37.5	2
2003[**]	11	28	28.5	32.1	0.3
2011[††]	6.5	20.4	28.6	43.1	1.3

Source: The Office for National Statistics, The Labour Force Survey

Table 14 compares the age of workers in the electronics industry in 2003 and 2011. The evidence is that the electronics industry still suffers from a shortage of young workers. Due to the changes in the Office for National Statistics' Labour Force Survey and the difficulties in classifying different workers it is impossible to come to a indisputable conclusion, but the figures suggest that the industry continues to struggle to attract younger workers.

Similarly the evidence is that the electronics industry continues to struggle to attract female workers. In 2003 the Labour Force Survey indicated that only 24 per cent of workers in the electronics industry were female.[228] By 2011 this figure had only increased to 26.5 per cent.[229] Furthermore, the evidence suggests that this situation is unlikely to improve in the future. Only 11.8 per cent of electronic and electrical engineering students at British universities in 2009 were female, whilst this figure was only slightly higher at 16.1 per cent for engineering and technology students.[230] Not only the electronics industry but also the education system is struggling

[§] The 2003 (DTI report) figures are those published in the government's report, but unfortunately the report does not specify which industry sub-categories have been included.

[**] The 2003 figures covers workers involved in the manufacture of office machinery and computers and workers involved in the manufacture of electrical machines and equipment.

[††] The 2011 figures covers workers employed in the manufacture of computers, electronic and optical equipment and workers employed in the manufacture of electrical equipment.

to attract female engineering students with the evidence suggesting that this situation has not significantly changed since 2003.

The industry clearly faces significant challenges in relation to skills; fortunately the government and the industry began to address this with the creation of the UK Electronics Skills Foundation (UKESF) in 2010.[231]

In spite of evidence of an under-supply of technical skills, those involved in the sector often argue that the British electronics industry suffers more from a lack of business skills. An electronics firm interviewed as part of the Department for Trade and Industry's 2004 report said that the 'key problem is the shortage of entrepreneurs not PhDs'.[232] The lack of business skills of graduates and industry employees in general is a recurrent issue raised by contributors to the report. Some attributed blame to the education establishment; a large company stated that 'in the US, PhDs are geared to business start-ups. In the UK they are geared to academia'.[233] Recently a report by the Open University found that 43 per cent of recruiters in the IT and Telecoms industries were struggling to find suitable candidates, citing a lack of business, self-management and communication skills.[234] A similar result was found by the Confederation of British Industry (CBI) in a survey of its members in 2009, though this reflected employers' views on all graduates.[235]

Since the government's 2004 report some universities have taken steps to increase the amount of business education they offer in conjunction with technical degrees. In 2000 the University of Cambridge and the Massachusetts Institute of Technology created the Cambridge-MIT Institute. The Institute created six interdisciplinary MPhil courses to fill the 'gap between specialised MPhils and the MBA'.[236] In 2008 10 per cent of Cambridge Universities' MPhil population were taking these courses.[237] In addition, the programme also created entrepreneurial workshops for undergraduates, funded competitions in student entrepreneurship societies and encouraged industry to develop greater links with universities to facilitate the exchange of knowledge.[238]

Cambridge's collaboration with MIT provides one example of how universities can take active steps and even create new courses to help students develop broader business skills. Another is the University of West Scotland's collaboration with IBM which offers students a chance to work with the latest IBM software as part of courses aimed specifically at training students on such software.[239] The evidence suggests that many universities, particularly those situated near or within the electronics clusters discussed in this report, are trying to furnish students with a wider array of skills so that they are attractive to employers in the area.

Universities, however, are only one arena in which students learn to develop business skills. Traditionally many students or graduates would have developed skills through employment, either in formal on-the-job training or simply by working. Certainly, the Silicon Valley case study demonstrated the important commercial experience that scientists and technicians gained when they were forced to bring their discoveries to market. Working for an established firm also provides graduates or older employees with the skills necessary to start their own venture. This has always been an important part of Silicon Valley and there are parallels in Britain: Cambridge Silicon Radio emerged from Cambridge Consultants Limited and ARM from Acorn Computers.

Another way in which technically skilled employees develop business skills is through mentoring. However, a recent study of entrepreneurs in Silicon Roundabout found many bemoaning a lack of mentoring and management advice, a criticism heard in other British clusters.[240]

Related to business skills, but of a far more intangible nature, are the entrepreneurial skills that individuals need to possess if they are to start or expand a business. There is evidence that the UK lags behind America and particularly Silicon Valley in this regard. In an attempt to quantify differences in start-up 'ecosystems', the 'Startup Compass' project collected data on over 16,000 start-ups from different tech clusters in the world. The project found that Silicon Valley companies have 46 per cent more mentors assisting them than their counterparts in London. Founders of companies in Silicon Valley had started twice as many companies than their peers in other clusters, including London. London had twice as many founders that began a business as a way to turn a quick profit, perhaps by selling the company to a larger competitor, than Silicon Valley.[241]

There is evidence that both the electronics clusters covered in this report and others in Britain contrast in terms of entrepreneurial culture from those in America. Creating an entrepreneurial culture is a difficult and elusive goal and therefore it is wise for policy-makers to concentrate on improving the business and technical skills of the workforce. Nevertheless, it is worth bearing in mind that simply having well educated employees will not produce an entrepreneurial culture unless people are willing to start companies, willing to take the risk that they may fail in doing so and content not to settle for making a quick profit on any business created.

Accessing finance

The UK electronics industry is innovation rich but funding poor. Access to finance is crucial for new firms to set up, develop and grow their business. Electronics start-ups tend to rely on risk finance — venture capital and business angel investments — because they often have intangible assets and are slow to generate revenues. However, an uncertain financing environment in the UK has encouraged caution amongst entrepreneurs and company directors, who are pushed towards developing smaller companies and exiting these by trade sales at earlier stages.

For SMEs, raising finance can be understood in terms of an 'escalator'. Business angel financing, whereby high net worth individuals invest money and often their own expertise, is particularly important in firms' seed and early growth stages, when the sums they require are too small to be economically viable for investment by venture capital funds. Once a company reaches a certain size or requires larger sums of money than a business angel can provide, venture capital funds can make follow-on investments to enable firms to grow and expand. In theory, growth or expansion capital should pave the way for exit via a trade sale or initial public offering (IPO). However, in recent years this funding escalator has broken down, in large part due to the contraction of the venture capital industry. Public funding and business angel activity are failing to plug the gap created by this decline. Further, last year Barclays, HSBC, Lloyds Banking Group, RBS and Santander UK collectively fell short of the SME lending target set by the government under Project Merlin by £1 billion.[242]

Data on UK business angel investment is scarce. However, in 2011 Colin Mason and Richard Harrison conducted a study of the British business angel market. It is based on a British Business Angels Association 2009-10 survey of 158 UK business angel network members. They found that the business angel market had remained remarkably stable despite the recession and estimated total angel investment activity in 2009-10 at £317.7 million. However, it should be noted that in 2009 NESTA (National Endowment for Science, Technology and the Arts) suggested that the US had three and half times more business angel investment per capita than the UK.[243]

As regards venture capital investments, a report published by the British Venture Capital Association (BVCA) showed that in 2010 £226 million was invested at the 'venture' stage (or seed and early stages) in 331 firms and a further £207 million at the expansion or growth stage into 138 firms.[244] The NESTA report showed that in 2009 32 per cent of venture capital was invested in technology-based firms, with 40 per cent of firms who received venture capital investments operating in the high-tech sector. In contrast, US venture capital investments are much more heavily focused on the technology sector. Between 1990 and 2004, 81 per cent of all US venture capital was invested in just five technology-based industries: computer hardware, software, semiconductors and other electronics, communications and biotechnology. It is unsurprising that the UK's electronics entrepreneurs covet the high volume of finance up for grabs in the US.

A report published by NESTA in September 2011 highlights the low availability of seed and early stage finance in particular. The venture capital available to UK companies (from funds that solely invest in the UK) in 2010 totalled only £286 million, up slightly on 2009 but roughly half that available in 2003. However, the report showed that the slight increase in UK venture capital investments between 2009 and 2010 was driven by an increase in later and expansion stage investments. The number of UK seed and early stage investments as a proportion of all venture capital investments was relatively stable until 2008 but fell from 37 per cent in 2009 to 22 per cent in 2010. In absolute terms the number of UK seed and early stage investments has been decreasing since 2006 and reached their lowest levels in 2010. UK VCs have become more risk averse, increasingly targeting larger, later stage deals.[245] Research commissioned by the Department of Business, Innovation and Skills has confirmed an early stage equity gap in the UK market for small and medium enterprises seeking between £250,000 and £2 million.[246]

Of course, a scarcity of funding in the UK continues to affect firms beyond the seed and early stages. Growth capital allows established firms to expand their activities and forms a vital part of the funding escalator. The insufficient availability of later stage or growth capital is also limiting the exit routes available to UK electronics firms. A BIS report published in 2009 confirmed the existence of an equity gap between £2 million, the ceiling of current government interventions, and £10 million, below which sum private VC funds rarely invest.[247] Four out of five high-tech start-ups in the UK do not progress to the level of expansion or growth funding, suggesting that UK venture capital markets fail to support start-ups through the entire funding escalator.[248]

BERR's 'Electronics System Design: A Guide to UK Capability 2009/10 Edition' listed 66 electronics system design businesses including fabless and chipless firms and other firms with design capabilities. This list, although not comprehensive, was intended to represent the best electronics system design firms. Of these 66 firms, 21 were foreign owned. By 2011 another eight had been acquired by foreign companies. Three had ceased trading. The acquisition market is driven by overseas companies, with the US the dominant buyer of UK technology businesses. The regularity with which British electronics firms are acquired by larger, foreign firms is a symptom of the low availability of funding for growth. Lacking funding, firms are often compelled to seek finance from large firms that take a controlling stake in the firm in return. Of course, this is not always the case: some firms actively choose to be taken over and would do so regardless of funding conditions. Nevertheless, it is worth noting that (ARM and CSR aside) the UK has very few leading fabless and chipless companies and no large electronics OEM. The ability of firms to choose to resist foreign takeover and grow will be pivotal to the future success of the UK electronics industry.

The dysfunctional UK public equity market has reduced exit opportunities for UK firms (and their investors). Nowhere is the inefficacy of the UK's initial public offering (IPO) model more apparent than in high-tech industry. The Alternative Investment Market (AIM) was set up by the London Stock Exchange (LSE) in 1995 to host smaller and younger firms that were unable to meet the more onerous listing requirements of the LSE and, indeed, of the US' NASDAQ. In 2008 around 1655 companies were listed on the index. However, the financial crisis led to many company failures and far fewer new flotations. In November 2011 the index comprised 1450 companies.[249] According to Thomson Reuters, the past three years have seen a total of eight high-tech IPOs on the

London Stock Exchange and on the AIM.[250] This fall in initial public offerings is not unique to the UK; in the US in 1980-2000 an average of 165 small firms undertook IPOs each year, compared to just 30 each year in 2001-09.[251] Nevertheless, the trend of breakthrough UK firms being acquired, combined with the stall in IPOs, may hamper the emergence of large, successful UK firms. In the run up to this year's budget the London Stock Exchange urged the government to abolish stamp duty on the shares of companies listed on the AIM as a way of boosting SME growth; the LSE argued that this measure would reduce the cost of capital for SMEs by up to 13 per cent. The LSE argued that stamp duty reduces liquidity as it puts investors off selling their holdings owing to the extra cost involved. A report by KPMG (and commissioned by the LSE) found that doing away with stamp duty on share transactions would increase total capital investment by up to £7.5 billion per year and would be revenue neutral to the Exchequer within the lifetime of a parliament.[252] A more effective market for high-tech firms is necessary if the UK wishes to produce more large electronics firms. Established firms like Cambridge Silicon Radio and ARM Holdings act as linchpins for entire networks of suppliers, spin-outs and start-ups. The UK needs to grow industry leaders able to encourage the kind of start-up culture which has shaped Silicon Valley.

The market failure in, especially small capital, financing is not easily solved by public sector interventions. The recovery of the venture capital industry will ultimately be driven by economic stability and increased investor confidence. Nevertheless, the government has implemented several initiatives with the potential to mobilise risk finance in support of small and medium electronics enterprises.

The UK's electronics SMEs perhaps stand to gain most from government policies which incentivise private investment in smaller, riskier (but potentially high growth) UK companies. The 2012 Budget eased restrictions on the government's enterprise investment scheme (EIS), a series of tax reliefs designed to encourage private individuals to invest in SMEs, and launched its seed enterprise investment scheme (SEIS), a similar initiative designed to encourage investment in start-ups. In a NESTA survey carried out in 2009, 82 per cent of business angels surveyed had used the EIS and 57 per cent of the 1080 investments made by these investors used the EIS. 24 per cent of these investments would not have been made in the absence of tax incentives, whilst 53 per cent of investors reported that they would have made fewer investments without these incentives.[253]

The second group of government initiatives which address the early stage funding gap are publicly-backed venture capital funds, of which there is now a large, although often bewildering, array. The UK government recognises that bureaucrats are not best placed to make decisions on capital investments, especially when dealing with complex high-tech industries. In the UK many of these schemes use private sector fund managers. There is evidence that returns to publicly backed VC funds tend to be worse than those for private funds, whilst hybrid funds, those using private funds to leverage public investments, usually achieve better returns than purely public funds.[254] However, according to a survey commissioned by the National Audit Office, only one third of entrepreneurs who received investment from government funds reported that they would not have been able to obtain funds elsewhere, raising questions as to how far the government is managing to plug an equity gap, as opposed to displacing private sector activity.[255] In contrast, a survey of Enterprise Capital Fund recipients (public-private hybrids which provide early stage equity finance to high growth potential SMEs initially seeking up to £2 million) found that many felt that publicly backed funds were not crowding out the private sector, which has sound commercial reasons for not being more involved in the early stage investments under £2 million. The majority also cited co-investment arrangements as an effective way of encouraging the private sector (in the form of business angels) to invest alongside the public sector.[256]

A couple of initiatives promise to boost the supply of capital to the UK's electronics SMEs. One of these is the Cambridge & Counties bank which recently opened for business. The venture, a collaboration between Cambridgeshire County Council and Trinity Hall College, will invest in SMEs in the Cambridgeshire area and so could provide funding for the many electronics firms located there. Although this initiative is currently only in Cambridge, it could provide a precedent for other areas, such as Silicon Glen, which would benefit from similar public/private initiatives. In terms of purely private initiatives the recent decision by Silicon Valley Bank to open a branch in the UK could also increase the credit available for high-tech firms, including those in the electronics industry. Both initiatives point to the importance of promoting competition in the banking sector; the government should support new entrants seeking to increase access to finance for SMEs.

Political understanding of the sector

In 'Electronics 2015: Making a Visible Difference' the Department for Trade and Industry (DTI) attempted to start with 'a clean sheet of paper' to create a comprehensive picture of the industry.[257] The difficulty of this task was compounded by the fact that there is very little official data on the sector. As recognised by the DTI:

> In our experience (and many others) the industry is difficult to define and measure. SIC [Standard Industrial Classification] codes are largely obsolete in definition and out-of-step with technical developments. Official data (which is largely published three years after the event) is largely meaningless for companies in a fast moving market like electronics, where product development and lifecycle is much shorter, and large cyclical swings can distort interpretation.[258]

In diverse and complex industries trade associations are often better placed than the government to provide accurate information. However, the electronics industry lacks a single trade association that encompasses the whole of the sector and is thus in a position to provide this. This is partly the result of the diversity of the electronics sector. Its bodies include Intellect, which cover the broader technology industry, and the NMI, which specialises in microelectronics and semiconductors. Furthermore, there are many electronics companies in the supply chains of other industries who may be part of their trade bodies because they feel that they provide a better forum for their interests, and therefore go unheard when government seeks the views of the electronics industry.

A problem, recognised by the government in the 2004 report, was, and perhaps still is, the number of trade bodies in the sector ('Electronics 2015' counted 30 at the time). The government felt that this impeded effective engagement with the sector. In some respects 'Electronics 2015' was particularly scathing, stating: 'there is no rationale for the current range and diversity of trade associations'. The report drew on the testimonies of many firms that believed that many associations in the sector were not doing a good job. Particularly damning was the fact that despite the number of associations only 20 per cent of firms in the industry belonged to one in 2004.[259]

In 2004 the DTI made a number of proposals to combat the problems of representation. The Department proposed the creation of the Electronics Leadership Council (ELC) which would work with the government. The Council would be supported by the UK Electronics Alliance (UKEA), which would bring trade bodies together. Unfortunately, neither the Council nor the Alliance has had the desired impact. The Council is a shadow of government-business councils in other industries, such as the Automotive Council, and the UK Electronics Alliance has struggled to create a unified structure for the many trade bodies. Today the Alliance continues to operate but meaningful work by trade bodies is carried out individually.

Perhaps recognising these failures, in spring 2012 ESCO (Electronic Systems – Challenges and Opportunities) was established to reengage the government with the sector.[260] Similarly to 2004 the project hopes to map and quantify the electronics industry.

However this time the project will encompass designers, manufacturers, installers and distributors of electronics systems, products and components. By examining the sector in its broadest sense ESCO hopes to communicate the pervasiveness of electronics in the British economy.[261] If this can be recognised, the hope is that an electronics systems community can emerge, allowing the government to work more effectively with companies and trade bodies in developing and implementing a strategy for the future success of the sector.

Announced in the spring of 2012 and with any results not expected until November, it is too soon to pass any kind of judgement upon ESCO. However the previous initiative provides a few salutary warnings and lessons for the industry and the government. The current Government needs to recognise the fact that electronics firms are horizontally spread across the British economy and supply other industries as well as consumers. The previous strategy was based on the mistaken belief that the electronics sector was organised vertically, with smaller companies supplying larger firms up the supply chain. Creating a council, where large firms can meet with the government, may work in vertical sectors like the automotive industry, but will not work in electronics, dominated as it is by SMEs.

What is needed is a more disaggregated understanding of the sector by the government and this is where trade bodies can help. It is no use expecting electronics to be represented by one trade body, although it is questionable whether the current range of bodies is necessary. Instead the government needs to understand the needs of different sub-sectors and ideally it should do this by having good links with the trade bodies that represent them. It may not be necessary to create an overarching council to bring the whole sector together if the sub-sectors feel that their needs are understood. The cooperation of other trade bodies is required as electronics firms in the trade bodies of other sectors should have the opportunity to voice their specific needs rather than being subsumed within the concerns of the industry they supply.

While the government clearly needs to reengage it is also important that engagement does not fizzle out, especially if it proves more difficult than expected. 'Electronics 2015' was produced in 2004 and after activity in the UKEA and ELC faded there was no attempt to rejuvenate industry-government engagement. Long-term engagement is vital and the Department for Business Innovation and Skills needs to ensure that it works with the industry to develop strong relationships.

Just as important as representation is the issue of measuring the industry. This again is difficult, in part because UK Standard Industrial Classification of Economic Activities (SIC) codes have to map onto the European Union's industrial classification system, NACE, and the United Nations' International Standard Industrial Classifications, ISIC. The government, working with industry, should hopefully take steps to reform the SIC codes, or, failing that, develop a measurement system that policy-makers and researchers can use. An effective trade body or group of trade bodies working together are perhaps in the best position to provide accurate, comprehensive and up-to-date information on the sector.

Airport capacity

Heathrow has a unique importance for the electronics industry, particularly for firms in the M4, corridor but also those in Cambridge and across the South of the country. Air links are particularly useful for electronics firms, which are often engaged in global supply chains and whose products often have high-value to weight ratios. It is no coincidence that the M4 corridor became the location of choice for the British or European headquarters of foreign electronics multinationals. The M4 corridor boasts attractive landscaped greenfield sites, skilled workers and government research institutes. However these benefits can be found in other locations. Heathrow provides global transport links easily accessed by the M4 motorway, an advantage unique to the region.

The importance of Heathrow has been picked up by most, if not all, scholars and analysts that have investigated the success of the M4 corridor.[262] Some have even argued that the benefits offered by Heathrow are so unique that policy-makers should be wary of attempting to replicate the success of the M4 corridor elsewhere.[263]

The government's repeated failure to address the issue of airport capacity in the South East could have a particularly pernicious effect upon firms based in the M4 corridor. Not only do they have to contend with the steadily diminishing capacity of Heathrow but they are also wary of the risk that Heathrow will be abandoned as the UK's primary airport if another international hub is built in the South East.

In 2011, in another attempt by yet another government to address the issue of capacity at airports in the South East, the Coalition rejected the idea of a third runway at Heathrow and stated its opposition to more runways at Gatwick and Stansted.[264] Such a stance seems myopic, especially given the absence of any coherent plan to provide significant additional capacity outside these three airports. It also ignores the fact that Heathrow is not only a transport hub, but also, as the M4 corridor shows, an anchor for businesses. Heathrow continues to play this important role, in spite of the fact that it now serves fewer destinations than Paris, Frankfurt and Amsterdam and is near full capacity.[265] However, its future success is far from clear and a number of reports have estimated the negative economic effects of a failure to expand Heathrow.[266]

The government has recognised the issue of airport capacity. The Chancellor George Osborne stated in his 2012 budget speech:

> I also believe this country must confront the lack of airport capacity in the South East of England – we cannot cut ourselves off from the fastest growing cities in the world.[267]

However it delayed the launch of a white paper on aviation from March to the summer of 2012. Ten policy documents on airport capacity have been produced since the last full-length runway serving London opened at Heathrow in 1946 and so it is not surprising that those interested in tackling the issue are wary of delays.[268]

The government has a difficult job balancing the concerns of businesses, unions and politicians against the environmental costs of increased air travel and the negative effects that airport expansion would have on local residents. However to this list of concerns should be added the unique role that Heathrow has played in the development of an immensely successful electronics, and wider industry, cluster in the M4 corridor. It is worth drawing attention to this because until now debates have often concerned expanding airport capacity in general, and have not adequately considered how the location for airport expansion will have an important effect upon regional economies. In the case of the electronics industry, failure to support Heathrow could have serious ramifications for electronics firms in the M4 corridor and, albeit to a lesser extent, across the UK.

Conclusion

Table 15: UK electronics production 2000 - 2011 (£ millions)

Sector	**2000**	**2008**	**2009**	**2010**	**2011**
EDP	11,501	1,498	1,270	1,255	1,205
Office Equipment	510	97	45	35	32
Control & Instrumentation	3,098	3,176	2,936	3,166	3,220
Medical Equipment	358	812	654	803	819
Industrial Equipment	548	623	580	626	635
Communications & Radar	8,410	5,170	4,958	5,142	5,245
Telecommunications	3,760	829	661	756	741
Consumer	1,872	359	155	86	73
Components	7,104	3,264	2,875	3,297	3,323
Total	37,161	15,828	14,134	15,166	15,292

Source: Reed Electronics Research, www.rer.co.uk

Table 16: Predicted UK electronics production 2012 - 2015 (£ millions) ‡‡

Sector	**2012**	**2013**	**2014**	**2015**
EDP	1,108	1,064	1,032	1,001
Office Equipment	28	26	23	21
Control & Instrumentation	3,268	3,379	3,494	3,606
Medical Equipment	823	856	890	923
Industrial Equipment	642	664	686	708
Communications & Radar	5,245	5,434	5,629	5,809
Telecommunications	711	725	711	697
Consumer	47	44	41	38
Components	3,193	3,255	3,261	3,252
Total	15,066	15,446	15,768	16,055

Source: Reed Electronics Research, www.rer.co.uk

Table 15 contains Reed Electronic Research's production figures for the British electronics industry from 2000 to 2011 and table 16 contains estimates for UK electronics production until 2015. Total production peaked at £37.2 billion in 2000 and has since fallen steadily. In 2008 production totalled £15.8 billion, fell to £15.3 billion in 2011 and RER expects it to increase to £16.1 billion in 2015. The figures show the contrasting fortunes of different sectors of the electronics industry. Three sectors, electronic data processing (EDP), consumer electronics and office equipment have witnessed dramatic declines since 2000, the most dramatic declines occurring in office equipment and consumer electronics; predicted to have production totalling only £21 million and £38 million respectively in 2015.

Elsewhere the picture is more positive. Examining the development of different sectors since 2000, the control & instrumentation, medical equipment and industrial equipment sectors all grew

‡‡ 2000 to 2011 are current figures at current exchange rates. 2012 to 2015 are forecasts at 2011 constant values and exchange rates (i.e. inflation is not included). Base year 2010.

between 2000 and 2011 and are expected to continue to grow between 2012 and 2015. The communications & radar and components sectors are expected to grow, albeit marginally, between 2012 and 2015, having shrunk by 38 per cent and 53 per cent respectively between 2000 and 2011. Aside from EDP, consumer electronics and office equipment, the only other sector predicted to continue its decline until 2015 is telecommunications

RER's figures deliver a mixed diagnosis on the British electronics industry. Positively, the UK has clearly already suffered significant declines in sectors in which it was failing to compete internationally; the dramatic falls in EDP, office equipment and consumer electronics since 2000 charts the move away from low-value assembling in Western Europe that seriously affected parts of the British electronics industry. The fall in telecommunications production is more of a concern, given that many developed countries including France, Sweden, Germany and Italy all possess larger industries than the UK.

It is encouraging that in those sectors in which Britain can thrive it is predicted that production will increase. Growth in the control & instrumentation, medical equipment, industrial equipment, communications & radar and components sectors is envisaged and these, generally low-volume high-value, sectors are precisely those in which Britain should excel. Furthermore, many are sectors that significant growth can be expected in the future.

Health care will form an increasing share of expenditure in developed countries as populations age, and so demand for medical equipment will rise. In addition, demand for electronics which modify a form of electrical energy will grow as new propulsion systems are developed in the automotive, aerospace and transport sectors. Power electronics will also be in demand as renewable energy generation grows and more is done to increase the efficiency of energy distribution through smart grids.

The concern is that, despite these encouraging market developments, the UK's electronics industry and manufacturing base is undermined or suffers from neglect. If it does then the growth these developments should generate will not be realised.

If the diagnosis is mixed so too is the prognosis. While the UK has areas of strength, both geographically and sectorally, it is clear that the country is not, as yet, fulfilling its potential. As section nine made clear this should be of concern to the government, and greater engagement with the sector is vital. Aside from this, the government need to seriously consider a number of policy interventions that could improve the prospects of the industry. The following interventions are no panacea, but if implemented would go some way in signalling to the industry and international investors that the government is seriously committed to fostering and supporting a vibrant electronics industry in Britain.

Policy

- The government should ensure that Britain is an attractive location for electronic systems and semiconductor manufacture. The national and local governments should both look to attract manufacturers, especially large volume foundries, with simplified planning procedures, financial incentives and the support of local colleges and universities.

- To help manufacturers the government should formulate an energy policy that ensures UK energy and electricity prices are competitive in the long and short-term. Policies that envisage long-term savings through short-term cost increases should be mitigated for manufacturers so that capacity is not lost.

- Education policy should be reformulated with more involvement from industry and the Department for Business Innovation and Skills. School students need to possess the necessary mathematical and science skills to take the GCSEs and A-Levels required by universities. They must also be aware of the career opportunities associated with these subjects and STEM degrees. The electronics and other high-tech industries need skilled employees, not just those with higher educational qualifications but also further educational qualifications and school leavers with the necessary basic numeracy and literacy. More needs to be done to attract British students to STEM subjects at colleges and universities. Increasing the number and generosity of bursaries for students taking these subjects could help.

- Fortunately in 2010 the government, along with trade bodies and firms created the UK Electronics Skills Foundation (UKESF) to address these issues. The Foundation has concentrated on both increasing interest in the industry amongst school pupils and supporting students wishing to study electrical engineering at university. Since 2010 the Foundation has run summer schools and offered scholarships to students, both with financial support from the industry. Intake for both the summer schools and the scholarships has grown since 2010 and the Foundation expects this to continue in the future.[269] The government must continue to support the UKESF and consider contributing additional resources to the Foundation.

- The government should consider reform of the EIS and SEIS schemes. Business angels using the schemes are restricted to investing in ordinary shares, which, in the case of the EIS, has caused conflicts in subsequent funding rounds and on exits. Venture capitalists usually invest using preference shares, or a class of ordinary shares with preferential rights, which allows them to be paid dividends before ordinary shareholders. The incentive to invest would be stronger if it were possible to invest in preferential shares whilst also using the EIS or SEIS.

- The government should seek to simplify public venture capital funding. The current structure is often difficult for businesses to negotiate, with too many funds pursuing different objectives. This complexity risks duplicating provision and requires drastic simplification. A simplified and integrated structure made up of a handful of public-private VC funds, rather than many smaller funds, would enable each one to manage a portfolio of high-risk investments. A more integrated approach would also allow funds to take electronics firms with high growth potential through multiple rounds of funding; from start-up through to exit. Although reform is needed it is important that a streamlined public funding structure holds on to and develops the networks which previous funds have established.

- The government should do all it can to improve the Alternative Investment Market. The LSE's suggestion, the removal of stamp duty, should be seriously considered and the government should consult with experts on further reforms that could improve the market.

- Long-term and sustained government-industry engagement should be cemented; the ESCO initiative could be a welcome first step in this. More importantly though, the government needs to examine new ways in which it can engage with the sector. Previous attempts have failed and should not be replicated, electronics is different to other manufacturing sectors and there needs to be greater recognition of this.

- The government should seriously consider building another runway and increasing capacity at Heathrow airport. If it chooses to increase airport capacity through expansion elsewhere in the south east then it should assess the effect of this upon the M4 corridor and attempt to mitigate any negative effect as far as possible.

Notes

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